Journal of Plant Physiology and Breeding
2015, 5(2): 51-61 ISSN: 2008-5168

Effect of Water Stress on Yield and Yield Components of Cumin (*Cuminum cyminum* L.) Ecotypes

Behzad Safari[1], Seyed Mohammad Mahdi Mortazavian[2*], Seyed Ahmad Sadat-Noori[2] and Behrooz Foghi[2]

Received: May 24 2015 Accepted: July 16, 2015
1MSc in Plant breeding, Department of Agronomy and Plant Breeding Sciences, College of Aburaihan, University of Tehran, Tehran, Iran
[2]Department of Agronomy and Plant Breeding Sciences, College of Aburaihan, University of Tehran, Tehran, Iran
*Corresponding author; Email: mortazavian@ut.ac.ir

Abstract

Cumin (*Cuminum cyminum* L.) is one of the most important herbs and medicinal plants that allocate main part of medicinal plant export in Iran. This investigation was conducted to study the effects of drought stress on important agronomic traits of different cumin ecotypes from the major cumin cultivation of the country. Forty-nine ecotypes from different regions of Iran were planted in a simple lattice design layout with two replications in drought stress and non-stress conditions during two years (2012 and 2013). Characteristics including number of umbels per plant, number of seeds per umbel, seed weight, harvest index and seed yield were evaluated. The combined analysis of variance showed significant differences among genotypes, among environments and the genotypes × environment interactions. The low irrigation (soil water supply at 30% field capacity) after flowering stage decreased the value of all traits but at different extent. The highest adverse effect was related to the seed yield. In average of both years, water shortage decreased seed yield about 33.6 percent. Moreover, 1000 seed weight was affected by the environmental condition at the lowest extent (3.8 percent). Also, based on means comparison, the highest and the lowest seed yield on the average of two years belonged to ecotypes from North Khorasan-Baneh in the normal condition (105.07 $g.m^{-2}$) and North Khorasan-Esfaraien under low irrigated condition (20.53 $g.m^{-2}$), respectively. Considering all evaluated traits under both conditions, ecotypes from North-Khorasan (Baneh) and Semnan (Shahmirzad) are proposed as good candidate ecotypes to further research in future.

Keywords: Cumin; Seed yield; Water stress; Yield components

Introduction

Cumin (*Cuminum cyminum* L.) is an important member of Apiaceae which constitute main part of the medicinal plant export in countries that are predominant habitat of this plant such as India, Iran and some other Asian countries (El-Sawi and Mohamed 2002; Kafi *et al*. 2006). It is originated in Syria, Egypt, Turkistan and East Mediterranean (Panda 2010). Cumin cultivation area in Iran was around 0.04 million hectares in 2010 with an average yield of 500 to 1500 kg/ha in the rainfed and irrigated conditions, respectively (Ghasemi Pirbalouti 2010). The areas of cumin production create numerous business opportunities because the planting operations of cumin require many human resources, thus create employment prospects in those regions (Bahraminejad *et al*. 2011). Traditionally, farmers have been adding cumin straw to their animal nutrition, and the result, particularly in lactating animals, has been beneficial (Bettaieb *et al*. 2010). Beside, cumin seed is generally used as a spicy food in the form of powder for imparting flavor to different food preparations (Kafi *et al*. 2006; Rai *et al*. 2012). It also has a variety of medicinal properties (Peter 2012). It is well documented that cumin has anti-microbial (Kivanç *et al*. 1991; Derakhshan *et al*. 2010; Akrami *et al*. 2015; Miri *et al*. 2015), anti-fungal (Kedia *et al*. 2014; Naeini *et al*. 2014) and anti-inflammatory (Hanafi *et al*. 2014) features. The seeds contain a volatile oil in the range of 2–5% depending on the variety and the origin of the cultivation. Major component of the oil is monoterpene hydrocarbon while sesquiterpenes are minor constituents (Sowbhagya 2013). The characteristic cumin odor is principally due to the aldehydes, especially cuminic aldehyde (Tassan and Russell 1975).

Like many other crops, environmental stresses, especially low water availability, play an important role in reduction of plant growth period and seed yield of cumin in arid and semi-arid regions of the world (Shao *et al*. 2008; Flexas *et al*. 2012). Presently, drought is not only a constraint in the arid and semiarid zones, but it is also increasingly affecting temperate regions occasionally subjected to severe drought events (Giorgi and Lionello 2008). Cumin is relatively salt resistant (Dhayal *et al*. 2001) and has no much needs of soil fertility (El-Fouly 1983). Average of yield reduction on a worldwide scale due to water deficit is estimated more than 50% (Wang *et al*. 2003). Cumin cultivation in arid and semi-arid regions impellent researchers to focus on plant behavior on water stress condition. Cumin yield components include number of umbel per plant, number of seeds per umbel and 1000-seed weight (Kafi *et al*. 2006). The number of umbel per plant explained alone about 96% of yield variation (Aminpur and Musavi 1995).

Tavoosi (2001) indicated that cumin is able to absorb water even in very low water potential. In that study, there were no significant differences for seed yield, number of umbrella per plant and number of seeds per umbrella between irrigation regimes. Farahza *et al*. (2002) in evaluating the effect of drought stress on yield components of cumin, using different field capacity treatments, observed that field capacity moisture level showed the highest seed yield, 1000 seed weight, number of umbrella per plant and biomass. Different times of irrigation during cumin growth under different conditions including three (Ahmadian *et al*. 2011), four (Yadav and Dahama 2003) and five (Jangir and Singh 1996) irrigations have been recommended. Tatari (2004) reported that increasing irrigation times enhanced biomass and decreased seed yield and harvest index significantly. The best treatment was obtained with two irrigations after flowering (Tatari 2004). Motamedi-Mirhosseini *et al*. (2011) applied three and five irrigations and reported that yield and the most yield components of cumin accessions were reduced under three as compared with five irrigation regimes. They showed that seed weight under drought stress has a tremendous impact on the yield. Vazin (2013) showed that water deficit decreases growth and plant biomass of cumin. He reported that metabolites such as lipids and total fatty acids decrease but secondary metabolites increase.

Cumin in different areas of compatibility can vary in terms of performance and genetic components according to the variation in genetic characteristics as well as the impact of the environment. The majority of experiments done so far are using one or limited number of cumin ecotypes and there is few research covering several ecotypes from different major cumin cultivation area of Iran. The objective of this study was to evaluate the response of different cumin ecotypes to drought stress.

Materials and Methods

In this study, the effects of drought stress on 49 cumin ecotypes collected from different parts of Iran were assessed over two years (2011-2012 and 2012-2013 growing seasons). The experiments were conducted at the research field of College of Aburaihan, University of Tehran, Iran, in Pakdasht (33º28′N, 51º46′E and 1180 m altitude). The experimental design at each site was simple lattice (7×7) design with two replications. The soil profile of the research field was presented in Table 1. Ecotypes were planted in two sites (normal site i.e. hold soil water in the filed capacity (FC) level and stress site i.e. keep soil water more tightly at 30% of FC) in each year.

Table 1. Characteristics of soil profile in the experimental location

Soil bulk density ($gr.cm^3$)	Sand%	Silt%	Clay%	pH	Soil	EC (ms.cm)	Soil depth (cm)
1.36	28.8	52	19.2	7.4	Silty-loam	3.55	0-30

Drought stress was initiated from 50% flowering stage. There was no rainfall from flowering stage till plant harvest. The seeds were sown manually at a depth of 1.5 to 2 cm of soil in plots of 2 m long with four rows for each ecotype. There was 60 cm distance between each experimental plot and the distance between plants was 5 cm in each row. All experimental plots were treated uniformly. Plants were harvested about four months after planting date. At harvest, seed yield (SYD) was measured on the basis of gram per plot area (m^2). The studied traits were measured in all accessions. The measured quantitative traits other than seed yield were as follows: number of umbel per plant (NUP), number of seed per umbel (NSU), 1000 seed weight (TSW) and harvest index (HIN). Mean of two-years for five lowest and five highest cumin ecotypes were drawn for NUP and TSW. For NSU and SYD, graph showing means of 10 top ranking ecotypes in different years and conditions were drawn. The efficiency of lattice design over randomized complete block design (RCBD) was verified. After data adjustment and calculating of lattice efficiency over RCBD (Yazdi Samadi *et al*. 1997), and also Bartlett's test for homogeneity of error variances, the combined analysis of variance under two irrigation conditions (normal and water stress) based on RCBD was performed after. All statistical analyses were carried out using SAS software (SAS Inc. 1999).

Results and Discussion

Adopting the experiment on the basis of lattice design showed higher efficiency (average of %106) over RCB design. This efficiency was the highest for the most important trait, seed yield (Table 2). To do further analysis, each data was adjusted by block effects within replications and intra-block error source of variation in the lattice output. Then, the combined analysis of variance was carried out based on RCBD for all ecotypes and traits at both conditions. The Bartlett's test determined that the experimental error variances were homogeneous across years and conditions. Combined analysis of variance revealed highly significant differences among water conditions, years and ecotypes regarding all evaluated traits (Table 3).

Table 2. Efficiency of the experiment based on lattice design over randomized complete block design for seed yield and its components of cumin ecotypes in four environments

Environments	Condition	Year	NUP	NSU	TSW	HIN	SYD
Environment1 (E1)	Normal	2012	105.69	116.35	100.00	100.01	153.22
E2	Stress	2012	100	101.82	83.97	100.01	147.69
E3	Normal	2013	114.50	95.87	90.63	101.35	107.27
E4	Stress	2013	114.89	124.06	90.63	95.53	100.63
Average efficiency % (rather RCBD)			108.77	109.52	91.30	99.22	120.37

NUP: Number of umbel per plant; NSU: Number of seed per umbel; TSW: 1000-seed weight; HIN: Harvest index; SYD: Seed yield.

Table 3. Combined analysis of variance of seed yield and its component for cumin ecotypes

S.O.V	df	NUP	NSU	TSW	HI	SYD
Environment (E)	3	90.01 **	15.45**	1.83**	0.67**	118493**
Year (Y)	1	14.54**	4.35**	2.80**	0.61**	283422**
Conditions (C)	1	251.36**	40.82**	1.34**	0.98**	61629**
Y × C	1	4.14**	1.18**	1.34**	0.43**	10427**
Rep (C × Y)	4	35.35	0.28	0.78	0.07	21998
Genotype (G)	48	1.68**	0.51**	0.69**	0.03**	1713**
G × E	144	0.207 **	0.08**	0.09**	0.016 **	420**
G × Y	48	0.14^{ns}	0.09**	0.009^{ns}	0.01**	181*
G × C	48	0.21**	0.10**	0.25**	0.02**	917**
G × C × Y	48	0.25**	0.05**	0.009^{ns}	0.01**	162*
Erorr	192	0.13	0.03	0.010	0.006	113
Total	391	1.39	0.23	0.14	0.02	1554
C.V. (%)	-	5.90	4.03	3.30	20.95	17.11

** and * significant at P≤0.01 and P≤0.05 respectively; ns: non-significant.

NUP: Number of umbel per plant; NSU: Number of seed per umbel; TSW: 1000-seed weight; HIN: Harvest index; SYD: Seed yield

Number of umbels per plant (NUP)

Regarding the number of umbels per plant (NUP) there were highly significant differences for all sources of variations except genotype × year (Table 3). Significant interactions resulted from the changes in the relative ranking of the genotypes or changes in the magnitudes of differences between genotypes from one environment to another. Significant difference between two years suggests the different reactions of genotypes, on the average, from a year to another. The same interpretation can be expressed for water condition. Drought stress had significant reduction effect on number of umbels per plant (Table 4). Number of umbels per plant was reduced, 33.34% on the average, in the water stress condition compared to the normal irrigation (Table 4). This result was in agreement with Alinian and Razmjoo (2014). Motamedi-Mirhosseini *et al.* (2011) also found that number of umbels per plant was reduced under drought condition. Alinian and Razmjoo (2014) found the highest umbels per plant in ecotypes from Isfahan. In our experiment the ecotype from South Khorasan-Darmian had the highest number of umbels per plant (38.35) while the lowest number (17.61) was obtained for the ecotype Golestan-Aghghala (Figure 1). Highly significant differences (P≤0.01) among the tested ecotypes, suggest the presence of genetic variability among them providing suitable materials to go further in cumin breeding programs for selecting candidate genotypes. The significant genotype × condition effect, demonstrated the different response of ecotypes in NUP to the soil water supply.

Table 4. Comparison of the effects of drought stress on seed yield and its components in cumin ecotypes

	NUP			NSU			TSW		
Water Stress	**2012**	**2013**	**Average**	**2012**	**2013**	**Average**	**2012**	**2013**	**Average**
Non stress	32.92	29.50	31.21	22.97	21.05	22.01	3.13	3.18	3.15
Stress (FC 30%)	24.58	17.03	20.80	17.11	17.02	17.07	2.89	3.18	3.04
Decrease (%)	25.33	42.28	33.34	25.21	19.12	22.46	7.49	0	3.78

Table 4 (Continued)

	HIN			SYD		
Water Stress	**2012**	**2013**	**Average**	**2012**	**2013**	**Average**
Non stress	0.37	0.36	0.37	88.92	35.51	62.22
Stress (FC 30%)	0.34	0.22	0.28	59.43	23.21	41.32
Decrease (%)	7.47	38.44	22.75	33.16	34.64	33.58

NUP: Number of umbel per plant; NSU: Number of seed per umbel; TSW: 1000-seed weight; HIN: Harvest index; SYD: Seed yield

Number of seeds per umbel (NSU)

Analysis of variance showed that the number of seeds per umbel was significantly affected by drought stress (Table 3). On the average, drought stress reduced 22.46% of the number of seeds per umbel (Table 4). Alinian and Razmjoo (2014) reported 16.58% reduction of seed number per umbel in their study under drought stress condition. All main effects and interaction effects were significant (Table 3). There was significant difference among the ecotypes for number of seeds per umbel (Table 3). The highest number of seeds per umbel was obtained for North Khorasan-Baneh ecotype in both years and both conditions (Figure 2). Its average number was 29.79 while the lowest number (16.61) was determined in Kerman-Bardsir ecotype. Our results were in consistence with the results of other researchers (Kafi and Keshmiri 2011; Motamedi-Mirhosseini *et al*. 2011; Alinian and Razmjoo 2014) who reported that drought treatments did affect the number of seeds per umbel of cumin. It could be concluded that drought stress could have a major effect on post flowering stages by reduction of seed number

.

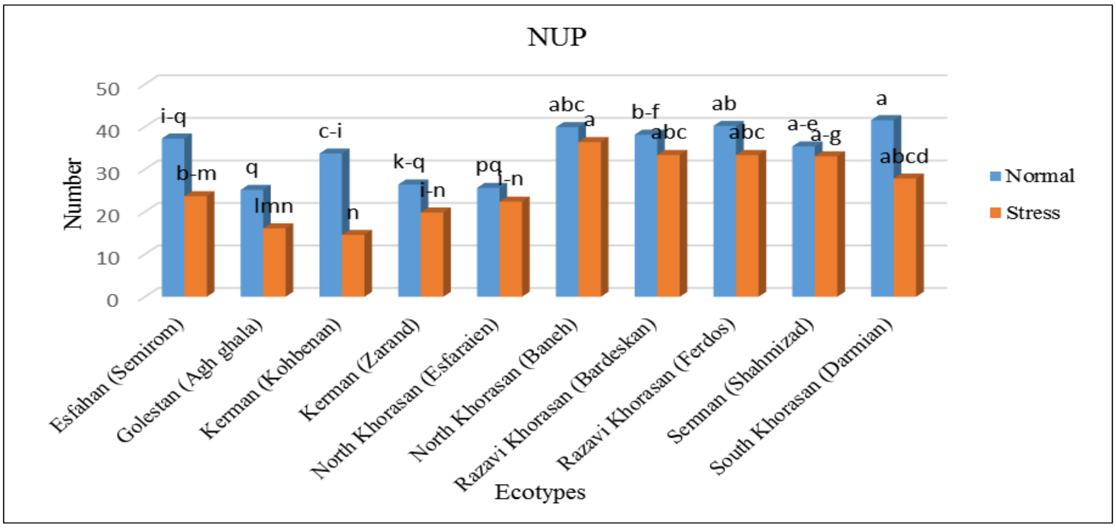

Figure 1. Effect of water condition on the number of umbel per plant (NUP) for five lowest and five highest ranking cumin ecotypes during two years; Means with non-similar letters are significantly different (P ≤ 0.05)

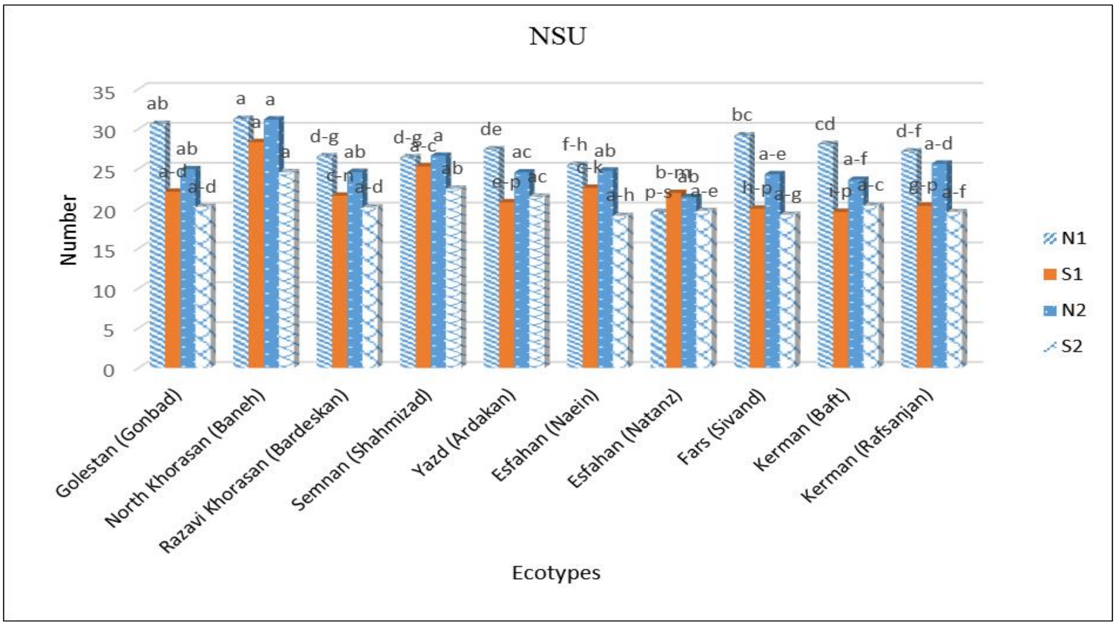

Figure 2. Effect of water condition on the number of seed per umbel (NSU) for 10 top ranking cumin ecotypes during two years; Means with non-similar letters are significantly different (P ≤ 0.05).

One thousands seed weight (TSW)

Results of the present experiment indicated that water stressed cumin ecotypes grown in low water condition have lower TSW than normal irrigated condition. Drought stress decreased TSW of about 3.78% in comparison with the control condition

(Table 4). The three-way interaction (G×C×Y) was not significant for TSW. There was no interaction between genotype and year suggesting the similar linear trend of TSW change during two years. Significant differences among the genotypes for TSW was found (Table 2). The year had no significant effect on seed weight. Genotypic effect accounted for approximately 64% of the total (G+E+GE) variance for TSW, while environmental source accounted for no more than 11%. For practical point of view, this means that researchers can focus on cumin breeding using this trait to get improved genotypes. The ultimate goal of genetic improvement strategies is to get improved genotypes for the traits of importance in order to achieve the development objective of agricultural production (Groen 2000). The highest (3.72 g) and the lowest (2.40 g) TSW was obtained from Golestan-Maraveh in the normal irrigation and North Khorasan-Esfaraien under low irrigated condition, respectively (Figure 3). These results were in agreement with the report of Motamedi-Mirhosseini *et al*. (2011). They also showed that seed weight is as an important trait in grain yield improvement under drought stress condition due to the high correlation between this trait and grain yield.

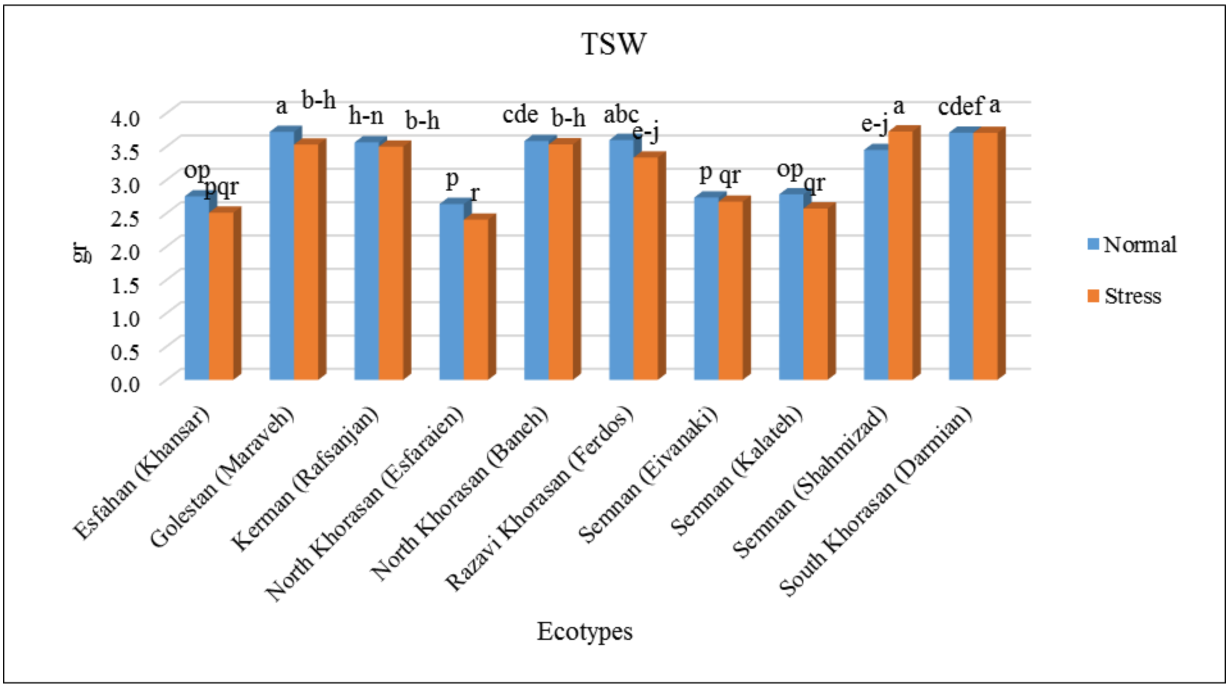

Figure 3. Effect of water condition on 1000 seed weight (TSW) for five lowest and five highest ranking cumin ecotypes during two years; Means with non-similar letters are significantly different (P ≤ 0.05)

Harvest Index

The biomass of a cereal crop is the total yield of plant material, and the harvest index, an important trait associated with the dramatic increases in crop yields that have occurred in the twentieth century (Sinclair 1998), is the ratio of the yield of grain to the biomass (Donald and Hamblin 1976). Analysis of variance showed that drought stress had significant effect on HI (Table 3). There was significant difference among ecotypes in their harvest index (P≤0.01) (Table 3). Drought stress decreased HI about 22.75 % in comparison with the control condition. The effect of year and all two-way and three-way interactions were significant. The highest harvest index (67%) was found for ecotype Esfahan-Semirom, while the lowest ratio (10%) was determined for the ecotype Kerman-Jopar (Table 4).

Seed yield

Higher seed yield is one of the objectives of cumin breeding. Based on the analysis of variance, the effect of drought stress on seed yield was significant (P≤0.01) (Table 3) and reduced the performance of cumin. Significant differences were observed (P≤0.01) among evaluated ecotypes and years for seed yield (Table 3). Changes in yield from one year to another can be attributed to the difference in climate between the two years. Severe water deficit during reproductive stages can reduce yield as a consequence of a large reduction in seed yield per unit area. The highest and the lowest seed yield was recorded for North Khorasan-Bane in the normal condition and first year (144.29 $g.m^{-2}$) and Kerman-Koohbanan in the low irrigated condition and second year (9.37 $g.m^{-2}$), respectively (Figure 4). Under water shortage conditions nutrient absorption and water uptake are limited which lead to reduction in the efficiency of key plant processes, including protein synthesis, light absorption, photosynthetic potential and respiration of plant. And as a result, plant yield is being restricted (Alam 1999; Ashraf and Foolad 2007). In this study, seed yield reduction of 33.58% was recorded under water stress. Reduction in seed yield of cumin was also reported by Ahmadian *et al*. (2011) and Alinian and Razmjoo (2014). Bettaieb Rebey *et al*. (2012) reported that seed yield of cumin increased under moderate, but reduced under severe drought stresses. They suggested that one of the reasons for seed yield reduction under water deficit was insufficient photosynthesis due to stomata closure that led to the reduction in CO_2 uptake. The deleterious effect of water deficit during reproductive stage on seed yield of other medicinal plants has also been reported (Bannayan *et al*. 2011; Saeidnejad *et al*. 2013; Seghatoleslami *et al*. 2015).

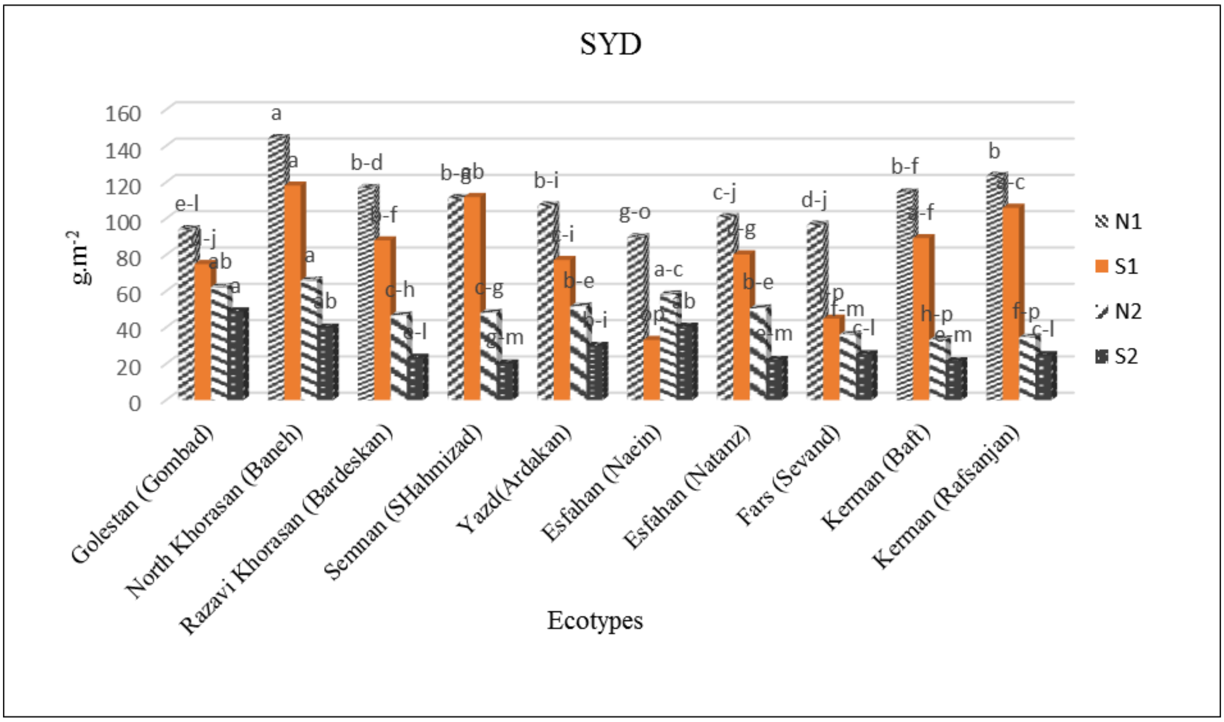

Figure 4. Effect of water condition on seed yield (SYD) on 10 extreme cumin ecotypes during two years; Means with non-similar letters are significantly different (P≤0.05)

Conclusion

As conclusion, drought stress had significant harmful effect on all important agronomic traits of cumin. According to our results, 1000 seed weight affected by environment condition in the lowest extent. It helps breeders to exploit this benefit for cumin improvement. On the other hand, deduction based on seed yield production on a year is not sufficient or informative for agronomist/breeders because of the high effect of environment on this trait. Sever water shortage cause reduction in the value of important agronomic traits of this crop and this was more sensible for seed yield and harvest index. Considering all evaluated traits, ecotypes from North-Khorasan (Baneh) and Semnan (Shahmirzad) in both conditions offer as good candidate ecotypes. In the normal condition ecotypes from Razavi-Khorasan (Bardeskan) and Kerman (Rafsanjan) and in the water stress condition ecotypes from Golestan (Gonbad) and South-Khorasan (Darmian) were regarded as the suitable ecotypes to further research in the breeding programs.

Acknowledgment

Financial support from the Iran National Science Foundation and from the Iranian Ministry of High Education, University of Tehran is gratefully acknowledged.

References

Ahmadian A, Tavassoli A and Amiri E, 2011. The interaction effect of water stress and manure on yield components, essential oil and chemical compositions of cumin (*Cuminum cyminum*). African Journal of Agricultural Research 6: 2309-2315.

Akrami F, Rodríguez-Lafuente A, Bentayeb K, Pezo D, Ghalebi S and Nerín C, 2015. Antioxidant and antimicrobial active paper based on Zataria (*Zataria multiflora*) and two cumin cultivars (*Cuminum cyminum*). LWT-Food Science and Technology 60: 929-933.

Aminpur R and Musavi S, 1995. The effects of the number of irrigation times on the cumin growth, yield and components of seed yield. Journal of Agricultural Sciences and Natural Resources 1: 1-7 (In Persian with English abstract).

Bahraminejad A, Mohammadi-Nejad G and Abdul Khadir M, 2011. Genetic diversity evaluation of Cumin (*Cumin cyminum* L.) based on phenotypic characteristics. Australian Journal of Agricultural Research 5: 304-310.

Bettaieb I, Bourgou S, Wannes WA, Hamrouni I, Limam F and Marzouk B, 2010. Essential oils, phenolics, and antioxidant activities of different parts of cumin (*Cuminum cyminum* L.). Journal of Agricultural and Food Chemistry 58: 10410-10418.

Bettaieb Rebey I, Jabri-Karoui I, Hamrouni-Sellami I, Bourgou S, Limam F and Marzouk B, 2012. Effect of drought on the biochemical composition and antioxidant activities of cumin (*Cuminum cyminum* L.) seeds. Industrial Crops and Products 36: 238–245.

Derakhshan S, Sattari M and Bigdeli M, 2010. Effect of cumin (*Cuminum cyminum*) seed essential oil on biofilm formation and plasmid integrity of *Klebsiella pneumoniae*. Pharmacognosy Magazine 6: 57-61.

Dhayal L, Bhargava S and Jakhar M, 2001. Salinity tolerance of cumin (*Cuminum cyminum* L.) genotypes during germination. Journal of Spices and Aromatic Crops 10: 145-146.

Donald C and Hamblin J, 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Advances in Agronomy 28: 361-405.

El-Fouly M, 1983. Micronutrients in arid and semi-arid areas: levels in soils and plants and the need for fertilizers with reference to Egypt. In "Nutrient balances and the need for fertilizers in semi-arid and arid regions”. Proceedings of the 17th Colloquium of the International Potash Institute, May 2-6, Rabat and Marrakech, Morocco.

El-Sawi SA and Mohamed M, 2002. Cumin herb as a new source of essential oils and its response to foliar spray with some micro-elements. Food Chemistry 77: 75-80.

Farahza K, Farahi A and Sharifi A, 2002. The effect of drought stress on yield components of *Cuminum cyminum*. Pajouhesh Va Sazandgi 54: 42-45 (In Persian with English abstract).

Flexas J, Gallé A, Galmés J, Ribas-Carbo M and Medrano H, 2012. The Response of Photosynthesis to Soil Water Stress. Plant Responses to Drought Stress. Springer, pp. 129-144.

Ghasemi Pirbalouti A, 2010. Medicinal and Aromatic Plants (Introduction and Application). IAU Press, Shahrekord, Iran (In Persian).

Giorgi F and Lionello P, 2008. Climate change projections for the Mediterranean region. Global and Planetary Change 63: 90-104.

Hanafi R, Sobeh M, Ashour L, El-Readi M, Desoukey S, Niess R, Abadi A and Wink M, 2014. Chemical composition and biological activity of essential oils of cumin and coriander fruits from Egypt. The Natural Products Journal 4: 63-69.

Jangir R and Singh R, 1996. Effect of irrigation and nitrogen on seed yield of cumin (*Cuminum cyminum*). Indian Journal of Agronomy 41: 140-143.

Kafi M, Mohassel MR, Koocheki A and Nassiri M, 2006. Cumin (*Cuminum cyminum*): production and processing Science Publishers, Ferdowsi University of Mashhad (In Persian).

Kedia A, Prakash B, Mishra PK and Dubey N, 2014. Antifungal and anti-aflatoxigenic properties of *Cuminum cyminum* (L.) seed essential oil and its efficacy as a preservative in stored commodities. International Journal of Food Microbiology 168: 1-7.

Kivanç M, Akgül A and Doğan A, 1991. Inhibitory and stimulatory effects of cumin, oregano and their essential oils on growth and acid production of *Lactobacillus plantarum* and *Leuconostoc mesenteroides*. International Journal of Food Microbiology 13: 81-85.

Miri VH, Ebrahimi SH and Tyagi AK, 2015. The effect of cumin (*Cuminum cyminum*) seed extract on the inhibition of PUFA biohydrogenation in the rumen of lactating goats via changes in the activity of rumen bacteria and linoleate isomerase enzyme. Small Ruminant Research 125: 56-63.

Motamedi-Mirhosseini L, Mohammadi-Nejad G, Bahraminejad A, Golkar P and Mohammadinejad Z, 2011. Evaluation of cumin (*Cuminum cyminum* L.) landraces under drought stress based on some agronomic traits. African Journal of Plant Science 5: 749-752.

Naeini A, Naderi NJ and Shokri H, 2014. Analysis and in vitro anti-Candida antifungal activity of *Cuminum cyminum* and *Salvadora persica* herbs extracts against pathogenic Candida strains. Journal of Medical Mycology 24: 13-18.

Panda H, 2010. Handbook on Spices and Condiments (Cultivation, Processing and Extraction). Asia Pacific Business Press Inc. Pp. 640.

Peter KV, 2012. Handbook of Herbs and Spices, Elsevier.

Rai N, Yadav S, Verma A, Tiwari L and Sharma RK, 2012. A monographic profile on quality specifications for a herbal drug and spice of commerce- *Cuminum cyminum* L. International Journal of Advanced Herbal Science and Technology 1: 1-12.

Shao HB, Chu LY, Jaleel CA and Zhao CX, 2008. Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus Biologies 331: 215-225.

Sowbhagya H, 2013. Chemistry, technology, and nutraceutical functions of cumin (*Cuminum cyminum* L): an overview. Critical Reviews in Food Science and Nutrition 53: 1-10.

Tassan C and Russell G, 1975. Chemical and sensory studies on cumin. Journal of Food Science 40: 1185-1188.

Tatari M, 2004. The effect of different levels of salt and irrigation times on growth and yield of cumin. MSc thesis, Ferdowsi University of Mashhad, Mashhad, Iran (In Persian with English summary).

Tavoosi M, 2001. The effect of irrigation regimes on yield and yield components of *Cuminum cyminum.* MSc thesis, Faculty Agriculture, Ferdowsi University of Mashhad, Iran (In Persian with English summary).

Vazin F, 2013. Water stress effects on Cumin (*Cuminum cyminum* L.) yield and oil essential components. Scientia Horticulturae 151: 135-141.

Wang W, Vinocur B and Altman A, 2003. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 218: 1-14.

Yadav R and Dahama A, 2003. Effect of planting date, irrigation and weed-control method on yield and water-use efficiency of cumin (*Cuminum cyminum*). Indian Journal of Agricultural Science 73: 494-496.

Yazdi Samadi B, Rezaei A and Valizadeh M, 1997. Statistical Designs in Agricultural Research. Tehran University Press, Iran (In Persian).