International Journal of Horticultural Science and Technology (2022) Vol. 9, No. 2, pp. 201-212

International Journal of Horticultural Science and Technology
Journal homepage: http://ijhst.ut.ac.ir

Identification of Suitable Parents for Essential Oil Yield in Coriander Half-sib Families under Different Environmental Conditions

Aram Sharifi-Zagheh[1], Amir Gholizadeh[2*], Behzad Sorkhilalehloo[3], and Mostafa Khodadadi[3]

1. Plant Breeding Department, Faculty of Agriculture, Tarbiat Modares University. Tehran, Iran.
2. Crop and Horticultural Science Research Department, Golestan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Gorgan, Iran.
3. Seed and Plant Improvement Institute, Agricultural Research Education and Extension Organization (AREEO), Karaj, Iran.

ARTICLE INFO

Article history:

Accepted: 7 September 2020,
Received in revised form: 21 April 2021,
Accepted: 17 June 2021

Article type:

Research paper

Keywords:

Coriander,
Drought tolerance,
Medicinal plant,
Synthetic cultivars,
Water deficit stress

ABSTRACT

Development of drought-tolerant cultivars with high essential oil yield is important for production of medicinal plants. So far application of half-sib mating has not been used in the coriander breeding for high essential oil yield and drought tolerance. In this study, 14 half-sib families of coriander derived from poly-cross design were evaluated under three irrigation treatments including: well water, mild water deficit stress and intense water deficit stress. In each environment, the half-sib families were evaluated using a randomized complete block design with three replications. Six drought-tolerance indices, including stress tolerance index (STI), geometric mean productivity (GMP), mean productivity (MP), harmonic mean (HM), stress tolerance (TOL) and stress susceptibility index (SSI) were calculated based on essential oil yield under non-stress (YP), mild stress (YM) and intense stress (YS). The results of correlation coefficients and biplot analysis revealed that STI, GMP, MP and HM indices could be effectively used for screening of drought tolerant genotypes of the coriander. Selection by these indices can be useful to identify a genotype with desirable essential oil yield in both non-stress and stress conditions. According to the results of three-dimensional graphs and view of biplot, half-sib families' No. 6, 7 and 14 under mild stress and half-sib families' No. 6, 7 and 12 under intense stress were selected as drought tolerant, and with high essential oil yield under non-stress and stress conditions. Therefore, these half-sib families can be used as a source of elite parents for synthetic cultivars in the coriander.

Introduction

Coriander (*Coriandrum sativum* L.) is an annual herb from Apiaseae family. Coriander is native to the south-western parts of Asia to North Africa (Nejad Ebrahimi et al., 2010). It displays widespread adaptation as a crop around the world, growing well under many different types of soils and weather conditions (Gholizadeh et al., 2018; Gholizadeh et al., 2019). In addition, the short life cycle in most coriander cultivars allows farmers to fit their cultivation into some parts of the growing season in almost any region (Lopez et al., 2008). The fresh and dried leaves of coriander are generally used as a vegetable, spice and also in cooking as an ingredient in many of foods (Nejad Ebrahimi et al., 2010). Coriander is mainly cultivated and widely distributed for its fruits. The dried fruits are widely applied as a condiment, especially for flavoring of sauces, meat products, bakery, and

* Corresponding Author, Email: a.gholizadeh@areeo.ac.ir
DOI: 10.22059/IJHST.2021.309561.390

confectionery items. Also, dried fruits are a source of essential oils (Msaada et al., 2009). Coriander seed oil includes among the 20 major essential oils in the market globally. Linalool is the main volatile compound in the seed (more than 50% of the total essential oil) (Ramadan and Moersel, 2003). Also, it has been revealed that the essential oils and various extracts of coriander have antibacterial (Burt, 2004; Cantore et al., 2004; Kubo et al., 2004), antioxidant (Wangensteen et al., 2004), antidiabetic (Gallagher et al., 2003), anti-cancerous and anti-mutagenic (Chithra and Leelamma, 2000) activities.

Climate conditions, altitude, different soil conditions, seasonal factors, and other environmental features such as water deficit affect the yield of essential oil. Water deficit stress is one of the most important factors limiting the growth and survival of plants in arid and semi-arid regions. Water is a major component of the fresh product and significantly affects the weight and quality of plants (Jones and Tardieu, 1998). Water deficit in plants may lead to physiological disorders such as a reduction in transpiration and photosynthesis (Sarker et al., 2005; Sousaraei et al., 2021). Also, water deficit may cause significant changes in the yield and composition of essential oils in aromatic and medicinal plants. For example, water deficit decreased the oil yields of rosemary (*Rosmarinus officinalis* L.) and anise (*Pimpinella anisum* L.) (Singh and Ramesh, 2000). Nadjafi et al. (2009) reported that water deficit increased the percentage of essential oil in the coriander but decreased the yield of essential oil. Having an average annual rainfall of 240 mm, Iran categorized in arid and semi-arid regions of the world. Of the million hectares of cultivated regions, only five millions are under irrigation because of intense water limitations (Ebrahimiyan et al., 2012). However, Iran is one of commercial coriander producers in the world (Nejad Ebrahimi et al., 2010). Coriander has been cultivated for many years in different parts of Iran. Therefore, developing the drought-tolerant cultivars with high essential oil yield is an important strategy in coriander breeding.

Drought susceptibility of a genotype is usually estimated based on yield reduction under relative stress compared to the non-stress conditions (Fernandez, 1992). Generally, some researchers used the indices such as geometric mean productivity (GMP) (Fernandez, 1992), mean productivity (MP) (Rosielle and Hamblin, 1981), harmonic mean (HM) (Jafari et al., 2009), stress susceptibility index (SSI) (Fischer and Maurer, 1978), stress tolerance index (STI) (Fernandez, 1992) and tolerance index (TOL) (Rossielle and Hamblin, 1981; Sousaraei et al., 2021) for screening of susceptible and tolerant genotypes based on their yields in the stress and non-stress conditions. Fernandez (1992) used these indices and yield in non-stress and stress conditions for categorizing the genotypes into four groups: genotypes which express uniform superiority in both non-stress and stress environments (group A), genotypes with high yield under either non-stress (group B) or stress (group C) environments, and genotypes with weak yield under both non-stress and stress environments (group D). Also, for selection based on a combination of indices, some researchers have used the principal component analysis (PCA) (Golabadi et al., 2006; Majidi et al., 2011; Ebrahimiyan et al., 2013). PCA is one of the most successful techniques for reducing the multiple dimensions of the observed variables into a smaller intrinsic dimensionality of independent variables (Johnson and Wichen, 2007).

Despite, coriander is a medicinal plant with high genetic diversity, which is cultivated in different parts of the world, half-sib mating has not been used in the coriander breeding for high essential oil yield and drought tolerance. Therefore, we attempted to evaluate the drought tolerance in 14 coriander half-sib families under different irrigation regimes to assess the efficiency of different drought selection indices and to identify drought-tolerant half-sib families as a source of elite parents for the synthetic cultivars.

Materials and Methods

Plant material and experimental site

Plant materials included 14 half-sib families of the coriander, including TN-59-10 (F1), TN-59-36 (F2), TN-59-80 (F3), TN-59-158 (F4), TN-59-160 (F5), TN-59-164 (F6), TN-59-230 (F7), TN-59-306 (F8), TN-59-347 (F9), TN-59-353 (F10), TN-59-357 (F11), TN-59-422 (F12), TN-59-450 (F13) and commercial cultivar (F14). Parental genotypes (endemic genotypes) provided from the Gene bank of the Seed and Plant Improvement Institute, Karaj, Iran. To produce half-sib families, all possible crosses were done between parents at a polycross design in 2014. Seeds were sterilized for 5 min in 10% sodium hypochlorite and then in 96% ethanol for 1 min and thoroughly washed by distilled water (Hojati et al. 2011). In this study, 14 half-sib families were evaluated in three irrigation treatments, including well water, mild water deficit stress and intense water deficit stress. In each environment, the half-sib families were evaluated through a randomized complete block design with three replications at the research field of the Tarbiat Modares University, Tehran, Iran. The physical and chemical characteristics of the soil in the experiment are presented in Table 1. Seeds of half-sib families were sown on 5 April in 2015. A set of genotypes in experiment 1 fully watered; in experiment 2 (mild water stress) genotypes fully watered until stem elongation beginning stage and watering was cut off till the flowering stage finished completely and then recovery watering was done for once; in experiment 3 (intense water stress) watering done similar to experiment 1 until the beginning of the flowering stage and then watering was cut off completely.

Table 1. Soil properties of different layers of the experimental field

Soil parameters	Soil depth (cm)		
	0-20	20-40	40-60
Sand (%)	70	68	66
Silt (%)	15	18	18
Clay (%)	15	14	16
Bulk Density (G Cm^{-3})	1.2	1.4	1.48
FC (%)	16.5	19	15
Organic C (%)	1.61	1.45	1.09
pH	7.75	7.75	7.74
EC (dS m^{-1})	1.3	1.3	1.3
Available N (kg ha^{-1})	29.00	34.10	43.00
Available P (kg ha^{-1})	195.00	226.8	214.00
Available K (kg ha^{-1})	2085.0	2304.5	2465.9

Measurement and statistical analyses

Plants were harvested at maturity stage, and then the fruit yield was recorded for each plot. The essential oil was extracted using the steam distillation method in which 30 g of well grinded fruit were subjected to hydro distillation for 90 min (Msaada et al., 2009). Essential oil yield of each family was also calculated by multiplying fruit yield in essential oil percent. The drought indices were analyzed based on essential oil yield under non-stress (YP), mild stress (YM) and intense stress (YS). Drought tolerance was calculated using the equations cited in Table 2. The combined analysis of variance for traits under non-stress and stress conditions was done according to the RCBD design using SAS version 9.1 statistical software. Correlation coefficients between essential oil yield in each of the water regimes and drought tolerance indices were determined using SAS PROC CORR. The principal component analysis was performed to reduce the multiple dimensions of data space and the biplot was drown using GGE-biplot software. Further information on GGE-biplot methodology and GGE-biplot package are available at http://www.ggebiplot.com. For specifying the drought-tolerant genotypes with high yield potential for essential oil in non-stress and stress environments, three-dimensional graphs based on YP, YM, YS and the best drought-tolerance indices was drown using SAS version 9.1 statistical software.

Table 2. Stress tolerance/susceptibility indices used for drought evaluation of coriander families

Stress tolerance indices	Equation[a]	References
Stress susceptibility index	$\mathrm{SSI}=\dfrac{1-\left(\dfrac{Y_S}{Y_P}\right)}{1-\left(\dfrac{\bar{Y}_S}{\bar{Y}_P}\right)}$	(Fischer and Maurer, 1978)
Geometric mean productivity	$\mathrm{GMP}=\sqrt{Y_P \times Y_S}$	(Fernandez, 1992)
Mean productivity	$\mathrm{MP}=\dfrac{Y_P+Y_S}{2}$	(Rosielle and Hambling, 1981)
Harmonic mean	$\mathrm{HM}=\dfrac{2\left(Y_P \times Y_S\right)}{Y_P+Y_S}$	(Kristin et al., 1997)
Tolerance index	$\mathrm{TOL}=Y_P-Y_S$	(Rosielle and Hambling, 1981)

Stress tolerance indices	Equation[a]	References
Stress tolerance index	$STI=\frac{(Y_P)\times(Y_S)}{(\bar{Y}_P)^2}$	(Fernandez, 1992)

[a]: Ys is the essential oil yield of families under drought stress conditions, Yp is the essential oil yield of families under non-stress condition, $\bar{Y}s$ and $\bar{Y}p$ are the mean essential oil yield of all families under drought stress and non-stress condition, respectively.

Results

The results of combined analysis of variance indicated that all the studied traits showed significant differences among different irrigation regimes (Table 3). These differences among different environments (non-stress, mild-stress and intense-stress) are due to the effect of drought stress on traits under study. There were highly significant differences among coriander half-sib families for all studied traits. These results indicate high genetic variation among half-sib families, which could be a useful resource for the selection of drought-tolerant families as a source of elite parents for synthetic cultivars. In addition, the interaction between half-sib families and the environment were significant for all the studied traits, suggesting that the values of these traits were significantly altered because of the different responses of half-sib families under different irrigation regimes (Table 3).

Table 3. Combined analysis of variance for coriander studied traits under different irrigation regimes

S.O.V	DF	Mean square		
		Essential oil	Fruit yield	Essential oil yield
Environment (E.)	2	0.01526**	16347274.58**	0.522**
Rep/E.	6	0.00014	18766.10	0.006
Families (F.)	13	0.00268**	282566.50**	0.186**
F × E	26	0.00138**	124657.61**	0.074**
Error	78	0.00008	15750.79	0.003

**: Significant at 0.01 level of probability.

In the present study, evaluation of 14 coriander half-sib families for drought tolerance was done through 6 selection indices, including STI, MP, GMP, HM, TOL, and SSI. An appropriate index should have a positive significant correlation with essential oil yield in the non-stress and stress conditions. Therefore, to identify the best index of selection for screening of drought-tolerant half-sib families, and using all stress-tolerance/sensitivity indices simultaneously the PCA was performed. Correlation coefficients between these indices and essential oil yield in non-stress (YP) and stress conditions (YM and YS) are shown in Tables 4 and 5. A vector view of biplot of the two first components was used to show the distribution pattern of half-sib families and interrelationships between YP and essential oil yield in any stress conditions (YM and YS with STI, MP, GMP, HM, TOL, and SSI indices (Fig. 1 and 2). The vector view is one of the applications of the biplot analysis to study the relationships between indices. In the vector view of the biplot, a vector is drawn from the biplot origin to each marker of the traits (indices) to facilitate visualization of the relationships among the traits (Yan and Rajcan 2002). The vector view explains a sufficient amount of the total variation of standardized data. Since the correlation coefficient between any two traits is approximated by the cosine of the angle among their vectors, the vector view of biplot is the best way for graphical displaying the interrelationships among traits (Yan and Rajcan, 2002). Two traits are positively correlated if the angle among their vectors is <90°, and is negatively correlated if the angle is >90°, and is the independent if the angle is equal to 90°. In biplot view, when a genotype located around or neighbor of the trait indicating that this genotype has the highest value for that trait.

The best selection index should be able to distinguish half-sib families which have uniform superiority in both non-stress and stress conditions. According to Figure 1, STI, MP, GMP, and HM indices had a positive and significant relationship with both YP and YM which are in accordance with the correlation analysis results (Table 4). Therefore, these indices (STI, MP, GMP, and HM) could effectively be used for screening of drought tolerance of half-sib families under mild stress conditions. The half-sib families which were located around or neighbor these indices identified as drought-tolerant families. Thus, according to the vector view of biplot (Fig. 1), half-sib families' No. 6, 7, and 14 were selected as the most drought-tolerant genotypes under mild stress condition. Also, in the intense stress conditions, the indices of STI, MP, GMP, and HM had a positive and significant relationship with both YP and YS (Fig.

2) and that observations are in accordance with the correlation analysis results (Table 5). Therefore, these indices could effectively be used for screening of drought-tolerant families under intense stress conditions. Thus, according to the vector view of biplot (Fig. 2), the half-sib families' No. 6, 7, and 12 were selected as the most drought-tolerant genotypes under intense stress condition.

Table 4. Simple correlation coefficients among tolerance indices and essential oil yield under non-stress (YP) and mild stress (YM) in the coriander families

	YP	YM	GMP	STI	HM	MP	TOL
YM	0.37						
GMP	0.65**	0.93**					
STI	0.62*	0.91**	0.97**				
HM	0.66**	0.91**	0.99**	0.97**			
MP	0.65**	0.94**	0.99**	0.96**	0.97**		
TOL	-0.05	0.90**	0.70**	0.69**	0.68**	0.72**	
SSI	-0.35	0.65**	0.42	0.41	0.42	0.40	0.86**

*: Significant at 0.05 level of probability.
**: Significant at 0.01 level of probability.

Table 5. Simple correlation coefficients among tolerance indices and essential oil yield under non-stress (YP) and intense stress (YS) in the coriander families

	YP	YS	GMP	STI	HM	MP	TOL
YS	0.68**						
GMP	0.90**	0.92**					
STI	0.92**	0.87**	0.98**				
HM	0.95**	0.83**	0.98**	0.98**			
MP	0.80**	0.98**	0.97**	0.93**	0.91**		
TOL	0.46	0.96**	0.78**	0.72**	0.66**	0.90**	
SSI	0.05	0.64*	0.42	0.35	0.32	0.54*	0.76**

*: Significant at 0.05 level of probability.
**: Significant at 0.01 level of probability.

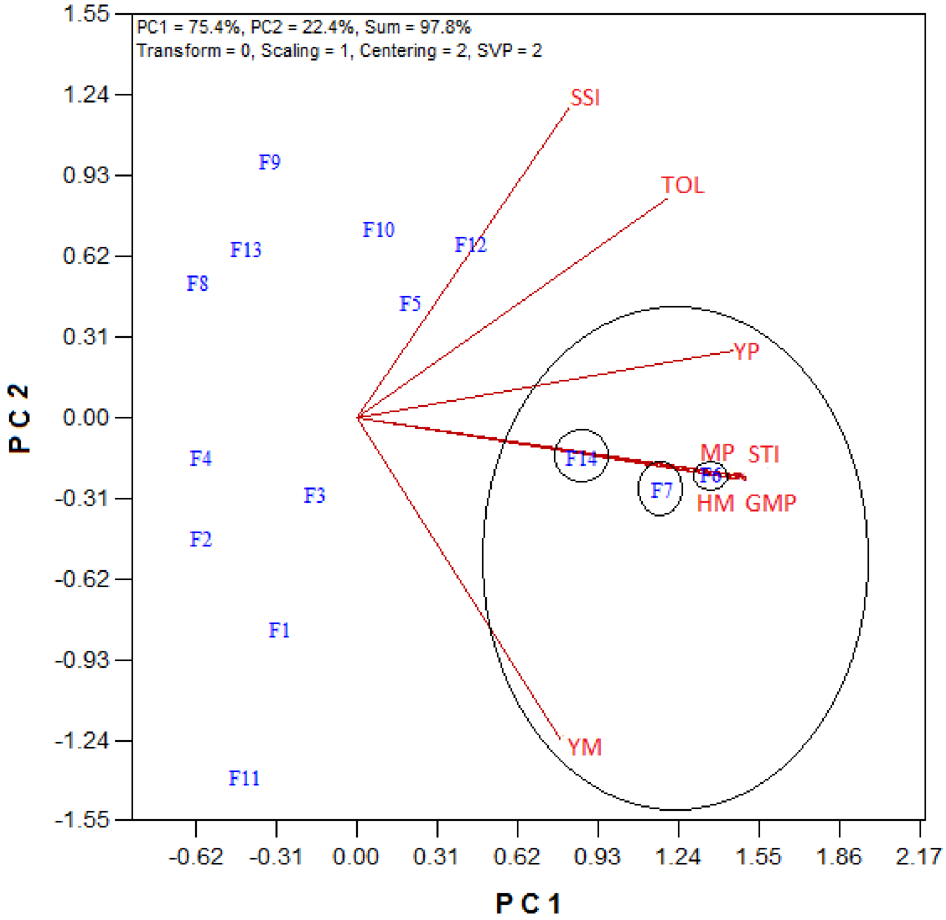

Fig. 1. Coriander half-sib families by trait biplot vector view for the whole dataset under both non-stress and mild stress conditions, showing the interrelationship among all measured indices

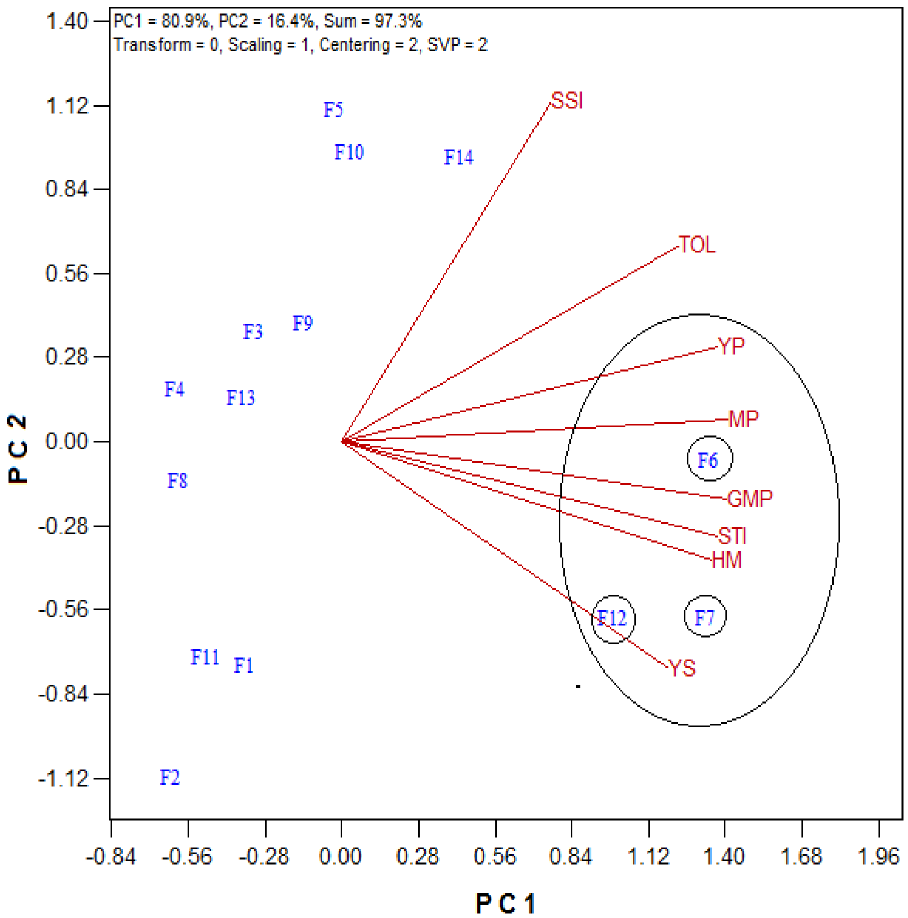

Fig. 2. Coriander half-sib families by trait biplot vector view for the whole dataset under both non-stress and intense stress conditions, showing the interrelationship among all measured indices

To identify the relationship between YP, YM, YS, and the best indices (STI, MP, GMP and HM), three-dimensional graphs for each one were also performed (Fig. 3 and 4). These graphs indicated the ability of these indices to detect proposed groups by Fernandez (1992). By using these indices and YP, YM, and YS variables, three dimensional diagrams could partition the half-sib families into four groups: (1) half-sib families with high essential oil yield under both non-stress and stress conditions (group A), (2) half-sib families with high essential oil yield under non-stress (group B) or (3) half-sib families with acceptable essential oil yield under stress (group C), and (4) half-sib families with poor performance under both non-stress and stress conditions (group D). A suitable index should be able to distinguish group A families from the other groups. Three-dimensional plots corresponding to STI, MP, GMP, and HM indices showed that half-sib families' No. 6, 7 and 14 under mild stress (Fig. 3) and half-sib families' No. 6, 7, and 12 under intense stress (Fig. 4) are drought tolerant: because they express uniform superiority in both non-stress and stress conditions.

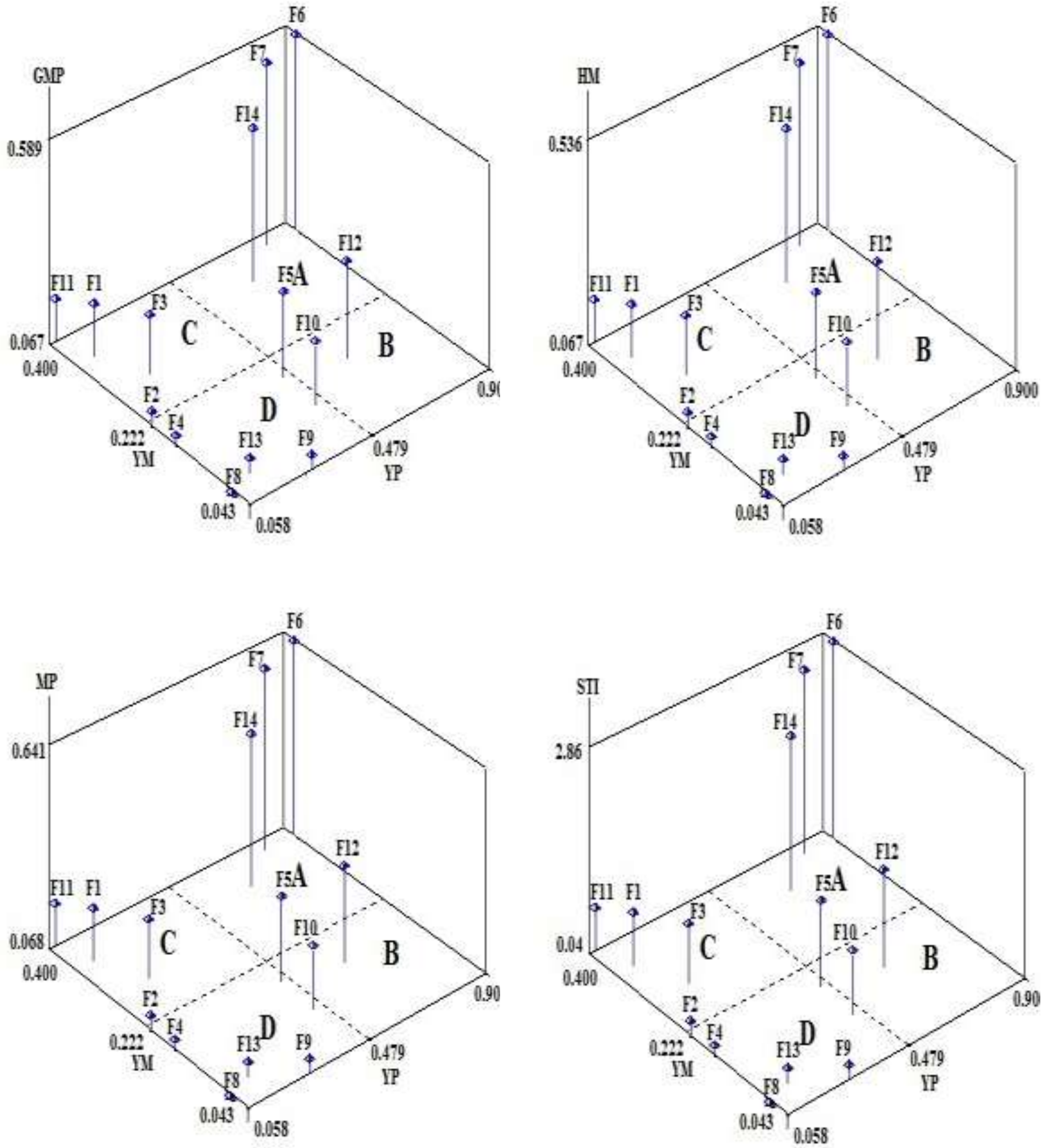

Fig. 3. Three dimensional graphs of essential oil yield under non-stress (YP), mild stress (YM) and geometric mean productivity (GMP), harmonic mean (HM), mean productivity (MP), stress tolerance index (STI) for 14 half-sib families of coriander

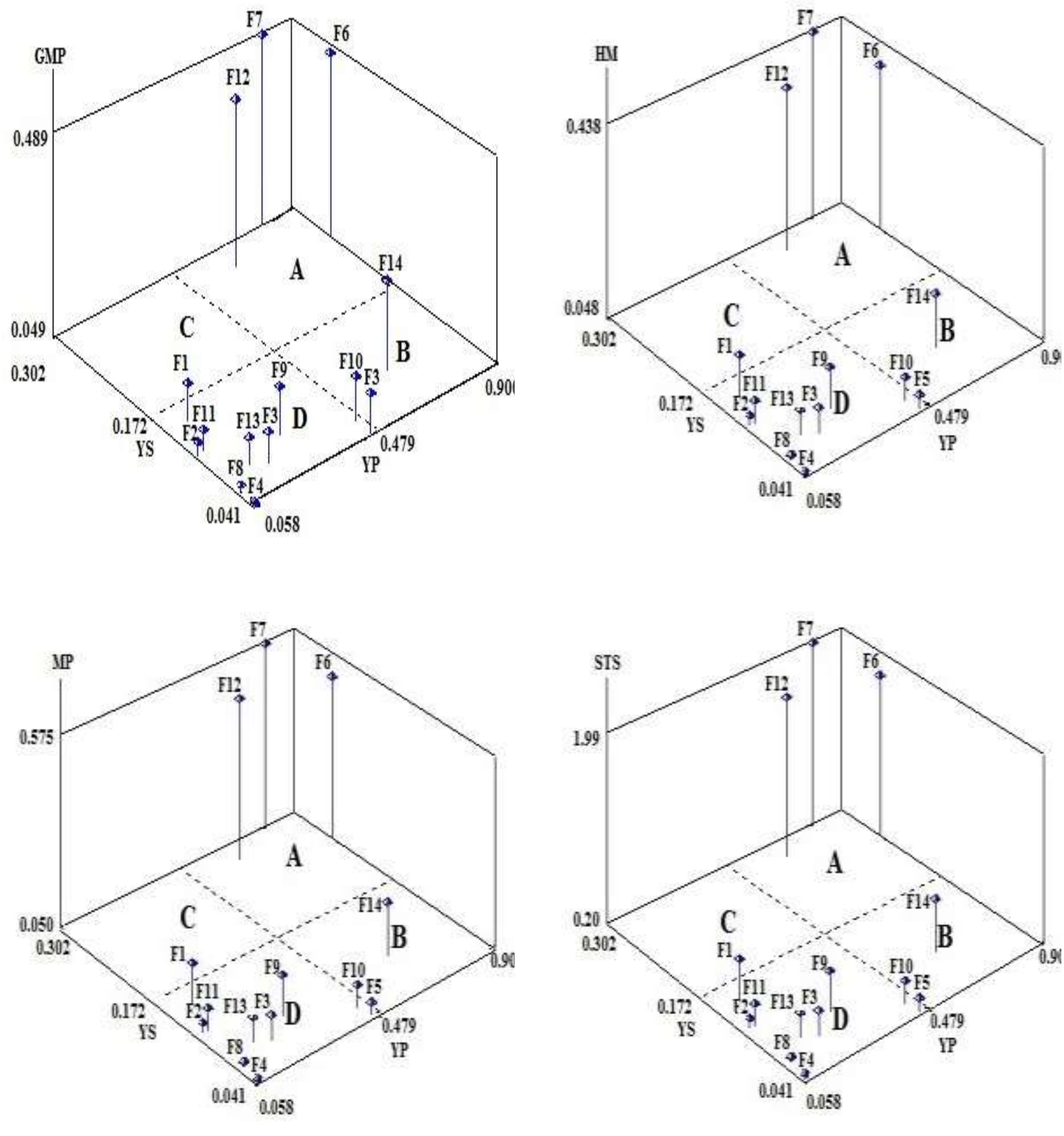

Fig. 4. Three dimensional graphs of essential oil yield under non-stress (YP), intense stress (YS) and geometric mean productivity (GMP), harmonic mean (HM), mean productivity (MP), stress tolerance index (STI) for 14 half-sib families of coriander

Discussion

Plant exposure to water deficit conditions may lead to physiological disorders such as a reduction in the transpiration and photosynthesis. The growth and biosynthesis of secondary metabolites in the medicinal and aromatic plants are strongly influenced by environmental factors such as water deficit stress (Burbott and Loomis, 1969; Nadjafi et al., 2009). Effects of water stress on yield and chemical components of essential oils in various plant species have been previously reported (Khalid, 2006; Khazaie et al., 2008; Hani et al., 2015). For example, Singh and Ramesh (2000) reported that water stress reduced the essential oil yield of rosemary, but the essential oil percent increased. Nadjafi (2006) reported that water deficit increased essential oil percent in *Nepeta binaludensis* but decreased essential oil yield. Also, Nadjafi et al. (2009) studied the effects of irrigation regimes on yield, yield components, content and composition of the essential oil of four Iranian landraces of the coriander and showed that water deficit significantly increased essential oil percent and linalool content in seeds but decreased the essential oil yield. They also observed the highest essential oil yield in optimum irrigation treatment. The highest essential oil yield in this treatment compared to other irrigation treatments was due to higher seed yield. Coriander is mainly cultivated and widely distributed for its fruits. The dried fruits are a source of essential oils (Msaada et al., 2009). Therefore, it seems that evaluation and improvement of the coriander genotypes for high essential oil yield is necessary. Generally, plant breeding is a cheaper and more stable approach to overcome the deleterious effects of drought stress through the development of cultivars having ability for high essential oil production under water deficit conditions. Whereas, crossing blocks in the coriander is difficult due to its very small flowers, production of commercial F_1 hybrids are not presently available for the coriander. To obtain new cultivars of the coriander seems that the half-sib mating such poly-cross designs are useful. Because the relatively simple crossing plan, production of adequate amount of individuals and using a much larger set of parents is possible in half-sib poly-cross designs (Comstock and Robinson, 1952). Half-sib mating, including poly-cross, top-cross and open-pollination are frequency used in forage grass breeding to evaluate general combining abilities of parental clones for developing the synthetic cultivars (Nguyen and Sleper, 1983). This study is unique in the using of half-sib families derived from ploy-cross of the coriander genotypes to identify drought-tolerant half-sib families as a source of elite parents for synthetic cultivars.

In this study, 14 half-sib families of coriander for drought tolerance were evaluated based on 6 selection indices, including STI, MP, GMP, HM, TOL, and SSI. These indices were calculated based on the essential oil yield of families under non-stress (YP), mild stress (YM) and intense stress (YS) conditions. To identify the distribution pattern of half-sib family and interrelationships among indices, a vector view of biplot of the two first components was used (Fig. 1 and 2). Biplot is a graphical tool for breeders and is a plot that simultaneously displays the effects of indices and the genotypes. The biplot was originally proposed by Gabriel (1971) as a graphical tool to present the results from principal component analysis (PCA). The study demonstrated that biplot was an excellent tool for visual evaluation of superior genotypes and indices compared to the statistical techniques such as linear correlation and other complex methods like a path coefficient analysis. The biplot visual methodology have used for the evaluation of the distribution pattern of genotypes and interrelationships among traits by Yan and Rajcan (2002) in soybean, Dehghani et al. (2008) in rapeseed and Dehghani et al. (2012) in bread wheat. According to the vector view of the biplot, the indices of STI, MP, GMP, and HM had a positive and significant relationship with essential oil yield in different irrigation regimes (YP, YM and YS) (Fig. 1 and 2), the obtained results were verified from the simple correlation data (Tables 4 and 5). Therefore, these four indices (STI, MP, GMP, and HM) could effectively be used for screening of drought-tolerant half-sib families under mild and intense stress conditions. Considering the vector view of biplot, half-sib families' No. 6, 7, and 14 under mild stress (Fig. 1) and families' No. 6, 7, and 12 under intense stress (Fig. 2) were selected as drought tolerant families. Therefore, these half-sib families can be used as a source of elite parents for synthetic cultivars in the coriander. The results of three-dimensional graphs were also in agreement with the results of biplot analysis to distinguish the half-sib families that have uniform superiority in the non-stress and stress conditions (group A).

Conclusion

According to the obtained results from the present study, the following suggestions are made: 1. to select a genotype with stable and high essential oil yield in non-stress and water stressed (mild and intense stress) conditions, STI, GMP, MP, and HM indices are identified as more effective indices. Selection by these indices can be useful to identify a genotype with desirable essential oil yield in both non-stress and stressed conditions (group A). 2. The half-sib families' No. 6, 7, and 14 under mild stress and families' No. 6, 7, and 12 under intense stress were selected as drought tolerant families and with high essential oil yield under non-stress and stress conditions. Therefore, these half-sib families can be used as source of elite parents for developing the synthetic cultivars in the coriander. 3. Finally, to achieve new cultivars in the coriander and other medicinal plants having similar characteristics with coriander, such as open-pollination habit, very small flowers, and lack of a suitable flowering system to produce commercial F_1 hybrids, the half-sib mating approaches such as a poly-cross could be utilized.

Acknowledgments
The authors would like to thank the Gene bank of the Seed and Plant Improvement Institute, Karaj, Iran for providing the plant materials.

Conflict of interest
The authors indicate no conflict of interest for this work.

References
Burbott A.J, Loomis W.D. 1969. Evidence for metabolic turnover of monoterpenes in peppermint. Plant Physiology 44, 173-179.

Burt S. 2004. Essential oils their antibacterial properties and potential applications in foods-a review. International Journal of Food Microbiology 94, 223-253.

Cantore P.L, Iacobellis N.S, De Marco A, Capasso F, Senatore F. 2004. Antibacterial activity of Coriandrum sativum L. and Foeniculum vulgare Miller var. vulgare (Miller) essential oils. Journal of Agricultural and Food Chemistry 52, 7862-7866.

Chithra V, Leelamma S. 2000. Coriandrum sativum effect on lipid metabolism in 1, 2-dimethyl hydrazine induced colon cancer. Journal of Ethnopharmacology 71, 457-463.

Comstock R, Robinson H. 1952. Genetic parameters, their estimation and significance. Proc. 6th Int. grasslands congress. pp. 284-291.

Dehghani H, Dvorak J, Sabaghnia N. 2012. Graphic analysis of biomass and seed yield of beard wheat in salt stress condition. Annals of Biological Research 3 (9), 4246-4253.

Dehghani H, Omidi H, Sabaghnia N. 2008. Graphic analysis of trait relations of rapeseed using the biplot method. Agronomy Journal 100, 1443-1449.

Ebrahimiyan M, Majidi M.M, Mirlohi A, Gheysari M. 2012. Drought-tolerance indices in a tall fescue population and its polycross progenies. Crop and Pasture Science 63, 360-369.

Ebrahimiyan M, Majidi M.M, Mirlohi A, Noroozi A. 2013. Physiological traits related to drought tolerance in tall fescue. Euphytica 190, 401-414.

Fernandez G.C.J. 1992. Effective selection criteria for assessing plant stress tolerance. Proc Intnl Symp Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. AVRDC Publ, Tainan, Taiwan, 13-18 August. pp. 257–27.

Fischer R, Maurer R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Crop and Pasture Science 29, 897-912.

Gabriel K.R. 1971. The biplot graphic display of matrices with application to principal component analysis. Biometrika 58, 453-467.

Gallagher A, Flatt P, Duffy G, Abdel-Wahab Y. 2003. The effects of traditional antidiabetic plants on in vitro glucose diffusion. Nutrition Research 23, 413-424.

Gholizadeh A, Dehghani H, Khodadadi M. 2019. Quantitative genetic analysis of water deficit tolerance in coriander through physiological traits. Plant Genetic Resources 17, 255-264.

Gholizadeh A, Dehghani H, Khodadadi M, Gulick, P.J. 2018. Genetic combining ability of coriander genotypes for agronomic and phytochemical traits in response to contrasting irrigation regimes. PLoS ONE 13(6), e0199630.

Golabadi M, Arzani A, Maibody S.M. 2006. Assessment of drought tolerance in segregating populations in durum wheat. African Journal of Agricultural Research 1, 162-171.

Hani M.M, Hussein S.A.A.H, Mursy M.H, Ngezimana W, Mudau F.N. 2015. Yield and essential oil response in coriander to water stress and phosphorus fertilizer application. Journal of Essential Oil Bearing Plants 18, 82-92.

Hojati M. Modarres-Sanavy S.A.M, Karimi M, Ghanati F. 2011. Responses of growth and antioxidant systems in Carthamus tinctorius L. under water deficit stress. Acta Physiologiae Plantarum 33, 105-112.

Jafari A, Paknejad F, Al-Ahmadi M.J. 2009. Evaluation of selection indices for drought tolerance of corn (Zea mays L.) hybrids. International Journal of Plant Production 3, 33-38.

Johnson R.A, Wichern D.W. 2007. Applied multivariate statistical analysis.' (Prentice Hall International: Englewood Cliffs, NJ)

Jones H, Tardieu F. 1998. Modelling water relations of horticultural crops a review. Scientia Horticulturae 74, 21-46.

Khalid K.A. 2006. Influence of water stress on growth, essential oil, and chemical composition of herbs (Ocimum sp.). International Agrophysics 20, 289-296.

Khazaie H.R, Nadjafi F, Bannayan M. 2008. Effect of irrigation frequency and planting density on herbage biomass and oil production of thyme (Thymus vulgaris) and hyssop (Hyssopus officinalis). Industrial Crops and Products 27, 315-321.

Kristin A.S, Serna R.R, Perez F.I, Enriquez B.C, Gallegos J.A.A, Vallejo P.R, Wassimi N, Kelley J.D. 1997. Improving common bean performance under drought stress. Crop Science 37, 43-50.

Kubo I, Fujita K.I, Kubo A, Nihei K.I, Ogura T. 2004. Antibacterial activity of coriander volatile compounds against Salmonella choleraesuis. Journal of Agricultural and Food Chemistry 52, 3329-3332.

Lopez P.A, Widrlechner M.P, Simon P.W, Rai S, Boylston T.D, Isbell T.A, Bailey T.B, Gardner C.A, Wilson L.A. 2008. Assessing phenotypic, biochemical, and molecular diversity in coriander (Coriandrum sativum L.) germplasm. Genetic Resourcces and Crop Evolution 55, 247-275.

Majidi M.M, Tavakoli V, Mirlohi A, Sabzalian M.R. 2011. Wild safflower species (Carthamus oxyacanthus B.) A possible source of drought tolerance for arid environments. Australian Journal of Crop Science 5, 1055-1063.

Msaada K, Taarit M.B, Hosni K, Hammami M, Marzouk B. 2009. Regional and maturational effects on essential oils yields and composition of coriander (Coriandrum sativum L.) fruits. Scientia Horticulturae 122, 116-124.

Nadjafi F, Damghani A.M, Ebrahimi S.N. 2009. Effect of irrigation regimes on yield, yield components, content and composition of the essential oil of four Iranian land races of coriander (Coriandrum sativum). Journal of Essential Oil Bearing Plants 12, 300-309.

Nadjafi F. 2006. Evaluation the ecological criteria of Nepeta binaludensis Jamzad for adaptation in low input agricultural systems. Unpublished thesis, PhD Thesis of Agroecology. Ferdowsi University of Mashhad, Iran. pp 120.

Nejad Ebrahimi S, Hadian J, Ranjbar H. 2010. Essential oil compositions of different accessions of Coriandrum sativum L. from Iran. Natural Product Research 24, 1287-1294.

Nguyen H, Sleper D. 1983. Theory and application of half-sib matings in forage grass breeding. Theoretical and Applied Genetics 64, 187-196.

Ramadan M.F, Moersel J.T. 2003. Analysis of glycolipids from black cumin (Nigella sativa L.), coriander (Coriandrum sativum L.) and niger (Guizotia abyssinica C.) oilseeds. Food Chemistry 80, 197-204.

Rosielle A, Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. Crop Science 21, 943-946.

Sarker B.C, Hara M, Uemura M. 2005. Proline synthesis, physiological responses and biomass yield of eggplants during and after repetitive soil moisture stress Scientia Horticulturae 103, 387-402.

Singh M, Ramesh S. 2000. Effect of irrigation and nitrogen on herbage, oil yield and water-use efficiency in rosemary grown under semi-arid tropical conditions. Journal of Medicinal and Aromatic Plant Sciences 22, 659-662.

Sousaraei N, Mashayekhi K, Mousavizadeh SJ, Akbarpour V, Medina J, Aliniaeifard S. 2021. Screening of tomato landraces for drought tolerance based on growth and chlorophyll fluorescence analyses. Horticulture, Environment, and Biotechnology 62, 521-535.

Wangensteen H, Samuelsen, A.B, Malterud K.E. 2004. Antioxidant activity in extracts from coriander. Food Chemistry 88, 293-297.

Yan W, Rajcan I. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Science 42, 11-20.

Hojati M, Modarres-Sanavy SAM, Karimi M, Ghanati F (2011) Responses of growth and antioxidant systems in *Carthamus* tinctorius L. under water deficit stress. Acta Physiol Plant 33 (1):105-112

COPYRIGHTS ©2021 The author(s). This is an open access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers

CC BY