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Yield Stability of Melon Genotypes under Drought Stress Conditions

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ABSTRACT

Development of cultivars with high yield under normal conditions and maintaining their yield under abiotic stresses is the main purpose of plant breeding programs in arid and semi-arid areas. The present study aimed to evaluate the yield stability of a collection of commercial melon varieties under drought stress. The trial was conducted in a field under normal conditions (plants were irrigated after 50 mm evaporation of a class A evaporation pan) and drought stress conditions (irrigation was carried out after 100 mm evaporation of a class A evaporation pan). In average, 3.32 kg fruit/plant and 2.76 kg fruit/plant were obtained under normal and drought stress conditions, respectively. The highest reduction in yield as the consequence of drought exposure was recorded for 'Mazandarani' (52%) and 'Samsoori' (48%). The most drought-tolerant genotypes were 'Mamaghani', 'Nahavandi', 'Shadegan', 'Crenshaw' and 'Suski-e-Sabz' as they had constant yield under both growing conditions. On the other hand, 'Samsoori' and 'Saveh' were the most sensitive genotypes to drought. For most of the measured traits, the values of broad-sense heritability were over 0.50 i.e. there was a large genetic diversity among melon genotypes. This variation can be utilized for selecting high potential fruit yield and drought-tolerant genotypes. Total soluble solids (TSS) (ºBrix) was 15.2% for 'Honey-Dew'. TSS (ºBrix) was obtained 10.7, 10.09, and 9.2% for Iranian genotypes of 'Khatooni', 'Samsoori', and 'Saveh', respectively. In conclusion, although some Iranian melon genotypes were recognized as drought tolerant, they need to be improved for TSS (ºBrix).

Introduction

Melon (*Cucumis melo* L.), a member of the *Cucurbitaceae* family, is one of the most important vegetable crops worldwide. China, Turkey, Iran, India, Kazakhstan and USA are the main melon producers (FAO, 2018). Iran as a secondary center of origin, possess a rich melon germplasm and currently more than 85000 hectares is cultivated in the country.

Drought stress is one of the major environmental constraints causing deterioration of conditions for survival, growth and final yield of plants. Climate change and global warming are the main issues impacting agriculture (Shi et al., 2021). Recently, researchers have shown that additional stress due to climate and socio-economic changes will be expected in most parts of Iran (Aghapour Sabbaghi et al., 2020). Challenges with accessibility to the irrigation water restricted the production of melon in many parts of the world. In Iran, plants experience drought stress at the end of growth season. Such stress is often called “terminal stress,” “post-flowering stress” or “late-season stress” (Blum, 2011).

Drip irrigation in conjunction with mulch coverage of soil can significantly reduce the amount of required water for irrigation. Alternatively, to mitigate the adverse effects of

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drought stress, cultivation of drought tolerant cultivars is suggested. Genetic improvement for development of tolerant cultivars provides an efficient and attractive approach for this end. Some melon and watermelon landraces are cultivated as rain fed in most parts of Iran despite of low precipitation. Thus, melon landraces in Iran are potentially drought tolerant. In recent years, many of melon landraces have been replaced by modern mostly commercial hybrid cultivars that are mainly imported by seed companies. The main advantage of modern cultivars is resistance to diseases, while they need more irrigation water for proportional yield. One solution for this issue is re-examining the traditional landraces in hope to find some tolerant genotypes. When there is not any drought tolerant cultivar, screening the germplasm to identify the potential drought tolerant genotypes is the first step (Zhang et al., 2011).

Yield stability is the most important index indicative of drought stress tolerance in plants (Guttieri et al., 2001). However, complexity of the factors such as plant growth stage, stress severity, time and duration of stress, physical and chemical properties of soil and their interaction also affect plant behavior in field conditions. Some morphological characters such as fruit yield, flesh and skin weight, cavity diameter and fruit weight are important for screening the melon genotypes for abiotic stresses (Naroui Rad et al., 2017). Despite of frequent reports about the genetic diversity of Iranian melon genotypes, there is the limited information available for their drought tolerance assessment. Among scarce number of studies, Akhoundnejad and Dasgan (2019) studied the effect of different irrigation levels on physiological performance of some drought tolerant melon genotypes. Out of nine studied genotypes, six genotypes showed no yield loss under stress conditions in comparison with normal conditions. Elsayed et al. (2019) assessed drought tolerant melon germplasm for adaptation to climate change. In a research conducted by Naroui Rad et al. (2017), 36 different Iranian varieties of melon were cultivated under drought conditions and different traits were measured. In their research, the irrigation was done after 75% water depletion of soil field capacity. The coefficients of variation for single plant yield and fruit weight were 47% and 45%, respectively. They found a negative correlation (−0.58) between relative water content and canopy temperature (Naroui Rad et al., 2017). Barzegar et.al. (2012) also investigated the effects of drought stress on some physiological traits of two Iranian melon cultivars (Zard-e-Jalali and Suski-e-Sabz). In their experiment three irrigation levels (starting irrigation at -50, -65, and -75 cbar) were tested. The results indicated that the drought levels caused significant effects on leaf area, stem length, proline accumulation, fruit weight as well as yield.

So far, little is known about the genetic tolerance of melon cultivars against drought stress. These indicate a need to screen different melon landraces against drought stress to find the most tolerant ones. The present study aimed to evaluate the yield stability following drought exposure among different melon genotypes including both Iranian landraces and foreign cultivars.

Material and Methods

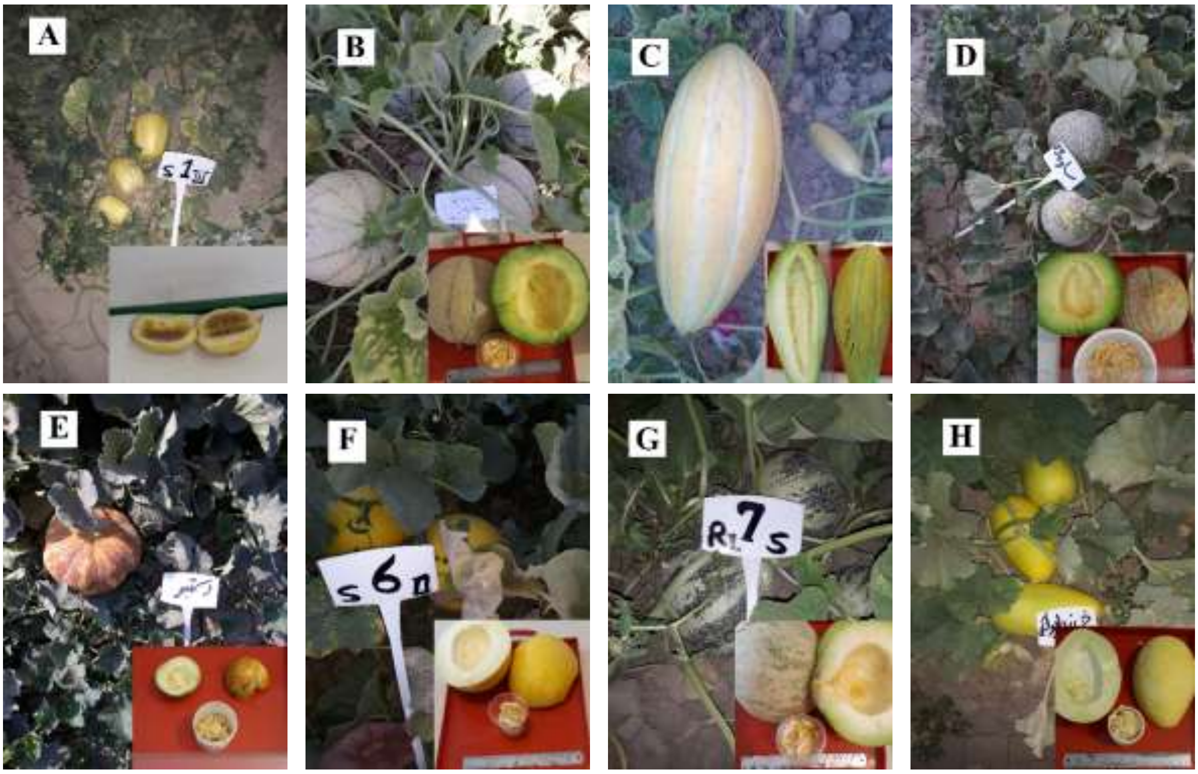
Plant material and experiment conditions

The experiment was conducted at the Lorestan Agriculture and Natural Resources Research Center, Borujerd, Iran (33° 49′ N, 48° 47′ E, 1501 m above sea level) during the growing season 2018-2019. The soil had a clay loam texture (pH 8.4) with an average bulk density of 1.48 g cm^{-3} in the top 30-cm layer. The electrical conductivity (EC) of soil was 2.23 $dS.m^{-1}$. The average annual temperature and the amount of precipitation from October 2018 to September 2019 was 14.7 °C and 460 mm, respectively. In addition, the electrical conductivity (EC) of irrigation water was 0.52 $dS.m^{-1}$. Thirty different melon genotypes were used in this experiment, including 19 melon genotypes from different parts of Iran and 11 genotypes from Uzbekistan, Japan, Afghanistan, USA, Turkey, and France (Table 1, Fig.1).

Table 1. The name and origin of thirty melon genotypes that were investigated in the present study. Fruit features were recorded in this experiment

No.	Variety name	Origin	Botanical group	Rind Color	Rind stripe	Rind netting	Flesh Color	Flesh Texture
1	Ginsen Makuwa	Korea	conomon	Yellow	1	Smooth	White	Crunchy
2	Samsoori	Iran	cantalupensis	Cream	1	Netted	Green	Soft and juicy
3	Khatooni	Iran	inodorus	Yellow	1	Netted	Lemon	Crunchy
4	Saveh	Iran	cantalupensis	Cream	1	Netted	Green	Soft and juicy
5	Dastanbou	Iran	dudaim	Orange	1	Smooth	White	Crunchy

No.	Variety name	Origin	Botanical group	Rind Color	Rind stripe	Rind netting	Flesh Color	Flesh Texture
6	Japuni	Japan	cantalupensis	Yellow	0	Smooth	Cream	Crunchy
7	Rish-baba	Iran	cantalupensis	Green	1	Netted	Green	Soft
8	Eyvanaki	Iran	inodorus	Yellow	0	Netted	White	Crunchy
9	Samsoori-N	Iran	cantalupensis	Cream	1	Netted	Green	Soft and juicy
10	Crenshaw	USA	inodorous	Green	1	Netted	Orange	Soft and juicy
11	Tile-torogh	Iran	cantalupensis	Green	1	Smooth	Green	Soft and juicy
12	Garmak	Iran	cantalupensis	Orange	1	Netted	Yellow	Soft and juicy
13	Melon Golden	Japan	cantalupensis	Yellow	0	Smooth	Orange	Smooth
14	Isabelle	France	cantalupensis	Orange	1	Smooth	Orange	Smooth and juicy
15	Nahavandi	Iran	inodorus	Green	1	Netted	White	Crunchiness
16	Turkish melon	Turkey	inodorus	Yellow	1	Netted	White	Smooth
17	Curi	Hybrid	cantalupensis	Yellow	0	Netted	Green	Smooth and juicy
18	Ghandoz	Afghanistan	inodorus	Green	1	Netted	White	Crunchiness
19	Mamghani	Iran	cantalupensis	Orange	1	Netted	Orange	Smooth and juicy
20	Mazandarani	Iran	wild melon	Green	1	Smooth	Lemon	Smooth
21	Shadegan	Iran	cantalupensis	Cream	1	Netted	Green	Smooth
22	Bozorgsar	Afghanistan	inodorus	Green	1	Netted	White	Crunchiness
23	Galia1	France	cantalupensis	Yellow	0	Netted	White	Smooth
24	Shahpasand	Hybrid	cantalupensis	Cream	1	Netted	Orange	Smooth and juicy
25	Honey Dew	USA	inodorous	Cream	0	Smooth	Orange	Smooth
26	Galia2	France	cantalupensis	Yellow	1	Netted	Green	Smooth
27	Suski-e-Sabz	Iran	inodorus	Green	1	Netted	Green	Crunchiness
28	Mahvalati	Iran	inodorus	Green	0	Smooth	Orange	Crunchiness
29	Uzbak1	Uzbekistan	inodorus	Green	1	Wrinkled	Lemon	Smooth
30	Uzbak2	Uzbekistan	inodorus	Green	0	Netted	White	Crunchiness



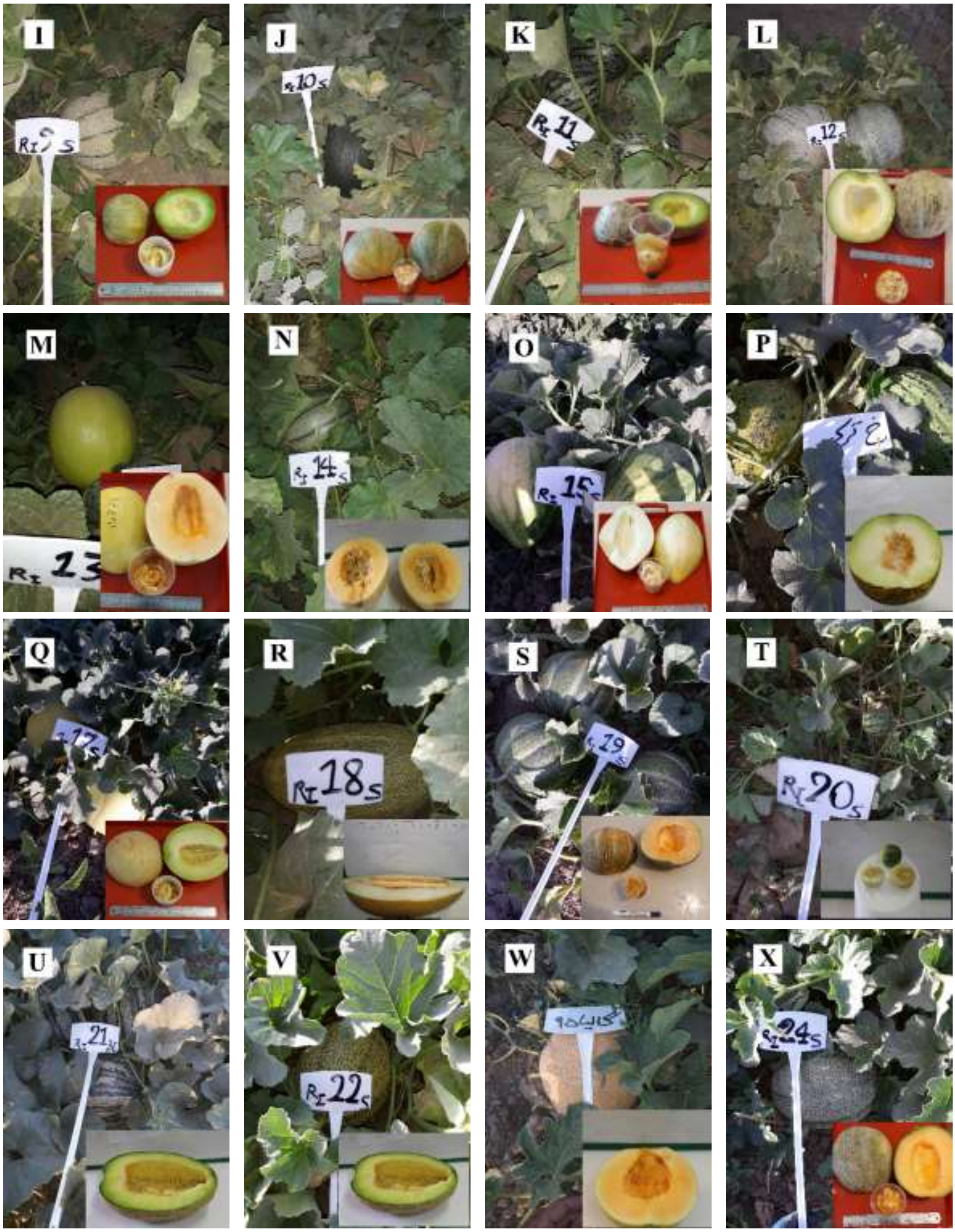

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Fig. 1. Representative fruits of 30 melon genotypes studied in this research. (A) 'Ginsen Makuwa', (B) 'Samsoori', (C) 'Khatooni', (D) 'Saveh', (E) 'Dastanbou', (F) 'Japuni', (G) 'Rish-baba', (H) 'Eyvanaki', (I) 'Samsoori-N', (J) 'Crenshaw', (K) 'Tile-torogh', (L) 'Garmak', (M) 'Melon Golden', (N) 'Isabelle', (O) 'Nahavandi', (P) 'Turkish melon', (Q) 'Curi', (R) 'Ghandoz', (S) 'Mamghani', (T) 'Mazandarani', (U) 'Shadegan', (V) 'Bozorgsar', (W) 'Galia1', (X) 'Shahpasand', (Y) 'Honey Dew', (Z) 'Galia2', (AA) 'Suski-e-Sabz', (AB) 'Mahvalati', (AC) 'Uzbak1' and (AD) 'Uzbak2'.

The seeds were sown in plastic potting trays placed in a greenhouse under 20-24 °C and 80% relative humidity conditions. After one month, the seedlings were transplanted to the field conditions. Two randomized complete block designs, each with three replications, were conducted. In each block, one row for each genotype was included 15 seedlings. Plants in each row were 70 cm apart. There was 2 m space between two adjacent rows. The irrigation regimes were included 50- and 100- mm evaporation from a class A evaporation pan as the normal (normal) and drought stress conditions, respectively. In other words, under normal conditions, the irrigation was applied after 50 mm evaporation from a class A evaporation pan. The amount of evaporation was recorded daily. Under drought stress conditions, the irrigation was carried out after 100 mm evaporation from a class A evaporation pan. These irrigation regimes were applied after the first fruits were setting.

Measurements

The characters were recorded on 10 random plants per genotype (10 samples) in each replication. Prior to fruit harvest, vegetative traits were measured. The vegetative traits included: leaf length (cm), leaf width (cm), number of nodes and branch length (cm) and leaf chlorophyll content. Leaf chlorophyll content was estimated using a SPAD (Soil-plant analyses development) analyzer (SPAD 502m, Minolta, Osaka, Japan). At maturity stage and after fruit harvest the following traits were measured: days to harvest, fruit weight (kg), number of fruits per plant, flesh thickness (cm), fruit length (cm), fruit width (cm), cavity diameter (cm), skin and flesh weight (kg), total seed weight (g), 100-seed weight (g), seed length (mm), seed width (mm), total soluble solids (TSS) (ºBrix) and yield (kg/plant). Under stress conditions, relative water content (RWC) was measured for 30 melon genotypes after 100- mm evaporation from a class A evaporation pan according to Blum (2011).

Statistical analysis

Data were subjected to ANOVA using Statistical Analysis Software (V. 9.1; SAS Institute, Cary, NC). The mean values were compared via the least significance difference (LSD) test. Principal component analysis (PCA) was conducted to reduce the dimensions of data and identify the interrelationships among the melon genotypes by the R version 4.0.3 (The R Foundation for Statistical Computing). To draw PCA bi-plots the packages 'ggplot2' and 'ggfortify' were used. Stepwise regression analysis was carried out to find effective independent traits on yield per plant (as the dependent trait) using SPSS (version 19).

To understand the extent of diversity, further analysis was carried out and genetic variance, broad-sense heritability and GCV% (genotypic coefficient of variation) were calculated for all measured traits. The experimental design was randomized complete block design (RCBD) with three replications in each conditions. According to the expected mean squares in ANOVA the phenotypic and genotypic variances were calculated using following formula:

$$V_e = MSE \quad (1)$$

where V_e is the error variance and MSE is the error mean squares.

$$V_g = \frac{(MSG-MSE)}{r} \quad (2)$$

where V_g is the genotypic variance, MSG is the mean squares of genotypes and r is the number of replications.

$$V_p = V_g + V_e \quad (3)$$

where V_p is the phenotypic variance.

Broad-sense heritability (h^2) for each trait was calculated as following:

$$h^2 = \frac{V_g}{V_p} \quad (4)$$

Genotypic (GCV) coefficient of variation was calculated according to following formula:

$$GCV = \frac{\sqrt{V_g}}{m} \times 100 \quad (5)$$

where m is the mean value for each trait in the experiment.

Results

Analysis of variance

The combined analysis of variance was carried out to show the behavior of genotypes under growth conditions (Table 2). Comparing the normal and drought stress conditions, did not show significant differences about fruit weight, cavity diameter, skin and flesh weight, total seed weight, seed width and branch length. However, the difference among genotypes was highly significant for all measured traits. There was a sharp increase in chlorophyll content under stress compared to normal conditions.

Table 2. Combined analysis of variance for measured traits in thirty melon genotypes evaluated under normal and drought stress conditions. The average values for each trait among 30 melon genotypes are shown for normal and stress conditions

Traits	Environment (df=1)	Replication (Environment) (df=4)	Accession (df=29)	Accession × Environment interaction (df=29)	Error (df=116)	Average under Normal conditions	Average under Stress conditions
Days to harvest	4067**	5.6	134**	10.5**	1.58	125	115
Fruit number (per plant)	68**	0.34	155**	131**	0.157	3.8	2.6
Fruit weight (kg)	0.000	0.080	6.14**	0.21	0.24	2.04	2.00
Flesh thickness (cm)	3.35**	0.124	6.84**	0.24*	0.14	4	3.7
Fruit length (cm)	10.5*	0.76	226**	5.35**	2.25	17.4	17.9
Fruit width (cm)	19*	0.94	71**	2.5*	1.4	14.6	13.9
Cavity diameter (cm)	1.34	0.51	21.9**	0.96*	0.52	6.4	7.6
Skin and flesh weight (kg)	0.002	0.14	5.5**	0.17	0.23	1.87	1.88
Total Seed weight (kg)	0.000	0.000	0.035**	0.0009*	0.0006	0.17	0.17
Seed length (mm)	12**	0.52	33.9**	1.53**	0.39	12.3	11.8
Seed width (mm)	1.05	0.15	6.3**	0.19**	0.08	5.16	5
Leaf length (cm)	51**	1.34	18.5**	1.25	1.23	12.2	11.1
Leaf width (cm)	110**	1.91	38**	4.8**	1.9	16.6	15.1
Internode number	85*	7.6	76**	21**	9.4	25.5	24
Branch length (cm)	14.5	524	5756**	975**	361	148	147
Chlorophyll	5311**	220	832**	594	132	72	83
TSS (ºBrix)	77.4**	0.68	24**	2.36**	0.73	10.6	11.9
Yield per plant (kg)	13.9*	1.37	5.5**	0.98**	0.45	3.32	2.76

The mean of fruit weight under normal conditions (2.04 kg) was very near to that under stress conditions (2 kg) but the mean of number of fruits per plant was decreased significantly under stress (2.5) compared to their number in the normal (3.8) conditions. A small decrease was found for flesh thickness under drought stress compared to normal conditions (Table 2). TSS (ºBrix) was increased under stress compared to normal conditions. Significant interactions for most traits indicated that the response of genotypes to drought stress were not the same. It means that the sensitivity of melon genotypes to drought stress is different. The difference in response of genotypes to drought stress is discussed in detail for yield per plant and TSS (ºBrix) in next parts.

According to the results of ANOVA carried out for each growth conditions separately, significant differences were observed among the genotypes for all the measured traits ($P < 0.01$; Table 3). There was also a large variation in fruit shapes among melon genotypes in this study (Fig. 1).

RWC values are shown in Figure 2 for 30 melon genotypes under stress conditions. The range of this trait was from 0.33 ('Rish-baba') to 0.81 ('Curi'). The average of RWC was 0.61.

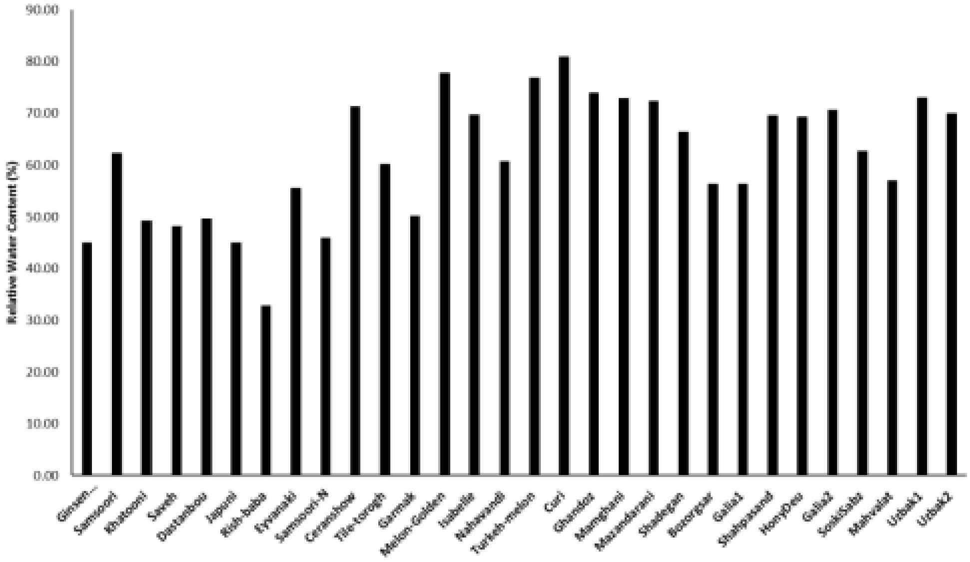

Fig. 2. Relative water content of melon genotypes measured after growth under the condition of 100 mm evaporation from a class A evaporation pan

Table 3. Analysis of variance for measured traits in thirty melon genotypes evaluated under normal and drought stress conditions. BRI: TSS (ºBrix), CHL: chlorophyll content measured with SPAD, BLE: branch length, LLE: leaf length, LWI: leaf width, INN: internode number, YPP: yield per plant, D: Days to harvest, W: fruit weight, T: flesh thickness, V: cavity diameter, Wi: fruit width, L: fruit length, H: hundred seed weight, FS: flesh and skin weight, S: total seed weight, Ls: seed length, Ws: seed width, N: fruit number in each plant

	Normal						Drought stress					
Traits	Replication (df=2)	Accession (df=29)	Error (df=58)	V_g	H^2	GCV%	Replication (df=2)	Accession (df=29)	Error (df=58)	V_g	H^2	GCV%
D	2.44^{ns}	109**	0.84	36	0.97	5	3.22^{ns}	52**	1.37	16	0.92	3
N	0.453*	285.77**	0.132	95	0.99	250	0.244^{ns}	22.98**	0.18	7.6	0.97	127
W	0.15^{ns}	3.31**	0.31	1	0.76	49	0.004^{ns}	3.36**	0.16	1.06	0.86	49
T	0.197^{ns}	4.02**	0.150	1.28	0.89	28	0.05^{ns}	3.05**	0.132	0.97	0.87	27
L	.177^{ns}	142.79**	2.32	46	0.96	39	1.24^{ns}	96.3**	1.89	31.47	0.94	31
Wi	1.37^{ns}	40.49**	1.34	13.05	0.90	25	0.515^{ns}	33.24**	1.14	10.7	0.90	23
V	0.54	10.13**	0.52	3.2	0.8	24	0.366*	12.15**	0.34	3.93	0.9	26

Traits	Normal						Drought stress					
	Replication (df=2)	Accession (df=29)	Error (df=58)	V_g	H^2	GCV%	Replication (df=2)	Accession (df=29)	Error (df=58)	V_g	H^2	GCV%
FS	0.158ns	2.71**	0.22	0.83	6 0.79	49	0.035ns	2.7**	0.179	0.84	2 0.82	48
S	0.001ns	0.0157**	0.00044	0.0050	0.92	44	0.00009ns	0.019**	0.0005	0.0062	0.93	47
Ls	0.28	17.5**	0.29	5.7	0.94	19	0.76	17.9**	0.49	5.8	0.92	20
Ws	0.022	3.03**	0.092	0.98	0.91	19	0.29	3.54**	0.073	1.15	0.94	21
LLE	0.43ns	9.49**	1.15	2.78	0.70	13	2.282ns	10.35**	1.30	3.01	0.69	15
LWI	0.829ns	20.4**	2.49	5.97	0.70	14	2.96ns	23.2**	1.27	7.31	0.85	18
INN	11.11ns	34.48**	13.96	6.84	0.67	10	7.1ns	60.8**	3.65	19.05	0.84	18
BLE	676.83ns	2687.02**	513.47	724	0.58	18	645ns	3824.12**	169	1218	0.87	23
CHL	218.75 ns	244.23ns	194.8	16	0.07	5	271	1196**	56.97	380	0.87	23
BRI	0.914 ns	13.23**	0.841	4.16	0.83	20	0.729	13.62**	0.34	4.42	0.92	17
YPP	0.86 ns	4.24**	0.38	1.28	0.77	34	1.73*	2.39**	0.44	0.65	0.59	29

*$P < 0.05$; **$P < 0.01$; ns non-significant

Normal conditions

To summarize the variation among genotypes, traits were divided into vegetative traits and fruit traits. The differences among genotypes for all traits were significant under both growing conditions; however, the obtained results are indicative of high diversity among genotypes rather than the extent of diversity for the traits. To understand the extent of diversity, further analysis was carried out and genetic variance, broad-sense heritability (h^2) and GCVs% were calculated for all measured traits. High broad sense heritability was found for most traits under normal conditions. However, the lowest h^2 was calculated for chlorophyll content under normal conditions (0.07), which was expected, as there was no significant difference for this trait among genotypes. The highest GCV% was found for the number of fruits (250%). This extraordinary value was the consequent of inflating the variance of this trait by high fruit number of 'Mazandarani' accession (55 per plant). Subsequently, fruit weight (49%), skin and flesh weight (49%), total seed weight (44%), and fruit length (39%) were the most diverse traits of genotypes. It means that there is high genetic diversity for these traits and selection of best plants in future breeding programs will be effective. However, the lowest GCVs% were recorded for days to harvest (5%), chlorophyll content (5%) and internode number (10%). In fact, although the difference of genotypes for harvest time was significant, the range of harvest time was narrow (116-135).

Figure 3 shows the bi-plot of PCA for vegetative traits under normal conditions. The vegetative traits were chlorophyll content, branch length, leaf length, leaf width, and internode number. To show the relationships between these traits with the two essential traits of melon (yield per plant and total soluble solids), they are shown at the same plot. There is not any association between botanical groups and vegetative traits. Nevertheless, interestingly there is a high significant correlation between leaf length (r= 0.52) and width (r=0.57) with yield per plant.

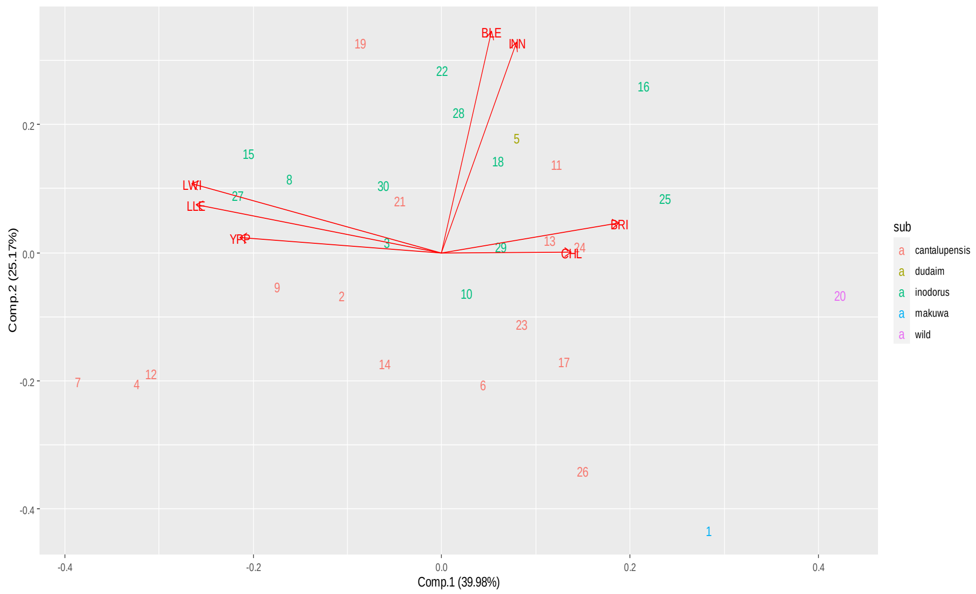

Fig. 3. Principal component analysis based on five vegetative traits and two traits of yield and TSS (ºBrix) measured in 30 melon genotypes under normal conditions. Mean measurements of three replications (10 plants in each replication) was used for this analysis. Trait vectors are also shown. BRI: brix or TSS (ºBrix), CHL: chlorophyll content measured with SPAD, BLE: branch length, LLE: leaf length, LWI: leaf width, INN: internode number, YPP: yield per plant. Altogether the two components explain approximately 65% of total variation. Each number is for one melon accession according to Table 1. The angle between the vectors shows the correlation between them.

Figure 4 shows the bi-plot of PCA for fruit traits measured under normal conditions. The traits in this analysis include days to harvest, fruit weight, flesh thickness, cavity diameter, fruit width, fruit length, brix or TSS (ºBrix), 100-seed weight, flesh and skin weight, total seed weight, seed length, seed width, number of fruit in each plant and yield per plant. This bi-plot is representative of 74.5% of total variations. There are high significant correlations between yield per plant, as the most important trait, with seed length (r=0.76), seed width (r=0.72), cavity diameter (r=0.70) and 100-seed weight (r= 60). In addition, high correlations were observed among fruit weight, flesh and skin weight, flesh thickness and fruit length. The genotypes are shown in this plot with numbers and different colors that show the botanical groups of melon genotypes. Inodorous group, with late maturity and big fruits, is clearly separated from other genotypes. Genotypes 'Ginsem Makuwa', 'Dastanbu', and 'Mazandarani' are also classified as three distinct genotypes.

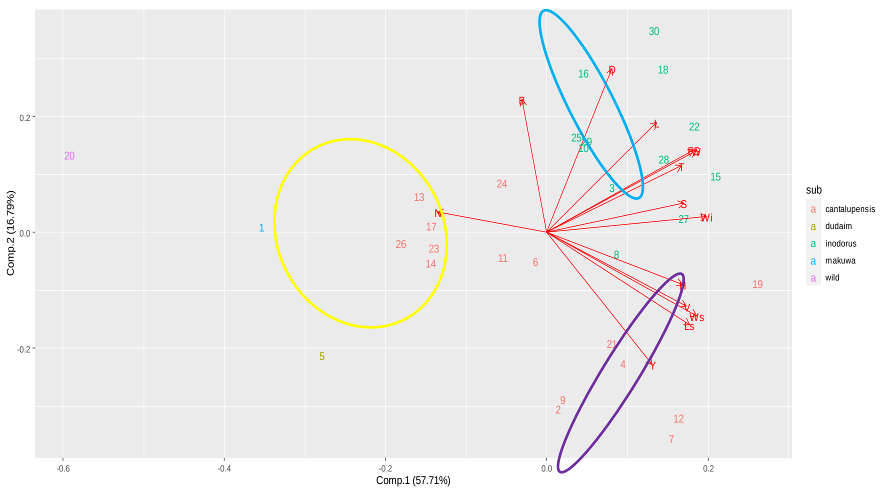

Fig. 4. Principal component analysis based on 14 traits measured in 30 melon genotypes under normal conditions. The traits are related to fruit. Mean measurements of three replications (10 plants in each replication) was used for this analysis. Trait vectors are also shown. D: Days to harvest, W: fruit weight, T: flesh thickness, V: cavity diameter, Wi: fruit width, L: fruit length, B: TSS (ºBrix), H: hundred seed weight, FS: flesh and skin weight, S: total seed weight, Ls:

seed length, Ws: seed width, N: fruit number in each plant, Y: yield per plant. Altogether the two components explain approximately 74.5 % of total variation. Each number is for one melon accession according to table 1. The angle between the vectors shows the correlation between them. Three distinct groups are shown in ellipses. Purple ellipse is shown three Iranian famous cantalupes, Rish-baba, Garmak and Mamaghani. These genotypes are shown to have the highest cavity diameter and a lot of seeds. Also they had the highest yield. The blue ellipse shows Nahavandi, Ghandoz, Bozorgsar and Uzbak2. These are inodorous genotypes with the biggest fruits. Yellow circle shows the foreign cantalupes and commercial melon hybrids which among other melon genotypes show the average values for most traits.

Drought stress conditions

High broad sense heritability was found for all traits under drought stress conditions. The highest GCV% was found for fruit number (127%) with the same description as provided before (see normal conditions). Following this trait, fruit weight (49%), skin and flesh weight (48%), total seed weight (47%), and fruit length (31%) were the most diverse traits among the genotypes, and these results are indicative of a good potential of these traits for breeding purposes. However, the lowest GCVs% were recorded for days to harvest (3%), leaf length (15%) and number of internodes (18%). Same as the normal conditions, the difference of genotypes for harvest time was significant, however, the range of harvest time was narrow (108-121).

The bi-plots of PCA for vegetative traits and fruit traits measured under drought stress conditions were very similar to that obtained under normal conditions (data not shown). In other words, similar to normal conditions, inodorous group was clearly separated from other melon genotypes. In addition, the correlations among traits were very close to the normal conditions.

Yield and TSS response under different growth conditions

Figure 5 shows the plot of yield under both drought and normal conditions. In average, the yields per plant were 3.32 and 2.76 kg/plant under normal and stress conditions, respectively, which is indicative of 17% of yield reduction. However, the reduction in yield per plant of melon genotypes was not equal for all genotypes. Under normal conditions, the highest yield obtained by 'Mamaghani' (5.82 kg/plant), 'Rish-baba' (5.78 kg/plant), 'Garmak' (5.22 kg/plant), 'Japuni' (4.73 kg/plant) and 'Samsoori-N' (4.7 kg/plant). The melon genotypes with highest yield per plant under stress conditions were 'Mamaghani' (4.93 kg/plant), 'Nahavandi' (3.91 kg/plant), 'Crenshaw' (3.88 kg/plant) and 'Shadegan' (3.71 kg/plant). In Figure 5, the genotypes near the trend line had average response toward drought stress. The genotypes above the line are those that are tolerant to drought, and have the least reduction in yield under stress conditions, and the genotypes below the trend line are those with highest reduction under stress conditions. For example, the yield of 'Samsoori', a popular cultivar from cantalupensis group, was 4.12 (kg/plant) and 2.16 (kg/plant) under normal and drought conditions, respectively. Forty-eight percent yield reduction as the consequence of drought exposure is indicative of high sensitivity of this genotype to drought stress. According to this plot, 'Nahavandi', 'Crenshaw', 'Shadegan', 'Suski-e-Sabz', and 'Mamaghani' are the most drought tolerant genotypes with the least reduction in yield under stress conditions.

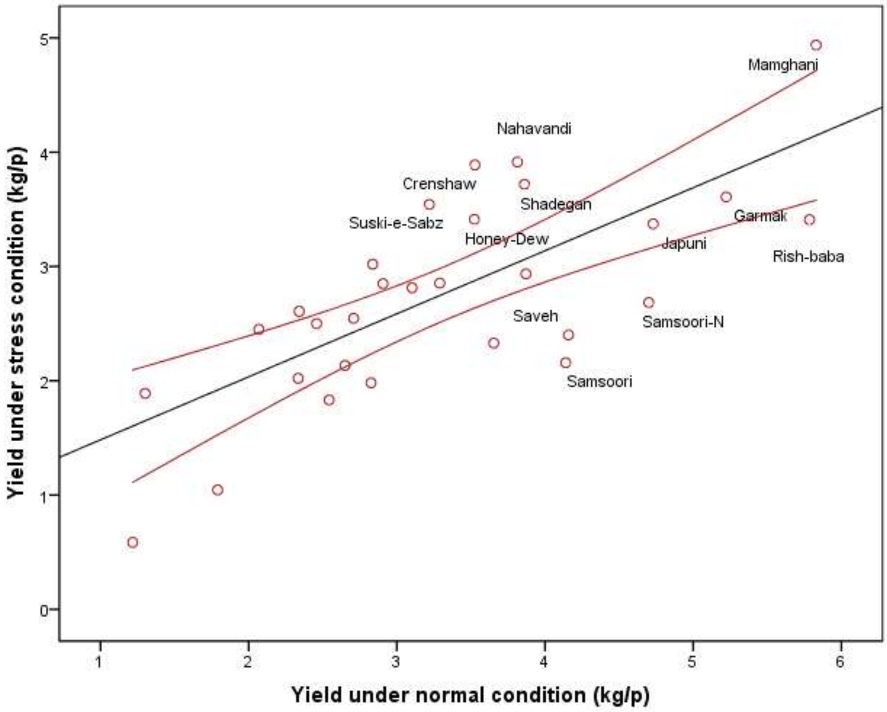

Fig. 5. Biplot of yield per plant under normal and stress conditions for 30 melon genotypes. Yield was measured in 10 plants in each replication. Under both conditions three replications were measured. The regression line is shown to reveal the average response of all genotypes to drought stress. The genotypes with high yield under normal and/or stress conditions are shown. Those genotypes above the regression line show the least reduction in yield under stress conditions in comparison to normal conditions. The slope is less than 1 which means yield under stress was lower than normal conditions.

The averages of TSS (ºBrix) were 10.6% and 11.6% under normal and stress conditions, respectively, which showing 12% increase under drought exposure (Fig. 6). Considering the average over two growth conditions, the top genotypes for TSS (ºBrix) were 'Honey-Dew' (15.2%), 'Japuni' (14.1%), 'Melon Golden' (13.9%), 'Ginsen-Makuwa' (13.9), 'Ghandoz' (13.1%), 'Tile-torogh' (13%), 'Crenshaw' (12.9%), 'Mahvalati' (12.4%), 'Galia2' (12.4%), and 'Shahpasand' (12.3%). The averages of TSS (ºBrix) for most Iranian commercial cultivars, 'Khatooni', 'Samsoori', and 'Saveh', were 10.7%, 10.09% and 9.2%, respectively, which are not satisfactory and should be noticed for improvement.

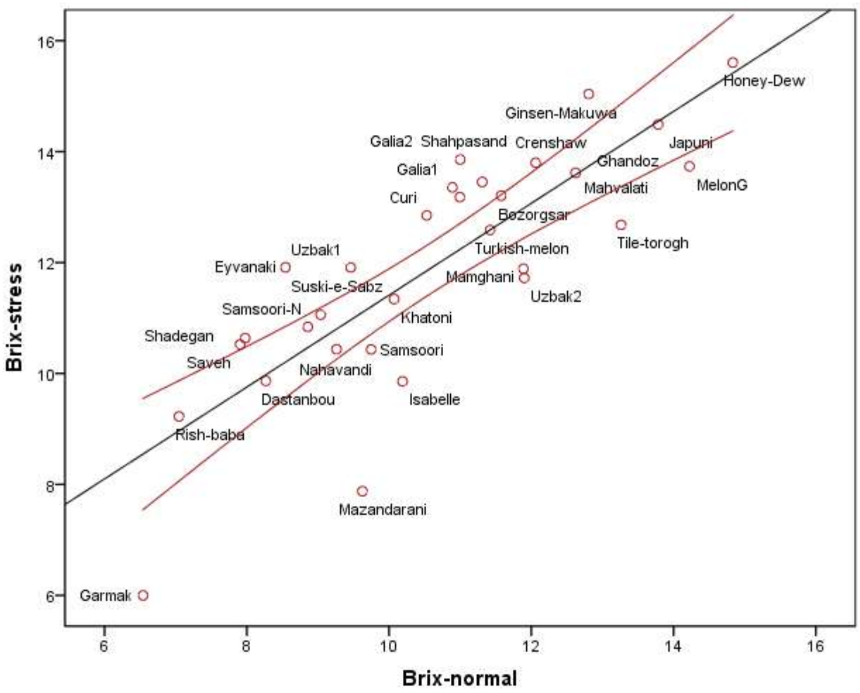

Fig. 6. Biplot of Brix% under normal and stress conditions for 30 melon genotypes. Brix% was measured in 10 plants in each replication. Under both conditions three replications were measured. The regression line is shown the average response of genotypes under two growing conditions. The highest Brix% was recorded in Honey-Dew while the lowest Brix% was for Garmak.

One of the most important features in melon that is very important for the market is flesh thickness. One of the remarkable features of modern melon is their thick flesh. The data obtained in this research showed that most of the Iranian genotypes have thin flesh while the modern hybrid cultivars have thick flesh. To have a better view of this trait, the ratio of flesh thickness to cavity diameter was calculated. The highest ratio was obtained for 'Curi' (0.8) and 'Turkish melon' (0.72), which their pictures are shown in Figure 1 (picture numbers 17 and 16, respectively). The most well-known Iranian cantaloupes, 'Samsoori' and 'Saveh', had ratios of 0.42 and 0.39, respectively. In addition, the most famous inodorous melon in Iran, 'Khatooni' had a ratio of 0.6. High genetic diversity and broad sense heritability was found for this trait in the current research.

Effective traits on yield per plant
To find the effective traits on yield per plant, stepwise regression was performed. Table 4 shows the results of this analysis for normal and stress conditions. Under normal conditions, seed length, fruit weight, fruit number and chlorophyll had a positive effect, while days to harvest had a negative effect on yield per plant. Under stress conditions, this analysis revealed fruit width as the only significant trait on yield per plant.

Discussion
The chlorophyll content was increased as the consequence of drought exposure in melon genotypes. Under normal conditions, plants grow until the end of growth season and new leaves develop that have naturally less chlorophyll, while under stress conditions due to shortage of water, new leaves do not develop, which leads to accumulation of chlorophyll in the old leaves.

In the present study, plants grown under normal conditions produced more fruits per plant (3.8) than drought stress conditions (2.5). A possible explanation for these results can be related to the retardation of development of new fruits because of drought stress, while under normal conditions the plants had opportunity to grow and to develop more fruits. Ibrahim et al. (2012) reported that drought stress significantly decreased weight, length, width, and flesh thickness of melon fruits. The main reason for this inconsistency is that in current study the drought stress was applied at the end of growing season while the others applied drought stress from the beginning of plant growth. In average, the time to harvest was 10 days earlier under stress conditions, compared to normal conditions. This can be related to the attempt of plants to keep their reproduction under stress conditions.

The average of RWC in this experiment under stress conditions was found 0.61. There was a high diversity among genotypes for this traits. The genotypes with high stability in yield under stress condition had high RWC while the sensitive genotypes such as 'Samsoori', 'Samsoori-N' and 'Saveh' found to have low RWC (Figure 2). It has been shown that when RWC is between 0.50 – 0.70, plants are under stress and tolerant genotypes express osmotic adjustment for avoiding further water loss (Blum, 2011).

TSSs (ºBrix) of melon fruits under stress conditions (11.9) were higher than the normal conditions (10.6). It seems that it is the common behavior of melon genotypes under drought stress and it has been observed in other studies (Mirabad et al., 2013). Sugar content in melon is the essential determinant of fruit quality and consumer acceptance (Argyris et al., 2017). High heritability for this trait was found in this study.

ANOVA results for different traits under each conditions showed significant difference among genotypes. This finding indicates the presence of considerable genotypic variation in the studied melon genotypes. Therefore, this variation can be used for selecting high potential fruit yield and drought-tolerant parents for future breeding programs. High genetic diversity was found among melon genotypes in this study. For most traits, the H^2_b was estimated over 0.5. In addition, high GCVs% were found for most traits. In a study conducted by Guliyev et al. (2018) the genetic diversity of melon genotypes collected from various parts of Azerbaijan was investigated. In their study, the highest GCV% was estimated 20.3 for yield while in current experiment, GCVs% for yield per plant under normal and stress conditions were 34 and 29, respectively. The reason for higher genetic diversity in current study is that melon genotypes in this experiment were collected from diverse places.

In this study, PCA analysis along with bi-plot was employed to show the relationship among the genotypes and the correlations among traits. In bi-plot of PCA, the angle between the vectors is an approximation of the correlation between the variables. A small angle indicates the variables are positively correlated, an angle of 90 degrees indicates the variables are not correlated, and an angle close to 180 degrees indicates the variables are negatively correlated (Sharma, 1995).

Yield reduction rate under drought stress conditions was variable among melon genotypes. Figure 5 depicts the yield per plant under normal and stress conditions for all studied genotypes. So far, different mechanisms for drought withstanding have been described in plants such as tolerance, avoidance and escape. Drought escape is a trait in plants that is related to early flowering under stress conditions. It means that if a genotype has a sufficiently early flowering, then in those locations with "late-season stress" they would in full or in part escape from drought exposure (Blum, 2011). However, it seems that this mechanism is frequently observed in grain plants such as cereals. Vegetables such as melon are producing flowers during time continuously. It means that after the harvest of first fruits, plant has the potential to develop new fruits. Our data support this hypothesis. 'Ginsen Makuwa', 'Dastanbou', 'Samsoori', 'Japuni' and 'Garmak' are those genotypes with earliest maturity, ranging from 116-118 days; however, they are not among the tolerant genotypes. The total amount of water consumed for plant production under normal conditions was approximately 9600 m^3/ha, while under stress conditions this amount was decreased to 7680 m^3/ha. It means that with cultivation of drought tolerant genotypes it is possible to save 1920 m^3/ha without significant reduction in yield. Enhancing crop water productivity under water deficit conditions is indicative of obtaining more production or value from consumed water (Jacob W. Kijne, 2003). Since the amount of consumed water in this study was calculated, therefore, it is possible to calculate the amount of water for production of melon in all genotypes. 'Nahavandi' genotype under stress conditions produced 3.91 kg per plant or 31.28 t/ha. It means that crop water productivity has been 4.07 kg/ m^3 of water consumed. Crop water productivity in different genotypes of melon in several studies have been reported in a range of 2.46-8.6 kg/ m^3 (Rashidi and Gholami, 2008).

In a study of genetic analysis of yield and fruit traits by diallel analysis, the narrow sense heritability was estimated to be 0.61 for flesh thickness (Pouyesh et al., 2017). Several QTLs have been reported for this trait previously (Wang et al., 2016). These findings show that improvement of flesh thickness in Iranian genotypes is possible with crossing them with modern cultivars.

Stepwise regression analysis showed that under stress conditions the effect of fruit width was significant on yield per plant. Heritability of yield per plant under stress conditions was obtained 0.59 while heritability of fruit width was obtained 0.90, hence, it is a proper trait for selection of best genotypes to have a higher yield under stress conditions. Under normal conditions, five traits were significantly effective on yield per plant. The effective traits with heritability estimated in parenthesis were seed length (0.94), days to harvest (0.97), fruit weight (0.76), fruit number (0.99) and chlorophyll content (0.07). As the heritability of seed length, days to harvest and fruit number are higher than yield per plant, they can be applied as selection indexes for producing high yield genotypes. Naroui Rad et al. (2017) also found that fruit number and fruit weight have significant effects on yield per plant in evaluation of 36 accessions of melon. Feyzian et al. (2009) found that umber of fruits per plant and fruit weight were the most effective traits on yield per plant in melon. Also, in other crops such as durum wheat (Topal et al., 2004) and sugarcane (Basnayake et al., 2015), due to low heritability of yield, the effective traits on yield with high heritability have been suggested for indirect selection.

Conclusion

A comprehensive comparison among a wide range of melon genotypes under drought stress revealed that yield stability was a key factor for evaluation of melon genotype. A good potential in melon genetic variation can facilitate the introducing of genotypes with yield stability and more water use efficiency under drought conditions. The development of genotypes with high yield under normal conditions and maintaining their yield under biotic and abiotic stresses are the main purposes of breeding programs. Accordingly, 'Mamaghani', 'Nahavandi', 'Shadegan', 'Crenshaw' and 'Suski-e-Sabz' genotypes were found to be more drought-tolerant; therefore, these genotypes are suggested as preferable and superior genotypes for cultivation in areas under drought stress conditions. The most effective traits on yield per plant were determined. These traits can be used for indirect selection of genotypes with higher yield. The data in this experiment shows that Iranian melon cultivars need to be improved for TSS (Brix%).

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Conflict of interest

The authors indicate no conflict of interest for this work

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