International Journal of Horticultural Science and Technology (2022) Vol. 9, No. 1, pp. 131-142

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

Estimation of yield combining ability and fruit-related traits using diallel analysis in melon (cucumis melo L.)

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ARTICLE INFO

Article history:

Received: 29 July 2020,
Received in revised form: 14 October 2020,
Accepted: 30 October 2020

Article type:

Research paper

Keywords:

General and specific combining ability,
Gene additive action,
Griffing,
Heritability

ABSTRACT

The purpose of this study was to estimate heritability, general and specific combining ability and the relationship between traits. Investigated traits were fruit number per plant, total yield per plant, average fruit weight, flesh thickness, flesh firmness, seed cavity size, total soluble solid, fruit length in melon. A complete diallel design was conducted for this purpose five parental genotypes were crossed and the hybrids were evaluated in a randomized complete block design with three replications. Analysis of variance of traits showed a significant differences between hybrids, therefore the first Griffing method was used to analyze the combining ability. The general combining ability effects were significant for all parents in the evaluated traits. The specific combining ability of yield per plant was higher than the general combining ability, which indicates the dominance and non-additive actions of genes. High narrow-sense heritability for yield per plant, flesh firmness and the number of fruit per plant (0.86, 0.72 and 0.70, respectively) indicated low environmental effect for these traits and the greater role of additive effects. The highest narrow-sense heritability was estimated for yield per plant (0.86). The role of non-additive effects of genes in controlling yield and flesh firmness traits was greater than additive effects. Therefore, the preparation of superior hybrids using breeding methods based on progeny tests will be effective in improving the mentioned traits in melon.

Introduction

Melon (*cucumis melo* L.) is one of the most important economic products in Iran and is widely cultivated. Iran is an important center of domestication, where it has been cultivated since 5000 years ago based on archaeological evidence (Bisognin, 2002). It is a common crop consumed by many Iranians, especially during the hot summer. Melon is the most polymorphic species of the cucurbit family, which is particularly true for fruit-related traits (Luan et al., 2010).

The use of hybrid seeds is very important in crop production. The choice of acceptable parents is one of the fundamental aspects for improving breeding program and the analysis of ability to combine potential parents allows identifying the most suitable parents for the transmission of desirable characters in commercial hybrids (Borem and Miranda, 2005). Several methods have been developed to study the genetic control of traits in plants. This information is obtained through quantitative genetic analysis such as diallel analysis, which is a common cross method for estimating genetic parameters and parental combination ability (Hallauer and Miranda, 1988). Diallel cross provides information on parental Heterotic relationships (Phumichai et al., 2008). Analysis of genetic information in plant breeding by different diallel methods is expressed by Griffing (Griffing, 1956). Diallel crosses are the most popular mating design used in plant breeding research to obtain information on genetic effects for parental lines or to estimate general combining ability (GCA), specific combining ability (SCA), variance components and heritability for a population from randomly chosen parental lines (Feyzian et al., 2009b). High yield, excellent quality, shape and size of fruit are prerequisites for the development of superior cultivars (Zalapa et al., 2006). Important traits in melon such as day to flowering, number of main branches, number of fruits and average fruit weight are correlated with yield (Lippert and Hall 1982; Taha et al., 2003; Vijay, 1987; Zalapa et al., 2006, 2008). Many studies have been done on the genetic control of fruit shape and show that this trait is highly heritable (Diaz et al., 2011; Eduardo et al., 2007; Monforte et al., 2004). In a study by Pouyesh et al., (2017) Seven parents of cantaloupes and their crosses were evaluated. The greatest general combining ability (GCA) for yield and fruit number was for Rish-baba (0.53 and 0.3 kg/plant, respectively). The cultivar Ananasi had the highest GCA for fruit weight and soluble solids content (SSC) (0.088 kg and 1.4, respectively). Ananasi presented the highest GCA values for fruit firmness, chlorophyll a and b and carotenoid content, as well as the highest total chlorophyll content. The cross Garmak × Rish-baba showed the highest specific combining ability (SCA) for yield. Feyzian et al., (2009b) using seven melon cultivars, including six local Iranian cultivars and one foreign cultivar in the form of a complete diallel design, traits such as ripening time, average fruit weight, yield and acceptable yield in pruning conditions were assessed over two years. The additive effect showed a greater role in fruit weight control and yield, while the dominance effect was more pronounced for traits such as ripeness and acceptable yield. In a study on cantaloupe conducted by Kalb and Davis (1989), it was found that the variance of general combining ability was very significant and was significantly higher than the variance of specific combining ability, which showed the importance of additive gene action. In another study, Barros et al., (2011) performed diallel analysis for yield and quality traits in melon, reporting that fruit number, yield, flesh firmness and soluble solids content were controlled by additive and non-additive gene effects. In the average fruit weight, flesh thickness and seed cavity size traits, the additive effect of genes played a more important role. In a study by Feyzian et al., (2009a) with genetic analysis of yield and its components by the diallel method in both pruning and non-pruning conditions on melons. They reported that the traits of fruit length, fruit width, flesh thickness and fruit weight in both condition, genes are controlled by the effects of relative dominance, while yield under pruning conditions is controlled by the effect of dominance.

The evaluation and determination of the type of gene action are important indicators for genetic improvement. Therefore, this study aimed to estimate gene function, combining ability and components of variance as well as estimate the narrow-sense and broad-sense heritability of traits. The results of this study can be implemented in developing breeding programs to increase and improve the quantity and quality of melons for the development of new commercial cultivars with high yield and smaller-sized fruits in breeding programs.

Material and methods

Three Iranian cultivars, namely "Khatouni", "Garmak", "Abadan", and two foreign cultivars of "Jafa" and "Japan" were crossed in 5 × 5 diallel crosses to produce the 20 possible F1 hybrids (Table 1). The study was conducted during two growing seasons 2017 and 2018 under field conditions in the horticulture station of the University of Tehran, Karaj, Iran. The field is located at 35º47' N latitude; 50º56' E longitude and 1312 m elevation. Average precipitation, temperature and humidity were 252 mm, 14.9ºC and 47% respectively. Total annual precipitation was 263 mm in the first year and 275 mm in the second year. Soil characteristics were, texture = clay loam, pH value = 8, electrical conductivity = 1.31 ds/m, organic matters = 0.94%, available K_2O = 256 mg/kg, available P_2O_5 = 84.5 mg/kg, total nitrogen = 0.1% and $CaCO_3$ = 6.7%. The soil was tilled by moldboard plowing and disking, 14 days before planting. The transplanting was done 14 days after planting in soil. Weeds were manually removed starting 30 days after transplanting. Five plants were used for each cross. The female and male flowers used in manual pollination were identified in day before anthesis by the appearance of a slight touch of yellow at the apex of the corolla tube. To protect the flowers from insect pollination, they were prevented from opening by tying the tips of the corolla tube. The following morning, male flowers and all their petals were removed and the stamens containing pollens were transferred into female flowers, then the flowers were closed again (Hazra et al., 2007). After harvesting of ripe fruits, seeds were extracted and stored for use in the next year. In the second season (summer of 2018), the seeds of both the parents and F1 hybrids were planted (total of 20 hybrids plus five parents). The experiment was arranged in a randomized complete block design (RCBD) with three replications and five plants per replication to evaluate 25 treatments (five parents and 20 hybrids). Spacing was 2 m between rows and 1 m between plants.

Table 1. The five melon parents used in diallel crosses and their descriptive features.

Name of cultivar	Origin	Distinctive features

Katouni	Khorasan	Long shape, cream to yellow skin, white to yellow flesh, group Inodorus	
Garmak	Bushehr	Oval shape, yellow skin, cream to yellow flesh, group Cantalupensis	
Jafa	Japan	Round shape, ivory and cream to red skin, orange flesh, group Cantalupensis	
Japan	Japan	Round shape, green skin, white to green flesh, group Cantalupensis	
Abadan	Abadan	Round shape, cream to yellow skin, yellow flesh, groupe Inodorus	

Fruit from plants in each replication were randomly harvested for the traits measurement: total number of fruits per plant (this trait was obtained by calculating the total number of fruits, which harvested per plant at the end season), average fruit weight (total number of fruit per plant divided by the total weight per plant), total fruit yield per plant (It was measured from the total weight in kilograms of harvested rips fruits per plant at the end of harvesting season), total soluble solids (drops of juice were extracted from the equatorial region of mesocarp, TSS measured using a refractometer), flesh firmness (was evaluated using a penetrometer with 11-mm-diameter tip), fruit thickness (It was measured as average length of flesh thickness fruits in centimeters for the selected fruits.), fruit length (it was measured as average length of fruits in centimeters for the selected plants) , fruit width (It was measured as average width of fruits in centimeters for the selected plants) and seed cavity size (it was evaluated as average seed cavity size of fruits in centimeters for the selected plants).

Statistical analysis

The analysis of variance for GCA, SCA and reciprocal effects was carried out according to Griffing (1956) method 1, model 1 with SAS procedure of diallel and estimates of $\delta^2 g$ (general combining ability), $\sigma^2 s$ (specific combining ability), $\delta^2 r$ (reciprocal effects) and their variances were computed for the random-effects to estimates h^2 (heritability) (Zhang and Kang, 1997). Broad-sense and Narrow-sense heritabilities were calculated according to Teklewold et al. (2005)

$$h^2 b = \frac{2\delta^2 gca + \delta^2 sca}{2\delta^2 gca + \delta^2 sca + \delta^2 e}$$

$$h^2 n = \frac{2\delta^2 sca}{2\delta^2 gca + \delta^2 sca + \delta^2 e}$$

The combining ability ratio (Baker ratio) was calculated according to Baker (1978) as follow:

$$GCA : SCA = \frac{2\delta^2 g}{(2\delta^2 g + \delta^2 s)}$$

Results

Fruit number per plant

Analysis of variance shows, there were highly significant ($p \leq .01$) differences among genotypes (Table 2). The parent with the highest ranking for fruit number per plant was "Garmak" (9.667) followed by "Japan" (8.667) and among the F1 hybrids, Jafa × Japan (10.333), followed by Japan × Garmak (7.333) displayed the best performance for this trait (Table 3). The highest and the lowest GCAs for fruit number per plant were also exhibited by "Jafa" and "Garmak" respectively (Table 5). The highest SCA for fruit number per plant was found for the cross Jafa × Japan (1.287), while the maximum positive reciprocal effect (REC) values were observed in hybrids of Garmak × Japan (1.5) (Table 6). The GCA: SCA ratio (0.53) confirmed the importance of additive gene action (Table 2). Broad sense and narrow sense heritabilities for this trait were 0.75 and 0.70 respectively (Table 2).

Table 2. Analysis of combining ability, GCA:SCA ratio and heritability estimates for measured traits in melons.

Source	df	MS								
		FN	FY	AFW	FF	FT	SCS	TSS	FL	FW
Rep	2	4.85^{ns}	9.96 ^{ns}	0.128 ^{ns}	5.62**	1.6**	0.022 ^{ns}	8.54**	0.61 ^{ns}	1.33 ^{ns}
Genotype	24	9.41**	24.1**	0.799**	5.03**	0.77**	3.45**	10.62**	132.74**	5.57**
GCA	4	16.34**	20.32**	2.58**	4.48**	1.99**	3.58**	28.26**	539.04**	16.89**
SCA	10	11.58**	29.78**	0.59**	3.97**	0.66**	2.65**	6.56**	24.16**	1.48 ^{ns}
REC	10	4.48**	20.27**	0.29*	6.306**	0.39*	4.19**	7.62**	78.80**	5.13**
Error	48	1.64	4.61	0.108	0.706	0.17	0.55	1.03	3.22	1.077
σ^2 g		65.37	81.31	10.32	17.93	7.96	14.33	113.05	2156.16	67.58
σ^2 s		115.84	297.83	5.95	39.77	6.69	26.52	65.63	241.65	14.88
σ^2 r		44.83	202.72	2.090	63.06	3.93	41.97	76.26	788.04	51.34
GCA:SCA		0.53	0.35	0.77	0.47	0.70	0.51	0.77	0.94	0.90
H^2 b		0.75	0.86	0.83	0.72	0.73	0.67	0.85	0.96	0.73
H^2 n		0.70	0.67	0.37	0.68	0.43	0.64	0.38	0.10	0.14

*,** and ns Significantly different from zero at 5% and 1% probability levels, and no Significantly different respectively. FN = Fruit number per plant, FY = Fruit yield per plant (Kg/plant), AFW = Average fruit weight (Kg), FF = Fruit firmness (N/cm^2), SCS = Seed cavity size (Cm), TSS = Total soluble solid (%), FL = Fruit length (Cm), FW = Fruit width (Cm).

Fruit yield per plant

The analysis of variance for fruit yield per plant indicated significant differences among genotypes. Analysis of combining ability shows that GCA, SCA, reciprocal effects were significant (Table 2). The GCA: SCA ratio (0.35) Obtained (Table 2). Among parents "Jafa" had the highest fruit yield per plant (15.450 kg/ plant) and among the F1 hybrids, Jafa × Abadan (14.114 kg/ plant), followed by Jafa × Japan (13.041 kg/ plant) and Khatouni × Abadan (11.949 kg/ plant) displayed superior performance for this trait (Table 3). The greatest positive GCA, that is contribution to higher yield, was exhibited by "Jafa" (0.944), and the greatest negative GCA for this trait was calculated for "Japan" (-1.075) (Table 5). The Hybrid of Khatouni × Abadan had the highest positive SCA (1.026 kg/ plant), while the highest positive reciprocal effect (REC) values were observed in hybrid Japan × Abadan (2.293 kg/plant) and Khatouni × Jafa (1.776) (Table 6). Broad sense and narrow sense heritabilities for this trait were 0.86 and 0.67 respectively (Table 2), suggest the improvement of this trait will be easily possible via selection.

Average fruit weight

Based on the ANOVA table, a significant difference existed among genotypes (Table 2). The parent with the highest ranking for average fruit weight was "Abadan" (3.059 kg) followed by "Jafa" (2.110 kg) and among the F1 hybrids, Khatouni × Garmak (2.366 kg), followed by Jafa × Khatouni (2.308 kg), Khatouni × Jafa (2.222 kg) and Khatouni × Abadan (2.144 kg) displayed the best performance for this trait (Table 3). The highest positive GCA was measured for "Abadan" (0.267), while the largest negative GCA calculated for "Japan" was (-0.481) (Table 5). Combining ability analysis showed significant effects of general and specific combining ability for average fruit weight trait, indicating the importance of both additive and dominance effects in controlling these traits. The GCA: SCA ratio (0.77) confirmed the importance of additive effect compared to the dominance gene action in shaping this trait (Table 2). Broad sense and narrow sense heritabilities for this trait were 0.83 and 0.37 respectively (Table 2).

Fruit firmness

Two parents "Japan" and "Jafa" had the highest fruit firmness (11.833 N/cm^2) and (11.667 N/cm^2) respectively and among F1 hybrids, Japan × Khatouni (11.833 N/cm^2), followed by Jafa × Japan (11.667 N/cm^2) had the highest flesh firmness (Table 3). The highest positive (0.457) and negative (-0.59) GCAs were recorded for "Japan" and "Khatouni" respectively and hybrids of Khatouni × Garmak (0.752) and Khatouni × Abadan (0.609) had the highest positive SCA. While the highest positive reciprocal effect (REC) values were observed in the hybrid of Khatooni × Japan (2.050) and Garmak × Jafa (1.575) (Tables 5 and 6). Broad sense and narrow sense heritabilities for this trait were 0.72 and 0.68 respectively (Table 2).

Table 3. Mean comparison of measured traits in melon parents and their F1 hybrid offsprings.

Genotypes	FN	FY	AFW	FF
Khatouni (1)	6.333±1.2 ce	11.080±1.91 bg	1.774±0.1 cg	10±0.57 cf
Garmak (2)	9.667±1.76 a	13.453±1.36 ac	1.426±0.11 fh	9.583±0.74 fh
Jafa (3)	7.333±0.33 bc	15.450±0.47 a	2.110±0.05 be	11.667±0.33 ab

Japan (4)	8.667±0.33 ab	11.650±0.69 bf	1.342±0.03 gh	11.833±0.16 ab
Abadan (5)	4.667±0.88 dg	14.288±2.85 ab	3.059±0.25 a	9.983±0.44 cf
1×2	4 fg	10.133±0.16 ch	2.366±0.18 b	9.833±1.48 dg
1×3	3.333±0.33 g	7.246±0.76 hj	2.222±0.33 bd	8.567±0.34 gi
1×4	5.667±1.2 cf	8.466±0.81 ej	1.605±0.32 eg	7.733±0.4 i
1×5	5.667±0.66 cf	11.949±0.47 ae	2.144±0.15 bd	9.750±0.8 eh
2×1	4.333±0.33 eg	8.461±0.9 ej	2.004±0.33 be	11.167±0.44 ad
2×3	4.667±0.66 dg	8.652±1.87 ei	1.895±0.32 bf	8.417±0.82 hi
2×4	4.333±0.33 eg	6.835±0.59 ij	1.577±0.09 eh	9.583±0.74 fh
2×5	4±1 fg	6.787±1.42 ij	1.729±0.11 dg	11.083±0.5 ae
3×1	4.667±0.33 dg	10.817±1.09 bh	2.308±0.08 bc	7.600±0.2 i
3×2	5.333±0.88 cg	8.748±0.66 ei	1.687±0.14 dg	11.567±0.23 ab
3×4	10.33±0.88 a	13.041±1.05 ad	1.262±0.01 gi	11.667±0.33 ab
3×5	6.333±1.2 ce	14.114±3.63 ab	2.100±0.36 be	11.567±0.23 ab
4×1	6.333±0.33 ce	7.870±0.56 gj	1.246±0.09 gi	11.833±0.16 ab
4×2	7.333±0.33 bc	7.664±0.14 gj	1.049±0.05 hi	12 a
4×3	6.667±0.66 bd	5.069±0.8 j	0.776±0.09 i	11±0.57 ae
4×5	6.667±0.66 bd	5.069±0.8 j	0.776±0.09 i	11±0.57 ae
5×1	5.667±0.33 cf	10.963±0.15 bg	1.946±0.09 bf	11.333±0.33 ac
5×2	4.333±0.33 eg	8.266±0.84 gj	1.907±0.11 bf	10.567±0.23 bf
5×3	4.667±0.33 dg	8.552±1.06 ej	1.724±0.18 dg	9.983±0.44 cf
5×4	5.333±0.33 cg	9.656±0.49 ei	1.723±0.18 dg	9.983±0.44 cf

FN = Fruit number per plant, FY = Fruit yield per plant (Kg/plant), AFW = Average fruit weight (Kg), FF = Fruit firmness (N/cm²).

Fruit thickness

In combining ability analysis, the fruit thickness general and specific combining ability were significant ($P<0.01$) (Table 2). Significance of the GCA and SCA effects shows that genes with additive effects and dominance are involved in controlling the fruit thickness. The parent with the highest ranking for fruit thickness was "Jafa" (4.967 cm) followed by "Garmak" (4.167 cm) and "Khatouni" (4.1 cm) and among the F1 hybrids, Abadan × Garmak (4.5 cm) followed by Abadan × Jafa (4.367 cm) displayed the best performance for this trait (Table 4). The highest positive (0.221) and negative (-0.402) GCAs were observed for "Garmak" and "Japan" respectively and the estimated SCA effects showed that hybrid Japan × Abadan (0.365) gave the highest positive SCA, and the highest positive reciprocal effect (REC) values were recorded in reciprocal hybrids of Japan × Abadan (0.4) (Tables 5 and 6). GCA: SCA ratio (0.70) indicates that the additive gene effects are more important in explaining the variation of this trait (Table 2). Since this trait has a positive and high correlation with the two traits of yield and average fruit weight, using it as a selection index will be very effective in increasing these two traits. Broad sense and narrow sense heritabilities for this trait were 0.73 and 0.43 respectively (Table 2).

Table 4. Mean comparison of measured traits in melon parents and their F1 hybrid offsprings.

Genotypes	FT	SCS	TSS	FL	FW
Khatouni (1)	4.1±0.05 be	6.333±0.2 fg	11.333±0.66 cf	30.733±0.39 ab	10.167±0.44 h
Garmak (2)	4.167±0.08 be	6.4±0.05 fg	10.667±0.33 ef	17.7±0.85 ef	14.267±0.28 ab
Jafa (3)	4.967±0.29 a	7.867±0.44 be	9.967±1.01 fg	15.9±0.97 ef	12.067±0.92 dg
Japan (4)	3.067±0.08 g	6.5±0.28 fg	12.5±0.86 bd	12.5±0.28 g	11.4±0.1 fh
Abadan (5)	3.567±0.37 eg	8.3±0.15 ad	8.667±0.16 gh	18.1±0.37 e	12.6±0.2 bg
1×2	4.167±0.44 be	6.667±0.72 eg	11.167±1.3 cf	28±2.88 bc	13.733±1.27 ad
1×3	3.267±0.14 fg	6.1±0.05 fg	7.933±0.34 h	28.333±0.49 bc	11.233±0.5 gh
1×4	3.033±0.23 g	5.867±0.74 g	14±0.57 b	32.4±1.42 a	10.167±0.44 h
1×5	4.333±0.44 ad	8.933±0.52 ab	10.333±0.33 eg	31.333±2.33 a	11.8±0.8 fh
2×1	4.1±0.3 be	8.533±0.26 ac	12.5±0.86 bd	30.867±0.46 ab	14±0.57 ab
2×3	4.333±0.27 ad	7.267±0.37 df	11.233±0.53 cf	18.833±0.44 e	14.933±0.75 a
2×4	3.567±0.47 eg	7.333±0.33 cf	11.333±0.33 cf	23.467±1.03 d	13.833±0.83 ac
2×5	3.767±0.14 cf	7.333±0.66 cf	10.667±0.33 ef	17.7±0.85 ef	14.267±0.28 ab
3×1	3.667±0.16 dg	9.167±0.44 a	9.933±0.63 fg	27.667±1.45 c	13.067±0.74 bf
3×2	4.267±0.42 bd	5.8±0.6 g	9.767±0.86 fg	15.9±0.97 ef	12.067±0.92 dg
3×4	3.067±0.08 g	5.767±0.24 g	11.833±0.92 ce	12.333±0.6 g	11.9±0.43 eg
3×5	4.333±0.49 ad	6.1±0.51 fg	9.967±1.01 fg	15.9±0.97 ef	12.067±0.92 dg

4×1	3.5±0.05 eg	5.733±0.12 g	14±0.57 b	18.767±0.81 e	11.867±0.56 fh
4×2	4.167±0.2 be	6.467±0.55 fg	17±0.57 a	14.9±0.51 fg	12.133±0.24 cg
4×3	3.567±0.29 eg	5.8±0.17 g	12.5±0.86 bd	12.5±0.28 g	11.4±0.1 fh
4×5	3.567±0.29 eg	5.8±0.17 g	12.5±0.86 bd	12.5±0.28 g	11.4±0.1 fh
5×1	3.667±0.12 dg	5.567±0.06 g	10.833±0.16 df	16.633±0.13 ef	13.6±0.15 ae
5×2	4.5±0.28 ab	7.767±0.53 be	12±0.28 ce	18.433±0.47 e	13.767±0.63 ad
5×3	4.367±0.03 ac	0.753±0.5 fg	12.833±0.16 bc	17.833±0.44 ef	14.267±0.37 ab
5×4	4.367±0.03 ac	0.753±0.5 fg	12.833±0.16 bc	17.833±0.44 ef	14.267±0.37 ab

FT = Flesh thickness (Cm), SCS = Seed cavity size (Cm), TSS = Total soluble solid (%), FL = Fruit length (Cm), FW = Fruit width (Cm).

Seed cavity size

The parent "Abadan" had the highest seed cavity size (8.2 cm), followed by "Jafa" (7.867 cm) and among the F1 hybrids, Jafa × Abadan (9.167 cm), followed by Khatouni × Abadan (8.933 cm) and Garmak × Khatouni (8.533 cm) revealed superior performance for this trait (Table 4). "Japan" had negative GCA for seed cavity size. The highest positive GCA was recorded for "Abadan" (0.249) (Table 5). The Hybrid of Khatouni × Jafa had the highest positive SCA (0.703), While the highest positive reciprocal effect (REC) values were observed in the reciprocal effect (REC) of Khatouni × Jafa (1.533) and Khatouni × Garmak (0.933) (Table 6). Broad sense and narrow sense heritabilities for this trait were 0.67 and 0.64 respectively (Table 2).

Total soluble solids

Among the parents, the highest value of this trait belonged to "Japan" (12.5 %) and among the F1 hybrids, Japan × Garmak (17 %), followed by Japan × Khatouni (14 %) displayed the best performance for this trait (Table 4). "Japan" showed the highest positive GCA (1.568), while "Jafa" showed the lowest values (-0.939). The estimated SCA effects showed that the hybrid of Jafa × Abadan gave the highest positive SCA (1.409). Meanwhile, the highest positive reciprocal effect (REC) values were observed in the hybrids of Garmak × Japan (2.833) and Jafa × Abadan (1.433) (Tables 5 and 6). Broad sense and narrow sense heritabilities for this trait were 0.85 and 0.38 respectively (Table 2).

Table 5. Estimation of general combining ability (GCA) of parental genotypes in diallel analysis of fruit related traits in melons.

Parent	FN	FY	AFW	FF	FT	SCS	TSS	FL	FW
Khatouni (1)	-0.62	0.036	0.188	-0.59	-0.105	0.107	-0.195	7.264	-0.671
Garmak (2)	-0.087	-0.527	-0.044	-0.034	0.221	0.181	0.168	0.067	1.076
Jafa (3)	0.213	0.944	0.069	-0.002	0.181	0.007	-0.939	-2.173	-0.144
Japan (4)	1.147	-1.075	-0.481	0.475	-0.402	-0.589	1.568	-3.313	-0.647
Abadan (5)	-0.653	0.621	0.267	0.151	-0.104	0.249	-0.602	-1.846	0.413

FN = Fruit number per plant, FY = Fruit yield per plant (Kg/plant), AFW = Average fruit weight (Kg), FF = Fruit firmness (N/cm^2), FT = Flesh thickness (Cm), SCS = Seed cavity size (Cm), TSS = Total soluble solid (%), FL = Fruit length (Cm), FW = Fruit width (Cm).

Fruit length

For the fruit length trait, parent "Khatouni" had the highest fruit length among parents (30.733 cm) and among the F1 hybrids, Khatouni × Japan (32. 4 cm), followed by Khatouni × Abadan (31.333 cm) and Garmak × Khatouni (30.867 cm) displayed superior performance for this trait (Table 4). For this trait, the mean squares of general and specific combining ability were significant and showed the effect of additive and non-additive action of genes on this trait. The highest positive (7.264) and negative (-3.313) GCA were respectively observed for "Khatouni" and "Japan" and the estimated SCA effects showed that hybrid Khatouni × Jafa (2.626) gave the highest positive SCA, and the highest positive reciprocal effect (REC) values were recorded in hybrids of Japan × Abadan (2.667) (Tables 5 and 6). GCA: SCA ratio (0.94) indicated that the role of additive effect was greater than the non-additive effect of genes in controlling this trait, which was in agreement with the research of Gurav et al., (2000). Broad sense and narrow sense heritability for this trait were 0.96 and 0.10 respectively (Table 2).

Fruit width

For the fruit width trait, the parent with the highest ranking for fruit width was "Garmak" (14.267 cm) followed by "Abadan" (12.6 cm), "Jafa" (12.067 cm) and among the F1 hybrids, Garmak × Jafa (14.933 cm), displayed the best performance for this trait (Table 4). Analysis of variance showed the mean squares of general combining ability and reciprocal crosses for the fruit width trait were significant (Table 2). The highest positive GCA was measured for “Garmak" (1.076), while the highest negative GCA calculated for “Khatouni" was (-0.671) (Table 5). Khatouni × Garmak had the highest positive SCA (0.811) (Table 6). In a study by Feizian et al., (2009c), they reported a direct, positive and high effect of fruit width with average fruit weight. Therefore, selection for this trait will be very effective in increasing the average fruit weight. GCA: SCA ratio (0.90) indicated a greater role of additive effects than non-additive effects in controlling this trait. Broad sense and narrow sense heritabilities for this trait were 0.73 and 0.14 respectively (Table 2).

Table 6. Estimation of specific combining ability (SCA) and reciprocal effect (REC) in the F1 generation for measured traits in melons.

Cross	FN	FY	AFW	FF	FT	SCS	TSS	FL	FW
S12	-0.98	0.016	0.290	0.752	0.119	0.496	0.329	1.819	0.811
S13	-1.447	-1.712	0.257	-1.696	-0.508	0.703	-1.465	2.626	0.314
S14	-0.38	-0.566	-0.033	-0.473	-0.125	-0.534	1.095	1.349	-0.289
S15	1.087	1.026	-0.160	0.609	0.102	0.033	-0.151	-1.717	0.307
S23	-0.98	-1.489	0.015	-0.345	-0.001	-0.471	-0.261	-0.811	-0.083
S24	-1.08	-0.921	0.087	-0.021	0.149	0.493	0.899	2.146	-0.069
S25	-0.947	-2.340	-0.155	0.335	-0.091	0.259	0.235	-0.437	-0.123
S34	1.287	-0.585	-0.320	0.489	-0.361	-0.451	0.005	-2.381	-0.183
S35	0.087	-0.004	-0.174	0.254	0.165	-0.817	1.409	0.603	0.247
S45	-0.347	-1.956	-0.287	-0.506	0.365	-0.371	0.169	0.043	0.444
R12	0.167	-0.836	-0.181	0.667	-0.033	0.933	0.667	1.433	0.133
R13	0.667	1.776	0.043	-0.483	0.2	1.533	1	-0.333	0.917
R14	0.333	-0.298	-0.180	2.050	0.233	-0.067	0.000	-6.817	0.850
R15	0.000	-0.493	-0.099	0.792	-0.333	-1.683	0.250	-7.350	0.900
R23	0.333	0.048	-0.104	1.575	-0.033	-0.733	-0.733	-1.467	-1.433
R24	1.5	0.414	-0.264	1.208	0.3	-0.433	2.833	-4.283	-0.850
R25	0.167	0.739	0.089	-0.208	0.367	0.217	0.667	0.367	-0.250
R34	-1.833	-3.986	-0.243	-0.333	0.250	0.017	0.333	0.083	-0.250
R35	-0.833	-2.781	-0.188	-0.792	0.017	0.200	1.433	0.967	1.100
R45	-0.667	2.293	0.474	-0.508	0.400	0.350	0.167	2.667	1.433

FN = Fruit number per plant, FY = Fruit yield per plant (Kg/plant), AFW = Average fruit weight (Kg), FF = Fruit firmness (N/cm^2), FT = Flesh thickness (Cm), SCS = Seed cavity size (Cm), TSS = Total soluble solid (%), FL = Fruit length (Cm), FW = Fruit width (Cm).

Discussion

The values of GCA mean squares were higher than those of SCA mean squares for all studied traits except yield, which implies the role of both additive and dominant gene effects in controlling these traits. In the line with our results, Feyzian et al., 2009b; Pradip et al., 2013 and Sanin et al., 2014 reported higher of GCA variance values compared with SCA variances in melon resulted in higher values of GCA: SCA ratio. Among the parents, “Jafa" had the highest general combining ability for yield per plant, thus “Jafa" may be useful in breeding programs intending to increase yield. The GCA: SCA for this trait was less than half, which indicates the greater role of genes with non-additive effects in controlling this trait. On the other hand, Zapala et al., (2008) expressed the genetic effects of dominance and epistasis in controlling this trait. Low specific heritability for yield was also estimated, indicating a non-additive action was more important in the inheritance of this trait. In Lippert and Hall (1982) research, low specific heritability was reported for this trait. Abadan parent had the highest general combining ability for average fruit weight and according to the higher value of GCA: SCA ratio indicates that the additive gene effects are more important in explaining the variation of this trait in these melons (Kalb and Davis, 1989). However, a greater role in controlling the average fruit weight was reported in the study of mean generation analysis on two cantalotpe cultivars (Zalapa et al., 2006). The fruit number per plant is one of the important breeding traits and affects yield. Among parents, “Japan" had the most general combining ability for fruit number per plant. On the other hand, this parent had a high broad sense and narrow sense heritabilities for this trait, suggest the improvement of this trait will be easily possible via selection. These results were close to the findings of a study on a cantaloupe cultivar that estimated specific heritability for this trait in the 0.68 and 0.70 range (Zalapa et al., 2008). Genotypes with the highest GCA effect, possess more genes with additive effects (Nataša et al., 2014) and they are of great importance to the generation of superior offsprings. This indicates that this trait is heritable (Ogbu et al., 2016). Accordingly, these genotypes could be used as an appropriate parent for breeding purposes for that trait (Zeinanloo et al., 2009; Nataša et al., 2014). Moreover, significant values of GCA for a trait indicates that selection and due to the accumulation of promising genes of the two parents in the resulting genotype, hybridization approaches would result in an interesting genetic improvement of this trait (Golabadi et al., 2015). It is worth noting that for the development of synthetic varieties, lines with higher GCA effects can be more efficient (Hemalatha et al., 2014). Therefore, these three parents ("Jafa", "Abadan" and "Japan") may be useful for further improving yield. Among the hybrids present in the current study, the Japan × Abadan hybrid had a positive and relatively high yield. If the goal is not for the breeder to achieve large fruits, which is receiving more attention today, choosing the trait of having more fruits per plant will lead to increased yield. Due to the high heritability for the fruit weight trait and the low impact of the environment on it, selection for this trait in the first generations can be successful. The high and positive correlation of this trait with yield also shows the high efficiency of selecting this trait to increase yield. The high diversity in melons indicates the existence of desirable genetic materials for different breeding purposes. Therefore, it can be recommended to have the same study on local accessions in order to guarantee the diversity among genotypes. These studies can be used to select superior cultivars in terms of the traits of interests. Therefore, at the beginning of breeding programs, experiments should be performed to estimate the combining ability of valuable melon accessions that have the desired trait for breeding. For short-term breeding goals of melons, the average and low fruit weight along with more fruits per plant and high sugar content of the fruit should be prioritized. The development of a breeding program to introduce elite inbred cultivars according to our current needs and supplying first generation hybrid seeds to the market will help the genetics improvement of melons.

Acknowledgments

The authors are thankful of the Horticultural Department of tehran University for providing research facilities.

Conflict of Interest

The authors indicate no conflict of interest for this work.

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