Adv. Hort. Sci., 2018 32(4): 459-470

DOI: 10.13128/ahs-22479

AHS
Advances in Horticultural Science

Combining ability and gene action of some tomato genotypes under low light condition

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Key words: combining ability, diallel, heritability, light intensity, reciprocal effects, *Solanum lycopersicum*.

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Citation:
EMAMI S., NEMATI S.H., AZIZI M., MOBLI M., 2018 - *Combining ability and gene action of some tomato genotypes under low light condition*. - Adv. Hort. Sci., 32(4): 459-470

Data Availability Statement:
All relevant data are within the paper and its Supporting Information files.

Competing Interests:
The authors declare no competing interests.

Received for publication 10 January 2018
Accepted for publication 16 May 2018

Abstract: Limitations in access to electricity in rural areas and substantial cost of supplemental lightning necessitate breeding as response to low light conditions. Seven inbred lines of tomato (*Solanum lycopersicum* L.) and their F1 hybrids, including reciprocals, developed through a 7×7 full diallel cross were evaluated under two different levels of light. Mean square for light (L) effect was significant for total yield, average fruit weight and days to first flower. Variation attributable to Genotypes and genotype × light (G×L) interaction had significant effect on all studied traits except days to ripening for which G×L interaction was not significant. Diallel analysis across two environments indicated that general (GCA), specific (SCA) and reciprocal combining ability (REC) were significant for all characters implying importance of additive and non-additive gene action along with cytoplasmic effects on genetic expression of yield, yield components and earliness. Ratio of SCA variance to SCA variance and estimates of narrow sense heritability ($h^2_{n.s}$) demonstrated higher weight of additive effects in inheritance of yield, fruit number and days to ripening, while indicating predominance of non-additive effects for fruit weight and early flowering. Interactions GCA×L and SCA×L were significant for almost all studied features. A particular genotype could not be recommended for all traits, but variation among genotypes in response to ambient light was promising for feasibility of plant breeding for non-optimal light intensity and duration.

1. Introduction

Tomato (*Solanum lycopersicum* L.), a member of solanaceae family, is a wide cultivated vegetable used for fresh and processing market. This day neutral plant is grown in various regions of the world with different climates (Mizoguchi *et al*., 2007; Gerszberg *et al*., 2015). Iran is among the top 10 countries producing tomato (FAOSTAT, 2014), but it performs very poorly in terms of tomato seed production and a large portion of the seeds, particularly hybrid cultivars, is imported to the country. The major obstacle to seed production in Iran is the absence of breeding programs for most of the vegetables including tomato; therefore, more attention to vegetables breeding in order to produce high quality seeds is required.

Hybrid breeding technique is one of the most important methods used for crop improvement. The information needed to develop proper F_1 hybrid cultivars via hybrid breeding could be achieved through different methods including diallel analysis, a method to analyze crosses made among (n) lines in all possible combinations (Griffing, 1956 a, b). The analysis is mainly adopted when dealing with limited number of parental lines and determines genetic parameters such as heterosis, general combining ability (GCA), specific combining ability (SCA), heritability, and nature of gene action. Heterosis demonstrates the superiority of F1 progenies compared to the average of their parents. General combining ability (GCA) shows the average performance of a parental line while specific combining ability (SCA) refers to the best combination of crosses. General combining ability (GCA) and specific combining ability (SCA) are the indicators of additive and non-additive gene effects, respectively. These parameters help plant breeders in the selection of suitable parental lines and appropriate breeding method (Sprague and Tatum, 1942).

It should be noted that despite of the advantages of hybrid cultivars over open pollinated ones, the high price of hybrid seeds developed via hybridization programs makes the use of them more economical for intensive and indoor cultivation (Zengin *et al.*, 2015). One of the major problems affecting plants growth in greenhouses is the decreased level of light received by plants due to significant loss of solar radiation caused by reflection and absorption by greenhouse covering material (Baeza and López, 2012) and high plant density, typically executed in greenhouse cultivations (Laurent *et al.*, 2017). Since light is one of the most crucial factors influencing growth rate, production quality and quantity of plant, supplying plants with adequate light intensity with suitable quality is of importance in greenhouses particularly during autumn and winter seasons (Hangarter, 1997).

In developing countries such as Iran, most of the greenhouses do not benefit from high technology and suffer from lack of accessibility to electricity, hence; supplemental lightning is not applied. Moreover, substantial price of energy resources and tendency toward lower energy consumption (Oz and Atilgan, 2015) necessitate hybrid breeding for low light conditions. To our knowledge breeding for low light condition has not been conducted in tomato, therefore, this study aimed to investigate if there existed any differences among various tomato genotypes in response to two different light conditions while considering the introduction of suitable parental lines and hybrids for each condition as well as determination of stable genotypes over two environments. Genetic parameters including combining ability, gene action and heritability were estimated to help breeders in choosing the best approach for the improvement of tomatoes regarding increased yield and earliness.

2. Materials and Methods

Plant material

Seven inbred lines of tomato consisted of 'Perimoga', 'La1793', 'AC06', 'CT6', 'MC3', 'C20' and 'Kingstone' (Table 1) were cultivated in a research greenhouse of Ferdowsi University of Mashhad, Mashhad, Iran under optimum conditions. The lines were crossed in all possible two-way combinations (full diallel cross system) to develop F1 hybrids with their reciprocals.

Experimental design

The experiment was performed in research greenhouse of Ferdowsi University of Mashhad with computerized temperature control system. A year round was divided into two growing seasons: the first grow-

Table 1 - Description of parental inbred lines crossed in 7×7 full diallel cross system

Plant material	Abbreviation	Origin	Growth habit	Leaf type	Fruti shape
Perimoga	P1	Russia	determinate	vulgare	oval
La1793	P2	USA	indeterminate	vulgare	round
AC06	P3	Iran	indeterminate	vulgare	round
CT6	P4	Russia	semi-indeterminate	grandifolium	oval
MC3	P5	Russia	indeterminate	vulgare	round
C20	P6	Russia	indeterminate	vulgare	oval
Kingstone	P7	Italy	semi-indeterminate	vulgare	oval

ing season was from March to August including warm seasons with high light intensity and long photoperiod (more sunny hours a day) and the second season covering cold seasons with low light intensity and short photoperiod (less sunny hours per day) started in September and ended up in January. To investigate the performance of tomato plants under two different light conditions, 21 F1 progenies together with reciprocals (42 F1 hybrid progenies) developed via a 7×7 full diallel cross system were cultivated during each of the two aforementioned growing seasons. Daily average of light intensity of experimental greenhouse during each month is represented in Table 2. The experiment was conducted in a completely randomized design with three replications per genotype in two different time span mentioned above (split plot).

Measurement of characters

The observations concerning the following characteristics were recorded as described below.

Total yield per plant (Kg)

It was calculated by summing up the weight of fruits obtained from all pickings during 8 weeks from each plant.

Average fruit weight (g)

The average fruit weight was an index of fruit size. All fruits collected from each harvest were weighted and the total weight of the fruits was divided into the number of the weighted fruits.

Number of fruits per plant

Harvested fruits of each plant in a period of 8 weeks were counted.

Days to first flower

The number of days from seeding until the formation of first flower on the plants was recorded.

Days to ripening

The number of days from flower anthesis to fruit ripening stage was determined through the date tagging of five flowers per plant at the time of anthesis. Fruit ripening was considered the time when genetically red fruits turned pink and yellow ones turned yellow (Garg *et al.*, 2008).

Statistical analysis

Obtained data in each environment were analyzed using Excel software (Microsoft office 2010) using Griffing's (1956, *a*, *b*) Method 3, Model 1 (fixed effects) formula. Combined analysis of data over two seasons was performed based on modified Method 3, Model 1 for several environments proposed by Singh (1973) as described below:

Where Y_{ijk} = observation of trait value of parents *i*

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_{ij} + l_k + (gl)_{ik} + (gl)_{jk} + (sl)_{ijk} + (rl)_{ijk} + e_{ijk}$$

and *j* in year *k*; μ = population mean; g_i / g_j = GCA effect of parent *i* / *j*; s_{ji} / s_{ji} = SCA effect of the hybrid developed from parent *i* × parent *j* / parent *i* × parent *j*; r_{ij} = REC effect of the hybrid produced by parent *i* × parent *j*; l_k=effect of environment *k*; $(gl)_{ik}$ / $(gl)_{jk}$ = interaction between GCA effect of parent *i* / *j* with environment *k*; $(sl)_{ijk}$ = interaction between SCA effect of cross *ij* with environment *k*; and e_{ijk} = error of observation *ijk*.

Broad-sense heritability ($H^2_{b.s}$) and narrow-sense heritability ($h^2_{b.s}$) over environments were estimated using following formula (Sharifi *et al.*, 2010):

$$H^2_{b.s}\% = \frac{2\sigma_g^2 + \sigma_s^2}{2\sigma_g^2 + \sigma_s^2 + (2\sigma_{gl}^2 / L) + (\sigma_{sl}^2 / L) + (\sigma_e^2 / RL)} \times 100$$

$$h^2_{b.s}\% = \frac{2\sigma_g^2}{2\sigma_g^2 + \sigma_s^2 + (2\sigma_{gl}^2 / L) + (\sigma_{sl}^2 / L) + (\sigma_e^2 / RL)} \times 100$$

Where L indicated light condition; σ^2g, σ^2s and σ^2r stand for variance components of GCA, SCA and REC, respectively; σ^2gl, σ^2sl and σ^2rl represent variance components of GCA×L, SCA×L and REC×L, respectively.

$$\text{Standard heterosis \%} = \frac{F_1 - \bar{Y}_{ij}}{\bar{Y}_{ij}} \times 100$$

Where F_1 and Y_{ij} are the mean performances of hybrids and parents, respectively.

Table 2 - Average of daily light intensity for each months (foot candle intensity/24h)

Average light intensity											
First growing season with high light intensity and duration						Second growing season with low light intensity and duration					
Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
680.7	694	750.5	863.3	893	760	650.7	547.3	550	527	535.5	655.7

The average of light intensity per day was calculated based on 24 hours a day including night hours (n= 24, one measurements every hour).

3. Results

ANOVA analysis

The variance analysis of genotypes for each season separately showed that genotypes were highly significant (Table 3); therefore, the compound analysis of variance over two environments was conducted (Table 4). Light condition was considered as main plot; therefore, error A refers to whole plot error. Some genotypes, namely 42 F1 hybrids grown under each light treatment along with the interaction between genotypes and environments, were the sub plot of the experiment and error B represent whole plot error. Compound ANOVA analysis for two seasons represented in Table 4 showed that light (L) effect was highly significant for total yield per plant, average fruit weight and days number to first flower but not significant for fruit number per plant and days number for fruit ripening. Genotypes and the interaction of genotypes with light (G×L) were highly significant for all studied traits except for days to ripening in which genotypes did not show any interaction with environment.

Estimation of genetic parameters

Compound analysis of variance for general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (REC) over two seasons for yield, yield components and earliness varied (Table 4). The results indicated that variances due to

Table 3 - Mean squares of ANOVA analysis over two light conditions for yield, yield components and earliness of F1 hybrids with their reciprocals developed via a 7×7 full diallel cross

Sources of variation	Degree of Freedom	Total yield per plant (Kg)	Average of fruit weight (g)	Fruit number per plant	Days to first flower	Days to ripening
Light (L)	1	16.69 **	14654.49 **	913.52	359.53 **	5.43
error A	4	0.74	261.6	140.91	0.61	8.8
Genotypes (G)	41	2.05 **	1944.73 **	1593.50 **	34.74 **	23.38 **
G×L	41	0.17 **	146.54 **	96.24 **	2.50 **	3.99
error B	164	0.07	34.01	18.33	0.97	2.81

** Significant at $P<0.01$ level.

Table 4 - Compound analysis of variance for combining ability over two environments for yield, yield components and earliness of F1 hybrids with their reciprocals developed via a 7×7 full diallel cross and estimates of heritability in broad and narrow senses as well as heterosis

Sources of variation	Degree of Freedom	Total yield per plant (Kg)	Average of fruit weight (g)	Fruits number per plant	Days to first flower	Days to ripening
GCA	6	1.28 **	3343.91 **	2063.32 **	54.66 **	23.20 **
SCA	14	1.35 **	430.82 **	644.60 **	9.55 **	8.68 **
REC	21	0.07 **	23.00 **	17.79 **	0.62 *	2.80 **
GCA×L	6	0.14 **	120.47 **	70.33 **	2.86 **	1.95
SCA×L	14	0.06 **	53.49 **	42.07 **	0.94 **	1.68 *
REC×L	21	0.03	25.29 *	14.49 **	0.19	0.92
error	164	0.02	11.34	6.11	0.32	0.94
Variance components						
$\sigma^2 g$	-	0.06	166.63	102.86	2.72	1.11
$\sigma^2 s$	-	0.33	104.87	159.62	2.31	1.94
$\sigma^2 r$	-	0.01	2.92	2.92	0.07	0.47
$\sigma^2 g / \sigma^2 s$	-	0.19	1.59	0.64	1.18	0.57
$\sigma^2 gl$	-	0.01	10.91	6.42	0.25	0.1
$\sigma^2 sl$	-	0.02	21.08	17.98	0.31	0.37
$\sigma^2 rl$	-	0	6.98	4.19	-0.07	-0.01
H^2 broad-sense (%)	-	94.77	94.94	95.7	94.38	90.38
h^2 narrow-sense (%)	-	26.02	72.22	53.89	66.25	48.34
Heterosis (%)		37.75	-22.95	55.04	3.05	-6.38

* Significant at $P<0.05$ level, ** Significant at $P<0.01$ level.

GCA, SCA and REC were highly significant for all studied characters. The significance of both GCA and SCA variances implies that all studied characters are controlled by either of additive or non-additive gene action. The effect of interaction GCA×L and SCA×L on all evaluated features were significant but fruit ripening period, which showed non-significant variance of GCA×L. The interaction of REC×L showed remarkable effect only on average fruit weight and fruits number per plant. For total yield, fruits number and days to ripening, the GCA ($\sigma^2 g$) was less than variance component of SCA ($\sigma^2 s$) in a way that $\sigma^2 g/\sigma^2 s$ was less than unity, demonstrating the predominance of non-additive gene action in controlling mentioned traits (Baker, 1978). The ratio of $\sigma^2 g/\sigma^2 s$ for fruit weight and days to first flower was higher than unity, illustrating the more important role of additive gene action for inheritance of these attributes.

Estimates of broad-sense heritability percentage (H^2 %) over environments was high for all studied traits ranged from 90 to 95% (Table 4). Narrow-sense heritability percentage (h^2 %) was low for total yield, fruits number and days to ripening while relatively high for fruit weight and days to flowering. Total heterosis percentage was high for yield and fruit number while negative for fruit weight. Unlike yield and yield components, in earliness characters negative values show superiority but heterosis for early flowering was positive. Negative but low heterosis was recorded for early maturity.

Estimation of mean values

Mean values of F1 hybrids for plant yield showed that hybrid ‘CT6×MC3’ (P4×P5) had the highest rate under both light conditions, while lowest amount was for hybrid ‘C20×MC3’ (P6×P5) (Table 5). ‘Perimoga×Kingstone’ (P1×P7) cross and its reciprocal produced heaviest fruits over two environments. Lightest fruits produced under normal light were for ‘MC3×La1793’ (P5×P2), but under low light, the fruits of hybrid ‘MC3×AC06’ (P5×P3) had the least weight. The Highest number of fruits per plant was produced by hybrid ‘La1793×C20’ (P2×P6) and the lowest was for ‘Kingstone×Perimoga’ (P7×P1). Hybrid ‘Perimoga×CT6’ (P1×P4) commenced flowering earlier than other progenies. Latest flowering under adequate light intensity was for ‘MC3×C20’ (P5×P6), while under low light, it was for hybrid ‘La1793×AC06’ (P2×P3). Overall, according to pooled data over two seasons, hybrid ‘C20×MC3’ (P6×P5) took more days to flower compared with other progenies. Longest fruit ripening duration was for hybrid ‘MC3×LA1793’ (P5×P2) and shortest period for ripening was observed in the cross of ‘ACO6×Kingstone’ (P3×P7).

Estimation of GCA, SCA and REC effect

For yield and yield components, positive values of GCA, SCA and REC indicate the superiority of genotypes while for earliness characters negative values are desired (Table 6). Most of the parental lines were not stable during two growing seasons and superior parents for each character differed with environmental changes. Parental line of ‘CT6’ (P4) was the best combiner for achieving higher yield in both seasons, and the lowest GCA in low light and high light condition was for ‘Kingstone’ (P7) and ‘La1793’ (P2), respectively. In total ‘Kingstone’ (P7) was the weakest genitor for yield across two environments. For fruit weight, although ‘Perimoga’ (P1) had the highest GCA in warm season, parental line ‘Kingstone’ (P7) acted as the best combiner in both seasons. The best donors for increased fruits number during sunny and cloudy seasons were ‘La1793’ (P2) and ‘MC3’ (P5), respectively and ‘La1793’ (P2) had the best GCA over both seasons. For days to first flower, parental genotype ‘Perimoga’ (P1) possessed the highest negative GCA and ‘MC3’ (P5) had the highest positive and significant GCA under each ambient light and over both of them. The best combiner concerning days to ripening in both tested environments was ‘La1793’ (P2) and the weakest performance was for ‘Kingstone’ (P7).

In yield and related trait, a positive value of SCA is repetitive of a successful cross between parental lines of that hybrid, while a negative value demonstrates that parental lines did not make up a good couple. For earliness, negative values of SCA are indicative of prosperity .Estimation of SCA for each evironment and over two environments indicated that the best combination for total yield was ‘La1793×C20’ (P2×P6) and the worst was for ‘MC3×C20’ (P5×P6) (Table 7). For fruit weight, Hybrid ‘AC06×Kingstone’ (P3×P7) had the highest SCA during sunny seasons, and the hybrid developed from ‘Perimoga×Kingstone’ (P1×P7) had the highest magnitude during cloudy seasons and over two seasons. The highest and lowest SCA estimations for fruits number were similar to total yield. The cross between ‘MC3×C20’ (P4×P6) was the most successful cross for decreased days to flowering during sunny months. ‘La1793×MC3’ (P2×P5) not only had the highest negative SCA during cold months, but also possessed the best SCA in total. For this trait,

Table 5 - Means values and standard deviation for yield components and earliness of F1 hybrids developed via 7×7 diallel cross over two light conditions (part A)

Genotypes ♀×♂	Total yield per plant (Kg)			Average of fruit weight (g)			Fruits number per plant		
	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled
P1×P2	2.72(±0.28)	1.48(±0.44)	2.10(±0.36)	70.13(±8.70)	45.90(±9.34)	58.02(±8.83)	38.93(±3.02)	31.90(±3.92)	35.42(±3.07)
P1×P3	3.54(±0.36)	2.87(±0.48)	3.20(±0.42)	85.63(±10.48)	55.17(±8.89)	70.40(±8.53)	41.33(±1.64)	52.27(±7.01)	46.80(±2.69)
P1×P4	3.81(±0.14)	3.50(±0.06)	3.65(±0.10)	88.53(±2.05)	56.47(±4.97)	72.50(±1.63)	43.00(±2.55)	62.20(±5.20)	52.60(±1.96)
P1×P5	3.61(±1.02)	3.18(±0.20)	3.40(±0.60)	84.73(±7.22)	57.33(±3.14)	71.03(±2.79)	42.10(±8.98)	55.70(±6.58)	48.90(±7.65)
P1×P6	2.24(±0.19)	2.23(±0.36)	2.24(±0.26)	40.60(±4.06)	43.80(±4.88)	42.20(±2.08)	55.27(±2.15)	51.87(±13.90)	53.57(±5.97)
P1×P7	2.47(±0.36)	2.13(±0.33)	2.30(±0.34)	114.20(±14.97)	96.80(±10.83)	105.50(±8.28)	21.80(±3.97)	21.87(±2.20)	21.83(±2.05)
P2×P1	2.29(±0.18)	1.58(±0.22)	1.94(±0.20)	64.33(±16.06)	42.17(±2.35)	53.25(±7.55)	36.60(±5.97)	37.50(±6.41)	37.05(±0.52)
P2×P3	2.69(±0.17)	1.60(±0.04)	2.14(±0.08)	58.53(±7.25)	33.77(±2.03)	46.15(±2.64)	46.20(±3.10)	47.27(±2.75)	46.73(±1.05)
P2×P4	3.27(±0.31)	2.77(±0.23)	3.02(±0.27)	46.13(±2.06)	39.83(±4.11)	42.98(±2.72)	70.70(±5.05)	70.07(±9.36)	70.38(±7.17)
P2×P5	2.81(±0.25)	2.55(±0.20)	2.68(±0.19)	36.90(±3.33)	35.03(±2.84)	35.97(±1.21)	76.10(±4.58)	72.67(±3.25)	74.38(±3.01)
P2×P6	4.20(±0.33)	2.77(±0.31)	3.49(±0.32)	44.63(±1.65)	32.63(±3.39)	38.63(±2.32)	94.03(±5.54)	84.80(±3.99)	89.42(±4.13)
P2×P7	3.24(±0.33)	2.74(±0.33)	2.99(±0.33)	51.80(±4.54)	56.80(±4.54)	54.30(±4.54)	62.57(±1.72)	48.17(±2.29)	55.37(±1.94)
P3×P1	3.33(±0.31)	2.42(±0.31)	2.87(±0.31)	76.60(±8.52)	54.03(±11.95)	65.32(±10.03)	43.50(±3.21)	45.27(±4.35)	44.38(±2.98)
P3×P2	3.14(±0.30)	1.98(±0.25)	2.56(±0.19)	61.00(±2.11)	37.07(±3.62)	49.03(±1.37)	51.33(±3.18)	53.17(±2.90)	52.25(±2.83)
P3×P4	3.34(±0.24)	2.62(±0.19)	2.98(±0.21)	68.20(±8.89)	54.23(±7.73)	61.22(±8.29)	49.17(±3.73)	48.57(±3.27)	48.87(±3.48)
P3×P5	2.97(±0.25)	2.44(±0.30)	2.70(±0.27)	40.07(±1.75)	33.47(±4.46)	36.77(±3.07)	73.97(±3.10)	72.83(±1.05)	73.40(±1.15)
P3×P6	2.81(±0.24)	2.48(±0.12)	2.65(±0.18)	61.50(±1.71)	37.90(±3.73)	49.70(±2.66)	45.63(±3.85)	65.67(±6.37)	55.65(±4.15)
P3×P7	3.03(±0.18)	2.50(±0.20)	2.77(±0.19)	99.03(±5.56)	78.47(±2.90)	88.75(±1.66)	30.63(±0.59)	31.93(±3.61)	31.28(±1.89)
P4×P1	4.27(±0.34)	3.69(±0.15)	3.98(±0.16)	83.03(±12.08)	64.67(±4.61)	73.85(±3.83)	51.77(±3.88)	57.20(±3.72)	54.48(±0.33)
P4×P2	2.86(±0.2)	2.66(±0.20)	2.76(±0.09)	47.97(±4.71)	38.27(±3.84)	43.12(±1.66)	59.60(±1.73)	69.50(±1.85)	64.55(±0.15)
P4×P3	3.18(±0.36)	3.01(±0.22)	3.09(±0.29)	66.53(±1.46)	54.90(±6.05)	60.72(±3.02)	47.80(±6.17)	54.83(±1.93)	51.32(±2.63)
P4×P5	4.57(±0.26)	3.80(±0.34)	4.19(±0.27)	63.20(±4.30)	47.50(±3.76)	55.35(±1.30)	72.40(±3.41)	80.00(±5.73)	76.20(±3.21)
P4×P6	3.32(±0.32)	3.14(±0.25)	3.23(±0.24)	63.83(±3.40)	50.20(±7.27)	57.02(±3.95)	52.27(±7.31)	62.77(±4.40)	57.52(±2.45)
P4×P7	3.03(±0.31)	2.75(±0.17)	2.89(±0.21)	87.20(±11.27)	62.80(±3.24)	75.00(±5.56)	34.90(±2.80)	43.77(±0.51)	39.33(±1.57)
P5×P1	3.37(±0.31)	2.97(±0.35)	3.17(±0.58)	76.83(±8.81)	47.27(±5.53)	62.05(±1.91)	44.03(±3.81)	62.77(±2.74)	53.40(±3.14)
P5×P2	2.52(±0.40)	2.35(±0.27)	2.44(±0.58)	30.27(±4.99)	29.53(±2.17)	29.90(±1.41)	83.33(±3.32)	79.47(±7.33)	81.40(±5.24)
P5×P3	3.29(±0.21)	2.10(±0.22)	2.69(±1.53)	44.13(±4.23)	26.87(±2.87)	35.50(±0.79)	75.00(±9.37)	77.90(±3.30)	76.45(±3.36)
P5×P4	4.00(±0.20)	3.60(±0.15)	3.80(±2.08)	56.17(±4.99)	45.23(±1.63)	50.70(±2.92)	71.53(±8.22)	79.47(±0.49)	75.50(±4.29)
P5×P6	1.87(±0.23)	1.51(±0.18)	1.69(±0.58)	42.17(±4.32)	37.67(±2.97)	39.92(±1.66)	44.33(±1.12)	40.10(±6.67)	42.22(±3.82)
P5×P7	2.34(±0.25)	1.97(±0.35)	2.16(±0.58)	54.40(±3.10)	32.77(±3.08)	43.58(±3.09)	42.87(±2.34)	59.70(±5.28)	51.28(±3.73)
P6×P1	2.57(±0.29)	1.97(±0.34)	2.27(±0.58)	55.63(±3.27)	36.90(±3.24)	46.27(±3.25)	46.10(±3.57)	53.10(±5.48)	49.60(±4.45)
P6×P2	3.79(±0.39)	3.06(±0.25)	3.43(±1.53)	44.53(±2.34)	37.33(±4.52)	40.93(±3.41)	84.90(±4.27)	82.13(±4.31)	83.52(±1.90)
P6×P3	2.99(±0.15)	2.59(±0.18)	2.79(±1.53)	55.77(±2.89)	43.10(±4.45)	49.43(±0.78)	53.70(±5.11)	60.27(±2.29)	56.98(±1.75)
P6×P4	2.96(±0.18)	2.69(±0.24)	2.82(±1.53)	51.57(±0.46)	40.37(±6.80)	45.97(±3.35)	57.23(±3.45)	67.10(±5.23)	62.17(±0.94)
P6×P5	1.77(±0.16)	1.24(±0.22)	1.51(±0.58)	50.93(±2.78)	40.23(±9.32)	45.58(±5.95)	34.67(±1.35)	31.03(±1.76)	32.85(±0.88)
P6×P7	3.27(±0.35)	3.17(±0.25)	3.22(±0.58)	69.43(±3.52)	54.47(±3.54)	61.95(±3.53)	46.97(±2.77)	58.43(±8.39)	52.70(±3.27)
P7×P1	2.18(±0.16)	1.83(±0.20)	2.00(±0.58)	116.40(±13.25)	99.53(±8.03)	107.90(±9.74)	18.97(±3.54)	18.30(±1.01)	18.63(±2.14)
P7×P2	2.94(±0.12)	2.47(±0.17)	2.70(±1.00)	48.90(±0.35)	45.97(±3.68)	47.43(±1.95)	59.97(±2.03)	53.73(±2.06)	56.85(±1.55)
P7×P3	3.25(±0.33)	2.62(±0.18)	2.93(±0.58)	108.60(±11.61)	72.67(±1.29)	90.62(±6.45)	29.93(±1.27)	35.90(±2.20)	32.92(±1.70)
P7×P4	2.86(±0.09)	2.60(±0.16)	2.73(±0.58)	70.83(±2.00)	73.50(±2.56)	72.17(±1.24)	40.40(±2.40)	35.27(±0.99)	37.83(±1.63)
P7×P5	2.67(±0.45)	2.18(±0.21)	2.42(±0.58)	60.07(±12.53)	39.57(±1.89)	49.82(±7.03)	44.73(±3.43)	54.97(±3.85)	49.85(±0.39)
P7×P6	2.82(±0.27)	2.77(±0.27)	2.80(±1.15)	65.97(±8.25)	54.10(±5.91)	60.03(±1.24)	42.77(±1.37)	51.57(±7.46)	47.17(±3.05)
F	11.42 **	16.70 **	16.47 **	25.61 **	28.12 **	45.39 **	49.16 **	33.15 **	76.95 **
LSD 0.05	0.50	0.41	0.40	11.51	8.69	7.52	6.80	8.11	5.23

P1= Perimoga, P2= La1793, P3= AC06, P4= CT6, P5= MC3, P6= C20, P7= Kingstone. Values in parenthesis represent standard errors.
** Significant at P<0.01.

To be continued

Continued

Table 5 - Means values and standard deviation for yield components and earliness of F1 hybrids developed via 7×7 diallel cross over two light conditions

Genotypes ♀ × ♂	Days to first flower			Days to ripening		
	L1	L2	Pooled	L1	L2	Pooled
P1×P2	56.00(±1.00)	54.33(±0.58)	55.17(±0.76)	14.00(±1.00)	15.67(±0.58)	14.83(±0.29)
P1×P3	56.67(±0.58)	54.00(±1.00)	55.33(±0.58)	16.67(±2.08)	18.67(±1.53)	17.67(±1.61)
P1×P4	54.00(±1.00)	50.67(±0.58)	52.33(±0.58)	18.33(±1.15)	18.33(±1.15)	18.33(±1.15)
P1×P5	62.67(±0.58)	60.33(±0.58)	61.50(±0.50)	19.00(±2.65)	20.67(±1.15)	19.83(±1.76)
P1×P6	58.00(±1.00)	54.67(±0.58)	56.33(±0.58)	18.00(±3.00)	18.00(±3.00)	18.00(±3.00)
P1×P7	57.33(±0.58)	53.33(±1.53)	55.33(±0.76)	19.33(±2.08)	18.67(±1.53)	19.00(±1.00)
P2×P1	56.67(±0.58)	54.67(±0.58)	55.67(±0.58)	19.00(±1.00)	16.67(±1.53)	17.83(±1.15)
P2×P3	60.33(±1.15)	60.67(±1.53)	60.50(±0.87)	18.33(±1.53)	17.33(±1.53)	17.83(±1.44)
P2×P4	60.67(±0.58)	58.67(±0.58)	59.67(±0.58)	16.33(±1.15)	15.67(±1.15)	16.00(±1.00)
P2×P5	60.67(±0.58)	58.67(±0.58)	59.67(±0.58)	15.67(±2.08)	15.67(±2.08)	15.67(±2.08)
P2×P6	61.67(±1.53)	60.33(±0.58)	61.00(±1.00)	17.00(±2.00)	17.00(±1.00)	17.00(±0.50)
P2×P7	58.33(±0.58)	58.00(±1.00)	58.17(±0.29)	16.33(±1.15)	17.00(±2.00)	16.67(±1.53)
P3×P1	57.33(±0.58)	54.67(±0.58)	56.00(±0.00)	18.33(±2.08)	18.33(±2.08)	18.33(±2.08)
P3×P2	60.00(±0.00)	59.67(±0.58)	59.83(±0.29)	20.33(±2.52)	19.33(±2.31)	19.83(±2.36)
P3×P4	56.00(±1.00)	55.67(±2.31)	55.83(±1.61)	16.67(±2.08)	16.67(±2.08)	16.67(±2.08)
P3×P5	60.00(±1.00)	56.33(±1.53)	58.17(±1.04)	20.00(±1.73)	17.33(±2.08)	18.67(±1.53)
P3×P6	60.67(±0.58)	59.00(±1.00)	59.83(±0.76)	17.00(±1.73)	17.00(±1.73)	17.00(±1.73)
P3×P7	58.33(±0.58)	56.33(±0.58)	57.33(±0.58)	22.67(±2.08)	22.67(±2.08)	22.67(±2.08)
P4×P1	54.67(±1.15)	51.33(±1.15)	53.00(±0.00)	17.00(±2.00)	17.00(±1.15)	17.00(±2.00)
P4×P2	60.00(±1.00)	58.00(±1.00)	59.00(±1.00)	15.00(±1.00)	14.00(±1.00)	14.50(±0.87)
P4×P3	58.00(±1.73)	57.00(±1.00)	57.50(±0.50)	14.67(±0.58)	15.33(±1.00)	15.00(±0.00)
P4×P5	61.67(±1.15)	59.67(±1.15)	60.67(±1.15)	18.00(±2.00)	18.00(±1.15)	18.00(±2.00)
P4×P6	56.33(±0.58)	54.33(±0.58)	55.33(±0.58)	20.00(±2.65)	21.00(±0.58)	20.50(±1.80)
P4×P7	57.67(±0.58)	55.67(±0.58)	56.67(±0.58)	18.67(±1.53)	18.67(±0.58)	18.67(±1.53)
P5×P1	62.00(±1.00)	59.33(±0.58)	60.67(±0.76)	20.33(±1.53)	19.33(±0.58)	19.83(±1.04)
P5×P2	61.67(±0.58)	58.33(±0.58)	60.00(±0.00)	13.00(±1.00)	12.67(±0.58)	12.83(±1.04)
P5×P3	61.00(±0.00)	57.33(±1.53)	59.17(±0.76)	19.67(±2.52)	16.00(±1.53)	17.83(±1.04)
P5×P4	60.67(±2.08)	58.67(±2.08)	59.67(±2.08)	19.00(±3.00)	20.33(±2.08)	19.67(±2.08)
P5×P6	63.67(±1.53)	58.67(±0.58)	61.17(±0.58)	21.00(±1.00)	20.33(±0.58)	20.67(±1.15)
P5×P7	61.00(±0.00)	58.33(±0.58)	59.67(±0.29)	21.33(±1.53)	15.00(±0.58)	18.17(±0.29)
P6×P1	58.33(±1.53)	55.33(±0.58)	56.83(±0.76)	17.67(±2.52)	17.67(±0.58)	17.67(±2.52)
P6×P2	62.33(±1.53)	59.67(±1.53)	61.00(±1.32)	15.00(±2.00)	15.33(±1.53)	15.17(±1.76)
P6×P3	59.67(±0.58)	59.33(±1.53)	59.50(±0.87)	16.00(±1.73)	19.67(±1.53)	17.83(±1.04)
P6×P4	56.67(±0.58)	54.33(±1.53)	55.50(±0.87)	20.00(±2.65)	18.33(±1.53)	19.17(±2.02)
P6×P5	63.33(±0.58)	60.33(±0.58)	61.83(±0.58)	18.67(±1.53)	18.67(±0.58)	18.67(±1.53)
P6×P7	59.00(±1.00)	55.33(±0.58)	57.17(±0.29)	20.67(±1.53)	21.33(±0.58)	21.00(±1.50)
P7×P1	58.00(±1.00)	52.67(±0.58)	55.33(±0.76)	20.67(±2.08)	20.67(±0.58)	20.67(±1.76)
P7×P2	60.00(±0.00)	59.00(±1.00)	59.50(±0.50)	20.00(±1.00)	18.00(±1.00)	19.00(±0.00)
P7×P3	58.33(±0.58)	56.33(±0.58)	57.33(±0.58)	20.67(±0.58)	20.67(±0.58)	20.67(±0.58)
P7×P4	58.33(±0.58)	56.33(±0.58)	57.33(±0.58)	17.33(±1.15)	18.67(±0.58)	18.00(±0.00)
P7×P5	62.00(±0.00)	59.33(±0.58)	60.67(±0.29)	20.00(±1.00)	17.67(±0.58)	18.83(±1.61)
P7×P6	58.67(±1.15)	53.33(±1.15)	56.00(±1.00)	19.00(±1.00)	19.00(±1.15)	19.00(±1.00)
F	18.69 **	19.82 **	28.14 **	4.20 **	19.82 **	4.82 **
LSD 0.05	1.52	1.66	1.28	2.98	2.59	2.53

P1= Perimoga, P2= La1793, P3= AC06, P4= CT6, P5= MC3, P6= C20, P7= Kingstone. Values in parenthesis represent standard errors.
** Significant at $P<0.01$.

Table 6 - General combining ability (GCA) effects of parental lines for yield, yield components and earliness in a 7×7 diallel cross over two light conditions

Parental lines	Total yield per plant (Kg)			Average of fruit weight (g)			Fruits number per plant			Days to first flower			Days to ripening		
	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled
P1	-0.02	-0.06	-0.04	18.32 **	10.97 **	14.64 **	-13.46 **	-11.38 **	-12.42 **	-1.93 **	-2.70 **	-2.31 **	-0.06	0.42	0.18
P2	-0.02	-0.24 **	-0.13 **	-16.82 **	-11.61 **	-14.22 **	14.63 **	6.67 **	10.65 **	0.74 **	1.77 **	1.25 **	-1.90 **	-2.11 **	-2.00 **
P3	0.09	-0.12 **	-0.02	5.22 **	-0.87	2.17 **	-2.98 **	-1.78 *	-2.38 **	-0.46 **	0.40 *	-0.03	0.2	0.36	0.28
P4	0.48 **	0.64 **	0.56 **	1.98	3.76 **	2.87 **	3.28 **	6.70 **	4.99 **	-1.63 **	-1.20 **	-1.41 **	-0.80 *	-0.34	-0.57 **
P5	-0.08	-0.06	-0.07 **	-13.35 **	-11.79 **	-12.57 **	8.71 **	10.29 **	9.50 **	2.94 **	2.30 **	2.62 **	0.67 *	-0.38	0.15
P6	-0.20 **	-0.08	-0.14 **	-12.68 **	-8.17 **	-10.42 **	3.99 **	4.51 **	4.25 **	0.74 **	0.24	0.49 **	0.1	0.79 **	0.45 *
P7	-0.25 **	-0.07	-0.16 **	17.34 **	17.71 **	17.52 **	-14.15 **	-15.01 **	-14.58 **	-0.40 *	-0.83 **	-0.61 **	1.77 **	1.26 **	1.51 **
LSD 0.05															
$g_i - g_j^a$	0.16	0.13	0.09	3.56	2.68	2.07	2.1	2.51	1.52	0.47	0.51	0.35	0.92	0.8	0.6

P1= Perimoga, P2= La1793, P3= AC06, P4= CT6, P5= MC3, P6= C20, P7= Kingstone.
* Significant at P<0.05 level, ** Significant at P<0.01 level.
[a] difference between GCA of two parental lines at P<0.05 level.

Table 7 - Specific combining ability (SCA) effects of F1 hybrids for yield, yield components and earliness in a 7×7 diallel cross over two light conditions

Genotypes ♀ × ♂	Total yield per plant (Kg)			Average o fruit weight (g)			Fruits number per plant			Days to first flower			Days to ripening		
	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled
P1×P2	-0.51 **	-0.70 **	-0.60 **	1.29	-4.52 *	-1.62	-14.90 **	-15.90 **	-15.40**	-1.72 **	-1.43 **	-1.58 **	0.21	-0.1	0.06
P1×P3	0.31 **	0.29 **	0.30 **	-6.87 **	-4.69 **	-5.78 **	7.36 **	6.62 **	6.99**	0.14	-0.23	-0.04	-0.89	-0.23	-0.56
P1×P4	0.53 **	0.48 **	0.50 **	1.03	-3.36	-1.16	6.07 **	9.07 **	7.57**	-1.36 **	-1.97 **	-1.66 **	0.28	-0.37	-0.04
P1×P5	0.55 **	0.66 **	0.60 **	11.36 **	3.93 *	7.64 **	-3.68 **	5.01 **	0.67	2.08 **	3.37 **	2.72 **	0.81	2.00 **	1.41 **
P1×P6	-0.42 **	-0.29 **	-0.36 **	-21.97 **	-11.65 **	-16.81 **	8.66 **	4.04 *	6.35**	0.11	0.6	0.36	-0.46	-1.33 *	-0.89 *
P1×P7	-0.45 **	-0.43 **	-0.44 **	15.16 **	20.30**	17.73 **	-3.51 *	-8.84 **	-6.17**	0.74 *	-0.33	0.21	0.04	0.03	0.04
P2×P3	-0.21 *	-0.38 **	-0.30 **	6.92 **	-1.3	2.81 *	-14.38 **	-9.97 **	-12.18**	0.64 *	1.13 **	0.89 **	2.78 **	2.13 **	2.46 **
P2×P4	-0.46 **	-0.22 *	-0.34 **	-2.56	-2.3	-2.43	-4.25 **	1.11	-1.57	1.98 **	0.90 **	1.44 **	0.11	-0.67	-0.28
P2×P5	-0.29 **	0.21 *	-0.04	-0.69	6.48 **	2.90 *	4.88 **	3.80 *	4.34**	-1.76 **	-2.43 **	-2.09 **	-2.69 **	-1.30 *	-1.99 **
P2×P6	1.16 **	0.70 **	0.93 **	9.64 **	5.56 **	7.60 **	19.35 **	16.98 **	18.17**	1.28 **	1.13 **	1.21 **	-0.46	-0.47	-0.46
P2×P7	0.31 **	0.38 **	0.35 **	-14.61 **	-3.91 *	-9.26 **	9.29 **	3.99 *	6.64**	-0.42	0.70 *	0.14	0.04	0.4	0.22
P3×P4	-0.37 **	-0.24 **	-0.30 **	-4.28	2.48	-0.9	-3.31 *	-8.53 **	-5.92**	-0.16	0.27	0.06	-1.99 **	-1.97 **	-1.98 **
P3×P5	0.07	-0.09	-0.01	-14.22 **	-6.37 **	-10.29 **	17.26 **	11.55 **	14.41**	-1.22 **	-2.73 **	-1.98 **	0.71	-1.27 *	-0.28
P3×P6	-0.04	0.20 *	0.08	1.65	0.34	1	-2.84 *	4.93 **	1.05	0.64 *	1.67 **	1.16 **	-2.06 **	-0.77	-1.41 **
P3×P7	0.25 *	0.22 *	0.23 **	16.80 **	9.54 **	13.17 **	-4.09 **	-4.60 **	-4.34**	-0.06	-0.1	-0.08	1.44 *	2.10 **	1.77 **
P4×P5	0.83 **	0.58 **	0.71 **	6.60 **	5.20 **	5.90 **	8.48 **	7.43 **	7.96**	0.61	1.20 **	0.91 **	0.38	1.93 **	1.16 **
P4×P6	-0.2	-0.18 *	-0.19 **	3.95	0.49	2.22	-4.01 **	-1.59	-2.80**	-1.86 **	-1.57 **	-1.71 **	2.44 **	1.27 *	1.86 **
P4×P7	-0.34 **	-0.43 **	-0.38 **	-4.75 *	-2.51	-3.63 **	-2.98 *	-7.48 **	-5.23**	0.78 *	1.17 **	0.97 **	-1.22 *	-0.2	-0.71
P5×P6	-0.95 **	-1.02 **	-0.98 **	8.13 **	9.71 **	8.92 **	-24.69 **	-34.54 **	-29.62 **	0.58	0.1	0.34	0.81	1.13	0.97*
P5×P7	-0.21	-0.33 **	-0.27 **	-11.20 **	-18.95 **	-15.07 **	-2.26	6.75 **	2.24 *	-0.29	0.5	0.11	-0.02	-2.50 **	-1.26 **
P6×P7	0.45 **	0.59 **	0.52 **	-1.4	-4.45 *	-2.93 *	3.53 *	10.19**	6.86 **	-0.76	-1.93 **	-1.34 **	-0.29	0.17	-0.06
LSD 0.05															
$S_{ij} - S_{ik}^a$	0.29	0.23	0.17	6.44	4.87	3.75	3.81	4.54	2.75	0.85	0.93	0.63	1.67	1.45	1.08
$S_{ij} - S_{kl}^b$	0.25	0.2	0.14	5.58	4.21	3.25	3.3	3.93	2.38	0.74	0.81	0.55	1.44	1.26	0.93

P1= Perimoga, P2= La1793, P3= AC06, P4= CT6, P5= MC3, P6= C20, P7= Kingstone. *Significant at P < 0.05 level.
** Significant at P<0.01 level.
[a] Difference between two SCA of two hybrids, with a common parent.
[b] Difference between two SCA of two hybrids, with non-common parent.

'Perimoga×MC3' (P1×P5) was the weakest combination across both environments. The most negative value of SCA for ripening period under low light belonged to 'La1793×MC3' (P2×P5) and under high light was for 'Kingstone×MC3' (P7×P5). Pooled value of SCA in this character showed that generally 'La1793×MC3' (P2×P5) and 'AC06×La1793' (P3×P2) had the highest and the lowest negative values, respectively.

The results of REC indicated that the best reciprocal combinations over two environments for total yield, average of fruit weight, fruits number, days to flowering and days to ripening was for 'AC06×La1793' (P3×P2), 'Kingstone×MC3' (P7×P5), 'MC3×La1793' (P5×P2), 'Kingstone×C20' (P7×P6) and 'MC3×La1793' (P5×P2), respectively (Table 8). The Lowest pooled REC in foregoing characters was for 'Kingstone×C20' (P7×P6), 'C20×CT6' (P6×P4), 'C20×MC3' (P6×P5), 'MC3×AC06' (P4×P3) and 'La1793×Perimoga' (P2×P1), respectively

4. Discussion and Conclusions

The results indicated that total yield, average fruit weight and flowering time were influenced by the amount of received light, while fruit number and fruit ripening period were not affected. Genotype effect was highly significant for all studied traits implying the feasibility of breeding. Despite of simultaneous influence of light and genotype on yield, fruit weight and days to flower, a comparison between magnitude of environment and genotype effects revealed that the genotype variation played more important in the expression of studied traits.

The significance of interaction genotype × light condition (G×L) for almost all characters except days to ripening revealed that there is a genotype variation in response to light intensity as regards yield, yield components and early flowering. Previous studies reported genotype variation regarding reaction to environmental light in different species (Stratton,

Table 8 - Reciprocal effect (REC) for yield, yield components and earliness in a 7×7 diallel cross over two light conditions

Genotypes ♀ × ♂	Total yield per plant (Kg)			Average of fruit weight (g)			Fruits number per plant			Days to first flower			Days to ripening		
	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled	L1	L2	Pooled
P2×P1	-0.22	0.05	-0.08	-2.9	-1.87	-2.38	-1.17	2.8	0.82	0.33	0.17	0.25	2.50 **	0.5	1.50 **
P3×P1	-0.11	-0.23 *	-0.17 *	-4.52	-0.57	-2.54	1.08	-3.5	-1.21	0.33	0.33	0.33	0.83	-0.17	0.33
P4×P1	0.23	0.1	0.17 *	-2.75	4.1	0.67	4.38 *	-2.5	0.94	0.33	0.33	0.33	-0.67	-0.67	-0.67
P5×P1	-0.12	-0.11	-0.11	-3.95	-5.03 *	-4.49 **	0.97	3.53	2.25	-0.33	-0.5	-0.42	0.67	-0.67	0
P6×P1	0.16	-0.13	0.02	7.52 *	-3.45	2.03	-4.58 **	0.62	-1.98	0.17	0.33	0.25	-0.17	-0.17	-0.17
P7×P1	-0.15	-0.15	-0.15 *	1.1	1.37	1.23	-1.42	-1.78	-1.6	0.33	-0.33	0	0.67	1	0.83
P3×P2	0.22	0.19	0.21 **	1.23	1.65	1.44	2.57	2.95	2.76 *	-0.17	-0.5	-0.33	1	1	1.00 *
P4×P2	-0.21	-0.06	-0.13	0.92	-0.78	0.07	-5.55 **	-0.28	-2.92 *	-0.33	-0.33	-0.33	-0.67	-0.83	-0.75
P5×P2	-0.14	-0.1	-0.12	-3.32	-2.75	-3.03	3.62 *	3.4	3.51 **	0.5	-0.17	0.17	-1.33	-1.50 *	-1.42 **
P6×P2	-0.21	0.14	-0.03	-0.05	2.35	1.15	-4.57 **	-1.33	-2.95 *	0.33	-0.33	0	-1	-0.83	-0.92
P7×P2	-0.15	-0.14	-0.15 *	-1.45	-5.42 *	-3.43 *	-1.3	2.78	0.74	0.83 *	0.5	0.67 *	1.83 *	0.5	1.17 *
P4×P3	-0.08	-0.19	0.06	-0.83	0.33	-0.25	-0.68	3.13	1.23	1.00 *	0.67	0.83 **	-1	-0.67	-0.83
P5×P3	0.16	-0.17	-0.01	2.03	-3.3	-0.63	0.52	2.53	1.52	0.5	0.5	0.5	-0.17	-0.67	-0.42
P6×P3	0.09	0.06	0.07	-2.87	2.6	-0.13	4.03 *	-2.7	0.67	-0.5	0.17	-0.17	-0.5	1.33 *	0.42
P7×P3	0.11	0.06	0.08	4.77	-2.9	0.93	-0.35	1.98	0.82	0	0	0	-1	-1	-1.00 *
P5×P4	-0.29 *	-0.1	-0.19 **	-3.52	-1.13	-2.33	-0.43	-0.27	-0.35	-0.5	-0.5	-0.5	0.5	1.17	0.83
P6×P4	-0.18	-0.22 *	-0.20 **	-6.13 *	-4.92 *	-5.53 **	2.48	2.17	2.32	0.17	0	0.08	0	-1.33 *	-0.67
P7×P4	-0.09	-0.08	-0.08	-8.18 **	5.35 *	-1.42	2.75	-4.25 *	-0.75	0.33	0.33	0.33	-0.67	0	-0.33
P6×P5	-0.05	-0.13	-0.09	4.38	1.28	2.83	-4.83 **	-4.53 *	-4.68 **	-0.17	0.83 *	0.33	-1.17	-0.83	-1.00 *
P7×P5	0.17	0.1	0.13	2.83	3.4	3.12	0.93	-2.37	-0.72	0.5	0.5	0.5	-0.67	1.33 *	0.33
P7×P6	-0.23	-0.2	-0.21 **	-1.73	-0.18	-0.96	-2.1	-3.43	-2.77*	-0.17	-1.00 *	-0.58 *	-0.83	-1.17	-1.00 *
LSD 0.05															
$R_{ij} - R_{ik}$ [a]	0.31	0.25	0.18	7.04	5.32	4.1	4.16	4.96	3.01	0.93	1.02	0.69	1.82	1.59	1.18

P1= Perimoga, P2= La1793, P3= AC06, P4= CT6, P5= MC3, P6= C20, P7= Kingstone.
* Significant at P<0.05 level, ** Significant at P<0.01 level.
[a] Difference between two RCA of two hybrids.

D.A., 1998; Martínez-Ferri *et al.*, 2001) promising for plant improvement regarding maintenance of high yield and earliness under lower level of light intensity. The remarkable effect of interaction G×L on studied traits except ripening period demonstrated that genotypes were not stable across two environments and should be evaluated in a range of environments. Importance of genotype selection across different environments for tomato improvement concerning yield and earliness attributing traits was reported by Chadha and Kumar (2001), and Biswas *et al.* (2011).

According to mean performances of hybrids, superior genotypes for various characteristics differed and none of them could be considered as the best for all of the attributes. In this regard, in order to commercialize F1 hybrids, breeding programs should be conducted to collect suitable features in one plant (Breseghello and Coelho, 2013).

Either of general combing ability (GCA) or specific combining ability (SCA) was highly significant for all of evaluated features illustrating both additive and non-additive gene action were involved in controlling yield, yield components and earliness. Our findings supports additive-dominance model reported by Chishti *et al.* (2008) and Biswas *et al.* (2011) for production and earliness traits. Significant contribution of REC to total sum squire is indicative of inter-allelic interactions in the expression of studied traits. Similarly, REC effect on fruit weight and number was reported by Hannan *et al.*, (2007 b).

Higher magnitude of SCA variance (σ^2s) in comparison with GCA variance (σ^2g) for total yield, fruit number and days to ripening indicated that these traits are mainly under the control of dominant effects. Similar findings were reported by Solieman (2009) and El-Gabry *et al.* (2014) for fruit yield and number. The predominance of non-additive gene action over additive effects for days to ripening was in agreement with Hannan *et al.* (2007a) but inconsistent with Garg *et al.* (2008) who found additive gene action to be more effective on days to ripening over two environments.

The ratio of σ^2g/σ^2s over two light conditions was greater than unity for fruit weight and days to flowering indicative of more weight of additive effects in inheritance of these features. Garg *et al.* (2008), Rai and Asati (2011) and Nadeem *et al.* (2013) also contributed the expression of fruit weight and early flowering to both additive and dominance gene actions with preponderance of additive effects. Biswas *et al.* (2011) who examined tomato genotypes across two environments, different in terms of temperature and light intensity, reported more important role of additive gene action in control of fruit weight.

The interaction GCA×L was significant for all characters except for days to ripening indicating the sensibility of additive effects to light condition. The significant interaction SCA×L was indicative of instability of dominance effects under different environmental light. REC×L varied for fruit weight and number demonstrating the susceptibility of cytoplasmic effects to environment in some traits and necessity of reciprocal crosses for choosing the most suitable genotypes for target environment.

Estimates of broad-sense heritability percentage ($H^2_{b.s}$%) across two different light conditions was high, demonstrating the low effect of environment and high response of studied traits to breeding programs. Relatively high narrow sense heritability percentage ($h^2_{n.s}$%) for fruit weight and early flowering indicated that these traits are largely controlled by additive effects; while, low $h^2_{n.s}$% of yield, fruit number and early maturity demonstrated higher weight of non-additive effects in inheritance of these traits. These findings agree with earlier work of Biswas *et al.* (2011) and Dutta *et al.* (2013) who reported low narrow sense heritability for yield and fruit number over two environments.

Importance of both additive and non-additive gene action with predominance of additive effects in expression of fruit weight and days to flowering revealed that selection breeding programs could be an effective strategy for genetic improvement of tomato for these characters, while exploitation of hybrid vigor should not be neglected (Grilli *et al.*, 2003). Yield, fruit number and early ripening were controlled by additive-dominance effects with higher weight of dominance effects implying hybrid breeding could be adopted for improvement of these characters (Gul *et al.*, 2010). Abd El-Maksoud *et al.* (2013) proposed recurrent selection program for improvement of traits controlled by both additive and non-additive effects. For such traits, hybridization in segregating generations followed by selection for outperforming genotypes has been recommended (Dutta *et al.*, 2013; Bhattarai *et al.*, 2016).

Limitation in access to clean energy resources in rural areas and global interest toward lower energy consumption necessitate breeding for low energy input. In the current study, genetic variation among tomato genotypes under different light conditions was observed and some genotypes showed more stability than others. None of parental lines or F1 hybrids exhibited high performance for all studied features, therefore, a particular genotype cannot be recommended. However, genetic knowledge obtained from this research could be used in planning tomato breeding programs. More important role of additive gene action in inheritance of fruit weight and early flowering indicate the effectiveness of selection breeding, while predominance of non-additive effects in genetic expression of plant yield, fruit number and early maturity suggest adoption of bi-parental mating for improvement of mentioned traits.

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