Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(5): 99-106
Received: 20-02-2019
Accepted: 13-04-2019

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Combining ability, heterosis and potence ratio analysis of earliness and important traits of tomato (*Solanum lycopersicum* L.)

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Abstract
Improvement of hybrids and cultivars for the heterosis breeding and high production needs recognition of good specific and general combiners. To estimate The GCA, SCA, heterosis, potence ratio and correlation coefficient for earliness, production and other traits in were estimated in 28 F1 hybrids produced from 8 lines tomato (*Solanum lycopersicum* L.). The line C.JPS3 was a good general combiner for earliness and the highest positive values of GCA effects were in the parent S.2274 for branch length and production per plant, K.2274 for length and diameter of fruit, C.JPS3 for SPAD index, P for weight of single fruit and A13012 for biomass. The best combination for number of leaves to first inflorescence, number of days to turning, production per plant and biomass were C20 × C.JPS3, C20 × S.L, P × H.1370 and A13012 × H.1370, respectively. The parental line S.L. produced the highest mean values for weight of single fruit and biomass and the parental line H.1370 had the highest mean value for production per plant. There were partial-to over-dominance involved in inheritance of these traits. Results of the phenotypic correlation coefficients indicated positive correlations between branch length and fruit length, fruit length and fruit diameter, number of days to turning and production per plant, number of days to turning and biomass, production per plant and biomass. Hybrids with high heterosis and good GCA and SCA for the traits can be used for exploitation of heterosis and released as promising hybrids after multi location testing.

Keywords: earliness, heterosis, potence ratio, production, tomato

Introduction

Tomato is one of the most valuable and popular solanaceous vegetables grown across the world and it has considerable demand in the international market (Hannan *et al.* 2007) [13]. Tomato hybrid cultivars are useful in commercial production since many farmers of tomato prefer to grow their hybrid seeds in spite of the relatively high costs because they want to gain maximum yield, good quality traits, and early maturity cultivars. Besides, most tomato breeding programs are considered to produce new hybrid cultivars to be good enough for the demands of both growers and customers.

There are various diallel methods to analyze data from a set of k parents and their k (k-1)/2 single-cross progenies. Although used the half diallel method for combining ability, other researchers utilized the set-up multiple regression approach, partitioning heterosis concerning average, general and specific combining abilities and also heterosis effects (Gardner and Eberhart 1966) [11].

Heterosis is widely known as a major aspect of the improved production of different crops during this century (Lamkey and Staub 1998) [18]. This biological phenomenon exhibiting itself in hybrids, which are more vital, adaptive and productive than their parents. Heterosis has been elucidated by additive and over-dominance effects (Birchler *et al.* 2006 [3], Semel *et al.* 2006) [25]. Breeders choose F1 hybrids, not only for heterosis but also for their uniformity and protection against irregular reproduction. Heterosis is occurring in tomato and has been reported by many researchers.

Combining ability is a useful tool, which gives effective genetic information for choosing parents regarding the performance of their hybrids (Chezhian *et al.* 2000) [4]. General Combining Ability (GCA) and Specific Combining Ability (SCA) are two major methods in the breeding programs for the plants for developing F1 hybrid genotypes. GCA is utilized for determining the mean performance of a hybrid in lines combinations. SCA designates as those cases in which conclusive hybrid crosses perform greater or less than would be anticipated on the basis of the average performance of the lines involved (Sprague and Tatum 1942) [30].

The great estimation of SCA demonstrates the importance of the non-additive gene actions to the total genetic variance (Falconer and Mackay 1996) [8].

One of the important characters in the history of plant breeding is earliness. Researchers revealed that this trait has been managed with high success because of its intermediate-high heritability (Banerjee 1989 [2], Kemble and Gardner 1992) [17], which has led breeders to develop early maturing crops with high adaptability (Foolad 2007) [10]. Earliness is also an efficient quantitative trait and is affected by the genetic-physiological composition of plants and environmental conditions. Earliness can be described in different ways. Basically, it represents the time from sowing to the harvestable product of the plant. Earliness also could be a result of the earlier transition from vegetative to reproductive growth or because of more quickly ripening of the fruit (Doganlar *et al*. 2000 [6], Tanksley 2004) [31].

In the cultivated tomato, earliness is generally associated with higher production of ripe fruit. In tomato hybrids, the F1 is usually earlier than the earliest parent in flowering time and in fruit setting (Power and Lyon 1941). Early maturity cultivars of tomato are highly beneficial since early season fruit harvests in order to the most top costs in the fresh market. Earliness is an important trait for selection of tomato, especially in regions with less seasonal rainfall (Ofori *et al*. 2005) [20]. The heritability of earliness in tomato has been found to be a quantitative trait (Peirce and Currence 1959) [22] and has ranged from moderate to high, rely upon on the stage of measuring and the cross under observation (Peirce and Currence 1959 [22], Tayel *et al*. 1959) [32]. Corbeil (1964) [5] revealed that in the expression of earliness and its components of inter- and intraspecific hybrids of genus *Lycopersicon*, dominance plays a significant role, but Fogel and Currence (1950) [9] reported that additive gene effects also had a major role in the expression of earliness.

Material and Methods

This study was carried out during three seasons (in the first half of 2015) in the greenhouse at Faculty of Agriculture, Ferdowsi University of Mashhad, Iran.

Experimental Material

The used original genetic plant materials were eight tomato lines, namely: C.JPS3 (P1), S.2274 (P2), H.1370 (P3), K.2274 (P4), S.L. (P5), C20 (P6), P (P7), A13012 (P8) (Table 1).

In the first season, the parental lines of tomato were grown in a greenhouse to study purity of their inbred lines. In the second season, these different parental lines were also grown in the greenhouse to conduct all needed crosses and selfing. In the third season, seeds of the eight tomato lines and their 28 F1 hybrids, in addition to two commercial cultivars 2971 and Super which used as check cultivars, were sown in the nursery and their seedlings were transplanted in the open-field for the evaluation of the trial.

All crosses along with parents were evaluated in a randomized block design with three replications spaced 60 cm apart. Each net plot had 10 plants and spacing between rows was 90 cm. Cultural practices were conducted according to technical recommendations.

Experimental Data

From five randomly selected plants for each plot, the following traits were recorded: number of days to the first flower, number of days to turning, number of leaves to first inflorescence (Earliness), length of the branch, fruit length, fruit diameter, SPAD index, the weight of single fruit, production per plant and biomass.

Statistical analysis and estimation of genetic parameters

Estimation of General and Specific combining abilities

Estimating of the general and specific combining ability effects were obtained using the methodology proposed by Griffing (1956) for analysis of half diallel with parents (Method 2), considering the fixed effect of treatments.

Estimation of heterosis percentages

Heterosis percentages, relative to the mid-parents, for the different studied characters, were calculated using the procedure illustrated by Mather and Jinks (1971) as follows:

$$\text{Mid-parent heterosis (\%)} = \frac{\text{F1} - \text{M.P}}{\text{M.P.}} \times 100$$

Where F1 = mean value of the particular hybrid population.
M.P. = mean value of the two parents for that hybrid (P1 + P2)/2.

Estimation of Potence Ratio

Potence ratio was calculated according to Smith (1952) to determine the degree of dominance as follows:

$$P = \frac{F1 - M.P.}{0.5\ (P2 - P1)}$$

Where P: relative potence of the gene set, F1: the first generation mean, P1: the mean of a lower parent, P2: the mean of a higher parent, M.P.: mid-parents value = (P1 + P2)/2. Complete dominance was indicated when P = +1; while partial dominance is indicated when "P" is between (−1 and +1), except the value zero, which indicates the absence of dominance. It is considered over-dominance when potence ratio exceeds ±1. The positive and negative signs indicate the direction of the dominance of either parent.

Phenotypic correlation coefficients

The phenotypic correlation coefficients were calculated for all possible pairs of the studied characters as illustrated by Al-Rawi and Khalf-Allah (1980) using the following formula:

$$\text{Phenotypic correlation (r)}: \frac{Co-variance\ XY}{\sqrt{variance\ (X) \times variance\ (Y)}}$$

Where X and Y were the characters (X) and (Y).

Results

Estimates of general and specific combining abilities

From the estimations of combining abilities, the results in Table 2 and 3 revealed that the best combiners, which showed the highest positive values of GCA effects (desirable form), were the parental S.2274 (P2) for length of branch and production per plant, K.2274 (P4) for length and diameter of fruit, C.JPS3 (P1) for SPAD, P (P7) for weight of single fruit and A13012 (P8) for biomass. The line C.JPS3 (P1) was good general combiner for the number of leaves to first inflorescence (Earliness) followed by the lines, S.L. (P5), S.2274 (P2) and K.2274 (P4) as these showed significant negative general combining ability effects (Table 1). Good general combiners for the number of days to turning, having negative general combining ability effects, were C.JPS3 (P1) followed by lines, S.2274 (P2) and P (P7). The best hybrid combinations that reflected the highest positive values of SCA effects were found to be those of the F1 hybrids P x H.1370 for production per plant, S.L x K.2274 for length of branch, H.1370 x C.JPS3 for length and diameter of fruit, C20 x H.1370 for SPAD, P x K.2274 for weight of single fruit and A13012 x H.1370 for biomass. This means that the parents of this particular cross can combine well to produce a hybrid with a high general performance. The best combination for the number of leaves to first inflorescence (Earliness) and also for the number of days to turning were C20 x C.JPS3 and C20 x S.L, respectively.

Furthermore, S.L x H.1370, A13012 x C20, C20 x S.2274, C20 x C.JPS3, K.2274 x S.2274, and A13012 x P combinations had high and positive SCA effect on the production per plant. Highly positive SCA of biomass was depicted by P x K.2274, C20 x H.1370 and C20 x K.2274 combinations. This indicated that the highest positive values of SCA effects of one parent in two combinations can produce a hybrid with high specific performance. The SCA effects range for production of per plant was -1834.11 (A13012 x H.1370) to 2165.13 (P x H.1370) (table 3).

Table 1: Eight parental lines of tomato with corresponding traits.

Parents	Origin	Descriptive features
P1 (C.JPS3)	Italy	Determinate, Good eating quality, early maturity, deep red fruit when mature
P2 (S.2274)	Italy	Determinate, Good eating quality, late maturity, light red fruit when mature
P3 (H.1370)	Italy	Determinate, Good eating quality, early maturity, deep red fruit when mature
P4 (K.2274)	Russia	Determinate, Good eating quality, early maturity, deep red fruit when mature
P5 (S.L)	Russia	Determinate, Good eating quality, early maturity, deep red fruit when mature
P6 (C20)	Russia	Determinate, Good eating quality, early maturity, deep red fruit when mature
P7 (P)	Russia	Determinate, Good eating quality, early maturity, deep red fruit when mature
P8 (A13012)	Russia	Indeterminate, Good eating quality, very late maturity, light red fruits fruit when mature

Table 2: Estimates of general combining ability (GCA) effects on the various studied traits of the eight parental lines of tomato.

Parental lines	Traits								
	Number of leaves to first inflorescence (Earliness)	Number of days to turning	Length of the branch (cm)	Fruit length (mm)	Fruit diameter (mm)	SPAD index	The weight of single fruit (g)	Production per plant (g)	Biomass (g)
C.JPS3 (P1)	-0.6	-3.8	22.7	2.3	-2.5	1.0	-0.2	-384.0	-236.2
S.2274 (P2)	-0.3	-2.8	28.1	-1.1	-0.4	-1.8	-3.3	156.2	-55.8
H.1370 (P3)	0.6	0.4	6.2	-0.6	0.9	-0.4	-1.6	-0.9	-0.9
K.2274 (P4)	-0.1	1.6	-6.9	3.3	1.7	-1.0	1.6	89.6	89.6
S.L. (P5)	-0.5	2.8	-33.7	0.5	1.3	0.8	-1.1	31.1	31.1
C20 (P6)	0.6	0.3	18.0	-0.3	-0.4	-1.9	3.6	45.9	45.9
P (P7)	0.2	-1.1	-2.7	-2.6	-0.2	-1.9	3.8	9.8	9.8
A13012 (P8)	0.1	2.5	-31.6	-1.7	-0.2	-1.9	-2.8	116.5	116.5
LSD (0.05)	0.1	0.8	0.4	0.9	0.6	1.4	2.6	110.0	6.8

Table 3: Estimates of specific combining ability (SCA) effects on the various studied traits of the 28 F1 hybrids, derived from all possible combinations of the eight parental cultivars of tomato.

Hybrids	Traits								
	Number of leaves to first inflorescence (Earliness)	Number of days to turning	Length of the branch (cm)	Fruit length (mm)	Fruit diameter (mm)	SPAD index	The weight of single fruit (g)	Production per plant (g)	Biomass (g)
S. 2274 x C.JPS3	-0.2	-6.5	38.9	0.1	-3.4	2.2	-2.1	478.1	-12.0
H.1370 x C.JPS3	0.3	-3.7	65.8	12.6	11.4	1.8	11.7	415.5	-88.9
H.1370 x S.2274	0.1	-3.2	-21.7	-3.7	-3.5	0.2	-6.7	-1099.9	-60.8
K.2274 x C.JPS3	-0.9	0.8	-85.4	1.7	-1.3	0.3	-8.2	-187.7	-140.0
K.2274 x S.2274	-0.2	-4.9	-34.4	-0.6	3.5	0.4	-3.2	553.5	90.6
K.2274 x H.1370	-0.5	4.2	95.2	4.1	-0.3	0.1	-19.4	-1041.1	-270.2
S.L x C.JPS3	-0.1	2.6	-126.0	-6.5	1.5	0.7	-7.0	-449.5	135.0
S.L x S.2274	0.1	2.8	-41.4	1.0	1.3	1.3	7.3	109.9	144.2
S.L x H.1370	0.2	0.7	-100.8	-1.6	-0.4	-3.4	-2.1	1851.1	-76.7
S.L x K.2274	-0.9	6.0	188.3	3.3	4.2	-0.3	-3.0	-90.2	-143.3
C20 x C.JPS3	-1.6	3.2	60.0	-1.9	-3.9	2.4	26.3	513.2	-78.8
C20 x S.2274	-0.4	6.4	38.5	3.6	0.9	-10.4	3.0	640.2	-4.6
C20 x H.1370	2.4	-2.8	45.9	-0.3	1.9	6.0	3.6	-581.4	178.5
C20 x K.2274	0.8	-1.5	-70.5	-2.2	-2.0	-0.8	-19.1	-141.1	168.0
C20 x S.L	0.2	-8.2	-7.9	-1.8	-4.4	-1.4	-3.2	-482.9	-84.1
P x Cal J PS 3	1.6	1.8	-17.4	-5.7	-5.3	1.3	-17.0	-787.1	-87.6
P x S.2274	0.3	0.6	61.8	-3.3	-0.7	2.2	-3.7	-710.8	-220.5
P x H.1370	-1.4	10.6	-22.1	0.9	-5.0	-4.1	20.1	2165.1	91.7
P x K.2274	0.3	-1.1	-100.6	-1.5	1.4	0.5	33.6	435.2	221.1

P x S.L	0.7	-4.3	25.9	-0.8	-1.5	1.8	-10.2	-407.4	192.6
P x C20	-1.5	-4.8	12.7	1.7	5.9	-0.1	-0.7	-1353.5	-129.2
A13012 x C.JPS3	-0.1	-0.8	60.0	-0.6	-1.8	-6.1	-6.7	-647.8	-22.3
A13012 x S.2274	0.1	1.9	-13.6	1.8	1.5	2.3	2.1	185.1	7.3
A13012 x H.1370	-0.5	-5.4	-56.2	-12.6	-3.1	-1.1	-8.9	-1834.1	225.5
A13012 x K.2274	1.3	-1.8	0.5	-1.4	-3.7	-1.1	20.9	734.1	163.4
A13012 x S.L	-1.2	4.5	1.4	4.2	0.2	3.9	14.4	-830.8	-195.1
A13012 x C20	0.6	8.0	-60.6	0.6	1.2	2.3	-6.3	1523.9	-3.9
A13012 x P	0.1	-4.0	36.9	6.1	5.2	0.9	-18.4	758.6	-58.3

General performances of the evaluated genetic populations

The results of the average yield, mid-parent heterosis and potence ratios of the tomato lines and their hybrids for the various studied traits are presented in Tables 4–6. Results of the mean values of the parental lines showed a relatively high degree of range values indicating the presence of a great deal of variability among the parental lines for the most studied traits. The parental line S.L. (P5) gave the highest mean values for the traits weight of single fruit and biomass. Concerning fruit length, fruit diameter, and SPAD index the significant highest mean values were indicated by the parental line K.2274 (P4), whereas the parental lines P (P7), C.JPS3 (P1) and S.2274 (P2) had the lowest mean values for fruit length, fruit diameter and SPAD index, respectively. The parental line H.1370 (P3) had the significant highest mean value for production per plant but C20 (P6), S.2274 (P2) and C.JPS3 (P1) reflected the lowest one. Regarding the length of the branch, the highest mean value was shown by the parental line A13012 (P8), while the parental lines P (P7), C20 (P6) and S.L. (P5) had the lowest mean values for this trait. For the number of leaves to first inflorescence (Earliness) and number of days to turning, parental lines S.L. (P5) and C.JPS3 (P1) reflected the lowest mean values, respectively. Due to these traits, low values revealed the best performance of parental lines.

Results of F1 hybrids showed that most of them produced average values that tended to be either more than their respective mid-parental values or exceeded the better-parental values. Among the 28 F1 hybrids, the significant highest mean value was found to belong to those of the F1 hybrids, P (P7) x H.1370 (P3) for production per plant, A13012 (P8) x K.2274 (P4) for biomass, P (P7) x K.2274 (P4) for weight single fruit, H.1370 (P3) x C.JPS3 (P1) for length and diameter of fruit, A13012 (P8) x S.L. (P5) for SPAD, S.L. (P5) x K.2274 (P4) for length of branch. S.2274 (P2) x C.JPS3 (P1) for the number of days to turning and P4 x P1, P5 x P4, P6 x P1, and P8 x P5 were the best combinations for the number of leaves to first inflorescence (Earliness). These two traits are the most important earliness trait, which ensures a higher market price of tomato.

Heterosis and potence ratio estimations of the F_1 hybrids

The estimation of heterosis, relative to mid-parental values reflected good effects with positive signs on six, eight, nine, eleven, twelve and thirteen F1 hybrids for the traits fruit length, fruit diameter, number of days to first inflorescence, biomass, number of days to turning, weight of single fruit and SPAD, respectively (Table 4-6). In contrast, the rest of F_1 combinations gave negative heterosis values, which did not reflect any desirable heterotic effects compare to their mid-parental lines for the previously mentioned traits. Desirable and positive heterotic effects were revealed on more than half of the F1 hybrids for the traits 19 and 22 lengths of branch and production per plant. The mid-parent heterosis varied from -1.3 to 4.1% for number of leaves to first inflorescence (Earliness), -8.9 to 13.5% for number of days to turning, -95.2 to 256.2 for length of branch, -18.6 to 13.7 for length of fruit, -9.3 to 12.7 for diameter of fruit, -12.8 to 4.9 for SPAD, -31.9 to 46.3 for weight of single fruit, -1770.9 to 2449.2 for production per plant, -323.5 to 375.0 for biomass.

The appraisal values for potence ratio (Table 4-6) illustrated that in most combinations the estimated potence ratio showed positive value for the traits number of leaves to first inflorescence (Earliness), number of days to turning, length of branch and production per plant. These results revealed, generally, various degrees of dominance; i.e., partial- to over-dominance that involved in the inheritance of these traits. For fruit length, fruit diameter, SPAD, the weight of single fruit and biomass the estimated values of potence ratios in most F1 crosses were negative for these traits. Negative values of potence ratio illustrated the presence of various degrees of recessiveness, i.e., partial- to under- recessiveness.

Potence ratios showed a positive nature for more than 20 F1 hybrids for production per plant and ranged from 0.1 to 140.0 (Table 4-6). These results indicated the presence of partial- to over-dominance, which involved in the inheritance of this trait. Significantly production per plant and length of the branch for sixteen F1 hybrid exhibited over-dominance of gene effects as potence ratio estimates were positive and more than one meaning that inheritance of these traits for sixteen F1 hybrids out of the evaluated 28 F1 crosses was exclusively due to over dominance. The combinations P3 x P1, P4 x P1, P5 x P1, P6 x P5, P7 x P1, P7 x P5 and P8 x P1 displayed the role of partial dominance for production per plant, with degrees 0.9, 0.9, 0.5, 0.4, 0.2, 0.3 and 0.1, respectively. Fourteen and twelve hybrids displayed the role of over dominance for the number of days to turning and number of leaves to first inflorescence (Earliness), respectively, where potence ratio was more than one and positive which would emphasize the major role of over dominance for the inheritance of these traits.

Phenotypic correlation coefficients

The results of the phenotypic correlation coefficients showed positive correlations between length of branch and fruit length, fruit length and fruit diameter, fruit diameter and SPAD index, number of days to turning and production per plant, number of days to turning and biomass, production per plant and biomass. On the contrary, negative correlations were detected between the length of branch and production per plant, the number of leaves to the first inflorescence (Earliness) and fruit length, fruit length and production per plant.

Table 4: Mean performance, heterosis percentage (relative to mid-parental value) and potence ratio of eight parental lines, their F1 hybrids and two check cultivars for the various studies traits of tomato.

Genotypes	Traits											
	Number of leaves to first inflorescence (Earliness)			Number of days to turning			Length of the branch (cm)			SPAD index		
	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)
C.JPS3 (P1)	6.0	-	-	27.5	-	-	197.4	-	-	42.8	-	-
S.2274 (P2)	7.5	-	-	30.3	-	-	199.3	-	-	40.8	-	-
H.1370 (P3)	6.0	-	-	32.7	-	-	255.4	-	-	41.0	-	-
K.2274 (P4)	6.0	-	-	33.3	-	-	180.8	-	-	49.5	-	-
S.L. (P5)	5.0	-	-	35.3	-	-	138.4	-	-	43.5	-	-
C20 (P6)	6.0	-	-	32.6	-	-	219.0	-	-	45.2	-	-
P (P7)	5.7	-	-	37.0	-	-	214.5	-	-	48.6	-	-
A13012 (P8)	5.3	-	-	28.3	-	-	359.0	-	-	48.2	-	-
P2 x P1	5.5	-1.3	-1.7	20.0	-8.9	-1.7	357.8	159.5	167.8	45.7	4.0	4.0
P3 x P1	6.8	0.8	15.7	26.0	-4.1	-0.7	362.8	136.4	1.7	46.7	4.9	5.4
P3 x P2	7.0	0.2	0.3	27.5	-4.0	3.4	280.6	53.3	1.9	42.3	1.4	14.0
P4 x P1	5.0	-1.0	-31.0	31.7	1.3	0.4	198.5	9.5	1.1	44.7	-1.5	-0.4
P4 x P2	6.0	-0.8	-1.1	27.0	-4.8	-3.2	254.9	64.9	7.1	41.9	-3.2	-0.7
P4 x P3	6.5	0.4	-25.0	39.3	6.3	19.0	362.6	144.5	3.9	43.0	-2.2	-0.5
P5 x P1	5.8	0.3	0.7	33.5	2.1	0.5	157.9	-10.0	-0.3	45.0	1.9	5.0
P5 x P2	5.9	-0.3	-0.3	35.9	3.0	1.2	221.1	52.3	1.7	44.5	2.4	1.7
P5 x P3	6.8	1.3	2.3	37.0	3.0	2.3	139.8	-57.1	-1.0	41.3	-0.9	-0.7
P5 x P4	5.0	-0.5	-1.0	43.5	9.2	9.2	415.8	256.2	12.1	43.8	-2.7	-0.9
P6 x P1	5.0	-1.1	-16.0	32.8	2.8	1.1	368.8	160.6	14.8	45.8	1.8	1.5
P6 x P2	6.5	-0.3	-0.5	37.0	5.5	4.8	352.7	143.5	14.5	30.1	-12.8	-5.8
P6 x P3	10.2	4.1	243.0	31.0	-1.7	-139.0	338.2	101.0	5.6	48.0	4.9	2.3
P6 x P4	7.8	1.7	52.0	33.5	0.5	1.5	208.7	8.8	0.5	40.7	-6.7	-3.1
P6 x P5	6.8	1.3	2.2	28.0	-6.0	-4.5	244.5	65.8	1.6	41.8	-2.6	-3.1
P7 x P1	7.8	2.0	12.0	30.0	-2.3	-0.5	270.7	64.7	7.6	49.0	3.3	1.1
P7 x P2	6.8	0.3	0.3	29.7	-4.0	-1.2	355.3	148.4	19.5	47.2	2.5	0.6
P7 x P3	6.0	0.1	0.5	43.0	8.2	3.8	249.5	14.5	0.7	42.3	-2.5	-0.7
P7 x P4	7.0	1.1	5.7	32.5	-2.7	-1.5	157.8	-39.8	-2.4	46.3	-2.8	-6.1
P7 x P5	7.0	1.7	-5.0	30.5	-5.7	-6.8	257.6	81.1	2.1	49.3	3.3	1.3
P7 x P6	5.8	-0.1	-0.3	27.5	-7.3	-3.4	296.1	79.3	35.2	44.7	-2.2	-1.3
P8 x P1	6.0	0.3	-1.0	31.0	3.1	7.4	319.2	41.0	0.5	40.3	-5.2	-1.9
P8 x P2	6.4	0.1	0.1	34.7	5.4	5.4	250.9	-28.2	-0.4	45.9	1.4	0.4
P8 x P3	6.8	1.3	2.7	30.7	0.2	0.1	186.5	-120.7	-2.3	43.8	-0.7	-0.2
P8 x P4	7.8	2.1	5.8	35.5	4.7	1.9	230.1	-39.8	-0.5	43.3	-5.5	-8.3
P8 x P5	5.0	-0.2	1.0	43.0	11.2	3.2	204.2	-44.6	-0.4	50.0	4.2	1.8
P8 x P6	7.8	2.1	5.3	44.0	13.5	6.3	193.9	-95.2	-1.4	45.8	-0.9	-0.6
P8 x P7	7.0	1.5	9.0	30.5	-2.2	-0.5	270.6	-16.1	-0.2	48.8	0.4	1.8
Check cultivar (2971)	6.8	-	-	19.3	-	-	217.2	-	-	40.8	-	-
Check cultivar (Super)	8.3	-	-	36.7	-	-	216.5	-	-	46.6	-	-
LSD $_{(0.05)}$	0.2			1.4			0.8			2.5		
LSD test at 0.05 level of probability.												

Table 5: Mean performance, heterosis percentage (relative to mid-parental value) and potence ratio of eight parental lines, their F1 hybrids and two check cultivars for the various studies traits of tomato.

Genotypes	Traits														
	Fruit length (mm)			Fruit diameter (mm)			Weight of single fruit (g)			Production per plant (g)			Biomass (g)		
	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)	Mean ($\bar{X}$)	Heterosis (M.P.%)	Potence ratio (*P*)
C.JPS3 (P1)	40.4	-	-	39.3	-	-	16.4	-	-	1134.1	-	-	580.0	-	-
S.2274 (P2)	41.8	-	-	42.9	-	-	40.2	-	-	1824.4	-	-	730.0	-	-
H.1370 (P3)	45.3	-	-	51.9	-	-	60.1	-	-	2853.2	-	-	897.5	-	-
K.2274 (P4)	47.5	-	-	55.7	-	-	52.8	-	-	2576.4	-	-	912.0	-	-
S.L. (P5)	42.1	-	-	47.7	-	-	66.5	-	-	2687.7	-	-	1157.5	-	-
C20 (P6)	42.0	-	-	48.1	-	-	22.8	-	-	1950.0	-	-	1098.4	-	-
P (P7)	40.0	-	-	54.6	-	-	39.2	-	-	2194.7	-	-	799.5	-	-
A13012 (P8)	46.6	-	-	54.6	-	-	21.8	-	-	2214.4	-	-	700.0	-	-
P2 x P1	43.5	2.4	3.3	42.2	1.1	0.6	30.5	2.2	0.2	3082.7	1603.4	4.7	507.5	-147.5	-2.0

P3 x P1	56.6	13.7	5.6	58.2	12.7	2.0	46.1	7.8	0.4	2739.3	745.6	0.9	485.5	-253.3	-1.6
P3 x P2	36.9	-6.7	-3.9	45.5	-1.9	-0.4	24.5	-25.6	-2.6	1764.0	-574.8	-1.1	694.0	-119.8	-1.4
P4 x P1	49.6	5.6	1.6	46.4	-1.1	-0.1	29.3	-5.2	-0.3	2523.6	668.4	0.9	525.0	-221.0	-1.3
P4 x P2	43.8	-0.8	-0.3	53.3	4.0	0.6	31.2	-15.3	-2.4	3805.0	1604.6	4.3	935.9	114.9	1.3
P4 x P3	49.1	2.7	2.5	50.8	-3.0	-1.6	16.7	-39.7	-10.9	1929.6	-785.2	-5.7	630.0	-274.8	-37.9
P5 x P1	41.4	0.1	0.1	49.2	5.7	1.3	30.6	-10.9	0.4	2261.8	350.9	0.5	800.0	-68.8	-0.2
P5 x P2	42.7	0.7	4.4	50.6	5.3	2.2	39.1	-14.3	-1.1	3080.1	824.0	1.9	931.0	-12.8	-0.1
P5 x P3	40.6	-3.1	-2.0	50.2	0.4	0.2	31.4	-31.9	-10.0	4540.5	1770.0	21.4	765.0	-262.5	-2.0
P5 x P4	49.4	4.5	1.7	55.6	3.9	1.0	33.6	-26.0	-3.8	2986.8	354.7	6.4	789.0	-245.8	-2.0
P6 x P1	42.4	1.2	1.5	41.7	-2.0	-0.5	65.9	46.3	14.3	3080.2	1538.1	3.8	542.5	-296.71	-1.1
P6 x P2	44.5	2.6	39.6	48.7	3.2	1.2	39.5	8.0	0.9	3747.3	1860.1	29.6	797.0	-117.21	-0.7
P6 x P3	41.1	-2.5	-0.1	51.0	1.0	0.5	41.8	0.4	0.1	2245.0	-156.6	-0.4	1035.0	37.0	0.4
P6 x P4	43.1	-1.6	-0.6	47.8	-4.1	-1.1	22.3	-15.5	-1.0	3072.8	809.6	2.6	1115.0	109.8	1.2
P6 x P5	40.8	-1.3	-14.1	45.0	-3.0	-15.5	35.5	-9.2	-0.4	2449.6	130.8	0.4	804.5	-323.5	-11.0
P7 x P1	36.3	-3.8	-19.3	40.5	-6.4	-0.8	22.8	-5.0	-0.5	1761.5	97.1	0.2	497.5	-192.3	-1.8
P7 x P2	35.3	-5.6	-6.0	47.2	-1.5	-0.3	33.0	-6.7	-13.5	2378.0	368.5	2.0	545.0	-219.8	-6.3
P7 x P3	40.0	-2.6	-1.0	44.2	-9.0	-6.8	58.5	8.9	0.9	4973.1	2449.2	7.4	912.0	63.5	1.3
P7 x P4	41.4	-2.3	-0.6	51.4	-3.7	-6.5	75.2	29.2	4.3	3630.8	1245.2	6.5	1132.0	276.3	4.9
P7 x P5	39.4	-1.7	-1.6	48.0	-3.1	-0.9	28.7	-24.2	-1.8	2506.9	65.7	0.3	1045.0	66.5	0.4
P7 x P6	41.1	0.1	0.1	53.8	2.5	0.8	42.9	11.9	1.5	1697.8	-374.6	3.1	738.0	-211.0	-1.4
P8 x P1	42.3	-1.2	-0.4	43.6	-3.4	-0.4	26.4	7.3	2.7	1689.8	15.6	0.1	669.5	29.5	0.5
P8 x P2	41.3	-3.0	-1.3	49.1	0.3	0.1	32.2	1.2	0.1	3062.9	1043.5	5.4	879.4	164.4	11.0
P8 x P3	27.3	-18.6	-29.0	45.8	-7.5	-5.5	22.9	-18.1	-0.9	762.9	-1770.9	-5.5	1152.5	353.8	3.6
P8 x P4	42.5	-4.6	-9.8	45.9	-9.3	-16.9	55.9	18.6	1.2	3718.7	1323.3	7.3	1181.0	375.0	3.5
P8 x P5	45.2	0.9	0.4	49.3	-1.8	-0.5	46.7	2.6	0.1	1872.5	-578.6	-2.4	764.0	-164.8	-0.7
P8 x P6	40.9	-3.4	-1.5	48.8	-2.6	-0.8	30.6	8.3	15.5	4364.1	2281.9	17.3	970.0	70.8	0.4
P8 x P7	44.1	0.8	0.2	52.9	-1.7	76.1	18.8	-11.7	-1.3	3580.5	2281.9	140.0	879.5	129.8	2.6
Check cultivar (2971)	43.1	-	-	36.3	-	-	24.6	-	-	4284.0	-	-	698.3	-	-
Check cultivar (Super)	44.3	-	-	45.6	-	-	23.8	-	-	1944.6	-	-	1041.7	-	-
LSD (0.05)	1.1			1.6			5.0			190.4			11.8		
LSD test at 0.05 level of probability.															

Table 6: Phenotypic coefficients of correlation values (r) for the different pairs of studied traits of tomato.

Traits	2	3	4	5	6	7	8	9
1. Number of leaves to first inflorescence (Earliness)	-0.09	-0.03	-0.29	-0.08	0.01	-0.13	0.29	0.06
2. Number of days to turning		-0.18	0.09	0.18	-0.08	0.22	0.31	0.39
3. Length of branch			0.31	0.12	-0.05	0.22	-0.49	-0.06
4. Fruit length				0.51*	0.01	0.14	-0.28	0.23
5. Fruit diameter					0.23	0.13	0.20	0.19
6. SPAD index						0.01	-0.05	-0.21
7. The weight of single fruit							0.27	0.37
8. Production per plant								0.24
9. Biomass								
* Significant at 0.05 level of probability.								

Discussion

General combining ability (GCA) of a parent is a factor that predicts the performance of a parent over a series of cross combinations (Rohini *et al*. 2017) [24]. Producing hybrids with better performance than their parents or other cultivars (commercially produced) are among the achieved results. Our results are in a harmony with the conclusions of El-Gabry (2014) for production per plant. Our results showed that the highest and positive general combining ability for two traits was obtained by S.2274 (P2) for the length of branch and production per plant. It can be used as the best combiner to develop high yield tomato hybrids. Parent P (P7) had the highest GCA for the weight of single fruit, moreover, parent C.JPS3 was the best combiner for the number of leaves to first inflorescence (Earliness), number of days to turning and SPAD. A13012 (P8) was the best parent for biomass, while, K.2274 (P4) was the best combiners for length and diameter of the fruit.

P x H.1370 was the best specific combination of the desirable significant SCA effects for the trait of production per plant. The second best cross for production per plant was S.L x H.1370 combination and the third best cross was A13012 x C20. The combinations by higher specific combing ability for one or few traits can be utilized as parents in breeding programs (El-Gabry *et al.* 2014). Among 28 hybrids, cross between P x K.2274 had the highest SCA for the weight of single fruit followed by C20 x C.JPS3, A13012 x K.2274 and P x H.1370. In some of the combinations, high and positive SCA effects were observed but they had both the parents as poor general combiners. These findings are in harmony with the observations of Sood and Kumar (2010) [28] and Pandey *et al*. (2012) [21], which also indicated that the elite hybrids need not necessarily involve parents showing good general combining ability effects only.

The significant mean squares of families for all traits indicated the presence of genetic variation among parents and their crosses and illustrated that both additive and non-additive gene actions are responsible for the inheritance of all studied traits. Our findings also indicated that tomato combinations can produce F1 hybrids which may perform superior in one or more characteristics than either of their parents or other commercial cultivars.

There are significant differences among the studied genotypes of tomato for the length of the branch, as a vegetative trait, this result is also found in Singh and Asati (2011) [26]. Moreover, our findings revealed various degrees of dominance effects; partial- to overdominance, in the genetic control of studied traits. These findings were in harmony with other researchers (Kansouh and Masoud 2007, Singh and Asati 2011) [26]. They reported that predominance variance for the non-additive component of all the studied traits indicating a successful situation for utilization of heterosis in tomato breeding. Soleiman (2009) [27] also found that most of the genetic differences among the general performances of the genotypes might be due to non-additive gene effects.

General performances of the 28 F1 hybrids revealed relative superiority over their performances for the traits length of branch and production per plant. Besides, estimation of heterosis percentage and potence ratio of mentioned traits presented positive values in most of the F1 hybrids. The advantage of crossbreeding on non-additive gene effects is through heterosis (Melchinger *et al*. 2007) [19]. and high value of heterosis is the result of the effects of non-additive genes. Various degrees of gene effects; i.e., partial- to over-dominance, were detected in the inheritance of length of branch and production per plant. Total fruit weight per plant and number of fruits per plant was inherited by over-dominance and partial dominance, respectively (Dordevic *et al*. 2010) [7]. Negative heterosis in most of the F1 hybrids of the weight of single fruit and biomass revealed various degrees of recessiveness; i.e., partial- to under-recessiveness. Other findings showed that overdominance effect plays an influential performance in the genetic control of the number of fruits per plant and average fruit weight (Ahmad *et al*. 2010, Souza *et al*. 2012) [29]. Negative heterosis was considered to be superior for the number of leaves to first inflorescence (Earliness) and Number of days to turning. The highest negative heterosis for these two traits was detected in S.2274 (P2) x C.JPS3 (P1). Therefore this combination has good performance for earliness. Positive potence ratio and heterosis in most of the combinations of production per plant and length of branch exhibited partial to over-dominance of gene effects.

Phenotypic correlation coefficients between (r = 0.51) fruit length and diameter were positive and significant. Correlation between (r = 0.27) weight of single fruit and production per plant was also positive. The result was in full agreement with some earlier studies (Hidayatullah *et al*. 2008, Rani *et al*. 2010) [23].

Having Information about combination abilities (GCA and SCA), heterosis, potence ratio and correlation among traits of the lines and their hybrids are fundamental in plant breeding. Our study showed that a parental line, parental cultivar or hybrid cannot be used to assess all studied traits, however, our findings revealed that the best crosses were P (P7) x H.1370 (P3) for production per plant, A13012 (P8) x K.2274 (P4) for biomass, P (P7) x K.2274 (P4) for weight single fruit, H.1370 (P3) x C.JPS3 (P1) for length and diameter of fruit, A13012 (P8) x S.L. (P5) for SPAD, S.L. (P5) x K.2274 (P4) for length of branch. S.2274 (P2) x C.JPS3 (P1) for the number of days to turning and P4 x P1, P5 x P4, P6 x P1, and P8 x P5 were the best combinations for the number of leaves to first inflorescence (Earliness). Our results also indicated that desirable and positive heterotic effects were revealed on more than half of the F1 hybrids for the traits 19 and 22 lengths of branch and production per plant. Moreover, the appraisal values for potence ratio illustrated that in most combinations the estimated potence ratio showed positive value for the traits number of leaves to first inflorescence (Earliness), number of days to turning, length of branch and production per plant.

Acknowledgments

Authors are thankful to Faculty of Agriculture, Ferdowsi University of Mashhad, Iran for the financial support.

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