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Combining ability studies in tomato for yield and processing traits

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Abstract

The experiment was conducted during 2014-16 at Vegetable Research Station of Sri Konda Laxman Telangana State Horticultural University at Hyderabad falls under the Southern Telangana zone, India. The treatment comprises thirty F1 hybrids along with eleven parents (five lines and six testers) and three commercial checks *i.e.* US-440, Arka Rakshak and NS-516. The experimental material was evaluated in Randomized Block Design with three replications under three diverse times. Nineteen observations were recorded relating to yield and quality traits. Estimates of *SCA* variance were higher than *GCA* variance with the ratio of *GCA* variance to *SCA* variance ($\sigma^2_{gca}/\sigma^2_{sca}$) lower than unity (<1) except days to 50% flowering, fruit pH, titrable acidity and lycopene content indicating the preponderance of non-additive gene action. Among the parents EC-620360 tops first followed by EC-608415, EC-619982, Punjab Chhuhara, Pusa Ruby and EC-520078 and among crosses EC-620428 $\times$ Arka Abha ranks first followed by EC-620360 $\times$ Pusa Ruby, EC-608415 $\times$ Arka Saurabh, EC-608415 $\times$ Arka Abha and EC-608415 $\times$ Punjab Chhuhara. The predominance of non-additive gene action over the additive component, which is ideal for exploitation through heterosis breeding. In few cases, crosses with both good general combiner parents had also exhibited high *sca* effects, indicating the role of additive $\times$ additive type of gene action offering a good scope for fixation of the heterotic effects through the isolation of high yielding homozygous lines in advanced generations.

Keywords: Tomato, combining ability, *GCA*, *SCA*

Introduction

Tomato (*Solanum lycopersicum* L., $2n=24$) is widely grown vegetable in the world from temperate to tropical climate. Cultivated forms originated from *Lycopersicum esculentum* var. *cerasiforme*. It surpasses all vegetables in terms of total contribution of essential nutrients to diet because of its wide consumption and diverse uses. It is consumed in fresh form as salad and in various processed forms like soup, sauce, ketchup, paste, puree, powder and canned whole fruit *etc.* and tops the list of processed vegetables. Tomato is incredibly versatile fruit; it contains one of the most powerful anti-oxidant compounds called lycopene which have effective anti-cancer properties (Islam *et al.*, 2010) [9]. Tomato also flushes out free radicals, protect against inflammation, heart diseases and prevent DNA damage in human body. It is also used for preparation of natural beauty cosmetics (Mahajan *et al.*, 2010) [13].

There are no popular hybrids which can serve dual purpose for meeting the needs of the processing industries and consumers. Most of the commercial hybrids developed are either for culinary or processing purposes. By developing dual purpose farmers can sell the produce to processing industries when there is severe glut in the markets thereby compensating low market prices.

Material and Methods

The experiment was conducted during 2014-16 at Vegetable Research Station of SKLTSHU at Hyderabad falls under the Southern Telangana Zone, situated at an altitude of 542.6 m above mean sea level. Geographically it lies at latitude of 17.19° N and a longitude of 79.23° E. The treatment comprises thirty F1 hybrids along with eleven parents (five lines and six testers) and three commercial checks *i.e.*, US-440, Arka Rakshak and NS-516. The experimental material was evaluated in Randomized Block Design with three replications under three diverse times

tailored at Vegetable Research Station, ARI, Rajendranagar, Hyderabad. Nineteen observations were recorded relating to yield and quality traits. The data were analysed statistically to test the significance of the treatments (Panse and Sukhatme, 1967) ^[15]. Statistical analysis of combining ability and narrow sense heritability in Line $\times$ Tester mating design was performed following the method given by Kempthorne (1957) ^[10] using statistical software INDOSTAT version 8.0. Significance of the combining ability effects was determined at 1% and 5% probability. Combining ability values for the characters like days to 50 per cent flowering, days to first fruit harvest, are to be considered desirable only if they are in negative direction. For rest of the traits studied, combining ability values in positive direction are preferred as desirable.

Results and Discussion

Analysis of variance

The pooled ANOVA for combining ability over three intervals revealed significant differences for all the traits studied.

Gene action

The components of heritable variation *viz.*, *GCA* variance (σ^2_{gca}) and *SCA* variance (σ^2_{sca}) and their ratios for all the nineteen characters are presented in Table 1. In present investigation, pooled analysis of combining ability revealed that the estimates of *SCA* variance (σ^2_{sca}) are higher than *GCA* variance (σ^2_{gca}) with the ratio of *GCA* variance to *SCA* variance ($\sigma^2_{gca}/\sigma^2_{sca}$) lower than unity (<1) for all characters except days to 50% flowering, fruit pH, titrable acidity and lycopene content indicating the preponderance of non-additive gene action involved in inheritance of traits. Hence, heterosis breeding and recombination breeding with postponement of selection at later generations are ideal to improve these traits. Similar non-additive gene action for yield and yield related characters were reported by Naveen *et al.* (2008) ^[20], Mondal *et al.* (2009) ^[17], Singh and Asati (2011) ^[28], Varun *et al.* (2012) ^[33], Pemba *et al.* (2014) ^[22], Ebenezer (2014) ^[8], Alex Sandro *et al.* (2015) ^[11] and Vipesh *et al.* (2015) ^[34].

Combining ability effects

The estimates of *gca* effects of parents and estimates of *sca* effects of crosses are presented in Table 4 to 13.

The character wise analysis of the *gca* and *sca* effects for different characters in three different dates at single location and pooled analysis are presented below.

Plant height determines the fruit bearing surface and is considered as one of the important growth attribute governing yield. Genotypes, EC-620360, EC-520078 and EC-620557 and crosses EC-620428 $\times$ Arka Abha, EC-620428 $\times$ EC-520078, EC-620360 $\times$ Arka Saurabh, EC-620360 $\times$ Punjab Chhuhara, EC-620360 $\times$ EC-620557, EC-608415 $\times$ Pusa Ruby, EC-608415 $\times$ EC-620557, EC-619982 $\times$ Punjab Chhuhara and EC-619982 $\times$ EC-520078 expressed positive significant *gca* and *sca* effects. EC-520078 was the superior general combiner. Non-additive gene action was found to be important as *GCA* variance was less than the *SCA* variance. The results are in line with the earlier reports of Varun *et al.* (2012) ^[33], Pooja Kapur *et al.* (2013) ^[24], Ebenezer (2014) ^[8], Kumar *et al.* (2017) ^[32], Raj *et al.* (2017) ^[3], Ramana *et al.* (2017) ^[25] and Savale and Patel (2017) ^[27]. High yield is manifested through enhancement in the vegetative characters like number of primary branches per plant. Positive significant *gca* effects were observed in EC-608415, EC-

619982, Punjab Chhuhara and Pusa Ruby, while *sca* effects were positively significant in EC-620407 $\times$ Arka Abha, EC-620407 $\times$ EC-520078, EC-620407 $\times$ EC-620557, EC-620428 $\times$ Arka Abha, EC-620360 $\times$ Arka Saurabh, EC-620360 $\times$ EC-620557, EC-608415 $\times$ Punjab Chhuhara, EC-608415 $\times$ Pusa Ruby, EC-619982 $\times$ Punjab Chhuhara and EC-619982 $\times$ Pusa Ruby. Ratio of *GCA* to *SCA* variance was less than unity indicating the role of non-additive gene action. Singh *et al.* (2008) ^[29], Singh *et al.* (2010) ^[30], Singh and Asati (2011) ^[28], Kumar *et al.* (2017) ^[32] and Ramana *et al.* (2017) ^[25] reported similar kind of results.

Days to 50% flowering indicates earliness. Among the genotypes evaluated EC-620407, EC-620428, EC-608415, EC-520078 and EC-620557 exhibited significant negative *gca* effects whereas EC-620407 $\times$ Arka Saurabh, EC-620407 $\times$ Arka Abha, EC-620407 $\times$ Pusa Ruby, EC-620428 $\times$ EC-520078, EC-620360 $\times$ Arka Abha, EC-620360 $\times$ Punjab Chhuhara, EC-620360 $\times$ EC-520078, EC-608415 $\times$ Punjab Chhuhara, EC-608415 $\times$ EC-620557, EC-619982 $\times$ Arka Saurabh and EC-619982 $\times$ EC-620557 exhibited significant negative *sca* effects. Ratio of *GCA* to *SCA* variance was high suggesting the importance of additive gene action. Conformity results were reported by Singh *et al.* (2008) ^[29], Sunil *et al.* (2013) ^[31], Shankar *et al.* (2013), Kumar *et al.* (2017) ^[32], Pujer *et al.* (2017) ^[21], Raj *et al.* (2017) ^[3] and Savale and Patel (2017) ^[27]. Negative estimates of *gca* and *sca* are considered to be favourable as they give rise to early duration hybrids.

Higher the number of flowers per cluster higher will be the fruits per plant and yield. The genotypes, EC-620360, EC-608415, EC-619982, Punjab Chhuhara and EC-520078 and crosses EC-620407 $\times$ Arka Saurabh, EC-620407 $\times$ EC-520078, EC-620428 $\times$ Arka Abha, EC-620360 $\times$ Punjab Chhuhara, EC-608415 $\times$ Arka Saurabh, EC-608415 $\times$ EC-520078 and EC-619982 $\times$ Pusa Ruby recorded significant positive *gca* and *sca* effects. The genotypes expressed similar type of results with respect to number of fruits per cluster where parents EC-608415, EC-619982, Punjab Chhuhara and EC-520078 and crosses EC-620407 $\times$ Arka Saurabh, EC-620407 $\times$ EC-520078, EC-620428 $\times$ Punjab Chhuhara, EC-620428 $\times$ EC-520078, EC-620360 $\times$ Arka Abha, EC-620360 $\times$ EC-620557, EC-608415 $\times$ EC-620557 and EC-619982 $\times$ Pusa Ruby exhibited positive significant *gca* and *sca* effects. Non-additive gene action was found to be involved due to high *SCA* variance. Present results are in conformity with the earlier findings of Mehta *et al.* (2005) ^[16], Varun *et al.* (2012) ^[33], Pemba *et al.* (2014) ^[22], Kumar *et al.* (2017) ^[32], Pujer *et al.* (2017) ^[21] and Ramana *et al.* (2017) ^[25].

Fruit length and fruit width are growth attributes directly associated with yield. EC-6200407, EC-620428, EC-620360, Arka Saurabh, Arka Abha, Punjab Chhuhara and EC-620557 manifested positive *gca* effects while EC-620407 $\times$ Arka Abha, EC-620407 $\times$ Punjab Chhuhara, EC-620428 $\times$ Arka Saurabh, EC-620428 $\times$ Pusa Ruby, EC-620360 $\times$ EC-520078, EC-620360 $\times$ EC-620557, EC-608415 $\times$ Arka Abha, EC-608415 $\times$ EC-520078, EC-619982 $\times$ Arka Saurabh and EC-619982 $\times$ Pusa Ruby manifested positive *sca* effects. The ratio of *GCA* to *SCA* variances was less than unity with non-additive gene action governing the trait. These results are in conformity with the earlier reports of Muhammad *et al.* (2009) ^[18], Singh *et al.* (2010) ^[30] Varun *et al.* (2012) ^[33] and Kumar *et al.* (2017) ^[32].

Among the parents EC-620360, Arka Saurabh, Arka Abha, Punjab Chhuhara, Pusa Ruby and EC-620557 while EC-620407 $\times$ Pusa Ruby, EC-620428 $\times$ Arka Saurabh, EC-620428

× Arka Abha, EC-620360 × Punjab Chhuhara, EC-620360 × EC-620557 EC-608415 × Arka Abha, EC-608415 × Punjab Chhuhara, EC-608415 × EC-520078, EC-619982 × EC-520078 and EC-619982 × EC-620557 among the crosses recorded significant positive *gca* and *sca* effects for average fruit weight. Non-additive gene action was found to be important which are in line with the earlier reports of Varun *et al.* (2012) [33], Ebenezer (2014) [8], Vipesh *et al.* (2015) [34], Kumar *et al.* (2017) [32], Pujer *et al.* (2017) [21], Raj *et al.* (2017) [3], Ramana *et al.* (2017) [25] and Savale and Patel (2017) [27].

Days to first fruit harvest is a measure of earliness, as early harvesting gives better returns and also widens the fruiting period of the genotypes. EC-620407, EC-620428, EC-620360, EC-608415, Pusa Ruby and EC-520078 among the parents and EC-620407 × Pusa Ruby, EC-620407 × EC-620557, EC-620428 × EC-620557, EC-620360 × Arka Saurabh, EC-620360 × EC-520078, EC-608415 × Arka Saurabh, EC-608415 × Arka Abha, EC-608415 × Pusa Ruby, EC-619982 × Arka Saurabh and EC-619982 × Punjab Chhuhara among the crosses manifested significant negative *gca* and *sca* effects. This character seems to be under the control of non-additive gene action. Conformity results were reported by Roopa *et al.* (2001) [26] and Ebenezer (2014) [8]. With respect to Days to last fruit harvest positively significant *gca* effects were observed in parents EC-620428, EC-620360, EC-619982, Arka Saurabh, Punjab Chhuhara and EC-620557, while *sca* effects were positively significant in crosses EC-620407 × Punjab Chhuhara, EC-620428 × Arka Saurabh, EC-620360 × Arka Saurabh, EC-620360 × EC-520078, EC-608415 × Pusa Ruby, EC-619982 × Pusa Ruby and EC-619982 × EC-520078. The low ratio of *GCA* to *SCA* variances was observed suggesting that the trait is under the control of non-additive gene action.

Positively significant *gca* effects for fruit yield per plant were observed in parents (EC-620360, EC-608415, Punjab Chhuhara, Pusa Ruby and EC-620557), while positively significant *sca* effects were observed in crosses EC-620407 × Arka Saurabh, EC-620407 × Arka Abha, EC-620428 × Pusa Ruby, EC-620360 × Punjab Chhuhara, EC-620360 × Pusa Ruby, EC-608415 × Arka Saurabh, EC-608415 × Arka Abha, EC-608415 × Punjab Chhuhara, EC-619982 × EC-520078 and EC-619982 × EC-620557 for fruit yield per plant. Lower ratio of *GCA* to *SCA* variances was observed indicating that the trait is under the control of non-additive gene action. Similar trend of results were reported by Ebenezer (2014) [8], Pemba *et al.* (2014) [22], Vipesh *et al.* (2015) [34], Basavaraj *et al.* (2016) [3], Kumar *et al.* (2017) [32], Pujer *et al.* (2017) [21], Raj *et al.* (2017) [32], Ramana *et al.* (2017) [25] and Savale and Patel (2017) [27].

Pericarp thickness is an important feature of the tomato fruit, as genotypes with thicker pericarp are better to withstand long distance transportation and remain firm for a longer period, when compared to thinly fleshed tomatoes (Kumari and Sharma, 2011) [7]. For pericarp thickness EC-620360, EC-619982, Arka Saurabh, Arka Abha, Punjab Chhuhara, Pusa Ruby and EC-620557 and crosses EC-620407 × Arka Saurabh, EC-620407 × Punjab Chhuhara, EC-620428 × Arka Saurabh, EC-620428 × EC-520078, EC-620360 × Arka Abha, EC-608415 × Arka Abha, EC-608415 × Punjab Chhuhara, EC-608415 × Pusa Ruby, EC-608415 × EC-620557, EC-619982 × Pusa Ruby and EC-619982 × EC-520078 exhibited significant positive *gca* and *sca* effects. The character seems to be under the control of non-additive genes as the ratio of *GCA* to *SCA* variances recorded less than one. The present

results are in line with the earlier findings of Pooja Kapur *et al.* (2013) [24], Pemba *et al.* (2014) [22], Vipesh *et al.* (2015) [34], Basavaraj *et al.* (2016) [3], Kumar *et al.* (2017) [32], Raj *et al.* (2017) [32] and Savale and Patel (2017) [27].

For the trait fruit pH EC-620407, EC-620360, EC-619982, Arka Saurabh, Arka Abha, Punjab Chhuhara and Pusa Ruby and three crosses *viz.*, EC-620407 × Arka Saurabh, EC-620428 × Punjab Chhuhara and EC-619982 × Arka Abha exhibited significant *gca* and *sca* effects and are top specific combiners. Additive gene action was found to be important as *GCA* variance was more than the *SCA* variance. The present results are in line with the earlier reports of Kulkarni *et al.* (2003) [11], Virupannavar *et al.* (2010) [35] and Basavaraj *et al.* (2016) [3].

Total soluble solids content of tomato fruits is essential for processing purpose. 50% to 65% of soluble solids contents are sugars, glucose and fructose and their amount and proportion influences the organoleptic quality of tomatoes (Adedeji *et al.*, 2006) [2]. Total soluble solids content of parents, EC-620428, EC-608415, EC-619982, Pusa Ruby, EC-520078, EC-620557 and crosses, EC-620407 × Punjab Chhuhara, EC-620360 × Pusa Ruby, EC-608415 × EC-620557, and EC-619982 × EC-520078 registered significantly positive *gca* and *sca* effects, respectively. Total soluble solids is an important trait which determines the quality of a fruit. Lower ratio of *GCA* to *SCA* variances was observed suggesting the importance of non-additive gene action. Similar kinds of results were reported by Premalakshmi (2006) [23], Kumari and Srivastava (2007) [12], Naveen *et al.* (2008) [20], Basavaraj *et al.* (2016) [3], Kumar *et al.* (2017) [32], Pujer *et al.* (2017) [21], Raj *et al.* (2017) [32], Ramana *et al.* (2017) [25] and Savale and Patel (2017) [27].

Titrate acidity values for EC-620360, Arka Saurabh, Arka Abha and Pusa Ruby and crosses *viz.*, EC-620407 × EC-520078, EC-620407 × EC-620557, EC-620360 × Pusa Ruby and EC-608415 × Arka Abha exhibited significant *gca* and *sca* effects respectively. Additive gene action was found to be important as *GCA* variance was more than the *SCA* variance. The present results are in line with the earlier reports of Makesh *et al.* (2002) [14], Dechin *et al.* (2012) [16] and Savale and Patel (2017) [27].

For ascorbic acid content positively significant *gca* effects were observed in parents EC-620428, EC-620360, EC-619982, Arka Abha, Punjab Chhuhara and Pusa Ruby while in crosses positive significant *sca* effects were observed EC-620407 × Arka Abha, EC-620407 × Punjab Chhuhara, EC-620407 × Pusa Ruby, EC-620407 × EC-520078, EC-620428 × EC-620557, EC-620360 × Arka Saurabh, EC-620360 × EC-520078, EC-620360 × EC-620557, EC-608415 × Arka Saurabh and EC-608415 × EC-520078. Variance of *GCA* to *SCA* is more than unity for this trait indicating the preponderance of non-additive gene action. The present results are in agreement with the findings of Sunil *et al.* (2013) [31], Pemba *et al.* (2014) [22], Alex Sandro *et al.* (2015) [1], Kumar *et al.* (2017) [32], Pujer *et al.* (2017) [21], Raj *et al.* (2017) [32] and Savale and Patel (2017) [27].

Positively significant *gca* effects were observed for total sugars in parents EC-620360, EC-619982, Arka Saurabh, Arka Abha, Punjab Chhuhara, Pusa Ruby and EC-620557, while *sca* effects were significantly positive in crosses, EC-620407 × Arka Saurabh, EC-620407 × Punjab Chhuhara, EC-620407 × EC-520078, EC-620407 × EC-620557, EC-620428 × Punjab Chhuhara, EC-620428 × EC-520078, EC-620428 × EC-620557, EC-620360 × Arka Abha, EC-620360 × Pusa Ruby, EC-620360 × EC-520078, EC-608415 × Arka Saurabh,

EC-608415 × Arka Abha, EC-608415 × Punjab Chhuhara, EC-608415 × Pusa Ruby, EC-619982 × Arka Saurabh and EC-619982 × Arka Abha. Non-additive gene action was found to be important as *GCA* variance was less than the *SCA* variance. The present results are in line with the earlier reports of Mondal *et al.* (2009) [17] and Savale and Patel (2017) [27].

For reducing sugars, parents EC-619982, Arka Saurabh, Arka Abha, Punjab Chhuhara, Pusa Ruby and EC-620557 and crosses *viz.*, EC-620407 × Arka Saurabh, EC-620407 × EC-520078, EC-620407 × EC-620557, EC-620428 × EC-520078, EC-620428 × EC-620557, EC-620360 × Arka Abha, EC-620360 × Pusa Ruby, EC-620360 × EC-620557, EC-608415 × Arka Saurabh, EC-608415 × Arka Abha, EC-608415 × Punjab Chhuhara, EC-608415 × Pusa Ruby, EC-619982 × Arka Saurabh and EC-619982 × Pusa Ruby manifested significant positive *gca* and *sca* effects. The estimates of *SCA* variance were found to be greater than that of the *GCA* variance pointing out the importance of non-additive gene action. These results are in conformity with the earlier reports Bhutani and Kalloo (1990) [5], Alex Sandro *et al.* (2015) [1], Pujer *et al.* (2017) [21] and Savale and Patel (2017) [27].

Lycopene content for parents, EC-620428, EC-619982, EC-520078 and EC-620557 and crosses *viz.*, EC-620407 × EC-520078, EC-620428 × Punjab Chhuhara, EC-620360 × EC-620557, EC-608415 × Pusa Ruby and EC-619982 × Pusa Ruby exhibited significant *gca* and *sca* effects. Additive gene action was found to be important. The present results are in line with the earlier reports of Dechin *et al.* (2012) [16], Narsimhamurthy *et al.* (2013) [19] Basavaraj *et al.* (2016) [3], Kumar *et al.* (2017) [32], Pujer *et al.* (2017) [21], Ramana *et al.* (2017) [25] and Savale and Patel (2017) [27].

The superior general combiners and specific combiners for each of the nineteen traits are presented in Table 2 and Table 3.

In majority of crosses, high *sca* was either due to high × low or low × low combining parents, which further substantiate the operation of non-additive gene action (additive ×

dominance and dominance × dominance epistatic interaction). An ideal combination to be explored is one where high magnitude of *sca* is present, in addition to high *gca* in both or at least one of the parent.

It is evident from the different studies, the predominance of non-additive gene action over the additive component, which is ideal for exploitation through heterosis breeding. In few cases, crosses with both good general combiner parents had also exhibited high *sca* effects, indicating the role of additive × additive type of gene action and hence, a good scope for fixation of the heterotic effects through the isolation of high yielding homozygous lines in advanced generations.

Table 1: Components of heritable variation and their ratios in pooled analysis

S. No.	Character	σ^2_{gca}	σ^2_{sca}	$\frac{\sigma^2_{gca}}{\sigma^2_{sca}}$
1.	Plant height	7.12	189.15	0.04
2.	Number of primary branches per plant	0.14	0.41	0.34
3.	Days to 50% flowering	90.39	52.92	1.71
4.	Number of flowers per cluster	0.21	1.90	0.11
5.	Number of fruits per cluster	0.13	1.92	0.06
6.	Fruit length	0.001	0.311	0.014
7.	Fruit width	0.005	0.489	0.001
8.	Average fruit weight	1.11	120.52	0.01
9.	Days to first fruit harvest	23.83	39.74	0.60
10.	Days to last fruit harvest	3.13	29.71	0.11
11.	Fruit yield per plant	0.003	0.502	0.007
12.	Pericarp thickness	0.09	0.39	0.25
13.	Fruit pH	0.006	0.002	3.00
14.	Total soluble solids	0.007	0.058	0.11
15.	Titration acidity	0.001	0.001	1.50
16.	Ascorbic acid content	0.42	4.79	0.09
17.	Reducing sugars	0.03	0.16	0.16
18.	Total sugars	0.06	0.09	0.72
19.	Lycopene content	0.29	0.04	6.32

σ^2_{gca} , σ^2_{sca} = Additive and non-additive components of heritable variation, respectively

Table 2: Superior general combiners for fruit yield and quality traits

Parents	Characters
EC - 620360	Plant height, number of flowers per cluster, number of fruits per cluster, fruit length, fruit width, average fruit weight, days to first fruit harvest, days to last fruit harvest fruit yield per plant, pericarp thickness, fruit pH, Titration acidity, total sugars, reducing sugars
EC - 608415	Number of primary branches per plant, days to 50% flowering, number of flowers per cluster, number of fruits per cluster, days to first fruit harvest, fruit yield per plant, total soluble solids
EC - 619982	Number of primary branches per plants, number of flowers per cluster, number of fruits per cluster, days to last fruit harvest, pericarp thickness, fruit pH, ascorbic acid, total sugars, reducing sugars, lycopene content
Punjab Chhuhara	Number of primary branches per plant, number of flowers per cluster, number of fruits per cluster, fruit length, average fruit weight, days to last fruit harvest, fruit yield per plant, pericarp thickness, fruit pH, ascorbic acid, total sugars, reducing sugars, lycopene content
Pusa Ruby	Plant height, number of primary branches per plant, fruit width, average fruit weight, days to first fruit harvest, fruit yield per plant, fruit pH, total soluble solids, titration acidity, ascorbic acid
EC- 520078	Plant height, number of primary branches per plant, days to 50% flowering, number of flowers per cluster, number of fruits per cluster, days to first fruit harvest, total soluble solids, ascorbic acid content, lycopene content

Table 3: Superior specific combiners for yield and quality traits

Crosses	Characters
EC-620407 × EC-520078	Plant height, number of primary branches per plant, average fruit weight, fruit length, days to 50% flowering, days to first fruit harvest, Titration acidity, ascorbic acid content, lycopene content
EC-620428 × Arka Abha	Number of primary branches per plant, average fruit weight, fruit yield per plant, Titration acidity, ascorbic acid content, total sugars, reducing sugars
EC-620428 × Pusa Ruby	Plant height, number of primary branches per plant, average fruit weight, number of flowers per cluster, number of fruits per cluster, ascorbic acid content, Titration acidity,
EC-620360 × Arka Abha	Number of primary branches per plant, average fruit weight, fruit length, total sugars, reducing sugars, lycopene content

EC-620360 × Pusa Ruby	Plant height, number of primary branches per plant, average fruit weight, days to first fruit harvest, fruit yield per plant, total soluble solids, titrable acidity, total sugars, reducing sugars
EC-608415 × Arka Saurabh	Number of primary branches per plant, fruit yield per plant, ascorbic acid content, pericarp thickness, days to first fruit harvest, average fruit weight,
EC-608415 × Arka Abha	Fruit width, average fruit weight, fruit yield per plant, Titrable acidity, ascorbic acid content, lycopene content
EC-608415 × Punjab Chhuhara	Plant height, number of primary branches per plant, fruit yield per plant, pericarp thickness
EC-608415 × EC-620557	Plant height, number of primary branches per plant, fruit length, fruit width, fruit yield per plant, total sugars, reducing sugars, lycopene content
EC-619982 × EC-620557	Number of primary branches per plant, fruit length, average fruit weight, pericarp thickness, total soluble solids, ascorbic acid content, total sugars, reducing sugars, lycopene content
EC-619982 × EC-520078	Plant height, days to 50% flowering, days to first fruit harvest, number of primary branches per plant, fruit pH, Titrable acidity, lycopene content
EC-608415 × Pusa Ruby	Plant height, number of primary branches per plant, fruit width, total soluble solids, total sugars, reducing sugars, lycopene content
EC-608415 × EC-520078	Plant height, number of primary branches per plant, fruit length, fruit width, Titrable acidity, ascorbic acid content, lycopene content

Table 4: Estimates of combining ability for plant height, number of primary branches per plant

Genotypes	Plant height				No. of primary branches per plant			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-3.54*	-4.97**	-5.47**	-4.66**	-0.40**	-0.27**	-0.32**	-0.33**
EC-620428	-0.85	0.68	-2.35	-0.84	-0.38**	-0.34**	-0.42**	-0.38**
EC-620360	3.26*	8.46**	8.12**	6.61**	0.05	0.04	0.11	0.07
EC-608415	1.09	0.16	3.43*	1.56	0.30**	0.21**	0.29**	0.27**
EC-619982	0.05	-4.33*	-3.72*	-2.67**	0.43**	0.36**	0.34**	0.38**
Arka Saurabh	-24.10**	-26.50**	-26.03**	-25.54**	-0.43**	-0.45**	-0.40**	-0.42**
Arka Abha	-19.34**	-19.88**	-20.44**	-19.89**	-0.36**	-0.39**	-0.38**	-0.38**
Punjab Chhuhara	-24.04**	-24.52**	-21.75**	-23.44**	0.53**	0.52**	0.70**	0.58**
Pusa Ruby	-6.46**	-5.88**	-5.23**	-5.86**	0.51**	0.54**	0.72**	0.59**
EC-520078	62.97**	62.13**	55.59**	60.23**	0.21**	0.20**	-0.30**	0.04
EC-620557	10.97**	14.65**	17.86**	14.50**	-0.46**	-0.43**	-0.34**	-0.41**
EC-620407 × Arka Saurabh	-0.40	-0.78	-4.47	-1.88	-0.50**	-0.59**	-0.22	-0.44**
EC-620407 × Arka Abha	4.79	0.52	5.69	3.66	0.40**	0.48**	0.16	0.35**
EC-620407 × Punjab Chhuhara	-0.38	-0.32	-8.59*	-3.10	-0.14	-0.20	-0.15	-0.16
EC-620407 × Pusa Ruby	-1.86	3.58	1.41	1.04	-0.50**	-0.66**	-0.74**	-0.63**
EC-620407 × EC-520078	-2.68	-1.81	12.06**	2.52	0.26	0.73**	0.81**	0.60**
EC-620407 × EC-620557	0.53	-1.18	-6.10	-2.25	0.48**	0.23	0.13	0.28**
EC-620428 × Arka Saurabh	4.24	1.35	6.39	3.99	0.06	0.16	0.08	0.10
EC-620428 × Arka Abha	9.66**	6.24	4.38	6.76**	0.40**	0.50**	0.52*	0.47**
EC-620428 × Punjab Chhuhara	-1.59	-4.11	-1.19	-2.30	-0.12	-0.17	-0.30	-0.20*
EC-620428 × Pusa Ruby	-5.53	-9.21*	-8.40*	-7.71**	-0.23	-0.24	-0.11	-0.20*
EC-620428 × EC-520078	10.85**	18.06**	7.68	12.20**	0.30*	-0.02	0.00	0.09
EC-620428 × EC-620557	-17.63**	-12.34**	-8.85*	-12.94**	-0.41**	-0.23	-0.18	-0.27**
EC-620360 × Arka Saurabh	9.12**	13.85**	15.15**	12.71**	0.46**	0.41*	0.42	0.43**
EC-620360 × Arka Abha	-2.57	-2.23	-2.84	-2.54	-0.14	-0.23	-0.23	-0.20*
EC-620360 × Punjab Chhuhara	4.81	6.41	8.25*	6.49**	-0.36*	-0.34*	-0.33	-0.34**
EC-620360 × Pusa Ruby	0.71	-2.94	-2.11	-1.45	-0.21	-0.07	0.01	-0.09
EC-620360 × EC-520078	-19.13**	-19.88**	-23.21**	-20.74**	-0.34*	-0.30	-0.41	-0.35**
EC-620360 × EC-620557	7.06*	4.79	4.75	5.53**	0.60**	0.53**	0.54*	0.56**
EC-608415 × Arka Saurabh	-4.96	-4.02	-9.31*	-6.10**	0.02	0.02	-0.10	-0.02
EC-608415 × Arka Abha	-10.59**	-7.66	-11.30**	-9.85**	-0.31*	-0.45**	-0.36	-0.37**
EC-608415 × Punjab Chhuhara	-8.38*	-6.06	-6.10	-6.85**	0.25	0.36*	0.30	0.30**
EC-608415 × Pusa Ruby	13.00**	9.87*	4.90	9.26**	0.69**	0.69**	0.50*	0.63**
EC-608415 × EC-520078	-5.63	-8.11	10.50*	-1.08	-0.39**	-0.38*	-0.11	-0.29**
EC-608415 × EC-620557	16.56**	15.98**	11.30**	14.61**	-0.26	-0.25	-0.22	-0.25**
EC-619982 × Arka Saurabh	-8.00*	-10.40*	-7.77	-8.72**	-0.04	0.00	-0.18	-0.07
EC-619982 × Arka Abha	-1.29	3.14	4.07	1.97	-0.36*	-0.30	-0.08	-0.25**
EC-619982 × Punjab Chhuhara	5.54	4.07	7.63	5.75**	0.37*	0.33*	0.49*	0.40**
EC-619982 × Pusa Ruby	-6.32	-1.30	4.19	-1.14	0.25	0.28	0.34	0.29**
EC-619982 × EC-520078	16.58**	11.74**	-7.03	7.10**	0.17	-0.04	-0.30	-0.05
EC-619982 × EC-620557	-6.51	-7.25	-1.09	-4.95*	-0.41**	-0.28	-0.27	-0.32**
SE (crosses)	3.39	4.08	4.00	2.12	0.14	0.15	0.21	0.09

*, ** Significant at 5 and 1% levels, respectively

Table 5: Estimates of combining ability for days to 50% flowering and number of flowers per cluster

Genotypes	Days to 50% flowering				No. of flowers per cluster			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-6.98**	-10.32**	-6.34**	-7.88**	-0.34**	-0.43**	-0.63**	-0.47**
EC-620428	0.08	-3.60**	0.49	-1.01**	-0.39**	-0.27**	-0.20	-0.29**
EC-620360	2.36**	-1.21**	2.93**	1.36**	0.01	0.08	0.27*	0.12**
EC-608415	-0.42	-4.32**	-1.18**	-1.97**	0.18**	0.15*	0.19	0.17**
EC-619982	4.97**	19.46**	4.10**	9.51**	0.54**	0.47**	0.38**	0.46**
Arka Saurabh	6.88**	3.46**	6.91**	5.75**	-0.71**	-0.66**	-0.74**	-0.70**
Arka Abha	2.94**	5.19**	2.84**	3.66**	-0.75**	-0.81**	-0.91**	-0.82**
Punjab Chhuhara	-1.12**	1.72**	-1.02**	-0.14	0.47**	0.53**	0.77**	0.59**
Pusa Ruby	6.68**	6.12**	7.11**	6.64**	-0.47**	-0.54**	-0.60**	-0.54**
EC-520078	-14.72**	-12.21**	-15.56**	-14.16**	1.64**	1.65**	1.69**	1.66**
EC-620557	-0.66*	-4.28**	-0.29	-1.74**	-0.19*	-0.16*	-0.21	-0.19**
EC-620407 × Arka Saurabh	-2.49**	1.66**	-2.86**	-1.23**	0.51**	0.59**	0.64*	0.58**
EC-620407 × Arka Abha	-0.56	-2.08**	-0.46	-1.03**	-0.47**	-0.51**	-0.37	-0.45**
EC-620407 × Punjab Chhuhara	0.51	-2.28**	1.08	-0.23	-0.14	-0.07	-0.15	-0.12
EC-620407 × Pusa Ruby	-4.29**	-3.01**	-4.06**	-3.79**	-0.28	-0.32	-0.21	-0.27**
EC-620407 × EC-520078	5.44**	1.32*	6.94**	4.57**	0.45**	0.30	-0.07	0.23*
EC-620407 × EC-620557	1.38	4.39**	-0.66	1.70**	-0.07	0.01	0.15	0.03
EC-620428 × Arka Saurabh	0.46	3.93**	0.64	1.68**	-0.54**	-0.40**	-0.37	-0.44**
EC-620428 × Arka Abha	0.72	-1.80**	-0.62	-0.57	0.61**	0.59**	0.46	0.55**
EC-620428 × Punjab Chhuhara	0.46	-2.00**	0.58	-0.32	0.11	-0.01	-0.06	0.01
EC-620428 × Pusa Ruby	-0.34	0.60	0.11	0.12	0.08	-0.03	-0.29	-0.08
EC-620428 × EC-520078	-0.28	-3.40**	-0.89	-1.52**	-0.41*	-0.11	0.41	-0.04
EC-620428 × EC-620557	-1.01	2.67**	0.18	0.61	0.16	-0.03	-0.14	-0.01
EC-620360 × Arka Saurabh	2.18**	5.88**	1.87**	3.31**	0.24	0.06	-0.02	0.10
EC-620360 × Arka Abha	-1.89	-3.86**	-1.40*	-2.38**	0.17	0.17	0.04	0.13
EC-620360 × Punjab Chhuhara	0.18	-2.72**	-0.20	-0.91*	0.35*	0.28	0.41	0.35**
EC-620360 × Pusa Ruby	2.38**	2.88**	1.33*	2.20**	-0.43**	-0.51**	-0.56	-0.50**
EC-620360 × EC-520078	-3.89**	-6.79**	-1.67*	-4.11**	-0.40*	-0.11	-0.16	-0.23*
EC-620360 × EC-620557	1.04	4.61**	0.07	1.91**	0.08	0.11	0.29	0.16
EC-608415 × Arka Saurabh	0.29	3.66**	0.64	1.53**	0.33*	0.32	0.28	0.31**
EC-608415 × Arka Abha	1.22	-1.08*	1.71**	0.62	-0.10	-0.10	-0.02	-0.07
EC-608415 × Punjab Chhuhara	0.29	-2.61**	-0.09	-0.80*	-0.23	-0.11	0.05	-0.10
EC-608415 × Pusa Ruby	0.49	0.99	0.78	0.75*	-0.45**	-0.33	-0.34	-0.37**
EC-608415 × EC-520078	1.22	-1.68**	-0.56	-0.34	0.43*	0.21	0.20	0.28**
EC-608415 × EC-620557	-3.51**	0.72	-2.49**	-1.76**	0.01	0.02	-0.17	-0.05
EC-619982 × Arka Saurabh	-0.43	-15.12**	-0.30	-5.29**	-0.54**	-0.57**	-0.53	-0.54**
EC-619982 × Arka Abha	0.50	8.81**	0.77	3.36**	-0.21	-0.15	-0.11	-0.16
EC-619982 × Punjab Chhuhara	-1.43*	9.61**	-1.37*	2.27**	-0.09	-0.09	-0.25	-0.14
EC-619982 × Pusa Ruby	1.77*	-1.46**	1.83**	0.71*	1.08**	1.19**	1.39**	1.22**
EC-619982 × EC-520078	-2.50**	10.54**	-3.83**	1.40**	-0.06	-0.28	-0.38	-0.24*
EC-619982 × EC-620557	2.10**	-12.39**	2.90**	-2.46**	-0.19	-0.10	-0.13	-0.14
SE (crosses)	0.69	0.50	0.64	0.35	0.16	0.18	0.30	0.10

*, ** Significant at 5 and 1% levels, respectively

Table 6: Estimates of combining ability for number of fruits per cluster, fruit length

Genotypes	No. of fruits per cluster				Fruit length			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-0.10	0.01	-0.09	-0.06	0.02	0.07	0.07	0.05**
EC-620428	-0.52**	-0.51**	-0.20*	-0.41**	0.09	0.09	0.09*	0.09**
EC-620360	-0.22**	-0.19*	0.01	-0.13**	0.26**	0.30**	0.35**	0.30**
EC-608415	0.30**	0.32**	0.11	0.24**	-0.35**	-0.42**	-0.46**	-0.41**
EC-619982	0.53**	0.38**	0.17	0.36**	-0.02	-0.04	-0.05	-0.04*
Arka Saurabh	-0.71**	-0.61**	-0.64**	-0.65**	0.52**	0.44**	0.38**	0.45**
Arka Abha	-0.59**	-0.65**	-0.92**	-0.72**	0.29**	0.47**	0.56**	0.44**
Punjab Chhuhara	0.12	0.14	0.11	0.12*	0.29**	0.21**	0.19**	0.23**
Pusa Ruby	-0.36**	-0.26**	-0.42**	-0.34**	-0.36**	-0.40**	-0.40**	-0.39**
EC-520078	1.69**	1.57**	2.27**	1.84**	-1.82**	-1.89**	-1.90**	-1.87**
EC-620557	-0.16*	-0.19*	-0.39**	-0.25**	1.08**	1.16**	1.17**	1.14**
EC-620407 × Arka Saurabh	0.14	0.17	0.33	0.21*	-0.15	-0.18	-0.19*	-0.18**
EC-620407 × Arka Abha	-0.31*	-0.34	-0.18	-0.28*	0.10	0.43**	0.58**	0.37**
EC-620407 × Punjab Chhuhara	-0.10	-0.12	-0.33	-0.18	0.17	0.14	0.15	0.15**
EC-620407 × Pusa Ruby	0.29	0.18	-0.06	0.13	0.03	0.04	-0.04	0.01
EC-620407 × EC-520078	0.30	0.48*	0.54*	0.44**	-0.34**	-0.49**	-0.48**	-0.44**
EC-620407 × EC-620557	-0.31*	-0.37	-0.30	-0.33**	0.19	0.07	-0.02	0.08
EC-620428 × Arka Saurabh	0.05	0.25	-0.46	-0.05	0.10	0.07	0.12	0.10*

EC-620428 × Arka Abha	0.16	0.10	-0.29	-0.01	-0.09	-0.09	-0.10	-0.09*
EC-620428 × Punjab Chhuhara	0.33*	0.22	0.29	0.28**	-0.43**	-0.33**	-0.33**	-0.36**
EC-620428 × Pusa Ruby	-0.42**	-0.22	-0.50*	-0.38**	0.64**	0.62**	0.60**	0.62**
EC-620428 × EC-520078	0.23	-0.21	0.77**	0.26*	-0.29*	-0.29*	-0.30**	-0.29**
EC-620428 × EC-620557	-0.36*	-0.14	0.19	-0.10	0.06	0.02	0.00	0.03
EC-620360 × Arka Saurabh	-0.12	-0.18	0.54*	0.08	-0.02	-0.08	-0.16	-0.09
EC-620360 × Arka Abha	0.32*	0.29	0.05	0.22*	-0.23	-0.30*	-0.44**	-0.32**
EC-620360 × Punjab Chhuhara	-0.06	-0.11	-0.10	-0.09	0.26*	0.33**	0.23*	0.27**
EC-620360 × Pusa Ruby	-0.68**	-0.63**	-0.51*	-0.61**	-0.66**	-0.55**	-0.47**	-0.56**
EC-620360 × EC-520078	-0.59**	-0.14	0.26	-0.16	0.17	0.12	0.10	0.13**
EC-620360 × EC-620557	1.14**	0.77**	-0.24	0.55**	0.46**	0.49**	0.74**	0.56**
EC-608415 × Arka Saurabh	0.02	-0.06	-0.21	-0.08	-0.14	-0.12	-0.06	-0.11*
EC-608415 × Arka Abha	0.05	0.07	0.20	0.10	0.43**	0.28*	0.29**	0.33**
EC-608415 × Punjab Chhuhara	-0.06	-0.06	-0.04	-0.05	-0.02	-0.04	0.01	-0.02
EC-608415 × Pusa Ruby	-0.48**	-0.36	-0.11	-0.32**	-0.26*	-0.34**	-0.32**	-0.31**
EC-608415 × EC-520078	0.30	0.11	-0.62*	-0.07	0.73**	0.96**	0.97**	0.89**
EC-608415 × EC-620557	0.17	0.29	0.78**	0.42**	-0.74**	-0.74**	-0.88**	-0.79**
EC-619982 × Arka Saurabh	-0.09	-0.20	-0.20	-0.16	0.20	0.32**	0.30**	0.27**
EC-619982 × Arka Abha	-0.21	-0.12	0.22	-0.04	-0.22	-0.32**	-0.33**	-0.29**
EC-619982 × Punjab Chhuhara	-0.11	0.06	0.18	0.04	0.01	-0.09	-0.07	-0.05
EC-619982 × Pusa Ruby	1.29**	1.04**	1.19**	1.17**	0.25*	0.23	0.23*	0.24**
EC-619982 × EC-520078	-0.24	-0.24	-0.95**	-0.48**	-0.28*	-0.29*	-0.29**	-0.29**
EC-619982 × EC-620557	-0.64**	-0.55**	-0.44	-0.54**	0.03	0.16	0.16	0.12**
SE (crosses)	0.15	0.20	0.24	0.11	0.12	0.12	0.10	0.04

*, ** significant at 5 and 1 % levels, respectively

Table 7: Estimates of combining ability for fruit width and average fruit weight

Genotypes	Fruit width				Average fruit weight			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	0.11**	0.00	0.09*	0.07**	1.03	0.80	1.10	0.98
EC-620428	-0.28**	-0.21**	-0.24**	-0.24**	-3.84**	-3.00**	-4.86**	-3.90**
EC-620360	0.28**	0.31**	0.31**	0.30**	9.63**	7.48**	9.63**	8.91**
EC-608415	-0.15**	-0.14**	-0.16**	-0.15**	-3.87**	-4.67**	-6.29**	-4.94**
EC-619982	0.03	0.04	-0.01	0.02	-2.95**	-0.62	0.41	-1.05*
Arka Saurabh	0.41**	0.27**	0.40**	0.36**	7.98**	10.36**	9.23**	9.19**
Arka Abha	0.76**	0.89**	0.87**	0.84**	16.44**	14.59**	16.41**	15.81**
Punjab Chhuhara	0.04	0.04	-0.01	0.03	5.83**	6.22**	5.91**	5.99**
Pusa Ruby	0.59**	0.62**	0.61**	0.60**	14.81**	16.09**	18.23**	16.38**
EC-520078	-2.06**	-2.08**	-2.10**	-2.08**	-54.23**	-59.08**	-62.09**	-58.47**
EC-620557	0.26**	0.25**	0.23**	0.25**	9.18**	11.82**	12.32**	11.10**
EC-620407 × Arka Saurabh	0.36**	-0.06	0.40**	0.23**	3.17	0.43	0.31	1.30
EC-620407 × Arka Abha	-0.91**	-0.83**	-0.68**	-0.80**	-5.79*	-0.96	0.56	-2.06
EC-620407 × Punjab Chhuhara	0.07	0.11	-0.05	0.04	-10.81**	-9.47**	-10.01**	-10.10**
EC-620407 × Pusa Ruby	0.07	0.18*	-0.06	0.06	14.32**	10.72**	13.34**	12.79**
EC-620407 × EC-520078	-0.35**	-0.23**	-0.33**	-0.30**	-0.52	-0.30	-0.39	-0.40
EC-620407 × EC-620557	0.75**	0.83**	0.72**	0.77**	-0.36	-0.41	-3.82	-1.53
EC-620428 × Arka Saurabh	-0.14*	0.02	-0.06	-0.06	17.81**	18.26**	21.65**	19.24**
EC-620428 × Arka Abha	-0.29**	-0.48**	-0.49**	-0.42**	1.76	4.05	5.69**	3.83**
EC-620428 × Punjab Chhuhara	-0.28**	-0.29**	-0.28**	-0.28**	-5.83*	-8.09**	-4.77*	-6.23**
EC-620428 × Pusa Ruby	0.52**	0.57**	0.69**	0.59**	-0.06	1.83	-5.42*	-1.22
EC-620428 × EC-520078	0.09	0.05	0.04	0.06	2.77	1.97	3.86	2.87*
EC-620428 × EC-620557	0.10	0.13	0.11	0.11**	-16.47**	-18.01**	-21.02**	-18.50**
EC-620360 × Arka Saurabh	-0.74**	-0.63**	-0.86**	-0.74**	-9.26**	-6.14**	-11.05**	-8.82**
EC-620360 × Arka Abha	0.01	-0.11	-0.12	-0.07	-3.72	-16.44**	-19.26**	-13.14**
EC-620360 × Punjab Chhuhara	0.32**	0.35**	0.45**	0.38**	16.23**	17.06**	18.88**	17.39**
EC-620360 × Pusa Ruby	0.09	0.05	0.12	0.09*	-2.63	-0.95	-2.34	-1.97
EC-620360 × EC-520078	0.04	0.06	0.10	0.07	-11.50**	-9.44**	-11.67**	-10.87**
EC-620360 × EC-620557	0.28**	0.28**	0.30**	0.29**	10.88**	15.91**	25.44**	17.41**
EC-608415 × Arka Saurabh	0.05	0.13	0.10	0.09*	-6.40**	-6.06**	-6.39**	-6.28**
EC-608415 × Arka Abha	0.92**	1.14**	1.05**	1.03**	8.85**	11.89**	12.80**	11.18**
EC-608415 × Punjab Chhuhara	0.15*	0.13	0.10	0.13**	8.27**	6.58**	1.31	5.39**
EC-608415 × Pusa Ruby	-0.67**	-0.78**	-0.77**	-0.74**	-13.55**	-13.63**	-9.04**	-12.07**
EC-608415 × EC-520078	0.43**	0.31**	0.41**	0.39**	2.42	2.93	4.47*	3.27*
EC-608415 × EC-620557	-0.88**	-0.94**	-0.89**	-0.90**	0.40	-1.70	-3.14	-1.48
EC-619982 × Arka Saurabh	0.47**	0.55**	0.43*	0.48**	-5.33*	-6.48**	-4.53*	-5.45**
EC-619982 × Arka Abha	0.27**	0.27**	0.24*	0.26**	-1.11	1.47	0.21	0.19
EC-619982 × Punjab Chhuhara	-0.27**	-0.31**	-0.22*	-0.27**	-7.86**	-6.07**	-5.41*	-6.45**
EC-619982 × Pusa Ruby	0.00	-0.01	0.02	0.00	1.92	2.03	3.47	2.47

EC-619982 × EC-520078	-0.22**	-0.18*	-0.23*	-0.21**	6.83**	4.84*	3.72	5.13**
EC-619982 × EC-620557	-0.25**	-0.31**	-0.24*	-0.27**	5.55*	4.22	2.54	4.10**
SE (crosses)	0.07	0.07	0.10	0.04	2.33	2.16	2.10	1.30

*, ** significant at 5 and 1 % levels, respectively

Table 8: Estimates of combining ability for days to first fruit harvest, days to last fruit harvest

Genotypes	Days to first fruit harvest				Days to last fruit harvest			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-2.30**	-3.18**	-1.88**	-2.45**	-3.22**	-4.21**	-3.92**	-3.79**
EC-620428	-0.41	-0.18	-0.49	-0.36*	3.56**	3.46**	3.80**	3.60**
EC-620360	-0.91**	-0.51	-0.88**	-0.77**	1.06*	1.79**	1.36*	1.40**
EC-608415	-1.08**	-1.23**	-1.60**	-1.30**	-2.67**	-3.10**	-3.20**	-2.99**
EC-619982	4.70**	5.10**	4.84**	4.88**	1.28*	2.07**	1.97**	1.77**
Arka Saurabh	9.38**	7.84**	9.34**	8.86**	4.27**	4.03**	4.67**	4.32**
Arka Abha	2.58**	3.24**	2.94**	2.92**	-0.20	-0.57	-0.60	-0.46
Punjab Chhuhara	4.84**	4.84**	4.54**	4.74**	8.13**	7.70**	7.93**	7.92**
Pusa Ruby	-6.89**	-6.69**	-6.99**	-6.86**	-9.40**	-9.57**	-10.20**	-9.72**
EC-520078	-15.62**	-15.29**	-15.52**	-15.48**	-10.07**	-10.70**	-11.33**	-10.70**
EC-620557	5.71**	6.04**	5.68**	5.81**	7.27**	9.10**	9.53**	8.63**
EC-620407 × Arka Saurabh	4.57**	-2.29**	4.54**	2.27**	-1.38	-0.92	-0.28	-0.86
EC-620407 × Arka Abha	-1.63*	0.98	-0.39	-0.35	0.09	0.68	-0.01	0.25
EC-620407 × Punjab Chhuhara	2.10**	2.71**	1.34	2.05**	1.76	1.74	1.46	1.65*
EC-620407 × Pusa Ruby	-2.83**	-1.09	-2.46**	-2.13**	-0.71	-0.32	-0.41	-0.48
EC-620407 × EC-520078	-0.43	0.51	-0.92	-0.28	-2.38	-2.19*	-2.28	-2.28**
EC-620407 × EC-620557	-1.77*	-0.82	-2.12**	-1.57**	2.62*	1.01	1.52	1.72*
EC-620428 × Arka Saurabh	2.68**	4.38**	2.16**	3.07**	2.84*	2.41*	1.67	2.31**
EC-620428 × Arka Abha	-0.52	-1.02	-0.44	-0.66	-0.69	-0.99	-0.40	-0.69
EC-620428 × Punjab Chhuhara	0.21	-0.62	0.29	-0.04	-1.02	-1.92	-1.27	-1.40*
EC-620428 × Pusa Ruby	1.94	1.91**	2.16**	2.00**	3.51**	3.01**	2.87*	3.13**
EC-620428 × EC-520078	-0.66	-0.82	-0.64	-0.71	-3.82**	-3.86**	-3.00*	-3.56**
EC-620428 × EC-620557	-3.66**	-3.82**	-3.51**	-3.66**	-0.82	1.34	0.13	0.22
EC-620360 × Arka Saurabh	-1.82*	-0.29	-1.79*	-1.30**	1.01	2.41*	2.78*	2.07**
EC-620360 × Arka Abha	2.98**	2.31**	2.61**	2.63**	1.14	1.01	0.71	0.96
EC-620360 × Punjab Chhuhara	2.71**	2.71**	3.01**	2.81**	1.14	1.08	1.18	1.13
EC-620360 × Pusa Ruby	1.11	0.91	1.21	1.08**	-5.99**	-6.99**	-6.69**	-6.56**
EC-620360 × EC-520078	-6.82**	-7.16**	-6.92**	-6.97**	2.68*	2.14*	2.44	2.42**
EC-620360 × EC-620557	1.84*	1.51*	1.88*	1.74**	0.01	0.34	-0.42	-0.02
EC-608415 × Arka Saurabh	-2.99**	-0.90	-2.40**	-2.10**	-0.93	-1.03	-1.00	-0.99
EC-608415 × Arka Abha	-1.86*	-1.97**	-1.67*	-1.83**	0.53	0.90	2.27	1.23
EC-608415 × Punjab Chhuhara	-0.79	-0.23	0.07	-0.32	0.20	0.30	0.07	0.19
EC-608415 × Pusa Ruby	-1.39	-2.03**	-1.73*	-1.72**	2.07	1.23	0.87	1.39*
EC-608415 × EC-520078	5.34**	4.90**	5.13**	5.13**	0.07	0.03	0.00	0.03
EC-608415 × EC-620557	1.68*	0.23	0.60	0.84*	-1.93	-1.43	-2.20	-1.86**
EC-619982 × Arka Saurabh	-2.43**	-0.90	-2.51**	-1.95**	-1.54	-2.87**	-3.17*	-2.53**
EC-619982 × Arka Abha	1.03	-0.30	-0.11	0.21	-1.08	-1.60	-2.57	-1.75*
EC-619982 × Punjab Chhuhara	-4.23**	-4.57**	-4.71**	-4.50**	-2.08	-1.20	-1.43	-1.57*
EC-619982 × Pusa Ruby	1.17	0.30	0.82	0.76	1.12	3.07**	3.37*	2.52**
EC-619982 × EC-520078	2.57**	2.57**	3.36**	2.83**	3.46**	3.87**	2.83*	3.39**
EC-619982 × EC-620557	1.90*	2.90**	3.16**	2.65**	0.12	-1.27	0.97	-0.06
SE (crosses)	0.76	0.68	0.72	0.40	1.24	1.01	1.33	0.68

*, ** significant at 5 and 1 % levels, respectively

Table 9: Estimates of combining ability fruit yield per plant and pericarp thickness

Genotypes	Fruit yield per plant				Pericarp thickness			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-0.18**	-0.17**	-0.14**	-0.17**	-0.11**	-0.02	-0.20**	-0.11**
EC-620428	-0.26**	-0.21**	-0.24**	-0.24**	-0.36**	-0.27**	-0.26**	-0.30**
EC-620360	0.06**	0.05	0.00	0.03*	0.21**	0.18**	0.23**	0.20**
EC-608415	0.45**	0.40**	0.42**	0.42**	-0.04	-0.17**	-0.12**	-0.11**
EC-619982	-0.06**	-0.07*	-0.04	-0.06**	0.30**	0.28**	0.35**	0.31**
Arka Saurabh	-0.12**	-0.11**	-0.03	-0.09**	0.64**	0.81**	0.56**	0.67**
Arka Abha	-0.07**	-0.06*	-0.05	-0.06**	0.34**	0.30**	0.32**	0.32**
Punjab Chhuhara	0.20**	0.19**	0.20**	0.20**	0.36**	0.25**	0.37**	0.33**
Pusa Ruby	0.34**	0.34**	0.35**	0.34**	0.20**	0.10*	0.12**	0.14**
EC-520078	-0.53**	-0.50**	-0.62**	-0.55**	-2.28**	-2.18**	-2.15**	-2.20**
EC-620557	0.19**	0.14**	0.16**	0.16**	0.75**	0.72**	0.77**	0.75**
EC-620407 × Arka Saurabh	0.17**	0.11	0.06	0.12**	0.05	0.90**	0.04	0.33**
EC-620407 × Arka Abha	0.08	0.08	0.13	0.10*	-0.33**	-0.43**	-0.20**	-0.32**
EC-620407 × Punjab Chhuhara	-0.01	0.07	0.02	0.03	0.50**	0.37**	0.47**	0.44**

EC-620407 × Pusa Ruby	0.04	0.06	0.05	0.05	-0.16	-0.26**	-0.14*	-0.19**
EC-620407 × EC-520078	-0.13*	-0.06	-0.07	-0.09*	-0.12	-0.38**	-0.08	-0.19**
EC-620407 × EC-620557	-0.16**	-0.26**	-0.20**	-0.21**	0.05	-0.21*	-0.08	-0.08*
EC-620428 × Arka Saurabh	0.05	0.08	-0.03	0.03	0.34**	0.04	0.34**	0.24**
EC-620428 × Arka Abha	-0.11*	-0.06	-0.11	-0.09*	0.04	0.00	0.04	0.03
EC-620428 × Punjab Chhuhara	-0.19**	-0.25**	-0.22**	-0.22**	-0.18	-0.25**	-0.14*	-0.19**
EC-620428 × Pusa Ruby	0.24**	0.19**	0.17*	0.20**	-0.34**	-0.47**	-0.54**	-0.45**
EC-620428 × EC-520078	0.13*	0.14*	0.21**	0.16**	0.12	0.77**	0.63**	0.51**
EC-620428 × EC-620557	-0.12*	-0.11	-0.02	-0.08*	0.01	-0.09	-0.32**	-0.13**
EC-620360 × Arka Saurabh	-0.05	0.02	0.15*	0.04	-0.13	-0.32**	-0.09	-0.18**
EC-620360 × Arka Abha	-0.51**	-0.50**	-0.39**	-0.47**	0.20*	0.30**	0.22**	0.24**
EC-620360 × Punjab Chhuhara	0.18**	0.17*	0.22**	0.19**	-0.07	-0.06	-0.14*	-0.09**
EC-620360 × Pusa Ruby	0.39**	0.31**	0.32**	0.34**	0.18	0.18*	0.12	0.16**
EC-620360 × EC-520078	0.13*	0.09	-0.23**	0.00	0.03	-0.04	-0.08	-0.03
EC-620360 × EC-620557	-0.15*	-0.08	-0.06	-0.10*	-0.20*	-0.05	-0.03	-0.09**
EC-608415 × Arka Saurabh	0.15**	0.12	0.15*	0.14**	-0.31**	-0.39**	-0.15*	-0.28**
EC-608415 × Arka Abha	0.56**	0.54**	0.47**	0.52**	0.15	0.08	0.03	0.09*
EC-608415 × Punjab Chhuhara	0.23**	0.22**	0.15*	0.20**	0.21*	0.32**	0.22**	0.25**
EC-608415 × Pusa Ruby	-0.47**	-0.43**	-0.40**	-0.43**	-0.06	0.16	0.15*	0.08*
EC-608415 × EC-520078	-0.34**	-0.35**	-0.18*	-0.29**	-0.36**	-0.57**	-0.58**	-0.50**
EC-608415 × EC-620557	-0.13*	-0.11	-0.19*	-0.14**	0.37**	0.39**	0.34**	0.37**
EC-619982 × Arka Saurabh	-0.33**	-0.34**	-0.32**	-0.33**	0.04	-0.23*	-0.13	-0.11**
EC-619982 × Arka Abha	-0.03	-0.06	-0.10	-0.06	-0.07	0.04	-0.09	-0.04
EC-619982 × Punjab Chhuhara	-0.21**	-0.20**	-0.18*	-0.20**	-0.45**	-0.38**	-0.40**	-0.41**
EC-619982 × Pusa Ruby	-0.20**	-0.14*	-0.15*	-0.16**	0.39**	0.39**	0.41**	0.39**
EC-619982 × EC-520078	0.20**	0.18**	0.28**	0.22**	0.32**	0.22*	0.11	0.22**
EC-619982 × EC-620557	0.56**	0.56**	0.47**	0.53**	-0.23*	-0.04	0.10	-0.06
SE (crosses)	0.05	0.07	0.07	0.04	0.10	0.09	0.07	0.03

*, ** significant at 5 and 1 % levels, respectively

Table 10: Estimates of combining ability for fruit pH, total soluble solids

Genotypes	Fruit pH				Total soluble solids			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-0.21**	-0.20**	-0.20**	-0.21**	-0.23**	-0.23**	-0.23**	-0.23**
EC-620428	0.09**	0.10**	0.09**	0.09**	0.12**	0.11**	0.14**	0.12**
EC-620360	-0.06**	-0.05**	-0.04**	-0.05**	-0.10**	-0.09**	-0.06**	-0.08**
EC-608415	0.25**	0.24**	0.25**	0.25**	0.12**	0.11**	0.09**	0.11**
EC-619982	-0.06**	-0.07**	-0.11**	-0.08**	0.09**	0.10**	0.06**	0.08**
Arka Saurabh	-0.08**	-0.08**	-0.08**	-0.08**	-0.31**	-0.29**	-0.31**	-0.31**
Arka Abha	-0.08**	-0.08**	-0.09**	-0.08**	-0.29**	-0.28**	-0.28**	-0.28**
Punjab Chhuhara	-0.14**	-0.14**	-0.13**	-0.14**	-0.35**	-0.37**	-0.39**	-0.37**
Pusa Ruby	-0.27**	-0.26**	-0.25**	-0.26**	0.23**	0.23**	0.20**	0.22**
EC-520078	0.27**	0.25**	0.24**	0.25**	0.62**	0.69**	0.71**	0.68**
EC-620557	0.31**	0.30**	0.31**	0.31**	0.10**	0.02	0.07**	0.07**
EC-620407 × Arka Saurabh	-0.04	-0.05	-0.05	-0.05**	0.05	0.04	0.04	0.04
EC-620407 × Arka Abha	-0.02	-0.02	-0.02	-0.02	0.05	0.01	0.01	0.02
EC-620407 × Punjab Chhuhara	0.15**	0.15**	0.15**	0.15**	0.17**	0.04	0.02	0.08*
EC-620407 × Pusa Ruby	-0.03	-0.04	0.00	-0.02	-0.20**	-0.13	-0.09	-0.14**
EC-620407 × EC-520078	-0.04	-0.03	-0.02	-0.03*	-0.06	-0.03	-0.01	-0.03
EC-620407 × EC-620557	-0.03	-0.02	-0.05	-0.03*	-0.02	0.08	0.03	0.03
EC-620428 × Arka Saurabh	0.03	0.03	0.03	0.03*	0.09	0.09	0.05	0.08*
EC-620428 × Arka Abha	0.04	0.04	0.05	0.04**	0.01	0.06	0.04	0.04
EC-620428 × Punjab Chhuhara	-0.15**	-0.15**	-0.17**	-0.16**	0.06	0.08	0.04	0.06
EC-620428 × Pusa Ruby	0.04	0.03	0.00	0.02	-0.04	-0.05	-0.18**	-0.09*
EC-620428 × EC-520078	0.02	0.04	0.04	0.03*	-0.18**	0.01	-0.06	-0.08*
EC-620428 × EC-620557	0.03	0.02	0.05	0.03*	0.06	-0.19**	0.11*	0.00
EC-620360 × Arka Saurabh	0.01	0.00	0.01	0.01	-0.15**	-0.15*	-0.10	-0.13**
EC-620360 × Arka Abha	-0.04	0.01	0.02	0.00	-0.06	-0.12	-0.07	-0.08*
EC-620360 × Punjab Chhuhara	0.00	-0.01	0.02	0.01	-0.16**	-0.10	-0.05	-0.10**
EC-620360 × Pusa Ruby	0.00	-0.01	0.02	0.00	0.34**	0.36**	0.39**	0.36**
EC-620360 × EC-520078	0.00	0.01	-0.04	-0.01	0.09	-0.02	-0.09	-0.01
EC-620360 × EC-620557	0.02	0.01	-0.03	0.00	-0.07	0.04	-0.08	-0.04
EC-608415 × Arka Saurabh	0.01	0.01	-0.01	0.00	0.04	0.04	0.01	0.03
EC-608415 × Arka Abha	0.01	0.02	0.01	0.01	-0.01	0.03	0.02	0.01
EC-608415 × Punjab Chhuhara	0.01	0.01	-0.02	0.00	-0.04	-0.01	0.02	-0.01
EC-608415 × Pusa Ruby	0.00	0.01	0.00	0.00	-0.05	-0.07	-0.04	-0.06
EC-608415 × EC-520078	-0.02	-0.03	0.01	-0.01	-0.05	-0.14*	-0.06	-0.08*
EC-608415 × EC-620557	-0.02	-0.03	0.01	-0.01	0.10	0.15*	0.06	0.10**
EC-619982 × Arka Saurabh	-0.02	0.01	0.02	0.00	-0.03	-0.02	0.00	-0.02
EC-619982 × Arka Abha	0.00	-0.05	-0.05	-0.03*	0.00	0.03	0.01	0.01
EC-619982 × Punjab Chhuhara	-0.02	0.00	0.02	0.00	-0.04	-0.02	-0.03	-0.03

EC-619982 × Pusa Ruby	-0.01	0.01	-0.01	0.00	-0.06	-0.10	-0.08	-0.08*
EC-619982 × EC-520078	0.04	0.01	0.01	0.02	0.20**	0.19**	0.23**	0.21**
EC-619982 × EC-620557	0.00	0.02	0.02	0.01	-0.08	-0.08	-0.12*	-0.09**
SE (crosses)	0.02	0.04	0.03	0.01	0.05	0.07	0.05	0.03

*, ** significant at 5 and 1 % levels, respectively

Table 11: Estimates of combining ability for titrable acidity and ascorbic acid content

Genotypes	Titrable acidity				Ascorbic acid content			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	0.00	-0.01**	0.01**	0.00	-2.71**	-2.73**	-2.91**	-2.78**
EC-620428	-0.01*	0.01**	0.00	0.00	1.01**	1.03**	0.73**	0.92**
EC-620360	0.04**	-0.02**	0.05**	0.03**	2.98**	3.09**	2.83**	2.97**
EC-608415	-0.01*	0.01**	-0.02**	0.00	-1.72**	-1.72**	-1.83**	-1.76**
EC-619982	-0.02**	0.00	-0.05**	-0.02**	0.44**	0.33**	1.17**	0.65**
Arka Saurabh	0.00	-0.03**	0.01**	0.00*	-0.51**	-0.43**	-0.65**	-0.53**
Arka Abha	0.02**	0.01**	0.03**	0.02**	0.89**	0.85**	0.62**	0.79**
Punjab Chhuhara	0.00	-0.01	0.01**	0.00	1.87**	1.77**	1.68**	1.77**
Pusa Ruby	0.01	0.03**	0.00	0.01**	0.79**	0.90**	0.67**	0.79**
EC-520078	-0.01*	0.00	-0.02**	-0.01**	0.68**	0.65**	0.02	0.45**
EC-620557	-0.02**	-0.01*	-0.04**	-0.02**	-3.73**	-3.74**	-2.34**	-3.27**
EC-620407 × Arka Saurabh	0.01	-0.06**	0.01	-0.01*	-0.91**	-0.98**	-0.75*	-0.88**
EC-620407 × Arka Abha	-0.02*	0.03**	-0.03**	-0.01	0.15	0.21	0.42	0.26**
EC-620407 × Punjab Chhuhara	0.03**	-0.05**	0.00	0.00	0.11	0.21	0.30	0.21**
EC-620407 × Pusa Ruby	-0.02	0.01	-0.02*	-0.01	0.26	0.22	0.40	0.29**
EC-620407 × EC-520078	-0.01	0.04**	0.01	0.02**	0.20	0.14	0.85**	0.40**
EC-620407 × EC-620557	0.00	0.02**	0.02*	0.01**	0.18	0.21	-1.23**	-0.28
EC-620428 × Arka Saurabh	0.00	0.04	-0.01	0.01	0.32	0.27	0.61*	0.40
EC-620428 × Arka Abha	-0.01	-0.01	0.00	-0.01	-0.09	-0.03	0.22	0.03
EC-620428 × Punjab Chhuhara	-0.01	0.00	-0.02*	-0.01*	0.20	-0.06	0.09	0.08
EC-620428 × Pusa Ruby	0.01	-0.01	0.00	0.00	-0.28	-0.04	0.28	-0.01
EC-620428 × EC-520078	0.00	-0.01	0.01	0.00	-0.11	-0.10	0.34	0.04
EC-620428 × EC-620557	0.01	-0.01*	0.02	0.00	-0.03	-0.03	-1.54**	-0.54**
EC-620360 × Arka Saurabh	-0.01	-0.01	-0.02*	-0.01*	0.02	0.23	0.45	0.23**
EC-620360 × Arka Abha	0.01	-0.02*	0.00	0.00	-0.08	-0.06	0.21	0.02
EC-620360 × Punjab Chhuhara	0.01	0.02**	-0.01	0.00	-0.16	-0.05	0.11	-0.03
EC-620360 × Pusa Ruby	0.00	0.02**	0.02	0.01*	0.08	-0.05	0.22	0.08
EC-620360 × EC-520078	0.00	-0.02**	0.00	-0.01	0.08	-0.01	0.61*	0.23**
EC-620360 × EC-620557	-0.01	0.00	0.01	0.00	0.06	-0.05	-1.59**	-0.53**
EC-608415 × Arka Saurabh	0.00	0.00	0.01	0.01	0.33	0.25	0.39	0.32**
EC-608415 × Arka Abha	0.03*	-0.01	0.02	0.01*	-0.10	-0.06	0.08	-0.03
EC-608415 × Punjab Chhuhara	-0.02	0.02**	0.01	0.00	-0.18	-0.05	0.61*	0.13
EC-608415 × Pusa Ruby	0.00	0.00	0.02*	0.01	0.03	-0.06	0.07	0.01
EC-608415 × EC-520078	-0.01	-0.01	-0.02	-0.01*	-0.03	-0.01	0.50	0.15**
EC-608415 × EC-620557	0.00	-0.01	-0.04**	-0.02**	-0.05	-0.06	-1.66**	-0.59**
EC-619982 × Arka Saurabh	-0.01	0.02**	0.01	0.01	0.23	0.24	-0.70*	-0.08
EC-619982 × Arka Abha	0.00	0.00	0.01	0.00	0.12	-0.06	-0.94**	-0.29**
EC-619982 × Punjab Chhuhara	-0.01	0.00	0.03*	0.01	0.02	-0.05	-1.12**	-0.38**
EC-619982 × Pusa Ruby	0.00	-0.02*	-0.02*	-0.01**	-0.07	-0.06	-0.97**	-0.37**
EC-619982 × EC-520078	0.01	0.00	-0.01	0.00	-0.13	-0.02	-2.30**	-0.82**
EC-619982 × EC-620557	0.01	-0.01	-0.02	-0.01	-0.16	-0.06	6.02**	1.94**
SE (crosses)	0.01	0.01	0.01	0.01	0.24	0.18	0.29	0.07

*, ** significant at 5 and 1 % levels, respectively

Table 12: Estimates of combining ability effects for total sugars, reducing sugars

Genotypes	Total sugars				Reducing sugars			
	E1	E2	E3	Pooled	E1	E2	E3	Pooled
EC-620407	-0.13**	-0.10**	-0.33**	-0.19**	-0.17**	-0.14**	-0.15**	-0.15**
EC-620428	0.09**	-0.10**	-0.29**	-0.10**	-0.01	-0.10**	-0.10**	-0.07**
EC-620360	-0.10**	-0.04**	0.76**	0.20**	-0.06**	-0.03	-0.04**	-0.04**
EC-608415	-0.04*	0.00	-0.19**	-0.08**	0.00	0.02	0.02	0.01
EC-619982	0.18**	0.25**	0.05**	0.16**	0.23**	0.25**	0.27**	0.25**
Arka Saurabh	0.26**	0.29**	0.11**	0.22**	0.29**	0.31**	0.31**	0.30**
Arka Abha	0.05**	0.06**	-0.03*	0.03**	0.00	0.04*	0.03*	0.02**
Punjab Chhuhara	0.10**	0.16**	0.08**	0.11**	0.13**	0.15**	0.14**	0.14**
Pusa Ruby	0.19**	-0.02	0.12**	0.10**	0.11**	0.01	0.00	0.04**
EC-520078	-1.17**	-1.13**	-0.71**	-1.00**	-1.13**	-1.10**	-1.11**	-1.11**
EC-620557	0.57**	0.63**	0.43**	0.54**	0.59**	0.59**	0.63**	0.60**
EC-620407 × Arka Saurabh	0.02	-0.02	0.15**	0.05**	0.09**	0.06	0.03	0.06**

EC-620407 × Arka Abha	-0.11**	-0.15**	-0.10**	-0.12**	-0.12**	-0.16**	-0.14**	-0.14**
EC-620407 × Punjab Chhuhara	0.10**	0.06*	0.17**	0.11**	0.02	0.01	0.01	0.01
EC-620407 × Pusa Ruby	-0.44**	-0.22**	-0.39**	-0.35**	-0.33**	-0.22**	-0.22**	-0.26**
EC-620407 × EC-520078	0.27**	0.22**	-0.14**	0.12**	0.23**	0.19**	0.20**	0.21**
EC-620407 × EC-620557	0.15**	0.10**	0.31**	0.19**	0.12**	0.11**	0.11**	0.11**
EC-620428 × Arka Saurabh	-0.29**	-0.20**	0.09**	-0.14**	-0.23**	-0.14**	-0.16**	-0.18**
EC-620428 × Arka Abha	-0.27**	-0.08**	0.01	-0.12**	-0.18**	-0.08*	-0.09**	-0.12**
EC-620428 × Punjab Chhuhara	-0.10*	0.07**	0.13**	0.04*	-0.06*	0.03	0.04	0.00
EC-620428 × Pusa Ruby	0.59**	-0.24**	-0.42**	-0.02	0.20**	-0.20**	-0.21**	-0.07**
EC-620428 × EC-520078	0.09*	0.27**	-0.20**	0.05**	0.18**	0.27**	0.26**	0.24**
EC-620428 × EC-620557	-0.02	0.18**	0.39**	0.18**	0.10**	0.12**	0.16**	0.13**
EC-620360 × Arka Saurabh	-0.03	-0.09**	-0.90**	-0.34**	-0.13**	-0.15**	-0.16**	-0.15**
EC-620360 × Arka Abha	0.20**	0.23**	-0.11**	0.11**	0.20**	0.19**	0.21**	0.20**
EC-620360 × Punjab Chhuhara	0.07	0.02	-0.31**	-0.07**	0.03	0.00	0.01	0.02
EC-620360 × Pusa Ruby	-0.12**	0.06*	0.68**	0.21**	-0.04	0.05	0.07*	0.03*
EC-620360 × EC-520078	-0.08*	-0.15**	1.54**	0.44**	-0.10**	-0.14**	-0.15**	-0.13**
EC-620360 × EC-620557	-0.04	-0.06*	-0.90**	-0.33**	0.04	0.03	0.01	0.03*
EC-608415 × Arka Saurabh	0.08*	0.06**	0.24**	0.13**	0.05	0.04	0.05	0.05**
EC-608415 × Arka Abha	0.06	0.01	0.10**	0.06**	0.08*	0.06	0.05	0.06**
EC-608415 × Punjab Chhuhara	0.12**	0.09**	0.16**	0.12**	0.08*	0.04	0.05	0.06**
EC-608415 × Pusa Ruby	0.02	0.28**	0.14**	0.15**	0.15**	0.25**	0.24**	0.21**
EC-608415 × EC-520078	-0.28**	-0.29**	-0.73**	-0.43**	-0.25**	-0.28**	-0.26**	-0.26**
EC-608415 × EC-620557	-0.01	-0.14**	0.09**	-0.02	-0.11**	-0.12**	-0.14**	-0.12**
EC-619982 × Arka Saurabh	0.22**	0.24**	0.42**	0.30**	0.23**	0.18**	0.23**	0.22**
EC-619982 × Arka Abha	0.12**	0.00	0.10**	0.07**	0.02	-0.01	-0.03	-0.01
EC-619982 × Punjab Chhuhara	-0.20**	-0.24**	-0.15**	-0.20**	-0.06	-0.09*	-0.12**	-0.09**
EC-619982 × Pusa Ruby	-0.05	0.12**	-0.02	0.02	0.02	0.12**	0.12**	0.09**
EC-619982 × EC-520078	-0.01	-0.05*	-0.47**	-0.17**	-0.06	-0.05	-0.06	-0.06**
EC-619982 × EC-620557	-0.08*	-0.08**	0.12**	-0.01	-0.15**	-0.15**	-0.15**	-0.15**
SE (crosses)	0.04	0.02	0.03	0.02	0.03	0.04	0.03	0.01

*, ** significant at 5 and 1 % levels, respectively

Table 13: Estimates of combining ability effects for lycopene content

Genotypes	Lycopene content			
	E1	E2	E3	Pooled
EC-620407	-0.36**	-0.36**	-0.36**	-0.36**
EC-620428	0.14**	0.17**	0.18**	0.17**
EC-620360	-0.03	-0.02	-0.08**	-0.05**
EC-608415	-0.32**	-0.35**	-0.23**	-0.30**
EC-619982	0.58**	0.56**	0.49**	0.54**
Arka Saurabh	-0.93**	-0.92**	-0.88**	-0.91**
Arka Abha	-0.64**	-0.60**	-0.59**	-0.61**
Punjab Chhuhara	-0.10**	-0.08*	-0.12**	-0.10**
Pusa Ruby	-0.38**	-0.43**	-0.40**	-0.40**
EC-520078	1.21**	1.18**	1.19**	1.19**
EC-620557	0.84**	0.85**	0.81**	0.83**
EC-620407 × Arka Saurabh	0.09	-0.08	-0.07	-0.02
EC-620407 × Arka Abha	-0.08	-0.11	-0.06	-0.09*
EC-620407 × Punjab Chhuhara	-0.15	-0.12	-0.14*	-0.14**
EC-620407 × Pusa Ruby	-0.09	-0.11	-0.22**	-0.14**
EC-620407 × EC-520078	0.54**	0.64**	0.59**	0.59**
EC-620407 × EC-620557	-0.31**	-0.21**	-0.10	-0.21**
EC-620428 × Arka Saurabh	-0.10	0.00	0.03	-0.02
EC-620428 × Arka Abha	-0.07	0.00	-0.11	-0.06
EC-620428 × Punjab Chhuhara	0.10	0.05	0.09	0.08*
EC-620428 × Pusa Ruby	0.04	0.06	0.02	0.04
EC-620428 × EC-520078	-0.10	-0.15*	-0.06	-0.10**
EC-620428 × EC-620557	0.12	0.02	0.04	0.06
EC-620360 × Arka Saurabh	0.06	0.01	-0.01	0.02
EC-620360 × Arka Abha	0.10	-0.01	0.08	0.06
EC-620360 × Punjab Chhuhara	0.00	-0.04	0.14*	0.03
EC-620360 × Pusa Ruby	-0.11	-0.06	-0.08	-0.08*
EC-620360 × EC-520078	-0.09	-0.13	-0.18**	-0.13**
EC-620360 × EC-620557	0.05	0.22**	0.06	0.11**
EC-608415 × Arka Saurabh	-0.04	0.05	-0.07	-0.02
EC-608415 × Arka Abha	0.09	0.12	-0.02	0.06
EC-608415 × Punjab Chhuhara	0.06	0.10	0.04	0.07
EC-608415 × Pusa Ruby	0.05	0.06	0.18**	0.10**

EC-608415 × EC-520078	-0.17*	-0.19**	-0.17**	-0.18**
EC-608415 × EC-620557	0.02	-0.13	0.03	-0.03
EC-619982 × Arka Saurabh	-0.01	0.01	0.12	0.04
EC-619982 × Arka Abha	-0.04	0.00	0.11	0.03
EC-619982 × Punjab Chhuhara	0.00	0.02	-0.13*	-0.04
EC-619982 × Pusa Ruby	0.11	0.05	0.10	0.08*
EC-619982 × EC-520078	-0.18*	-0.18**	-0.18**	-0.18**
EC-619982 × EC-620557	0.12	0.10	-0.03	0.07
SE (crosses)	0.08	0.07	0.06	0.04

*, ** significant at 5 and 1 % levels, respectively

Table 14: Pooled Analysis of Variance for combining ability

Source of variation	d.f.	Plant height (cm)	Number of primary branches per plant	Days to 50% flowering	Number of flowers per cluster	Number of fruits per cluster	Fruit length (cm)	Fruit width (cm)	Average fruit weight (g)	Days to first fruit harvest	Days to last fruit harvest
Environments	2.00	7851.35**	8.81**	513.51**	10.84**	12.92**	2.75**	1.92**	1875.82**	497.99**	771.50**
Replications x Environments	4.00	20.99	0.07	0.64	0.20	0.20	0.02	0.00	23.14	3.20	6.96
Treatments	40.00	8485.76**	3.95**	841.29**	10.13**	10.72**	10.86**	10.58**	6981.45**	991.09**	643.29**
Parents	10.00	5661.06**	4.30	1023.21**	12.46**	15.52**	14.21**	10.61**	5941.81**	1627.30**	388.20**
Parent vs. Crosses	1.00	16158.28**	4.48**	236.99**	8.70**	15.55**	0.99**	2.70**	2695.34**	567.51**	1967.13**
Crosses	29.00	9195.22**	3.81**	799.40**	9.37**	8.90**	10.05**	10.85**	7487.75**	786.32**	685.60**
Lines	4.00	1022.11	6.36*	2150.22**	7.59*	5.10*	3.67	2.36	1635.39	435.47**	558.12**
Testers	5.00	49229.51**	10.60**	2647.09**	41.29**	40.78**	48.5**	50.40**	37620.35**	3868.19**	3286.77**
Lines x Testers	20.00	821.28**	1.60**	67.32**	1.75**	1.69**	1.70**	2.66**	1125.07**	86.02**	60.81**
Parents x Environments	20.00	67.42	0.14	1.79	0.24	0.09	0.22**	0.16**	21.31	3.40**	4.85
(Parent vs. Crosses) x Environments	2.00	771.86**	0.73**	108.86**	1.07**	1.54**	0.19**	0.13**	174.05**	0.09	63.08**
Crosses x Environments	58.00	87.66**	0.11	102.98**	0.11	0.39**	0.04	0.03*	40.09**	3.67**	2.69
Lines x Environments	8.00	90.88	0.06	420.15**	0.26**	0.45	0.03	0.03	31.16	2.83	3.11
Testers x Environments	10.00	98.19	0.34**	49.33	0.12	0.58	0.09**	0.04	72.49*	3.01	6.68**
Lines x Testers x Environments	40.00	84.39**	0.07	52.95**	0.08	0.32**	0.03*	0.03**	33.77**	4.01**	1.61
Error	174.00	40.56	0.07	1.13	0.08	0.10	0.02	0.02	15.26	1.49	4.16

*, ** significant at 5 and 1 % levels, respectively

Source of variation	d.f.	Fruit yield per plant (kg)	Pericarp thickness (mm)	Fruit pH	Total soluble solids (°Brix)	Titration acidity (%)	Ascorbic acid content (mg/100g)	Total sugars (%)	Reducing sugars (%)	Lycopene content (mg/100 g)
Environments	2.00	0.54**	1.73**	0.03**	0.03	0.04**	4.42**	2.21**	0.41**	4.83**
Replications x Environments	4.00	0.00	0.01	0.00	0.02	0.00	0.32	0.01	0.00	0.02
Treatments	40.00	2.71**	10.72**	0.87**	1.91**	0.01**	84.64**	2.83**	3.14**	7.67**
Parents	10.00	0.82**	11.92**	1.55**	3.03**	0.01**	148.77**	3.35**	3.78**	10.44**
Parent vs. Crosses	1.00	47.75**	2.80**	0.51**	1.29**	0.11**	2.23**	1.07**	0.34**	10.93**
Crosses	29.00	1.80**	10.58**	0.64**	1.54**	0.00**	65.37**	2.71**	3.02**	6.61**
Lines	4.00	3.62**	3.38*	1.63**	1.26**	0.02**	282.32**	1.59*	1.25**	7.32**
Testers	5.00	4.49**	54.84**	2.32**	7.40**	0.01**	140.08**	12.36**	15.48**	31.38**
Lines x Testers	20.00	0.77**	0.96**	0.03**	0.14**	0.00**	3.30**	0.52**	0.26**	0.27**
Parents x Environments	20.00	0.00	0.09**	0.01**	0.06**	0.00**	2.12**	0.01**	0.01**	0.18**
(Parent vs. Crosses) x Environments	2.00	0.02	0.25**	0.11**	0.33**	0.02**	3.80**	0.27**	0.05**	1.26**
Crosses x Environments	58.00	0.02	0.09**	0.00	0.01	0.00**	2.63**	0.49**	0.01**	0.02
Lines x Environments	8.00	0.01	0.08	0.00**	0.01	0.01**	1.22	1.36**	0.02	0.03
Testers x Environments	10.00	0.02	0.09	0.00	0.01	0.00*	2.53	0.30	0.02	0.01
Lines x Testers x Environments	40.00	0.02	0.10**	0.00	0.01	0.00**	2.93**	0.36**	0.01**	0.02
Error	174.00	0.01	0.01	0.00	0.01	0.00	0.04	0.00	0.00	0.01

*, ** significant at 5 and 1 % levels, respectively

Conclusion

In the present investigation the high estimates of *gca* effects was observed for different attributes of economic importance may be useful for sorting out outstanding parents with favourable alleles for different components of yield. Superior general combiners for fruit yield and quality traits are presented in table 2.

High *gca* effects are related to additive gene effects or additive × additive effects, which represent the fixable genetic components of variance, as also pointed out by Griffing (1956 a). It may therefore, be suggested that the parents with high *gca* effects for a particular character may be used in

hybridization programme for the improvement of that character. These superior general combiners are recommended for use in breeding programmes to generate genetic variability in desirable direction for effective selection to improve the respective traits. Specific combining ability helps in the identification of superior cross combinations for commercial exploitation of heterosis. Superior specific combiners for fruit yield and quality traits are presented in table 3. These superior specific combiners have highest magnitude of significant *sca* effects in favourable direction are recommended for heterosis breeding.

References

- Alex Sandro Torre Figueiredo, Juliano Tadeu Vilela de Resende, Marcos Ventura Faria, Juliana Tauffer de Paula Kelin Schwarz, Daniel Suek Zanin. Crop Breeding and Applied Biotechnology. 2015; 15:154-161.
- Adedeji O, Taiwo KA, Akanbi CT, Ajani R. Physicochemical properties of four tomato cultivars grown in Nigeria. J. Food Processing and Preservation, 2006; 30(1):79-86.
- Basavaraj LB, Vilas DG, Shivappa M Karadi, Vijayakumar DR, Nagesh GC, Reshmika PK. Combining ability analysis for fruit yield and quality traits in tomato (*Solanum lycopersicum* L.). Green Farming. 2016; (1):26-30.
- Bharathkumar MV, Sadashiva AT, Punith Kumar R. Combining ability, gene action and heritability analysis for early blight resistance, yield and quality traits in tomato (*Solanum lycopersicum* L.). Journal of Applied and Natural Science. 2017; 9(3):1495-1500.
- Bhutani RD, Kalloo G. Genetics of reducing sugars in tomato (*Lycopersicon esculentum* Mill). Haryana Journal of Horticultural Science. 1990; 19:125-128.
- Dechin Droka, Raj Kumar, Subodh Joshi, Yadav RK. Genetic studies of quality traits in tomato (*Solanum lycopersicum* L.) under low temperature. Vegetable Science, 2012; 39(2):189-191.
- Kumari S, Sharma MK. Exploitation of heterosis for yield and its contributing traits in tomato (*Solanum lycopersicum* L.). International Journal of Farm Science, 2011; 1(2):45-50.
- Ebenezer Babu Rajan. Studies on combining ability for yield and yield contributing traits in tomato (*Lycopersicum esculentum* L.). Plant Archives, 2014; 14(1):541-544.
- Islam BMR, Ivy NA, Rasul MG, Zakraria M. Character association and path analysis of exotic tomato (*Solanum lycopersicum* L.) genotypes. Bangladesh Journal of Plant Breeding Genetics, 2010; 23(1):13-18.
- Kempthorne D. An introduction to genetic statistics. Wiley, New York, 1957.
- Kulkarni GP. Investigations on bacterial wilt resistance in tomato. Ph. D. Thesis University of Agricultural Sciences Dharwad India, 2003.
- Kumari W, Srivastava JP. Combining ability of quality traits and yield in tomato (*Solanum lycopersicon* (Mill.) Wettst.). Vegetable Science. 2007; 34(1):99-100.
- Mahajan S. Cold, Salinity and Drought stresses: An overview. Biochemical and Biophysical. 2010; 444:139-158.
- Makesh S, Puddan M, Ashok S, Banu MR. Heterosis studies for quality and yield in tomato (*Lycopersicon esculentum* Mill.). Advances in Plant Science. 2002; 15(2):597-601.
- Panse VG, Sukhatme PV. Statistical methods for agricultural workers. Indian Council of Agricultural Research Publication New Delhi. 1967, 87-89.
- Mehta S, Kumar D, Mishra M. Combining ability for yield and other horticultural traits in tomato (*Lycopersicon esculentum* Mill.) Udyanika, 2005; 11(2):107-112.
- Mondal C, Sarkar S, Hazra P. Line x Tester analysis of combining ability in tomato (*Lycopersicon esculentum* Mill.). Journal of Crop and Weed. 2009; 5(1):53-57.
- Muhammad Yussouf Saleem, Muhammad Asghar, Muhammad Ahsanul Haq, Tariq Rafique, Atif Kamran, Asif Ali Khan. Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Lycopersicon esculentum* Mill.). Pakistan Journal of Botany. 2009; 41(3):1107-1116.
- Narasimhamurthy, Paramanahally, Hanumanthe gouda, Ramanjini gouda. Identification of superior parents for fruit quality and yield attributing traits. International Journal of plant Breeding, 2013, 50-54.
- Naveen Garg, Devinder S, Cheema, Ajmer Datta S. Genetics of yield, quality and shelf life characteristics in tomato under normal and late planting conditions. Euphytica, 2008; 159:275-288.
- Parvati Pujer, Jagdeesha RC, Mahesh Badiger. Genetic component of variance and combining ability using diallele analysis in cherry tomato for yield and quality (*Solanum lycopersicum* L. var. Cerasiforme Mill.). International Journal of Advances Biological Research. 2017; 7(3):543-548.
- Pemba Sherpa, Tania Seth, Varun Durwas Shende, Pandiarana N, Subhra Mukherjee, Arup Chattopadhyay. Heterosis, dominance estimate and genetic control of yield and post harvest quality traits of tomato. Journal of Applied and Natural Science. 2014; 6(2):625-632.
- Premalakshmi V, Thiagaraj T, Veeraragavathatham D, Arumugam T. Heterosis and combining ability analysis in tomato (*Lycopersicon esculentum* (Mill.) Wettst.) for yield and yield contributing traits. Vegetable Science. 2006; 33:5-9.
- Pooja Kapur, Vidyasagar, Sanjay Chadha. Combining ability and gene action studies over environments in bacterial wilt resistant tomato genotypes. Vegetable Science, 2013; 40(2):164-168.
- Ramana V, Srihari D, Reddy RVSK, Sujatha M, Bhav MHV. Combining ability studies in tomato (*Solanum lycopersicum* L.) for yield attributes, yield and quality. Journal of Pharmacognosy and Phytochemistry, 2017, 933-937.
- Roopa L, Sadashiva AT, Reddy KM, Gopalakrishna Rao KP, Narasimhaprasad BC. Combining ability studies for long shelf life in tomato. Vegetable Science, 2001; 28(1):24-26.
- Savale SV, Patel AI. Combining ability analysis for fruit yield and quality traits across environments in tomato (*Solanum lycopersicum* L.). International Journal of Chemical Studies, 2017; 5(5):1611-1615.
- Singh AK, Asati BS. Combining ability and heterosis studies in tomato under bacterial wilt condition. Bangladesh Journal of Agricultural Research. 2011; 36(2):313-318.
- Singh CB, Rai N, Ramesh Kumar Singh, Singh MC, Singh AK, Chaturvedi AK. Heterosis, combining ability and gene action studies in tomato (*solanum lycopersicum* l.). Vegetable Science. 2008; 35(2):132-135.
- Singh B, Kaul S, Kumar D, Kumar V. Combining ability for yield and its contributing characters in tomato. Indian Journal of Horticulture. 2010; 67(1):50-55.
- Sunil Kumar M, Akhilesh Kumar Pal, Anil Kumar Singh, Kailash Sati, Deepak Kumar. Studies on genetic parameters to improve the genetic architecture of tomato (*Solanum lycopersicum* L.). International Journal of Applied Biology and Pharmaceutical Technology. 2013; 4(4):234-237.
- Tanvi Raj, Madan Lal Bhardwaj, Saheb Pal, Rajesh Kumar Dogra. Combining Ability and Gene Action Studies in Some Genetic Stocks of Tomato (*Solanum*

- lycopersicum* L.). International Journal of Current Microbiology and Applied Sciences. 2017; 6(10):138-144.
33. Varun Durwas Shende, Tania Seth, Subhra Mukherjee, Arup Chattopadhyay. Breeding tomato (*Solanum lycopersicum* L.) for higher productivity and better processing qualities. SABRAO Journal of Breeding and Genetics, 2012; 44(2):302-321.
34. Vipesh Kumar, Jindal SK, Dhaliwal MS. Combining ability studies in tomato (*Solanum lycopersicum* L.). Agricultural Research Journal. 2015; 52(2):121-125.
35. Virupannavar H, Dharmatti PR, Yashwant Kumar KH, Ajjappa Sogalad. Combining ability studies on bacterial wilt resistance in tomato for processing qualities and yield. Asian Journal of Horticulture. 2010; 5(1):111-113.