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Studies on Character Improvement in Tomato (*Solanum lycopersicum* L.) by Heterosis

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Authors' contributions

This work was carried out in collaboration among all authors. Author MMRS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MHR and MRA managed the analyses of the study and finalized the writing. Author LA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Most of the tomato varieties in Bangladesh are of inbred type and produced low yield indicating need to develop high yielding variety through the hybridization. Heterosis breeding is used to improve yield and quality of tomato because traditional methods cannot be used to achieve this goal. A half diallel design was employed to develop F_1s from seven parents of winter tomato. 21 F_1s along with their parents were evaluated for yield and quality traits. Heterosis analysis revealed that heterotic vigor was present for growth and yield characters among hybrids. Heterosis for better parent was negative for days to flowering, days to harvest, harvest duration, number of locules, and number of seeds per fruit but positive for fruit set, number of fruits per plant, yield per plant, pericarp thickness and TSS. None of the hybrid was heterotic for all characters simultaneously. The hybrids G5, G13, G16, G17, G18, and G20 had 25.73, 19.92, 39.20, 36.49, 53.77, and 50.31% higher heterosis compared to the better parent, respectively, for fruit yield per plant as well as for many

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other yield contributing traits. High heterosis for yield appears to be the consequence of heterosis of yield attributing traits; therefore, these hybrids offer scope of developing improved commercial lines through heterosis breeding.

Keywords: Heterosis breeding; quantitative trait; tomato; yield.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular and extensively consumed vegetable over the world. Currently, tomato is grown around the globe for either fresh market or processing [1] and considered as a high value crop. As a cash crop, it has a great demand in local as well as the international market. Unfortunately, the production of tomato in Bangladesh is limited due to the scarcity of high yielding varieties. As a result, a huge quantity of tomato is imported every year from the neighboring countries to meet up the local market demand. Recently, the crop has received more attention to the policy makers and researchers. As the development of hybrid varieties with higher yield has been thought to be an effective strategy increasing tomato production, a number of projects have been implemented recent years developing new hybrids in Bangladesh. On the other hand, heterosis breeding is predicted to be the most powerful genetic approach developing hybrids with higher yield [2]. Heterosis, which is the superiority in performance of hybrid individuals compared with their parents [3], has been reported for a wide range of crop species including both self and cross-pollinated crops. Therefore, the estimation of heterosis is one of the goals to assess the hybrid vigor selecting promising hybrids.

Heterosis was first observed by Hedrick and Booth [4] in tomato for higher yield. Afterwards a numerous studies have been done in relation to heterosis for yield, its components and quality traits [3,5,6,7,8]. However, the exploitation of heterosis is a quick and an effective way of selecting hybrids for high yield potential, earliness and quality attributes. Unfortunately, a very few attempts in this regard has been taken in the past in Bangladesh. The present study was therefore, executed to estimate the level of percent better and mid parent heterosis among F_1 hybrids of tomato. This information would be useful to investigate the performance and relationship of F_1 hybrids with their parents and to select suitable parents and/or population for designing an effective breeding programme.

2. MATERIALS AND METHODS

2.1 Planting Materials

Seven inbred lines of tomato namely VRT001 (P1), VRT007 (P2), VRT008 (P3), C11 (P4), C41 (P5), LE02 (P6) and TLB133 (P7) were used in the hybridization. A half diallel mating fashion was followed in developing F_1s in winter 2009-10 (Table 1). Twenty one F_1s along with the seven parents were evaluated in winter 2010-11. Parental genotype denoting VRT is virus tolerance, LE is *Lycopersicon esculentum,* TLB is tolerance to late blight and C is heat tolerance.

2.2 Experimental Site

The experiment was conducted at the Vegetable Research Field of Horticulture Research Centre (HRC), Bangladesh Agricultural Research

Table 1. Developed F_1 hybrids by a half diallel fashion

Parent (P)	P1	P2	P3	P4	P5	P6	P7
P1 (WP10)	-	P1× P2 (^{Z}G1)	P1 × P3 (G2)	P1 × P4 (G3)	P1 × P5 (G4)	P1 × P6 (G5)	P1 × P7 (G6)
P2 (VRT003)			P2 × P3 (G7)	P2 × P4 (G8)	P2 × P5 (G9)	P2 × P6 (G10)	P2 × P7 (G11)
P3 (VRT004)				P3 × P4(G12)	P3 × P5 (G13)	P3 × P6 (G14)	P3 × P7 (G15)
P4 (LE009)					P4 × P5 (G16)	P4 × P5 (G17)	P4 × P5 (G18)
P5 (TLB182)						P5 × P6 (G19)	P5 × P6 (G20)
P6 (WP02)							P6 × P7 (G21)
P7 (TLB111)							-

^{Z}*Hybrid*

Institute (BARI) Bangladesh from October 2010 to March 2011. The climate of the experimental site is subtropical characterized by heavy rainfall from May to September and scanty rainfall rest of the year. The soil of the experimental site was sandy loam in texture and acidic in nature with a pH around 6.0. This area belongs to the "Shallow red-brown terrace" soil of Madhupur tract as reported by Haider et al. [9]. The land was prepared and fertilized as described by Salim et al. [10].

2.3 Seedling Raising and Transplanting

Seeds were sown thinly in a raised seed bed on October 15, 2010. Seed bed was shaded partially with black net after sowing the seeds. Young seedlings were also covered by a fine mesh white net to protect them from insect attack. 7-days old seedlings were transplanted to a second seed bed at the spacing of 5 x 5 cm for hardening. Thirty days old seedlings were transplanted in the main field on November 15, 2010. Light irrigation was given to each seedling immediately after transplanting for their better establishment.

2.4 Experimental Design and Plot Layout

Tomato seedlings were grown in a raised seed bed and 30-days old seedlings were transplanted in the main field following randomized complete block design with three replications. Each genotype with spacing of 60 cm x 40 cm represented double row having 12 plants per row accommodating in total 24 plants per plot. The unit plot was separated by 50 cm irrigation drain, while blocks were separated by 75 cm drain. Recommended cultural practices as well as plant protection measures were followed.

2.5 Data Collection and Statistical Analysis

Data for different characters (Table 2) were recorded from 10 randomly selected plants of parents and F_1s. Analysis of variance (ANOVA) was performed as suggested by Gomez and Gomez [11]. Heterosis was estimated using basic formula described by Falconer [12]. Usually, the magnitude of heterosis depends on the accumulation of favorable dominant alleles in the F_1 population. If the parental populations differ from each other for favorable dominant alleles, the magnitude of heterosis supposed to be proportionally higher. This relationship was estimated by the basic formula 1. Where; d = magnitude of dominance, y = difference between the parental population for allelic frequencies at the locus.

$$\text{Heterosis in F1} = \sum d\, y^2 \quad (1)$$

For estimation of heterosis in each character the mean values of the 21 F_1's have been compared with better parent (BP) for heterobeltiosis and with mid parent (MP) for heterosis over mid parental value. Percent heterosis was calculated by the formula 2 and 3.

$$\text{Heterosis (BP)} = \frac{(\overline{F1}-\overline{BP})}{\overline{BP}} \times 100 \quad (2)$$

$$\text{Heterosis (MP)} = \frac{(\overline{F1}-\overline{MP})}{\overline{MP}} \times 100 \quad (3)$$

Where, F_1 = mean performance of F_1 hybrid, BP = mean performance of better parent and MP = mean performance of mid parent.

The test of significance for heterosis was done by using standard error of the value of better parent and mid parent as suggested by Turner [13]. Mean error variance from the combined analysis of variance of parents and F1's were used for calculating the standard error (SE) of difference. The mean values over replications were used for the comparison. Finally, critical difference (CD) was calculated by the formula 4 and 5 for heterosis over better and mid parent respectively. Note that the difference between F_1 and the parent used for the estimation of heterosis were taken into account cross wise. While the difference between F_1 and the parent was greater than CD it was considered significant and vice versa.

$$\text{CD (BP)} = \sqrt{\frac{2}{r}\text{EMS}} \times t \quad (4)$$

$$\text{CD (MP)} = \sqrt{\frac{3}{2r}\text{EMS}} \times t \quad (5)$$

Where, EMS = error mean square from ANOVA Table, r = number of replications and t = tabulated value either at 5% or 1% level of probability.

Table 2. ANOVA for various traits of 21 F_1s and seven parents of tomato

Characters	Mean squares		
	Replications (^{Y}df = 2)	Genotypes (df = 27)	Error (df = 54)
Days to 1st flowering	0.94	8.47**	0.77
Days to 50% flowering	3.62	24.29**	0.58
Days to 1st harvest	9.33	41.37**	10.54
Harvest duration	52.27	95.44*	14.33
Plant height at 1st harvest (cm)	60.69	174.81**	11.253
Fruit set percentage (%)	130.47	107.71	67.81
Number of fruits per plant	7.20	291.75**	9.65
Fruit length (cm)	1.48	1.44**	0.21
Fruit diameter (cm)	0.65	4.33**	0.13
Average fruit weight (g)	38.56	1829.54**	29.67
Yield per plant (kg)	0.11	0.47**	0.07
Total soluble solid (%)	0.35	6.09**	0.26
Locules per fruit	0.81	5.55**	0.76
Pericarp thickness (mm)	4.51	4.53**	0.44
Seeds per fruit	1505.23	1063.47**	5.04
1000-seed weight (g)	2.99	0.27**	0.001

*^{Y}Degree of freedom; *, ** = Significant difference at P = 0.05 and P = 0.01 respectively*

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Analysis of variance (ANOVA) for the genotypes *i.e*. parents and F_1s showed highly significant differences (*P* = 0.05 or *P* = 0.01) for the maximum characters studied except fruit set percentage (Table 2). The estimation of percent heterosis observed in F_1s over mid and better parent was presented in Tables 3 to 5.

3.2 Days to 1st Flowering

All the F_1s showed highly significant differences (*P* = 0.05 or *P* = 0.01) heterosis for flowering time, ranging from -9.89 to -0.09% over mid parent and -11.59 to -2.22% over better parent (Table 3). Out of 21 F_1 combinations, the highest heterobeltiotic effect of -11.59% was found in cross G4 followed by G15 (-11.50%), and G20 (-11.44%). The entire cross combinations produced negative heterosis indicating early flowering in hybrids when compared with their parents. Earliness actually leads to the early production and early supply in the market, resulting good price for the producers. Thus the heterosis for flowering time is considered to be an economic parameter for this study. The negative heterosis for flowering time was also reported in earlier studies [5,6,14,15].

3.3 Days to 50% Flowering

The significant differences (*P* = 0.05 or *P* = 0.01) were also observed among the crosses for the heterosis over mid and better parent (Table 3). Positive heterosis was shown for mid parent whereas negative heterosis ranging from -4.45 to -14.82% was shown for better parent. Negative heterosis showed in flowering indicating earliness by the hybrids as compared to their parents. As the farmers prefer to get a high price from the early supply, therefore, negative heterosis for this trait is preferable. This study is in accordance with the findings of Patwary et al. [16], Islam et al. [17] and Baishya et al. [18], those who reported negative heterosis for this trait over better parent in their studies.

3.4 Days to 1st Harvest

Out of 21 cross combinations, 20 exhibited significant different (*P* = 0.05 or *P* = 0.01) negative heterosis over better parent ranging from -3.05 to -11.92% whereas 18 combinations showed negative heterosis over mid parent (Table 3). The results were very similar to Sharma et al. [19] who reported heterosis ranged of -2.90 to -11.20% over better parent in tomato. More than 10% negative heterosis over better parent was observed from three F_1s *viz*. G5 (–11.92%), G1 (–10.38%), and G12 (–10.18%), which was superior to the previous study -7.14% of heterosis over better parent, reported by Sharma et al. [20]. Negative heterosis here is suggesting early harvest of tomato fruits. Therefore, those genotypes can further be utilized to develop inbred lines toward a variety development program.

3.5 Harvest Duration (days)

Harvest duration showed significant negative better parent heterosis in fourteen F_1s whereas negative mid parent heterosis was showed in thirteen F_1s (Table 3). The highest significant negative heterosis over better parent was estimated from the cross combination G1 (–6.77%) followed by G12 (–6.68%). On the other hand, the highest negative heterosis over mid parent was also estimated from the cross G1 (–6.50%). In contrast, four crosses produced significant positive heterosis over better parent *viz*. G18 (5.58%), G16 (4.72%), G8 (3.87%), and G17 (3.05%), which also showed positive heterosis over their mid parent (Table 3). Positive heterosis suggests longer harvest period whereas negative heterosis suggests shorter harvest period. Generally, longer and shorter harvest duration is preferred by the homestead and commercial growers, respectively. Positive heterosis for the trait was also reported by Kumari and Sharma [14] and Khan and Jindal [21]. Therefore, these genotypes would be the effective combination in exploiting heterosis for the homestead and commercial growers as their desire.

3.6 Plant Height at 1st Harvest

Significant negative heterosis for better parent was manifested by five F_1s viz. G11 (-15.32%), G20 (-10.56%), G13 (-10.25%), G1 (-9.76%) and G19 (-7.74%). Only two F_1s *viz*. G11 (-11.85%), and G20 (-6.76%) produced significant negative heterosis for their mid parent (Table 3). Significant positive heterosis for better parent was also found from the crosses G14 (16.60%) and G17 (8.87%). This result is similar to that of Baishya et al. [18] and Padma et al. [22]. Patwary et al. [16] reported both positive and negative heterosis for their study whereas Fageria et al. [23] reported only positive heterosis. So, these genotypes can further be used to develop inbred lines toward developing of both taller and dwarf varieties.

3.7 Fruit Set (%)

Seventeen out of 21 F_1s produced significant different (P = 0.05 or P = 0.01) positive heterosis over their better parent whereas 16 produced significant positive heterosis over their mid parent (Table 4). Nine cross combinations *viz*. G20 (25.57%), G8 (17.00%), G18 (14.82%), G9 (10.29%), G1 (8.48%), G10 (7.12%), G19 (4.71%), G16 (3.72%) and G11 (2.04%) produced significant positive heterosis either their mid or better parent indicating potential increment of fruit set. On the other hand, seven F_1s performed negative heterosis ranging from -1.68 to -22.11% indicating a reduction in fruit setting. Both positive and negative heterosis in respect of fruit setting was reported by El-Ahmadi and Stevens [24].

3.8 Number of Fruits per Plant

About 50% of the F_1s showed significant different (P = 0.05 or P = 0.01) positive heterosis over their better parent ranging from 7.86 to 45.99% (Table 4). More than 40% heterosis over their better parent was produced by four crosses *viz*. G3, G10, G13, G18. On the other hand, about 76% of the F_1s produced significant positive heterosis over their mid parent ranging from 12.05 to 63.55% (Table 4). This result suggested a potential increment of fruits number in the tomato plant. This study showed a bit higher amount of heterosis for fruits number than the previous study by Patwary et al. [16]. It could be due to the variation of the parents used in the study. Our study also had an agreement with the previous research [6,18,19,20,23].

3.9 Fruit Length (cm)

Fourteen hybrids showed positive heterosis, of which 5 hybrids exhibited positive significant heterosis over better parents (Table 4). More than 10% heterosis was estimated from four crosses *viz*. G6, G4, G14, and G20. Only one hybrid G18 (-12.93%) produced the significant negative heterosis over better parent. Since, only a genotype out of twenty one showed significant negative heterosis over better parent, indicating character is mainly governed by non-additive gene effects. Islam et al. [18] also reported similar results for fruit length. Significant positive heterosis has been reported by Ahmad *et* al. [6], and Sharma et al. [20]. These findings of significant positive heterosis over mid and better parent are in line with the findings of Singh et al. [5] and Kumar and Singh [25] as well.

3.10 Fruit Diameter (cm)

About 62% hybrids exhibited with significant positive heterosis over better parent, whereas 76% produced significant positive heterosis over mid parent (Table 4). The highest value of positive heterotic effect was exhibited by the cross G4 (53.70%) followed by G2 (48.46%), G13 (46.54%), G7 (42.50%) and G14 (40.00%).

One-third of the hybrids produced significant negative heterosis for either mid or better parent, which suggested that the character is possibly governed by non-additive gene action. Heterosis for fruit diameter in tomato was also reported by Ahmad et al. [6], Padma et al. [23], and Sharma et al. [20].

3.11 Average Fruit Weight (g)

The entire cross combinations except G18 and G4 exhibited with negative heterosis over mid and better parent, whereas two hybrids G18 (12.09%) and G4 (12.01%) showed significant positive heterosis over mid parent (Table 4). The best hybrid was G18, which showed the highest per *se* performance with the highest heterosis (12.09%) over mid parent. Positive heterosis for fruit weight has been reported by Sharma et al. [19,20], whereas both positive and negative heterosis over better parent reported by Patwary et al. [16] and Ahmad et al. [6] in their studies. These findings of positive heterosis over mid parent and check co-relate with the findings of Kumari and Sharma [14] and Marbal et al. [26].

3.12 Total Soluble Solid (TSS)

Significant positive heterosis over mid and better parent was observed in all the F_1s confirming additive gene effect for the trait (Table 4). The highest positive heterosis was observed in cross G20 (141.67%) followed by G17 (84.76%), and G16 (80.83%). Similar range of heterosis was also noted by the previous studies [8,17,19,20,22,27]. Total soluble solid is responsible for the sweetness of tomato hereafter high TSS is a preferable character in processing tomatoes. So, these genotypes can further be advanced toward developing a processing variety.

3.13 Fruit Yield per Plant (kg)

Off 21 crosses, six produced significant different (P = 0.05 or P = 0.01) positive heterosis over better parent, whereas 15 produced significant positive heterosis over mid parent (Table 5). More than 20% heterosis over better parent was observed in five F_1s *viz*. G18 (53.77%), G20 (50.31%), G16 (39.20%), G17 (36.49%), and G5 (25.70%). The cross combinations G18 (70.00%), G16 (58.74%) and G20 (55.63%) showed higher positive heterosis over mid parent. This result suggested a potential yield increment by the heterosis, and is predicted to be the reason of high yielding parents used in the hybridization [28]. Eight genotypes exhibited with significant negative heterosis over either mid or better parent. Positive better parent heterosis ranging from 13.58 to 282.63% was reported in heat tolerant tomato [16], which was higher than this study. Bhatt et al. [8,27] observed 2.92 to 54.17% better parent heterosis for yield per plant in tomato, which is very identical to our findings. Similarly, heterobeltiosis in tomato hybrids was also reported in many studies [3,6,14,25,26,29,30]. Therefore, these genotypes may be selected as heterotic hybrids for yield and can further be advanced toward developing a high yielding variety.

3.14 Number of Locules per Fruit

Seven cross combinations out of 21 showed positive heterobeltiosis but only two was significant. Positive heterosis for this trait ranged from 1.94 to 56.66% (Table 5). On the other hand, nine cross combinations produced significant negative heterosis over better parent ranging from -18.15 to -51.38%. More than 35% negative heterosis was manifested by five F_1s namely G8 (– 51.38%), G16 (–46.03%), G18 (–46.03%), G17 (–40.02%) and G15 (–36.29%). Similarly, eight F_1s showed significant positive heterosis over mid parent and five F_1s showed significant negative heterosis over mid parent. The hybrid G20 showed no heterosis regarding locule number in fruit (Table 5). However, the estimation of negative heterobeltiosis from -4.50 to -51.39% was observed from the study, indicating the importance of non-additive gene action for the trait. As a result, heterosis breeding can be exploited very well to reduce the locule number in tomato fruits. This result supported by Duhan et al. [31], Kurian et al. [7] and Dod et al. [32] in where identified heterotic hybrids for lower locule number in tomato. On the other hand, Ahmad et al. [6] reported significant positive heterosis for this trait. From the quality point of view, less locule is desirable in tomato. This study is predicted the potential genotypes for future breeding in reducing locule as we have seen negative estimation of heterosis.

3.15 Pericarp Thickness

The highly significant different (P = 0.05 or P = 0.01) heterosis was estimated by the majority of the hybrids towards positive heterosis over mid parent, whereas 12 hybrids produced significant positive heterosis for better parent ranging from 26.67 to 109.06% (Table 5). More than 25% heterosis exhibited by the 57% hybrids, indicating possibility of the enhancement of fruit quality by improving pericarp thickness.

Table 3. Percent heterosis over mid parent (MP) and better parent (BP) for days to 1st flowering, days to 50 % flowering, days to 1st harvest, harvest duration and plant height at 1st harvest in winter tomato

Genotypes	Days to 1st flowering		Days to 50% flowering		Days to 1st harvest		Harvest duration		Plant height at 1st harvest (cm)	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
G1	-9.890**	-10.87**	14.129**	-12.10**	-9.979**	-10.38**	-6.495**	-6.77**	-1.087	-9.76*
G2	-0.090**	-9.35**	0.268**	-7.64**	-0.086**	-9.89**	-0.056**	-6.49**	0.146**	6.12
G3	-2.571**	-4.32**	30.297**	-7.64**	-4.573*	-9.02**	-2.953**	-5.92**	-0.531	-6.394
G4	-9.290**	-11.59**	39.753**	-12.10**	-8.299**	-8.98**	-5.378**	-5.84**	5.172*	-4.18
G5	-8.834**	-10.15**	21.191**	-10.97**	-10.619**	-11.92**	-4.046**	-4.96**	10.810**	7.64
G6	-8.644**	-9.30**	28.177**	-14.82**	-5.660**	-7.78**	0.888	-0.58	8.778**	3.08
G7	-5.836**	-7.19**	11.644**	-12.10**	-6.899**	-7.85**	1.441*	0.76	13.370**	-3.47
G8	-2.222**	-2.22*	2.923	-8.91**	-2.877	-5.04*	5.400**	3.87**	0.971	-2.31
G9	-3.011**	-4.44**	14.573**	-9.56**	-5.703**	-6.82**	1.561*	0.78	-1.098	-1.25
G10	-3.357**	-3.71**	6.805**	-4.45**	-5.436**	-6.40**	-3.556**	-4.20**	9.213**	-2.94
G11	-3.284**	-5.01**	13.311**	-8.65**	-3.348	-5.93**	-2.161**	-3.87**	-11.851**	-15.32**
G12	-10.216**	-11.50**	1.038	-14.01**	-7.207**	-10.18**	-4.678**	-6.68**	8.902**	-4.61
G13	-5.933**	-8.63**	18.200**	-12.10**	-7.578**	-9.59**	-4.937**	-6.30**	5.535*	-10.25**
G14	-4.769**	-6.48**	19.816**	-5.73**	-6.977**	-6.98**	-4.775**	-4.78**	22.472**	16.60**
G15	-6.817**	-7.16**	21.154**	-12.35**	-3.774*	-7.27**	-0.686	-3.06**	9.953**	-3.18
G16	-3.755**	-5.18**	11.696**	-12.10**	-2.000*	-3.05*	5.442**	4.72**	1.355	-2.09
G17	-4.093**	-4.44**	3.398	-12.73**	-2.703**	-5.82**	5.263**	3.05*	18.877**	8.87*
G18	-1.102	-2.87**	7.447*	-4.94**	0.786	0.32	5.898**	5.58**	5.484*	4.72
G19	-5.660**	-6.72**	13.927**	-13.38**	-7.284**	-9.31**	-4.745**	-6.11**	3.951	-7.74*
G20	-8.501**	-11.44**	23.821**	-16.67**	-4.324**	-5.78**	-2.185**	-3.15**	-6.762**	-10.56**
G21	-8.036**	-10.01**	11.162**	-15.43**	-6.181**	-9.59**	-3.419**	-5.73**	7.221**	-1.15
SE	0.620	0.72	0.539	0.62	2.296	2.65	2.677	3.09	2.372	2.74
CD at 5%	0.507	0.83	0.442	0.72	1.879	3.07	2.192	3.60	4.766	7.78
CD at 1%	0.675	1.10	0.588	0.96	2.503	4.09	2.919	4.82	6.347	10.36

**, ** = Significant difference at P = 0.05 and P = 0.01 respectively*

Table 4. Percent heterosis over mid parent (MP) and better parent (BP) for fruit set (%), number of fruits, fruit length, fruit diameter, average fruit weight, and TSS% in winter tomato

Genotypes	Fruit set (%)		Number of fruits per plant		Fruit length (cm)		Fruit diameter (cm)		Average fruit weight (g)		Total soluble solid (TSS %)	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
G1	17.873**	8.48**	16.130**	-0.79	14.129**	-5.10	18.182**	17.50**	-18.374**	-23.37**	43.992**	40.78**
G2	-0.209**	-22.1083**	-0.024	-14.73*	0.268**	3.47	0.493**	48.46**	-0.153**	-30.77**	0.487**	45.07**
G3	-14.062**	-22.1083**	4.847	40.47**	30.297**	6.03	0.242	-14.35**	1.402	-49.55**	60.432**	50.81**
G4	2.278	-11.3983**	14.251**	10.08	39.753**	26.91**	79.342**	53.70**	12.014**	-1.87	75.949**	41.26**
G5	-5.431**	-9.92**	45.655**	27.97**	21.191**	3.93	25.897**	25.53**	-15.462**	-26.28**	34.054**	26.02**
G6	-3.437*	-14.20**	23.217**	-3.43	28.177**	27.47**	37.422**	6.81*	-13.165**	-38.18**	89.394**	52.44**
G7	-1.727	-8.21**	-1.680	-24.83**	11.644**	9.03*	42.500**	42.50**	-14.049**	-33.07**	34.302**	34.04**
G8	18.968**	17.00**	18.833**	10.36*	2.923	0.17	-14.538**	-26.62**	-11.228**	-26.96**	51.266**	39.22**
G9	17.851**	10.29**	52.504**	26.34**	14.573**	3.83	31.680**	12.31**	-13.790**	-19.95**	74.170**	37.48**
G10	11.079**	7.12**	46.113**	41.42**	6.805**	2.91	24.397**	24.04**	-18.484**	-24.68**	58.228**	45.63**
G11	6.043**	2.04	38.380**	24.60**	13.311**	-6.19	17.764**	-8.85**	-18.163**	-39.32**	71.779**	35.92**
G12	1.652	-6.51**	30.239*	-5.34	1.038	0.69	8.434**	-6.90**	-23.550**	-48.02**	50.947**	38.69**
G13	1.689	-10.69**	58.967**	43.51**	18.200**	4.86	71.815**	46.54**	-9.009**	-32.77**	84.049**	45.07**
G14	-9.178**	-12.14**	0.562	-21.29**	19.816**	12.85**	40.405**	40.00**	-1.410	-27.41**	47.368**	35.40**
G15	-3.204*	-12.76**	-13.762	-38.61**	21.154**	-1.56	56.522**	21.15**	-1.887	-37.74**	83.599**	45.07**
G16	9.104**	3.72	63.554**	27.84***	11.696**	-1.21	0.366	-24.41**	-7.057**	-18.52**	114.227**	80.83**
G17	-2.192	-7.18**	39.286**	25.52**	3.398	-2.93	-11.594**	-24.28**	-1.117	-12.91**	84.758**	84.76**
G18	17.400**	14.82**	50.968**	45.99**	7.447*	-12.93**	-2.376	-32.00**	12.090**	-2.04	97.817**	67.44**
G19	15.743**	4.71	12.053**	-4.65	13.927**	6.88	38.009**	17.99**	-13.097**	-13.56**	103.010**	71.36**
G20	29.269**	25.57**	41.351**	7.86*	23.821**	11.88**	51.534**	34.61**	0.955	-21.08**	142.475**	141.67**
G21	5.802**	-1.68	22.581**	7.23	11.162**	-5.11	21.945**	-5.42	-6.990*	-27.01**	86.357**	57.74**
SE	5.823	6.72	2.197	2.54	0.326	0.38	0.255	0.29	3.851	4.45	0.254	0.29
CD at 5%	1.941	3.17	1.798	2.94	0.267	0.44	0.209	0.34	3.152	5.15	0.208	0.34
CD at 1%	2.586	4.22	2.394	3.91	0.356	0.58	0.278	0.45	4.198	6.86	0.277	0.45

**, ** = Significant difference at P = 0.05 and P = 0.01 respectively*

Table 5. Percent heterosis over mid parent (MP) and better parent (BP) for yield, number of locules, pericarp thickness, number of seeds and 1000-seed weight in winter tomato

Genotypes	Fruit yield per plant (kg)		Number of locules per fruit		Pericarp thickness (mm)		Number of seeds per fruit		1000-seed weight (g)	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
G1	-3.967	-13.21**	52.624**	48.04**	100.667**	89.91**	-23.822**	-29.60**	10.891**	9.375**
G2	-0.144**	-20.72**	0.254**	-4.50	0.254**	-4.75	0.066**	2.91*	0.017**	-9.907**
G3	14.286**	-5.98	0.000	-18.96**	59.627**	26.67**	-65.341**	-65.41**	13.238**	-13.932**
G4	26.923**	7.94	67.598**	56.66**	80.317**	79.18**	19.874**	-10.30**	19.284**	18.110**
G5	26.588**	25.70**	22.549**	15.47	78.650**	77.81**	-30.740**	-34.59**	7.486**	2.941**
G6	20.533**	5.61	20.950**	13.06	38.436**	34.07*	-14.287**	-23.42**	1.581**	0.000**
G7	-7.364*	-9.81*	28.088**	-4.50	37.066**	0.33	-12.614**	-16.51**	-18.480**	-26.935**
G8	7.759*	-5.66	-38.588**	-51.38**	66.221**	26.67**	-67.249**	-67.56**	-1.606**	-4.297**
G9	29.639**	1.51	5.916	1.94	105.034**	95.21**	-42.850**	-59.39**	14.902**	14.453**
G10	18.908**	6.79	26.103**	15.47	121.891**	109.06**	-37.866**	-38.93**	19.318**	15.809**
G11	18.310**	-4.91	5.916	1.94	58.621**	54.88**	-41.260**	-43.38**	-13.450**	-13.619**
G12	21.778**	9.16	3.704	-4.50	-23.130**	-27.54**	-32.397**	-34.45**	7.257**	-6.192**
G13	50.125**	19.92***	12.570*	-18.15**	18.960*	-10.00	33.333**	-2.50	2.600**	-8.359**
G14	10.390**	1.59	-8.576	-27.29**	37.849**	5.08	-27.156**	-28.82**	9.916**	1.238**
G15	9.223*	-10.36*	-12.383*	-36.29**	10.915*	-17.54	-18.898**	-25.18**	-2.414**	-12.384**
G16	58.739**	39.20**	-29.895**	-46.03**	41.149**	11.48	14.594**	-17.81**	-14.516**	-16.535**
G17	40.488**	36.49**	-30.095**	-40.52**	19.070**	-5.19	-28.994**	-29.55**	7.782**	1.838**
G18	70.000**	53.77**	-29.895**	-46.03**	9.677*	-15.00	-52.369**	-54.76**	5.812**	2.724**
G19	-2.493	-16.59**	4.439	-7.62	97.788**	95.66**	-20.550**	-42.74**	15.209**	11.397**
G20	55.627**	50.31**	0.000	0.00	86.230**	81.47**	-31.146**	-52.12**	0.587	0.000
G21	18.280**	4.27	-13.055	-23.10*	45.543**	40.31**	-57.053**	-59.51**	15.312**	12.132**
SE	0.184	4.27	0.616	0.71	0.470	0.54	1.587	1.83	0.022	0.03
CD at 5%	0.151	0.25	0.505	0.82	0.385	0.63	1.299	2.12	0.018	0.03
CD at 1%	0.201	0.33	0.672	1.10	0.512	0.84	1.730	2.83	0.024	0.04

**, ** = Significant difference at P = 0.05 and P = 0.01 respectively*

Table 6. Promising F_1 hybrids showing higher per se performance and better-parent heterosis (BPH) for yield per plant and significant BPH for other characters

Genotypes	Yield per plant (kg)	BPH (%) for yield	BPH for other characters
G18	3.06	53.77**	# of locule, # of seeds per fruit, 1000-seed weight, harvest duration, TSS
G20	2.42	50.31**	Days to 1st flowering, days to 50% flowering, days to 1st harvest, harvest duration, fruit length, fruit diameter, TSS, pericarp thickness, # of seeds per fruit, # of fruits per plant
G16	2.77	39.20**	Days to 1st flowering, days to 50% flowering, days to 1st harvest, harvest duration, fruit diameter, TSS, # of seeds per fruit, # of fruits per plant
G17	2.88	36.49**	Days to 1st flowering, days to 50% flowering, days to 1st harvest, harvest duration, plant height, fruit diameter, TSS, # of seeds per fruit, # of fruits per plant, 1000-seed weight
G5	2.67	25.70**	Days to 1st flowering, days to 50% flowering, days to 1st harvest, harvest duration, fruit diameter, TSS, # of seeds per fruit, # of fruits per plant, 1000-seed weight
G13	3.02	19.92**	Days to 1st flowering, days to 50% flowering, days to 1st harvest, harvest duration, fruit diameter, TSS, # of fruits per plant, # of locule

*** = Significant difference at P = 0.05; # refers to number*

Only a single hybrid G12 produced significant negative heterosis for both mid and better parent. The results of the study in relation to pericarp thickness were agreed by the previous studies [14,16,19,21,33,34]. Pericarp thickness usually contributes much for long storability. Positive heterosis is the indicator of additive gene action for the trait, and is predicted to increase pericarp thickness of tomato using these genotypes in a variety development program.

3.16 Number of Seeds per Fruit

Significant negative heterosis was manifested by 19 hybrids varying from -10.30 to -67.56% for both mid and better parent (Table 5). The highest negative heterotic value was achieved by the hybrid G8 (-67.56) followed by G3 (-65.41), G21 (-59.51) and G9 (-59.39) whereas the lowest negative heterosis was provided by the hybrid G4. Ahmad et al. [6] and El-Ahmadi and Stevens [24] reported higher degree of heterosis for this trait. Negative heterosis is an indication of the reduction of seeds in tomato as the consumers expect. So, these cross combinations can be further used toward developing less seeded tomato varieties.

3.17 1000-Seed Weight

The highly significant different (P = 0.05 or P = 0.01) positive heterosis was observed by 48% of the hybrids over better parent (Table 5) indicating seed quality can be improved through the hybridization. More than 10% positive heterosis was manifested by five hybrids viz. G4 (18.11%), G10 (15.81%), G9 (14.45%), G19 (11.39%), and G21 (12.13%). Nine hybrids provided significant negative heterosis ranging from -4.30 to -26.94%. This result is in accordance with the findings of Subburamu et al. [35].

4. CONCLUSION

None of the cross combinations was heterotic for all characters simultaneously. In this study, promising hybrids for yield per plant with significant over better parent in desirable direction and also revealed for other traits *viz.* days to flowering and harvesting, number of fruits per plant, fruit length, fruit diameter, pericarp thickness, number of locules per fruit, plant height, TSS, 1000-seed weight (Table 6). As a result, high heterosis for yield appears to be the consequence of heterosis of the yield attributing traits. Among the hybrids G5, G13, G16, G17, G18 and G20 were promising for yield per plant as well as for many other yield contributing traits. Therefore, these hybrids can be used to develop high yielding varieties along with other quality traits.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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