

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

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 F₁s from seven parents of winter tomato. Twenty one F₁s 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 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, quality 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.

37 Heterosis was first observed by Hedrick and Booth [4] in tomato for higher yield. Afterwards a numerous
38 studies have been done in relation to heterosis for yield, its components and quality traits [3,5,6,7,8].
39 However, the exploitation of heterosis is a quick and an effective way of selecting hybrids for high yield
40 potential, earliness and quality attributes. Unfortunately, a very few attempts in this regard has been taken
41 in the past in Bangladesh. The present study was therefore, executed to estimate the level of percent
42 better and mid parent heterosis among F₁ hybrids of tomato. This information would be useful to
43 investigate the performance and relationship of F₁ hybrids with their parents and to select suitable
44 parents and/or population for designing an effective breeding programme.

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2. MATERIALS AND METHODS

48 **2.1 Planting materials:** Seven inbred lines of tomato namely VRT001 (P1), VRT007 (P2), VRT008 (P3),
49 C11 (P4), C41 (P5), LE02 (P6) and TLB133 (P7) were used in the hybridization. A half diallel mating
50 fashion was followed in developing F₁s in winter 2009-10 (Table 1). Twenty one F₁s along with the seven
51 parents were evaluated in winter 2010-11. Parental genotype denoting VRT is virus tolerance, LE is
52 *Lycopersicon esculentum*, TLB is tolerance to late blight, and C is heat tolerance.

53 **2.2 Experimental site:** The experiment was conducted at the Vegetable Research Field of Horticulture
54 Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI) Bangladesh from October
55 2010 to March 2011. The climate of the experimental site is subtropical characterized by heavy rainfall
56 from May to September and scanty rainfall rest of the year. The soil of the experimental site was sandy
57 loam in texture and acidic in nature with a pH around 6.0. This area belongs to the "Shallow red-brown
58 terrace" soil of Madhupur tract [9]. The land was prepared and fertilized as described by Salim *et al.* [10].

59 **2.3 Seedling raising and transplanting:** Seeds were sown thinly in a raised seed bed on October 15,
60 2010. Seed bed was shaded partially with black net after sowing the seeds. Young seedlings were also
61 covered by a fine mesh white net to protect them from insect attack. 7-days old seedlings were
62 transplanted to a second seed bed at the spacing of 5 x 5 cm for hardening. Thirty days old seedlings
63 were transplanted in the main field on November 15, 2010. Light irrigation was given to each seedling
64 immediately after transplanting for their better establishment.

65 **2.4 Experimental design and plot layout:** Tomato seedlings were grown in a raised seed bed and 30-
66 days old seedlings were transplanted in the main field following randomized complete block design with
67 three replications. Each genotype with spacing of 60 cm x 40 cm represented double row having 12
68 plants per row accommodating in total 24 plants per plot. The unit plot was separated by 50 cm irrigation
69 drain, while blocks were separated by 75 cm drain. Recommended cultural practices as well as plant
70 protection measures were followed.

71 **2.5 Data collection and statistical analysis:** Data for different characters (Table 2) were recorded from
72 10 randomly selected plants of parents and F₁s. Analysis of variance (ANOVA) was performed as
73 suggested by Gomez and Gomez [11]. Heterosis was estimated using basic formula described by
74 Falconer [12]. Usually, the magnitude of heterosis depends on the accumulation of favorable dominant

75 alleles in the F₁ population. If the parental populations differ from each other for favorable dominant
 76 alleles, the magnitude of heterosis supposed to be proportionally higher. This relationship was estimated
 77 by the basic formula 1. Where; d = magnitude of dominance, y = difference between the parental
 78 population for allelic frequencies at the locus.

$$\text{Heterosis in F}_1 = \sum d y^2 \dots\dots\dots (1)$$

79
 80 For estimation of heterosis in each character the mean values of the 21 F₁'s have been compared with
 81 better parent (BP) for heterobeltiosis and with mid parent (MP) for heterosis over mid parental value.
 82 Percent heterosis was calculated by the formula 2 and 3.

$$\text{Heterosis (BP)} = \frac{(F_1 - BP)}{BP} \times 100 \dots\dots\dots (2)$$

$$\text{Heterosis (MP)} = \frac{(F_1 - MP)}{MP} \times 100 \dots\dots\dots (3)$$

84
 85 Where, F₁ = mean performance of F₁ hybrid, BP = mean performance of better parent and MP = mean
 86 performance of mid parent.

87
 88 The test of significance for heterosis was done by using standard error of the value of better parent and
 89 mid parent as suggested by Turner [13]. Mean error variance from the combined analysis of variance of
 90 parents and F₁'s were used for calculating the standard error (SE) of difference. The mean values over
 91 replications were used for the comparison. Finally, critical difference (CD) was calculated by the formula 4
 92 and 5 for heterosis over better and mid parent respectively. Note that the difference between F₁ and the
 93 parent used for the estimation of heterosis were taken into account cross wise. While the difference
 94 between F₁ and the parent was greater than CD it was considered significant and vice versa.
 95

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

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

96
 97
 98 Where, EMS = error mean square from ANOVA table, r = number of replications and t = tabulated value
 99 either at 5% or 1% level of probability.

100 3. RESULTS AND DISCUSSION

101
 102 **3.1 Analysis of variance:** Analysis of variance (ANOVA) for the genotypes *i.e.* parents and F₁s showed
 103 highly significant differences (*P* = 0.05 or *P* = 0.01) for the maximum characters studied except fruit set

104 percentage (Table 2). The estimation of percent heterosis observed in F1s over mid and better parent
105 was presented in Table 3 to Table 5.

106 **3.2 Days to 1st flowering:** All the F1s showed highly significant differences ($P = 0.05$ or $P = 0.01$)
107 heterosis for flowering time, ranging from -9.89 to -0.09% over mid parent and -11.59 to -2.22% over
108 better parent (Table 3). Out of 21 F1 combinations, the highest heterobeltiotic effect of -11.59% was
109 found in cross G4 followed by G15 (-11.50%), and G20 (-11.44). The entire cross combinations produced
110 negative heterosis indicating early flowering in hybrids when compared with their parents. Earliness
111 actually leads to the early production and early supply in the market, resulting good price for the
112 producers. Thus the heterosis for flowering time is considered to be an economic parameter for this
113 study. The negative heterosis for flowering time was also reported in earlier studies [5,6,14,15].

114 **3.3 Days to 50% flowering:** The significant differences ($P = 0.05$ or $P = 0.01$) were also observed among
115 the F1 crosses for the heterosis over mid and better parent (Table 3). Positive heterosis was shown for
116 mid parent whereas negative heterosis ranging from -4.45 to -14.82% was shown for better parent.
117 Negative heterosis showed in flowering indicating earliness by the hybrids as compared to their parents.
118 As the farmers prefer to get a high price from the early supply, therefore, negative heterosis for this trait is
119 preferable. This study is in accordance with the findings of Patwary *et al.* [16], Islam *et al.* [17] and
120 Baishya *et al.* [18], those who reported negative heterosis for this trait over better parent in their studies.

121 **3.4 Days to 1st harvest:** Out of 21 genotypes, 20 exhibited significant different ($P = 0.05$ or $P = 0.01$)
122 negative heterosis over better parent ranging from -3.05 to -11.92% whereas 18 combinations showed
123 negative heterosis over mid parent (Table 3). The results were very similar to Sharma *et al.* [19] who
124 reported heterosis ranged of -2.90 to -11.20% over better parent in tomato. More than 10% negative
125 heterosis over better parent was observed from 3 F1s viz. G5 (-11.92%), G1 (-10.38%), and G12 (-
126 10.18%), which was superior to the previous study -7.14% of heterosis over better parent, reported by
127 Sharma *et al.* [20]. Negative heterosis here is suggesting early harvest of tomato fruits. Therefore, those
128 genotypes can further be utilized to develop inbred lines toward a variety development program.

129 **3.5 Harvest duration (days):** Harvest duration showed significant negative better parent heterosis in
130 fourteen F1s whereas negative mid parent heterosis was showed in thirteen F1s (Table 3). The highest
131 significant negative heterosis over better parent was estimated from the cross combination G1 (-6.77%)
132 followed by G12 (-6.68%). On the other hand, the highest negative heterosis over mid parent was also
133 estimated from the cross G1 (-6.50%). In contrast, four crosses produced significant positive heterosis
134 over better parent viz. G18 (5.58%), G16 (4.72%), G8 (3.87%), and G17 (3.05%), which also showed
135 positive heterosis over their mid parent (Table 3). Positive heterosis suggests longer harvest period
136 whereas negative heterosis suggests shorter harvest period. Generally, longer and shorter harvest
137 duration is preferred by the homestead and commercial growers, respectively. Positive heterosis for the
138 trait was also reported by Kumari and Sharma [14] and Khan and Jindal [21]. Therefore, these genotypes
139 would be the effective combination in exploiting heterosis for the homestead and commercial growers as
140 their desire.

141 **3.6 Plant height at 1st harvest:** Significant negative heterosis for better parent was manifested by 5 F1s
142 viz. G11 (-15.32%), G20 (-10.56%), G13 (-10.25%), G1 (-9.76%) and G19 (-7.74%). Only two F1s viz.
143 G11 (-11.85%), and G20 (-6.76%) produced significant negative heterosis for their mid parent (Table 3).
144 Significant positive heterosis for better parent was also found from the crosses G14 (16.60%) and G17
145 (8.87%). This result is similar to that of Baishya et al. [18] and Padma et al. [22]. Patwary et al. [16]
146 reported both positive and negative heterosis for their study whereas Fageria et al. [23] reported only
147 positive heterosis. So, these genotypes can further be used to develop inbred lines toward developing of
148 both taller and dwarf varieties.

149 **3.7 Fruit set (%):** Seventeen out of 21 F1s produced significant different ($P = 0.05$ or $P = 0.01$) positive
150 heterosis over their better parent whereas 16 produced significant positive heterosis over their mid parent
151 (Table 4). Ten cross combinations viz. G20 (25.57%), G8 (17.00%), G18 (14.82%), G9 (10.29%), G19
152 (4.71%), G16 (3.72%) and G11 (2.04%) produced significant positive heterosis either their mid or better
153 parent indicating potential increment of fruit set. On the other hand, seven F1s performed negative
154 heterosis ranging from -1.68 to -22.11% indicating a reduction in fruit setting. Both positive and negative
155 heterosis in respect of fruit setting was reported by El-Ahmadi and Stevens [24].

156 **3.8 Number of fruits per plant:** About 50% of the F1s showed significant different ($P = 0.05$ or $P = 0.01$)
157 positive heterosis over their better parent ranging from 7.86 to 45.99% (Table 4). More than 40%
158 heterosis over their better parent was produced by four crosses viz. G3, G10, G13, G18. On the other
159 hand, about 76% of the F1s produced significant positive heterosis over their mid parent ranging from
160 12.05 to 63.55% (Table 4). This result suggested a potential increment of fruits number in the tomato
161 plant. This study showed a bit higher amount of heterosis for fruits number than the previous study by
162 Patwary et al. [16]. It could be due to the variation of the parents used in the study. Our study also had an
163 agreement with the previous research [6,18,19,20,23].

164 **3.9 Fruit length (cm):** Fourteen hybrids showed positive heterosis, of which 5 hybrids exhibited positive
165 significant heterosis over better parents (Table 4). More than 10% heterosis was estimated from four
166 crosses viz. G6, G4, G14, and G20. Only one hybrid G18 (-12.93%) produced the significant negative
167 heterosis over better parent. Since, only a genotype out of twenty one showed significant negative
168 heterosis over better parent, indicating character is mainly governed by non-additive gene effects. Islam
169 et al. [18] also reported similar results for fruit length. Significant positive heterosis has been reported by
170 Ahmad et al. [6], and Sharma et al. [20]. These findings of significant positive heterosis over mid and
171 better parent are in line with the findings of Singh et al. [5] and Kumar and Singh [25] as well.

172 **3.10 Fruit diameter (cm):** About 62% hybrids exhibited with significant positive heterosis over better
173 parent, whereas 76% produced significant positive heterosis over mid parent (Table 4). The highest value
174 of positive heterotic effect was exhibited by the cross G4 (53.70 %) followed by G2 (48.46 %), G13 (46.54
175 %), G7 (42.50 %) and G14 (40.00 %). One-third of the hybrids produced significant negative heterosis for
176 either mid or better parent, which suggested that the character is possibly governed by non-additive gene

177 action. Heterosis for fruit diameter in tomato was also reported by Ahmad *et al.* [6], Padma *et al.* [23], and
178 Sharma *et al.* [20].

179 **3.11 Average fruit weight (g):** The entire cross combinations except G18 and G4 exhibited with negative
180 heterosis over mid and better parent, whereas two hybrids G18 (12.09%) and G4 (12.01%) showed
181 significant positive heterosis over mid parent (Table 4). The best hybrid was G18, which showed the
182 highest per se performance (data were not shown) with the highest heterosis (12.09%) over mid parent.
183 Positive heterosis for fruit weight has been reported by Sharma *et al.* [19,20], whereas both positive and
184 negative heterosis over better parent reported by Patwary *et al.* [16] and Ahmad *et al.* [6] in their studies.
185 These findings of positive heterosis over mid parent and check co-relate with the findings of Kumari and
186 Sharma [14] and Marbal *et al.* [26].

187 **3.12 Total soluble solid (TSS):** Significant positive heterosis over mid and better parent was observed in
188 all the F1s confirming additive gene effect for the trait (Table 4). The highest positive heterosis was
189 observed in cross G20 (141.67%) followed by G17 (84.76%), and G16 (80.83%). Similar range of
190 heterosis was also noted by the previous studies [8,17,19,20,22,27]. Total soluble solid is responsible for
191 the sweetness of tomato hereafter high TSS is a preferable character in processing tomatoes. So, these
192 genotypes can further be advanced toward developing a processing variety.

193 **3.13 Fruit yield per plant (kg):** Off 21 crosses, six produced significant different ($P = 0.05$ or $P = 0.01$)
194 positive heterosis over better parent, whereas 15 produced significant positive heterosis over mid parent
195 (Table 5). More than 20% heterosis over better parent was observed in 5 F1s viz. G18 (53.77%), G20
196 (50.31%), G16 (39.20%), G17 (36.49%), and G5 (25.70%). The cross combinations G18 (70.00%), G16
197 (58.74%) and G20 (55.63%) showed higher positive heterosis over mid parent. This result suggested a
198 potential yield increment by the heterosis, and is predicted to be the reason of high yielding parents used
199 in the hybridization [28]. Eight genotypes exhibited with significant negative heterosis over either mid or
200 better parent. Positive better parent heterosis ranging from 13.58 to 282.63% was reported in heat
201 tolerant tomato [16], which was higher than this study. Bhatt *et al.* [8,27] observed 2.92 to 54.17% better
202 parent heterosis for yield per plant in tomato, which is very identical to our findings. Similarly,
203 heterobeltiosis in tomato hybrids was also reported in many studies [3,6,14,25,26,29,30]. Therefore,
204 these genotypes may be selected as heterotic hybrids for yield and can further be advanced toward
205 developing a high yielding variety.

206 **3.14 Number of locules per fruit:** Seven cross combinations out of 21 showed positive heterobeltiosis
207 but only two was significant. Positive heterosis for this trait ranged from 1.94 to 56.66% (Table 5). On the
208 other hand, nine cross combinations produced significant negative heterosis over better parent ranging
209 from -18.15 to -51.38%. More than 35 % negative heterosis was manifested by five F1s namely G8 (-
210 51.38 %), G16 (- 46.03 %), G18 (- 46.03 %), G17 (- 40.02 %) and G15 (- 36.29 %). Similarly, eight F1s
211 showed significant positive heterosis over mid parent and five F1s showed significant negative heterosis
212 over mid parent. The hybrid G20 showed no heterosis regarding locule number in fruit (Table 5).
213 However, the estimation of negative heterobeltiosis from -4.50 to -51.39% was observed from the study,

214 indicating the importance of non-additive gene action for the trait. As a result, heterosis breeding can be
215 exploited very well to reduce the locule number in tomato fruits. This result supported by Duhan *et al.*
216 [31], Kurian *et al.* [7] and Dod *et al.* [32] in where identified heterotic hybrids for lower locule number in
217 tomato. On the other hand, Ahmad *et al.* [6] reported significant positive heterosis for this trait. From the
218 quality point of view, less locule is desirable in tomato. This study is predicted the potential genotypes for
219 future breeding in reducing locule as we have seen negative estimation of heterosis.

220 **3.15 Pericarp thickness:** The highly significant different ($P = 0.05$ or $P = 0.01$) heterosis was estimated
221 by the majority of the hybrids towards positive heterosis over mid parent, whereas 12 hybrids produced
222 significant positive heterosis for better parent ranging from 26.67 to 109.06% (Table 5). More than 25%
223 heterosis exhibited by the 57% hybrids, indicating possibility of the enhancement of fruit quality by
224 improving pericarp thickness. Only a single hybrid G12 produced significant negative heterosis for both
225 mid and better parent. The results of the study in relation to pericarp thickness were agreed by the
226 previous studies [14,16,19,21,33,34]. Pericarp thickness usually contributes much for long storability.
227 Positive heterosis is the indicator of additive gene action for the trait, and is predicted to increase pericarp
228 thickness of tomato using these genotypes in a variety development program.

229 **3.16 Number of seeds per fruit:** Significant negative heterosis was manifested by 19 hybrids varying
230 from -10.30 to -67.56% for both mid and better parent (Table 5). The highest negative heterotic value was
231 achieved by the hybrid G8 (-67.56) followed by G3 (-65.41), G21 (-59.51) and G9 (-59.39) whereas the
232 lowest negative heterosis was provided by the hybrid G4. Ahmad *et al.* [6] and El-Ahmadi and Stevens
233 [24] reported higher degree of heterosis for this trait. Negative heterosis is an indication of the reduction
234 of seeds in tomato as the consumers expect. So, these cross combinations can be further used toward
235 developing less seeded tomato varieties.

236 **3.17 1000-seed weight:** The highly significant different ($P = 0.05$ or $P = 0.01$) positive heterosis was
237 observed by 48% of the hybrids over better parent (Table 5) indicating seed quality can be improved
238 through the hybridization. More than 10% positive heterosis was manifested by five hybrids *viz.* G4
239 (18.11%), G10 (15.81%), G9 (14.45%), G19 (11.39%), and G21 (12.13%). Nine hybrids provided
240 significant negative heterosis ranging from -4.30 to -26.94%. This result is in accordance with the findings
241 of Subburamu *et al.* [35].

242

243 4. CONCLUSION

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

250 other yield contributing traits. Therefore, these hybrids can be used to develop high yielding varieties
251 along with other quality traits.

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COMPETING INTERESTS

255 Authors have declared that there was no competing interests exist
256

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332 **Table 1 Developed F1 hybrids by a half diallel fashion**

Parent (P)	P1	P2	P3	P4	P5	P6	P7
P1 (WP10)	-	P1 × P2 (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 × P6 (G17)	P4 × P7 (G18)
P5 (TLB182)						P5 × P6 (G19)	P5 × P7 (G20)
P6 (WP02)							P6 × P7 (G21)
P7 (TLB111)							-

333 ⁴Hybrid

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336 **Table 2 ANOVA for various traits of 21 F1s and seven parents of tomato**

Characters	Mean Squares		
	Replications (df = 2)	Genotypes (df = 27)	Error (df = 54)
Days to 1 st flowering	0.94	8.47**	0.77
Days to 50% flowering	3.62	24.29**	0.58
Days to 1 st harvesting	9.33	41.37**	10.54
Harvest duration	52.27	95.44*	14.33
Plant height at 1 st 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

337 ^YDegree of freedom; *, ** = Significant difference at $P = 0.05$ and $P = 0.01$ respectively

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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 1 st flowering		Days to 50% flowering		Days to 1 st harvest		Harvest duration		Plant height at 1 st 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

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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

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

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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

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

350 Table 6 Promising **F1 hybrids** showing higher per se performance and better-parent heterosis
 351 (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 1 st flowering, days to 50% flowering, days to 1 st 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 1 st flowering, days to 50% flowering, days to 1 st harvest, harvest duration, fruit diameter, TSS, # of seeds per fruit, # of fruits per plant
G17	2.88	36.49**	Days to 1 st flowering, days to 50% flowering, days to 1 st 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 1 st flowering, days to 50% flowering, days to 1 st harvest, harvest duration, fruit diameter, TSS, # of seeds per fruit, # of fruits per plant, 1000-seed weight
G13	3.02	19.92**	Days to 1 st flowering, days to 50% flowering, days to 1 st harvest, harvest duration, fruit diameter, TSS, # of fruits per plant, # of locule

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

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