Heterosis and Combining Ability for Earliness, Yield, and Fruit Quality of Some Egyptian Melon Inbred Lines via Line × Tester Analysis

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Abstract

Six sweet melon (*Cucumis melo* var. *aegyptiacus*) inbred lines, 'Ana-3' (L_1), 'Esm-4' (L_2), 'War-4' (L_3), 'Fal-5' (L_4), 'Mas-4' (L_5) and 'Kha-4' (L_6), were utilized in line × tester top crosses with three muskmelon (*Cucumis melo* var. *reticulatus*) inbred lines '*Kur-2*' (T_1), '*Gw-4*' (T_2) and '*Hira-2*' (T_3), resulting in 18 hybrids (F_1) during the fall season (August-November) of 2008. The eighteen nested genotypes were evaluated in comparison with their respective parents during the hot summer season (June-September) of 2009, in newly reclaimed sandy soil in open fields. Growth performance at flowering stage, number of days to the first female flower ($D1^{ST}$ FF), earliness (EY), total yield (TY) and fruit quality characters were determined. Also, field tolerance to gummy stem blight (GSBT) during fruit maturity period was recorded. All genotypes (parents and hybrids) differed significantly from each other for all investigated traits. In terms of general combining ability (SCA), the three lines L_1, L_2 and L_3 and two testers T_1 and T_3 may be considered as good combining parents for simultaneous improvement of most of the yield and fruit quality traits. For both yield and fruit quality traits, the crosses $L_3 \times T_2$, $L_4 \times T_1$ and $L_5 \times T_3$ exhibited significant SCA effects for yield traits and total soluble solids (TSS %), $L_2 \times T_1$ for both yield traits and fruit shape index (FSI) and $L_2 \times T_2$ for main stem length (MSL; cm), average fruit weight (AFW; g) and flesh thickness (FTh; cm). MSL, TY, FTh, net flesh percentage and GSBT showed positive significant average heterobeltiosis, while number of branches, number of leaves, EY, AFW, TSS and FSI manifested negative significant average heterobeltiosis for several crosses.

INTRODUCTION

Cucurbits play a significant role in human nutrition, especially in tropical and sub-tropical countries where their consumption is high. Commercial melons are divided into many distinct botanical groups including *Cucumis melo* var. *aegyptiacus* (sweet melon) and *Cucumis melo* var. *reticulatus* (muskmelon) (Glala et al., 2010; Luan et al., 2010). Although Egypt has promising melon genetic resources, most of the commercially grown cultivars are produced by foreign seed companies. Moreover, some of the imported cultivars are not well adapted for local environmental conditions and consumer preferences (Abou-Hadid, 2002; Glala et al., 2010). Therefore, the development of locally adapted, competitive, high yielding genotypes with export quality may be a unique and valuable practical solution for this problem. High yield, uniform fruit shape, fruit size and excellent quality are prerequisites for the release of superior melon cultivars (Zalapa et al., 2006). A better understanding of the components of genetic variation and its effects on economic traits, led to better breeding results. The mating design (line×tester) suggested by Kempthorne (1957) has been extensively used to estimate general combining ability (GCA) and specific combining ability (SCA) variances and their effects. Also, it is used in understanding the nature of gene action involved in the expression of economically important quantitative traits. Thus, GCA and SCA estimates, which are useful in devising breeding strategies, were reported in some cucurbits (El-Shawarf and Baker, 1981). Firpo et al. (1998) and Obiadalla-Ali (2006) concluded that inbreeding and crossing methods could be a useful tool in increasing the population means for yield traits through hybrid or synthetic cultivar production. Heterosis for yield and its associated components has been reported in melon (Abdalla and Aboul-Naser, 2002; Lippert and Legg, 1972). Lippert and Legg (1972) evaluated the gene action of yield-related traits in melon, and determined that both GCA effects were significant. Dhaliwal and Tarsem (1996) reported for a line×tester design in muskmelon that mass selection (MS) due to GCA lines (except TSS%), GCA testers and SCA hybrids was highly significant for the studied earliness and fruit yield characters. Magnitude of GCA lines was greater compared to the other two components. The objectives of this study was to measure and evaluate additive and non-additive gene action, GCA, SCA, heterobeltiosis, components of genetic variance, and average percentage contribution of the lines, testers and their interactions among 18 hybrids resulting from the crossing of six lines with three testers and also to investigate the possibility of breeding new local Egyptian F_1 hybrids based on Egyptian germplasm resources and conventional breeding techniques.

MATERIALS AND METHODS

This study is built on results of many consecutive studies conducted from 1999 to 2008, which led to the selection of promising inbred lines. Based on these results, six sweet melon (*Cucumis melo* var. *aegyptiacus*) inbred lines i.e., 'Ana-3', 'Esm-4', 'War-4', 'Fal-5', 'Mas-4' and 'Kha-4' were top crossed to three testers (muskmelon (*Cucumis melo* var. *reticulatus*) inbred lines i.e., 'Kur-2', 'Gw-4' and 'Hira-2') during the fall season (August-November) of 2008. During the 2009 season, an open field experiment was carried out to evaluate 27 genotypes, consisting of 6 inbred lines, 3 testers, 18 testcrosses during the hot summer season (June-September), in newly reclaimed sandy soil. Direct seed sowing was done in complete randomized block design with three replicates and 10 plants per replicate, in 5 m long and 1.5 m wide beds, at a planting distance of 0.5 m between plants. The recommended cultivation practices for melon production during the hot summer season were applied for each cultivation area throughout the growing season according to the recommendation of the Egyptian Ministry of Agriculture.

At flowering stage, main stem length (MSL; cm), number of branches (NB) and number of leaves (LN) were recorded as indicator for plant growth vigor. Moreover, further records were taken on the date of the first female flower anthesis, the number of days to the first female flower ($D1^{ST}$ FF) were calculated as indicator for flowering earliness. The yield of the first 3 pickings (25% of total harvest) was calculated as the early yield (EY (kg/plant)). At the end of the harvesting period, the total yield (TY (kg/plant)) was calculated. In addition, five medium-sized marketable fruits were selected from each plot to determine fruit quality properties, such as total soluble solids (TSS %), average fruit weight (AFW; g), fruit length, diameter and fruit shape index (FSI), flesh thickness (FTh; cm) and net flesh percentage (NF %). The latter was obtained after excluding skin and seed cavity weight from total fruit weight. Also, the degree of field tolerance to gummy stem blight (GSBT) was recorded during the fruit maturity period.

After recording the observations for each character, the analysis of variance was carried out according to Gomez and Gomez (1984). The mean squares from line×tester design and the general combining ability (GCA) and specific combing (SCA) variances and effects were calculated according to the procedures developed by Kempthorne (1957), adopted by Singh and Choudhry (1985). Heterosis over the best parent or "heterobeltiosis" was computed for all characters measured. The statistical analysis was processed by SAS computer program.

RESULTS AND DISCUSSION

The mean squares for all studied traits are shown in Table 1. Variability among genotypes was highly significant ($P \leq 0.01$) for all the twelve characters, indicating the presence of genetic differences among the concerned genotypes. Significant differences were observed among crosses and lines, while variability among testers was significant for all characters except main stem length (MSL) and net flesh percentage (NF), indicating that the lines and testers differed significantly in their GCA. Lines×testers revealed significant differences for all characters, except number of branches (BN), number of days from sowing to female flowering ($D1^{ST}$ FF) and flesh thickness (FTh). This suggests that SCA effects were also significant for most traits. Highly significant differences were observed among parents, while parents versus crosses showed significant and highly significant differences for all characters except BN, average fruit weight (AFW) and fruit shape index (FSI). These results are in line with those reported by Dhaliwal and Tarsem (1996), Kalb and Davis (1984), and Gurav et al. (2000).

The contribution of the lines to the total variation was much greater than the contribution of the testers for all studied traits, except number of leaves (LN) and total soluble solids (TSS), indicating that most of the total GCA variance was due to the GCA variance of the lines for these characters. On the other hand, for LN and TSS, most of the total GCA variance was due to the GCA variance of the testers.

The non-additive component of genetic variance played the main role in the inheritance of all studied traits except FSI, as shown by analysis of combining abilities and analysis of genetic variance components. This was further confirmed by the GCA/SCA ratios of all the traits studied in the F_1 generation, which were below the value of one (Table 2). Lopez-Anido et al. (1998) reported the importance of non-additive gene actions for vegetative characters. The results for $D1^{ST}$ FF, AFW, FTH, TSS, FSI and TY are in agreement with those obtained by Kalb and Davis (1984), El-Mighawry (1998), Zalapa et al. (2006), and Feyzian et al. (2009) in muskmelon.

The effects of GCA of lines and testers are presented in Table 3. The lines L_2 and L_3 and the testers T_1 and T_3 showed highly significant positive GCA values for yield traits (earliness EY and total yield TY). L_6 and T_3 were found to be good general combiners for BN, T_2 for LN and L_2, L_5 and L_6 for MSL, so these lines can be regarded as good general combiners for these traits. On the other hand, the lines L_1, L_3 and L_4 and the tester T_3 showed highly significant positive GCA values for field tolerance for gummy stem blight (GSBT). Concerning fruit quality traits L_1, L_2, T_1 and T_2 were found to be a good general combiner for AFW, lines L_2, L_3 and T_1 for FSI, L_1 for NF, lines L_1, L_5 for FTh and L_3 and T_1 for TSS. These parents appear to have a relatively large number of favorable alleles for these characters.

These data suggest that the three lines 'Ana-3' (L1), 'Esm-4' (L2) and 'War-4' (L3) and two testers 'Kur-2' (T1) and 'Hira-2' (T3) can be considered as good combiner parents and may be recommended to be incorporated in any future breeding program for simultaneous improving of most of the yield and fruit quality traits. Novel combinations of beneficial alleles at multiple loci could lead to new potential for inbred improvement (Ragsdale, 2003).

Contribution of the variation due to lines, testers and line×tester crosses to the total variation is presented in Table 4. The contribution of the variation due to lines×testers (interaction SCA variance) to the total variation was greater than 50% (i.e., greater than GCA variance) for $D1^{ST}$ FF and NF%, suggesting that SCA variance was more important than GCA variance in the inheritance of these characters. For other traits, line×tester interaction variance contributed less than 50% to the total variance, suggesting that SCA variance was less important than GCA variance in the inheritance of these other characters.

The results of specific combining ability analysis are presented in Table 5. Out of the 18 crosses studied, only few exhibited significant SCA effects in the desired directions for all traits, indicating that the role of non-additive genetic (dominance and epitasis) variance was of low magnitude. The highest positive estimates of significant SCA effects were exhibited by the crosses $L_2 \times T_1$, $L_3 \times T_2$, $L_4 \times T_1$, $L_6 \times T_2$ and $L_5 \times T_3$ for the yield traits (EY and TY), also $L_1 \times T_3$ for these two traits plus LN but $L_2 \times T_2$ and $L_6 \times T_3$ for MSL. The following combinations exhibited significant SCA effects for one or more fruit quality traits: $L_6 \times T_2$ exhibited significant SCA effects for TSS, FSI and also GSBT, $L_1 \times T_2$ for NF% and GSBT, $L_2 \times T_2$ for AFW and FTH, $L_3 \times T_3$ for AFW and FSI, $L_4 \times T_2$ for FSI and

GSBT, $L_1 \times T_1$, $L_3 \times T_2$, $L_4 \times T_1$ and $L_5 \times T_3$ for TSS, $L_2 \times T_1$ for FSI and $L_2 \times T_3$ and $L_3 \times T_1$ for GSBT. None of the lines or testers showed significant estimates of SCA for $D1^{ST}$ FF. As for both yield and fruit quality traits, the crosses $L_3 \times T_2$, $L_4 \times T_1$ and $L_5 \times T_3$ exhibited significant SCA effects for yield traits (EY and TY) and TSS, $L_2 \times T_1$ for yield traits and FSI and $L_2 \times T_2$ for MSL, AFW and FTh. Lines L_1, L_2 and L_3 which were the best general combiners for most traits, also showed high SCA effects in various tester combinations. However, 'Kur-2' (T_1) which was the best general combiner, showed low SCA effects in crosses, while T_2 which was the lowest general combiner, showed high SCA effects, indicating that a parent having a good GCA effect, may not necessarily produce better hybrids. In contrast, a parent with poor GCA might produce better hybrids.

The superiority of poor×poor general combiners to others might be owing to over dominance and epitasis. The aforementioned crosses which showed significant SCA effects, involved parents with good×good, good×poor and poor×poor combining abilities suggesting the presence of additive as well as non-additive gene actions in the expression of the investigated characters. These results are in line with those reported by Kalb and Davis (1984) and Gurav et al. (2000). Such crosses are likely to generate good segregates only if the allelic genetic systems are present in a favorable combination and epistatic effects present in the crosses act in the same direction to maximize the desirable characteristics (Abo El-Zahab et al., 2008). These authors also reported that high general combiners for various traits may be included in a multiple crossing program and desirable segregates in early generations may be subjected to bi-parental mating for the accumulation of favorable genes for various traits.

Percent heterosis relative to the best parent (heterobeltiosis) was calculated (Table 6). The degree of heterobeltiosis varied from cross to cross and from character to character. Positive average heterobeltiosis ranged from 6.7, 57.8, 2.65, 0.15 and 16.96% for MSL, TY, FTh, NF and GSBT respectively. That indicates that average dominance of the alleles of these traits was very high. While negative average heterosis ranged from -1.41, -26.07, -18.64, -15.09, -13.90, -16.02 and -8.95% for BN, LN, $D1^{ST}$ FF, EY, AFW, TSS and FSI, respectively. This indicates that average dominance of the alleles of these traits was very low. Similar results for $D1^{ST}$ FF and MSL were obtained by Ahmed et al. (2003) in summer squash and for $D1^{ST}$ FF, EY, TY, and three plant growth vigor traits by Kalb and Davis (1984) in muskmelon. Out of the 18 crosses, a desirable heterosis was observed in 10 crosses for MSL, 7 for BN, 18 for D1ST FF, 7 for EY, 11 for TY, 3 for AFW, 2 for TSS, 9 for FTh, 8 for NF, 7 for FSI and 11 for GSBT. No cross was found to have desirable heterosis for LN. These crosses could therefore be considered promising for the improvement of the respective traits (aroma and flavor).

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Tables

Table 1. Mean squares from line×tester analysis for plant growth, yield and fruit quality traits.

Source	df	Plant growth vigor			No. of days to first female flower (FFFD)	Yield		Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thickness (cm) (FTh)	Net flesh (%) (FLNP)	Fruit shape (Index) (FSI)	Gummy stem blight tolerant (GSBT)
		Main stem length (cm) (MSL)	Branch no. (BN)	Leaf no. (LN)		Early (kg/plant) (EY)	Total (kg/plant) (TY)						
Genotype	26	3290.76**	5.87**	696.71**	52.51**	1.00**	31.45**	0.48**	5.23**	0.57**	32.33**	0.32**	4.72**
Parents	8	5401.30**	5.48*	1488.62**	84.76**	0.46**	12.21**	1.06**	5.09**	0.96**	61.39**	0.60**	2.70**
Crosses	17	2132.51**	6.09**	306.63**	19.68**	1.30**	33.94**	0.24**	5.43**	0.37**	14.90**	0.20**	5.38**
Par. vs. crosses	1	6096.53**	5.19	992.60**	352.60**	0.24**	143.10**	0.05	3.04*	0.81*	96.07**	0.01	9.63**
Lines (L)	5	5174.62**	7.32*	341.97**	45.00**	2.89**	67.39**	0.31**	1.73*	0.57**	15.96*	0.46**	14.69**
Testers (T)	2	20.67	11.06*	1055.69**	43.69**	1.22**	26.95**	0.49**	23.06**	0.56*	5.31	0.32**	2.18**
L×T	10	1033.82**	4.48	139.15*	2.22	0.53**	18.62**	0.15**	3.75**	0.23	16.29*	0.06*	1.36**
Error	52	162.04	2.41	70.24	8.89	0.02	0.46	0.04	0.75	0.14	6.88	0.03	0.31

*, ** Significant at 0.05 and 0.01 level of probability, respectively.

Table 2. Components of genetic variance from line x tester analysis of various character.

Component		Plant growth vigor			No. of days to first female flower (D1ST FF)	Yield		Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thick (cm) (FTh)	Net flesh (%) (NF)	Fruit shape (index) (FSI)	Gummy stem blight tolerant (GSBT)
		Main stem length (cm) (MSL)	Branch no. (BN)	Leaf no. (LN)		Early (kg/p) (EY)	Total (kg/p.) (TY)						
gca	F=0 VA	131.77	0.19	20.09	2.09	0.09	1.84	0.01	0.20	0.02	-0.17	0.02	0.48
	F=1 VA	65.88	0.10	10.04	1.05	0.05	0.92	0.01	0.10	0.01	-0.08	0.01	0.24
	F=0 D/VA	8.82	14.27	4.57	-4.25	7.23	13.17	14.20	19.89	7.06	-75.60	2.00	2.91
	F=1 D/VA	4.41	7.09	2.29	-2.12	3.57	6.58	7.20	9.89	3.75	-37.80	1.00	1.46
sca	F=0 VD	1162.4	2.75	91.88	-8.90	0.67	24.2	0.14	4.00	0.12	12.54	0.04	1.40
	F=1 VD	290.59	0.69	22.97	-2.22	0.17	6.05	0.04	1.00	0.03	3.14	0.01	0.35
gca/sca		0.23	0.14	0.44	-0.47	0.28	0.15	0.14	0.10	0.27	-0.03	1.00	0.69

Table 3. General combining ability (GCA) effects of lines and testers for various characters.

Parents	Plant growth vigor: Main stem length (cm) (MSL)	Plant growth vigor: Branch no. (BN)	Plant growth vigor: Leaf no. (LN)	No. of days to first female flower ($D1^{ST}$ FF)	Yield: Early (kg/p) (EY)	Yield: Total (kg/p) (T)	Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thick. (cm) (FTh)	Net flesh (%) (NF)	Fruit shape (index) (FSI)	Gummy stem blight tolerant (GSBT)
(L1)	-34.89**	-0.94	-10.8**	-2.65	-0.13**	0.87**	0.15*	0.20	0.34**	2.15*	-0.32**	0.75**
(L2)	18.22**	0.28	2.57	-2.43	0.49**	2.79**	0.29**	0.18	0.13	0.85	0.20**	-1.08**
(L3)	1.67	0.17	4.35	-0.43	0.83**	2.90**	-0.04	0.50*	-0.20	0.13	0.27**	0.86**
(L4)	-22.67**	-1.06*	-4.09	2.02	-0.41**	-1.81**	-0.09	-0.79**	-0.10	-0.81	-0.04	1.75**
(L5)	25.89**	0.17	3.46	2.69*	-0.09*	-0.64**	-0.08	0.01	0.16*	-0.86	0.06	-1.03**
(L6)	11.78**	1.39**	4.46	0.80	-0.69**	-4.10**	-0.22**	-0.12	-0.30**	-1.46	-0.17**	-1.25**
(T1)	-0.78	-0.83*	-2.2	-0.98	0.14**	0.89**	0.11*	1.29**	0.15	0.61	0.15**	-0.03
(T2)	1.22	0.11	8.52**	-0.81	-0.30**	-1.40**	0.08*	-0.81**	0.04	-0.43	-0.07	-0.33*
(T3)	-0.44	0.72*	-6.31**	1.80	0.16**	0.51**	-0.19**	-0.48**	-0.19*	-0.18	-0.08*	0.36**
SE: Line	4.24	0.52	2.79	1.41	0.05	0.23	0.07	0.29	0.12	0.87	0.06	0.18
: Tester	3.00	0.37	1.98	0.99	0.03	0.16	0.05	0.20	0.09	0.62	0.04	0.13

*Significant at 0.05 level of probability and ** Significant at 0.01 level of probability.

Table 4. Proportional contribution (%) of lines, testers and line×tester interaction for various characters.

Character	Plant growth vigor: Main stem length (cm) (MSL)	Plant growth vigor: Branch no. (BN)	Plant growth vigor: Leaf no. (LN)	No. of days to first female flower ($D1^{ST}$ FF)	Yield: Early (kg/p) (EY)	Yield: Total (kg/p) (TY)	Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thick. (cm) (FTh)	Net flesh (%) (NF)	Fruit shape index (FSI)	Gummy stem blight tolerant (GSBT)
Contribution of												
Lines	71.37	35.37	32.80	67.25	65.26	58.40	38.12	9.36	45.8	31.51	66.05	80.36
Testers	0.11	21.36	40.50	26.12	11.01	9.34	24.58	49.99	17.81	4.19	18.21	4.77
Lines and testers	28.52	43.26	26.69	6.63	23.73	32.26	37.3	40.65	36.4	64.3	15.74	14.87

Note: higher values indicate stronger effects.

Table 5. Specific combining ability (SCA) estimates of hybrids from line×tester analysis of various characters.

Hybrid	Plant growth vigor: Main stem length (cm) (MSL)	Plant growth vigor: Branch no. (BN)	Plant growth vigor: Leaf no. (LN)	No. of days to first female flower ($D1^{ST}FF$)	Yield: Early (kg/p) (EY)	Yield: Total (kg/p) (TY)	Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thick. (cm) (FTh)	Net flesh (%) (NF)	Fruit shape index (FSI)	Gummy stem blight tolerant (GSBT)
$L_1 \times T_1$	-10.78	1.17	-3.91	0.54	-0.23**	-0.65*	0.10	1.34**	-0.21	-2.82	0.03	-0.08
$L_1 \times T_2$	3.56	-1.11	-6.96	-0.30	-0.15	-1.65**	-0.16*	-1.12*	-0.13	3.75*	0.05	0.56*
$L_1 \times T_3$	7.22	-0.06	10.87*	-0.24	0.39**	2.30**	0.05	-0.22	0.34	-0.93	-0.08*	-0.47
$L_2 \times T_1$	5.11	-0.39	0.09	-0.35	0.42**	0.91*	0.06	0.26	-0.33	-1.81	0.21*	-0.25
$L_2 \times T_2$	30.11**	1.33	8.04	-0.19	-0.56**	-0.70	0.29*	-0.40	0.38*	1.89	-0.24*	-0.78*
$L_2 \times T_3$	-35.20**	-0.94	-8.13	0.54	0.13	-0.21	-0.35**	0.14	-0.05	-0.08	0.03	1.03**
$L_3 \times T_1$	13.33	0.72	-1.02	0.31	-0.18*	-1.95**	-0.04	-0.99*	0.04	-0.25	-0.03	0.81**
$L_3 \times T_2$	-16.67*	0.11	-5.07	0.81	0.48**	3.41**	-0.25*	0.78*	-0.15	0.03	-0.08*	-0.56*
$L_3 \times T_3$	3.33	-0.83	6.09	-1.13	-0.31**	-1.46**	0.29*	0.21	0.11	0.22	0.11*	-0.25
$L_4 \times T_1$	5.00	0.61	5.43	-1.46	0.30**	2.93**	0.13	1.23*	0.27	2.00	-0.06	-0.42
$L_4 \times T_2$	-3.33	0.33	0.04	0.70	0.11	-0.14	0.02	-0.66	0.11	-2.40	0.12*	0.56*
$L_4 \times T_3$	-1.67	-0.94	-5.46	0.76	-0.41**	-2.79**	-0.15*	-0.56	-0.39	0.40	-0.06	-0.14
$L_5 \times T_1$	-5.56	-0.61	-1.13	0.20	-0.16*	-0.56	-0.11	-1.54**	0.14	0.77	-0.02	0.03
$L_5 \times T_2$	-3.22	-0.56	4.15	-0.30	-0.22**	-2.41**	0.07	0.44	-0.15	-2.25	0.03	-0.33
$L_5 \times T_3$	8.78	1.17	-3.02	0.09	0.38**	2.98**	0.04	1.10*	0.01	1.48	-0.02	0.31
$L_6 \times T_1$	-7.11	-1.50	0.54	0.76	-0.15	-0.68	-0.15*	-0.3	0.09	2.11	-0.13	-0.08
$L_6 \times T_2$	-10.44	-0.11	-0.19	-0.74	0.33**	1.49**	0.02	0.97*	-0.06	-1.01	0.11*	0.56*
$L_6 \times T_3$	17.56*	1.61	-0.35	-0.02	-0.18*	-0.81*	0.12	-0.66	-0.03	-1.09	0.02	-0.47
SE	7.35	0.90	4.84	1.72	0.08	0.39	0.12	0.5	0.21	1.51	0.10	0.32

* Significant at 0.05 level of probability and ** Significant at 0.01 level of probability.

Table 6. Heterosis (%) relative to the best parent of each top-cross.

Crosses	Plant growth vigor			No. of days to first female flower ($D1^{ST}$ FF)	Yield		Average fruit weight (g) (AFW)	Total soluble solids (%) (TSS)	Flesh thick. (cm) (FTh)	Net flesh (%) (NF)	Fruit shape (index) (FSI)	Gummy stem blight tolerant (GSBT)
	Main stem length (cm) (MSL)	Branches no. (BN)	Leaf no. (LN)		Early (kg/p) (EY)	Total (kg/p) (TY)						
$L_1 \times T_1$	8.42	0.00	-41.78**	-14.29**	-43.18**	138.51**	-10.99**	15.51**	-11.10	-4.07	-23.97**	11.10**
$L_1 \times T_2$	20.72	-6.66**	-39.13**	-29.31**	-54.98**	12.57**	-27.76**	-34.86**	-11.97	1.99	-35.8**	22.23**
$L_1 \times T_3$	-18.21	-9.53**	-31.8**	-23.08**	26.03**	168.54**	-31.48**	-22.50**	-5.97	-2.86	-43.51**	11.1**
$L_2 \times T_1$	-9.36	-22.72**	-21.79**	-38.35**	43.79**	189.48**	-14.20**	4.62**	17.47	-0.97	1.86**	-50.02**
$L_2 \times T_2$	7.87	13.64**	-5.53	-37.59**	-34.58**	69.36**	-2.99**	-28.44**	39.97	6.60	-32.01**	-70.01**
$L_2 \times T_3$	-34.89**	-9.08**	-38.91**	-30.07**	57.47**	154.76**	-52.32**	-18.75**	15.00	4.57*	-18.74**	200.00**
$L_3 \times T_1$	116.76**	11.12**	-17.78*	-18.92**	26.19**	145.5**	57.73**	-4.62**	21.34	-0.01	39.31**	62.47**
$L_3 \times T_2$	42.79**	40.00**	-18.97**	-20.69**	97.99**	152.41**	26.27**	-14.68**	10.69	3.13	19.05**	0.00
$L_3 \times T_3$	11.04	-4.76**	-18.83**	-19.66**	48.88**	128.46**	61.33**	-15.00**	19.49	3.66	32.56**	37.50**
$L_4 \times T_1$	4.84	-27.27**	-34.19**	-8.91**	-26.13**	104.25**	-13.80**	4.62**	-2.78	1.48	-24.99**	20.01**
$L_4 \times T_2$	27.93*	-18.18**	-28.31**	-14.66**	-56.61**	-10.38**	-22.20**	-39.75**	-10.19	-2.36	-26.97**	40.02**
$L_4 \times T_3$	-15.22	-27.27**	-50.74**	-8.55**	-67.10**	-21.62**	-52.20**	-34.38**	-30.56	1.21	-36.39**	40.02**
$L_5 \times T_1$	-7.33	-15.79**	-19.11**	-9.17**	-35.2**	-1.51	-30.94**	-14.85**	3.80	0.03	-6.57**	-37.50**
$L_5 \times T_2$	-4.44	0.00	-9.09	-15.52**	-57.24**	-55.29	-20.39**	-22.32**	-7.63	-2.07	-16.29**	-40.01**
$L_5 \times T_3$	2.44	23.81**	-31.38**	-8.55**	28.87**	39.70	-40.26**	-11.25**	-9.51	2.58	-19.83**	75.02**
$L_6 \times T_1$	-16.29	-22.72**	-22.13**	-3.06	-76.13**	-55.83	-28.64**	-3.96**	12.03	-0.33	12.25**	-50.02**
$L_6 \times T_2$	-17.19	9.10**	-13.04	-21.55**	-72.97**	-57.03**	-16.73**	-18.65**	2.39**	-5.01*	13.71	0.00
$L_6 \times T_3$	0.68	40.91**	-26.78**	-13.67**	-76.69**	-61.40**	-30.65**	-29.06**	-4.84**	-4.81*	5.14	33.30**
Average	6.70	-1.41	-26.07	-18.64	-15.09	57.80	-13.90	-16.02	2.65	0.15	-8.95	16.96
LSD5%	20.79	2.54	13.69	4.87	0.24	1.11	0.32	1.42	0.62	4.28	0.28	0.90
1%	27.69	3.38	18.23	6.47	0.32	1.47	0.43	1.89	0.83	5.70	0.37	1.20

*, **Significant at 5% and 1% levels of probability, respectively.