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Manifestation of heterosis for fruit yield, quality and shelf-life in tomato (*Solanum lycopersicum* L.) hybrids incorporating *rin*, *nor* or *alc* alleles in main- and late-seasons of north Indian plains

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Abstract : Sixty F_1 hybrids of tomato developed by crossing 15 normally ripening lines with 4 mutant homozygotes were evaluated along with a standard check (TH-1) for 14 traits in two seasons to ascertain the extent of standard heterosis and to identify a few promising cross-combinations. Significant and desirable standard heterosis was observed for all the traits in both main and late- season. Not even a single hybrid exhibited significant and negative standard heterosis in any environment for total yield per plant, marketable yield per plant, average fruit weight and shelf-life index. The standard heterosis up to 165.88 and 239.13% for total yield, 174.60 and 302.16% for marketable yield, 102.28 and 195.96% for number of fruits, 101.77 and 78.24% for average fruit weight, -43.33 and -33.67% for firmness index, 50.15 and 105.99% for number of locules, 71.51 and 126.47% for pericarp thickness, 29.69 and 38.97% for alcohol insoluble solids, 30.71 and 40.15% for lycopene, 70.61 and 33.84% for dry matter, 52.63 and 38.78% for total soluble solids, 40.98 and 45.10% for titratable acidity, 17.95 and 8.04% for ascorbic acid, 77.78 and 77.78% for shelf life was observed in main and late-season, respectively. The promising cross-combinations were Castle Rock x *nor*-RM-1, IPA-3 x *nor*-RM-1, Nemadoro x *nor*-RM-1 and UC-82-B x *nor*-RM-1 in main-season and LT-44 x *alc*-IIHR-2050, LT-42 x *rin*-RM-2, Punjab Upma x *nor*-RM-1, IPA-3 x *nor*-RM-1 and LT-44 x *rin*-RM-2 in late-season.

Keywords: *alc,* heterosis, *nor, rin,* shelf life, tomato

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Introduction

Tomato is one of the most important vegetable crops cultivated all over the world for both table and processing purposes. In India, the acreage under this vegetable has increased substantially from 4.60 lakh hectare in the year 2000 to 6.20 lakh hectare in 2010 with a significant rise in productivity from 16.15 to 19.33 metric ton/ha during the corresponding period (FAO, 2012). This increase in productivity is principally due to the cultivation of F_1 hybrids which yield higher than open pollinated varieties. This is so because this self-pollinated crop has tremendous potential for heterosis and high price of hybrid seed is compensated for by the realized higher profits obtained from cultivation of F_1 hybrids (Cheema and Dhaliwal, 2005). The popularity of F_1 hybrids can be increased further if they provide enhanced post-harvest shelf life in addition to yield and flavour attributes. A few pleiotropic, single gene ripening mutants such as slow-ripening alcobaca (*alc*), ripening inhibitor (*rin*) (Robinson and Tomes, 1968), and non-ripening (*nor*) (Tigchelaar *et al.*, 1973) inhibit or greatly slow down a wide range of processes related to ripening of normal tomato fruit. The F_1 hybrids incorporating *rin*, *nor* or *alc* alleles have been reported to improve fruit shelf-life (Dhatt *et al.*, 2002), extend fruit availability period (Garg *et al.*, 2008b), develop acceptable colour (Lu *et al.*, 1994) and flavour attributes (Agar *et al.*, 1994). These hybrids have been released for commercial cultivation in many countries, *viz.*, Australia, Russia, China, Poland, Bulgaria, USA and Israel. In Australia, 'Red Centre' (HRAS 87-70 x *rin*-HRAS 81-85) and 'Juliette' (79T-1 x *rin*-795054-1) hybrids have been released (Nguyen *et al.*, 1991; Nguyen, 1994). In Russia, a high yielding *nor* hybrid, *viz.*, Vasilisa, has been released (Gavrish and Bogdanov, 1992). In China, an outstanding *nor* hybrid, *viz.*, Changling, was released (Lu *et al.*, 1994). The F_1 hybrid (S15 x *nor*) was registered as 'Rafa' in Poland. It provided high yield and good quality fruits

(Seroczynska *et al*., 1998). Mountain Crest, an F_1 hybrid (NC 84173PVP x NC 1 *rin* EC) was released as a fresh market tomato for commercial cultivation in the USA (Gardner, 2006). However, in India, this is still an underexploited area. Keeping these points in view, the present study was conducted to ascertain the magnitude and direction of standard heterosis for fruit yield, quality and shelf-life attributes in main- and late-season planting conditions and to identify the promising cross-combinations.

Materials and Methods

The present study was conducted on a loamy sand soil having low available nitrogen and organic matter, medium available phosphorus and high available potassium, of the Vegetable Research Farm, Punjab Agricultural University, Ludhiana, India, at 30°55' north latitude, 75°54' east longitude and at an altitude of 244 m above sea level. Fifteen normally ripening lines, *viz*., Castle Rock (L_1), Punjab Upma (L_2), VFN-8 (L_3), Spectrum (L_4), Nemadoro (L_5), Sausatito (L_6), UC-82-B (L_7), LT-2 (L_8), IPA-3 (L_9), LT-35 (L_{10}), LT-44 (L_{11}), 8-2-1-2-5 (L_{12}), LT-3 (L_{13}), LT-42 (L_{14}), LT-43 (L_{15}), and four ripening mutant homozygote testers, *viz*., *nor*-RM-1 (T_1), *rin*-RM-2 (T_2), *alc*-IIHR-2050 (T_3), *alc*-IIHR-2052 (T_4), were crossed in a line×tester mating design (Kempthorne, 1957) to develop 60 F_1 hybrids. The experimental material comprising 19 parental lines, 60 F_1 hybrids and one standard check hybrid, *viz*., TH-1, was evaluated in a randomized complete block design (RBD) with three replications in two environments (seasons), *i.e.*, E_1 (main-season, transplanting in second week of December) and E_2 (late-season, transplanting in second week of March). The recommended cultural and plant protection measures were adopted to raise the crop. The observations were recorded in respect of total yield (kg/plant), marketable yield (kg/plant), number of fruits per plant, average fruit weight (g), firmness index (Dhatt and Singh, 2004), number of locules, pericarp thickness (mm), alcohol insoluble solids (AIS) (mg/100 g dry matter), lycopene (mg/100 g), dry matter (%), total soluble solids (TSS) (°brix), titratable acidity (mg/100 ml), ascorbic acid (mg/100 ml juice) (AOAC, 1975), shelf life index (Garg *et al*., 2008a). The standard heterosis over the check (TH-1), a hybrid released by the Punjab Agricultural University, for cultivation in the state, was worked out and tested for significance using standard methods.

Results and Discussion

The analysis of variance revealed significant differences among all the genotypes for all the characters in both seasons. The estimates of heterosis (%) over the check hybrid (TH-1) for different traits in two environments are presented in table 1.

Yield and its contributing traits: There was no hybrid showing significantly negative standard heterosis for yield and its contributing characters (number of fruits and average fruit weight) in any environment except for number of fruits in E_1 wherein 14 hybrids recorded significant negative values (table 1). Significant and positive standard heterosis was exhibited by 9 and 12 hybrids for total yield, 8 and 11 for marketable yield, 6 and 8 for number of fruits and, 24 and 12 hybrids for average fruit weight in E_1 and E_2, respectively. The magnitude of standard heterosis varied from -48.74 (L_1 x T_3) to 165.88% (L_4 x T_1) and -40.95 (L_8 x T_4) to 239.13% (L_{11} x T_3) for total yield, -58.59 (L_1 x T_3) to 174.60% (L_5 x T_1) and -89.72 (L_8 x T_4) to 302.16% (L_{14} x T_2) for marketable yield, -66.15 (L_1 x T_3) to 102.28% (L_4 x T_1) and -61.41 (L_8 x T_4) to 195.96% (L_{13} x T_1) for number of fruits, -21.63 (L_{12} x T_2) to 101.77% (L_3 x T_3) in E_1 and -23.61 (L_{12} x T_2) to 78.24% (L_3 x T_3) for average fruit weight in E_1 and E_2, respectively. Dhatt *et al*. (2001b) found standard heterosis in the main-season to the tune of 41.73% for total yield and 174.15% for number of fruits in the cross-combination IPA-3 x *rin*-Rutger. Nguyen *et al.* (1991) reported 60% heterosis over Flora Dade in the *rin* heterozygote for marketable yield. Dhatt *et al*. (2001b) observed standard heterosis up to 70% and 41.57% respectively for average fruit weight in F_1 hybrids involving ripening mutants. Of sixty F_1 hybrids, significant and positive standard heterosis in both the environments was shown by 4 hybrids (L_4 x T_1, L_5 x T_1, L_9 x T_1 and L_{12} x T_1) for total yield, 4 hybrids (L_4 x T_1, L_5 x T_1, L_9 x T_1 and L_{13} x T_1) for number of fruits, 1 hybrid (L_5 x T_1) for marketable yield, and by 10 hybrids (L_1 x T_3, L_3 x T_3, L_3 x T_4, L_4 x T_4, L_5 x T_3, L_8 x T_3, L_{10} x T_3, L_{10} x T_4, L_{11} x T_3 and L_{13} x T_4) for average fruit weight.

Flavour and nutritional quality attributes: Flavour in tomato is contributed to by sugars, acids and volatile compounds. The cultivars having large locular portion and with high concentration of acids and sugars have better flavour than those with a small locular portion (Stevens *et al*., 1977). Here, significantly positive standard heterosis was shown by 7 and 22 hybrids for number of locules, 47 and 8 hybrids for TSS, 9 and 6 hybrids for titratable acidity in E_1 and E_2, respectively (table 1). The extent of standard heterosis varied from -39.94 to 50.15% (L_3 x T_3) and -25.09 to 105.99% (L_3 x T_3) for number of locules, –15.79 (L_4 x T_2) to 52.63% (L_6 x T_1, L_{10} x T_2) and -36.73 (L_6 x T_4) to 38.78% (L_6 x

Table 1: Estimates of standard heterosis (%) over TH-1 for fruit yield, quality and shelf life in tomato hybrids involving ripening mutants in main (E_1) and late-season (E_2) of north Indian plains

Hybrid	Total yield (kg/plant)		Marketable yield (kg/plant)		No. of fruits/plant		Average fruit weight (g)		Firmness index		No. of locules		Pericarp thickness (mm)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
$L_1 \times T_1$	81.54*	11.60	96.34*	19.73	15.38	9.09	38.37*	-16.00	-10.00*	-12.24*	20.12*	12.36*	30.70*	82.35*
$L_1 \times T_2$	-27.91	37.14	-24.75	27.36	-41.88*	-4.73	19.60	23.56	-33.33*	-28.57*	-39.94*	-25.09*	28.68*	85.29*
$L_1 \times T_3$	-48.74	95.67	-58.59	74.13	-66.15*	12.04	50.01*	54.22*	-24.44*	-23.47*	20.12*	37.45*	28.68*	66.18*
$L_1 \times T_4$	1.68	17.32	10.18	-17.58	-34.74	-14.34	45.78*	-1.96	-17.78*	-13.27*	-19.82*	19.85*	19.49*	70.59*
$L_2 \times T_1$	27.91	180.69*	28.28	46.27	11.23	102.63*	15.71	12.37	-13.33*	-14.29*	-30.03*	0.00	25.00*	51.47*
$L_2 \times T_2$	-24.84	133.07	-27.27	184.74*	-23.99	84.85	-18.75	-2.29	-27.78*	-27.55*	-39.94*	-25.09*	1.10	22.06*
$L_2 \times T_3$	-26.58	38.70	-32.32	-7.13	-31.85	11.52	1.79	14.12	-11.11*	-11.22*	10.21*	24.72*	-2.02	41.18*
$L_2 \times T_4$	-12.36	77.92	4.97	-11.28	-13.79	28.28	7.09	9.87	-28.89*	-15.31*	-19.82*	-6.37	10.29*	83.82*
$L_3 \times T_1$	59.12	120.35	51.69	40.13	17.15	46.26	24.61	4.70	0.00	18.37*	-19.82*	-2.62	18.38*	61.76*
$L_3 \times T_2$	-19.44	43.90	-34.67	-29.19	-49.00*	-5.45	51.90*	-4.72	-5.56*	6.12*	10.21*	19.85*	5.70*	44.12*
$L_3 \times T_3$	-22.17	91.77	-43.69	-25.37	-59.77*	-18.38	101.77*	78.24*	-11.11*	-10.20*	50.15*	105.99*	-8.09*	22.06*
$L_3 \times T_4$	-25.38	43.03	-37.75	-45.77	-62.91*	-21.90	71.08*	42.20*	-20.00*	-21.43*	40.24*	62.17*	-21.88*	32.35*
$L_4 \times T_1$	165.88*	216.19*	159.24*	110.12	102.28*	179.47*	16.78	-17.21	5.56*	8.16*	-19.82*	12.36*	26.65*	83.82*
$L_4 \times T_2$	7.64	60.17	10.10	-3.81	-18.59	11.11	4.85	5.56	-21.11*	-10.20*	-30.03*	-12.73*	50.18*	60.29*
$L_4 \times T_3$	9.09	132.03	13.26	143.78*	-18.55	42.63	25.83	34.01	-13.33*	-7.14*	-19.82*	21.72*	24.08*	25.00*
$L_4 \times T_4$	-4.15	106.58	5.30	66.17	-37.75	4.65	33.77*	52.84*	-26.67*	-8.16*	-19.82*	-10.11*	7.72*	52.94*
$L_5 \times T_1$	124.92*	228.57*	174.60*	200.50*	69.09*	104.04*	16.24	14.05	-22.22*	-11.22*	-30.03*	-10.11*	31.25*	61.76*
$L_5 \times T_2$	-18.14	96.28	-33.41	78.28	-22.02	60.40	10.53	-2.55	-43.33*	-21.43*	-19.82*	-12.73*	51.65*	105.88*
$L_5 \times T_3$	44.60	74.03	81.62	50.91	-22.17	-8.69	42.05*	50.78*	-27.78*	-17.35*	0.00	0.00	-20.96*	26.47*
$L_5 \times T_4$	-20.85	77.49	-7.20	85.74	-44.22*	13.94	38.70*	6.49	-30.00*	-20.41*	-39.94*	-14.61*	1.10	67.65*
$L_6 \times T_1$	59.75	181.39*	61.94	170.65*	37.36	77.78	3.23	24.54	11.11*	28.57*	-19.82*	-6.37	32.72*	66.18*
$L_6 \times T_2$	0.12	127.01	-15.00	46.43	-11.11	54.87	-3.79	44.01*	-18.89*	-13.27*	-9.91*	8.61*	34.74*	61.76*
$L_6 \times T_3$	-14.80	12.03	-24.70	-58.54	-53.76*	-29.90	74.21*	36.55	-16.67*	-8.16*	-19.82*	23.60*	-3.49	47.06*
$L_6 \times T_4$	6.03	82.94	5.56	26.04	-15.78	22.55	-0.96	15.84	-14.44*	-8.16*	-39.94*	3.00	5.70*	63.24*
$L_7 \times T_1$	116.35*	99.13	145.05*	21.89	60.54*	30.30	28.61	9.53	7.78*	11.22*	-9.91*	-8.24*	53.13*	94.41*
$L_7 \times T_2$	-17.43	37.66	-18.81	26.04	-17.61	17.17	-11.30	-0.42	-2.22	-2.04	-39.94*	-17.60*	28.68*	76.47*
$L_7 \times T_3$	41.66	71.77	55.05	-12.11	-1.14	23.23	31.44*	4.26	4.44	5.10	-9.91*	17.98*	12.32*	62.06*
$L_7 \times T_4$	-18.57	60.61	-20.28	88.23	-28.26	4.24	26.91	13.19	-25.56*	-18.37*	-30.03*	0.00	-2.02	76.47*
$L_8 \times T_1$	66.56*	45.89	78.84	-40.30	-1.37	-11.39	15.96	16.48	-20.00*	-17.35*	-30.03*	-25.09*	20.77*	85.29*
$L_8 \times T_2$	-6.96	-10.48	-20.71	-64.01	-30.37	-28.28	21.97	-23.37	-23.33*	-18.37*	-39.94*	-12.73*	56.25*	70.59*
$L_8 \times T_3$	-28.89	44.76	-39.42	-13.43	-55.40*	-30.42	49.24*	47.14*	-34.44*	-33.67*	-19.82*	0.00	10.29*	61.76*
$L_8 \times T_4$	-33.71	-40.95	-37.30	-89.72	-57.60*	-61.41	34.85*	19.72	-24.44*	-18.37*	-9.91*	1.12	28.68*	94.12*
$L_9 \times T_1$	93.70*	188.74*	106.82*	59.54	63.25*	139.39*	33.69*	-19.74	-20.00*	-8.16*	-30.03*	-21.35*	37.87*	76.47*
$L_9 \times T_2$	-24.84	21.99	-25.45	-40.30	-27.38	-9.09	-6.23	9.63	-28.89*	-24.49*	-39.94*	-17.60*	20.96*	47.65*
$L_9 \times T_3$	-9.22	119.48	-14.65	-7.13	-29.80	28.08	24.52	32.11	-12.22*	-10.20*	0.00	24.72*	8.27*	58.82*
$L_9 \times T_4$	42.94	104.76	45.51	-5.97	7.55	12.12	13.54	48.06*	11.11*	18.37*	-24.92*	12.36*	2.94	42.65*
$L_{10} \times T_1$	99.68*	44.16	134.02*	-62.35	35.81	-12.73	25.68	0.61	5.56*	12.24*	-9.91*	24.72*	0.00	41.18*
$L_{10} \times T_2$	-17.54	14.72	-22.30	-68.99	-29.80	-12.73	1.70	7.61	-24.44*	-19.39*	-24.92*	-6.37	71.51*	126.47*
$L_{10} \times T_3$	13.60	45.71	21.46	-7.63	-33.22	-29.29	45.99*	58.58*	8.89*	18.37*	0.00	12.36*	-4.04*	38.24*
$L_{10} \times T_4$	-23.11	53.33	-35.10	-63.18	-50.20*	-26.99	57.30*	38.05*	-5.56*	11.22*	-9.91*	12.36*	25.55*	76.47*
$L_{11} \times T_1$	105.85*	22.16	161.54*	-44.78	67.24*	-10.71	7.36	-2.36	5.56*	8.16*	-19.82*	-12.73*	30.88*	61.76*
$L_{11} \times T_2$	-17.57	227.19*	3.21	249.75*	-29.91	80.81	5.07	35.48	-26.67*	-22.45*	-9.91*	-4.49	43.01*	91.47*
$L_{11} \times T_3$	-13.63	239.13*	8.84	184.74*	-40.54	33.33	35.70*	73.29*	-16.67*	-10.20*	-30.03*	24.72*	31.25*	76.47*
$L_{11} \times T_4$	-16.21	111.43	2.90	166.17*	-44.73*	54.34	30.38*	1.74	-22.22*	-20.41*	-9.91*	-6.37	24.08*	82.35*
$L_{12} \times T_1$	74.17*	201.73*	124.37*	63.68	22.42	159.60*	5.70	-17.34	27.78*	30.61*	-19.82*	0.00	30.88*	58.82*
$L_{12} \times T_2$	-5.29	70.74	15.91	75.79	-2.68	81.01	-21.63	-23.61	15.56*	29.59*	-39.94*	-25.09*	15.44*	76.47*
$L_{12} \times T_3$	-21.17	52.64	-27.15	17.74	-29.74	28.48	-4.57	25.05	11.11*	17.35*	0.00	12.36*	-4.04*	32.35*
$L_{12} \times T_4$	-10.60	128.83	3.96	139.97	-17.49	56.85	-7.00	10.64	5.56*	16.33*	-24.92*	-25.09*	22.61*	72.06*
$L_{13} \times T_1$	32.29	225.19*	35.10	228.36*	46.10*	195.96*	-10.91	-11.79	-11.11*	4.08	-30.03*	-6.37	26.65*	91.18*
$L_{13} \times T_2$	-35.96	101.73	-44.22	82.42	-33.65	116.57*	-17.71	-13.97	-5.56*	-11.22*	-30.03*	-25.09*	5.70*	76.47*
$L_{13} \times T_3$	-43.20	94.81	-41.11	56.72	-58.72*	38.18	23.09	24.53	-24.44*	-9.18*	20.12*	19.85*	26.65*	51.47*
$L_{13} \times T_4$	31.16	64.50	24.04	9.45	-19.52	-18.38	45.36*	69.39*	-22.22*	-16.33*	-39.94*	-21.35*	3.13	62.06*
$L_{14} \times T_1$	54.85	199.74*	62.25	210.95*	31.23	91.72	18.26	19.75	-22.22*	-7.14*	-19.82*	0.00	34.74*	44.12*
$L_{14} \times T_2$	-18.73	222.94*	-9.62	302.16*	-31.79	103.64*	12.14	37.68	-22.22*	-13.27*	-39.94*	-15.73*	43.93*	105.88*
$L_{14} \times T_3$	0.32	131.77	4.29	150.75*	-38.60	17.17	75.84*	29.89	-11.11*	3.06	-9.91*	24.72*	-3.49	44.12*
$L_{14} \times T_4$	9.46	92.21	23.71	55.89	-33.89	26.06	70.37*	15.28	2.22	8.16*	-9.91*	1.12	28.68*	54.41*
$L_{15} \times T_1$	-2.55	-12.55	-13.06	-37.81	-30.87	-26.46	38.28*	-11.84	2.22	1.02	-39.94*	-6.37	34.74*	47.06*
$L_{15} \times T_2$	5.62	29.44	5.10	-51.08	-28.49	18.06	38.27*	-16.74	-14.44*	-11.22*	-2.40	31.09*	47.06*	57.35*
$L_{15} \times T_3$	-10.56	174.03*	-11.41	99.00	-42.50*	53.13	47.70*	31.31	38.89*	48.98*	0.00	4.87	7.17*	47.06*
$L_{15} \times T_4$	-40.06	29.44	-38.64	-34.49	-63.12*	-25.66	17.20	10.74	-11.11*	-11.22*	-19.82*	-12.73*	5.70*	42.65*
S.E.	0.797	0.282	0.606	0.146	12.48	4.09	8.90	13.49	0.022	0.027	0.11	0.11	0.11	0.09

Hybrid	AIS (g/100 g dry matter)		Lycopene (mg/100 g)		Dry matter (%)		TSS (°brix)		Titratable acidity (mg/100ml)		Ascorbic acid (mg/100 ml)		Shelf life index	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
$L_1 \times T_1$	-4.80	-9.86	-13.91*	-11.68	42.98*	3.80	13.16*	0.00	-16.39*	-17.65	-8.97	-19.64*	12.22*	10.00
$L_1 \times T_2$	-7.42*	-18.78*	-5.51*	-8.03	11.84*	30.42*	-7.89	18.37*	-11.48	45.10*	-11.54	-13.39	15.89*	11.11
$L_1 \times T_3$	-15.28*	-11.74*	4.46	11.31	21.27*	17.49*	18.42*	-8.16	31.15*	19.61	0.00	-10.71	59.22*	33.33*
$L_1 \times T_4$	-13.54*	-7.51	11.02*	31.39*	-2.19	28.52*	-2.63	-2.04	-21.31*	-11.76	10.26	-1.79	50.67*	22.22*
$L_2 \times T_1$	4.37	-36.62*	-11.81*	-21.53*	20.61*	19.96*	21.05*	18.37*	0.00	-5.88	-35.90*	-22.32*	24.11*	27.78*
$L_2 \times T_2$	13.97*	4.69	-5.77*	-14.96*	23.03*	-15.97*	13.16*	-22.45*	-31.15*	-37.25*	-20.51*	-41.07*	19.44*	61.11*
$L_2 \times T_3$	-10.48*	-22.54*	-2.10	1.82	53.51*	17.87*	10.53*	-20.41*	-26.23	-25.49*	-25.64*	-14.29	26.33*	33.33*
$L_2 \times T_4$	-0.44	9.62	-0.26	2.19	-5.70	-7.98	13.16*	-12.24*	-21.31*	0.00	17.95*	-12.80	21.00*	44.44*
$L_3 \times T_1$	-15.72*	-4.23	-6.30*	-26.28*	32.24*	8.37*	18.42*	-10.20*	31.15*	37.25*	-12.82	-25.30*	12.33*	11.11
$L_3 \times T_2$	11.14*	-4.46	-1.57	-21.17*	11.84*	12.17*	5.26	-16.33*	-26.23*	-17.65	-22.12*	-15.18	20.89*	33.33*
$L_3 \times T_3$	-18.12*	-18.78*	3.15	-15.33*	-12.28*	-17.87*	-7.89	-34.69*	9.84	25.49*	15.38*	-8.33	37.00*	38.89*
$L_3 \times T_4$	-31.00*	-27.70*	4.72	-12.04	23.46*	11.22*	5.26	-20.41*	-4.92	5.88	-3.85	-13.39	24.33*	35.56*
$L_4 \times T_1$	-9.61*	12.68*	-7.35*	1.46	-11.40*	0.38	-7.89	4.08	-4.92	5.88	-17.31*	-8.04	11.11	11.11
$L_4 \times T_2$	13.10*	18.31*	2.10	4.38	14.69*	2.66	-15.79*	-16.33*	21.31*	31.37*	-24.36*	-19.35*	23.56*	33.33*
$L_4 \times T_3$	15.72*	-24.41*	7.35*	8.39	10.53*	-0.76	31.58*	16.33*	4.92	5.88	15.38*	8.04	34.89*	48.22*
$L_4 \times T_4$	-22.71*	-13.15*	19.42*	25.91*	5.70	25.67*	18.42*	-14.29*	-4.92	-25.49*	-5.45	-26.79*	12.44*	18.44
$L_5 \times T_1$	-13.54*	8.45	-8.66*	-14.23	16.89*	1.90	31.58*	-20.41*	0.00	-31.37*	3.85	-28.57*	14.78*	16.67
$L_5 \times T_2$	16.16*	-11.74*	-6.30*	-1.09	15.57*	-14.83*	26.32*	-18.37*	-26.23*	5.88	-60.26*	-48.21*	16.67*	18.44
$L_5 \times T_3$	3.93	-34.27*	-2.89	9.85	17.32*	-0.38	10.53*	-16.33*	-11.48	-25.49*	-22.44*	-17.86	51.89*	55.56*
$L_5 \times T_4$	0.00	-25.82*	2.10	13.87	7.02	1.52	7.89	-8.16	9.84	-11.76	-9.94	-12.50	44.44*	44.44*
$L_6 \times T_1$	-13.10*	-27.70*	-17.32*	-25.18*	54.39*	-4.18	52.63*	38.78*	31.15*	25.49*	-26.60*	-4.46	18.89*	18.44
$L_6 \times T_2$	-0.87	-22.54*	-9.19*	-12.77	5.48	19.01*	28.95*	-6.12	-16.39*	-25.49*	-16.35*	-12.50	11.11	10.67
$L_6 \times T_3$	-5.24	-3.29	-2.36	0.00	6.80	-2.09	31.58*	-14.29*	40.98*	13.73	-10.26	-8.04	38.89*	27.78*
$L_6 \times T_4$	1.31	27.70*	-1.57	-6.20	7.46	-11.41*	15.79*	-36.73*	-31.15*	-25.49*	-15.38*	-31.25*	45.78*	38.89*
$L_7 \times T_1$	11.35*	-7.98	-19.42*	-27.01*	21.49*	3.61	44.74*	-2.04	14.75	-5.88	-8.65	-3.57	16.11*	11.11
$L_7 \times T_2$	15.72*	38.97*	-13.91*	-19.34*	0.66	-21.48*	18.42*	-18.37*	-21.31*	-31.37*	-14.10*	-15.18	17.44*	33.33*
$L_7 \times T_3$	-3.49	11.03*	-6.82*	2.92	23.03*	10.84*	-2.63	-2.04	-4.92	5.88	-16.03*	0.00	54.00*	55.56*
$L_7 \times T_4$	29.26*	6.57	-5.51*	-8.39	9.21*	18.25*	36.84*	-14.29*	0.00	-11.76	-5.13	-14.29	45.67*	77.78*
$L_8 \times T_1$	-18.34*	0.47	-7.35*	-7.66	21.05*	8.56*	21.05*	-16.33*	-11.48	-37.25*	-19.87*	-16.07	43.33*	11.11
$L_8 \times T_2$	-8.73*	-0.94	-5.51*	-6.93	33.33*	17.30*	26.32*	-12.24*	26.23*	-25.49*	-28.85*	-34.82*	58.33*	33.33*
$L_8 \times T_3$	13.54*	-6.10	0.52	20.07*	-3.73	31.56*	28.95*	-2.04	4.92	-17.65	-34.62*	-17.86	77.78*	41.11*
$L_8 \times T_4$	-6.11	-2.35	-0.79	8.76	19.08*	-21.67*	18.42*	-14.29*	-26.23*	-31.37*	-21.79*	-34.82*	55.56*	27.78*
$L_9 \times T_1$	-3.06	-7.04	7.35*	16.06*	6.14	10.46*	36.84*	-10.20*	9.84	-5.88	-16.67*	-21.43*	13.56*	66.67*
$L_9 \times T_2$	-48.03*	-22.54*	9.45*	27.37*	28.29*		28.95*	-4.08	4.92	0.00	-15.06*	-16.67	10.00	11.11
$L_9 \times T_3$	-8.73*	-13.62*	17.85*	31.75*	13.60*	23.95*	23.68*	-14.29*	4.92	-11.76	-9.62	-8.93	14.78*	72.22*
$L_9 \times T_4$	-15.28*	-6.10	30.71*	40.15*	8.77	-0.57	34.21*	-14.29*	14.75	-17.65	3.85	-25.00*	44.44*	33.33*
$L_{10} \times T_1$	-25.76*	-27.23*	-21.26*	-20.80*	42.54*	16.35*	34.21*	-14.29*	-11.48	-17.65	-43.91*	-19.64*	12.44*	11.11
$L_{10} \times T_2$	29.69*	2.35	-6.56*	-15.69*	-30.26*	-10.08*	52.63*	0.00	-21.31*	-17.65	-28.21*	-25.30*	10.56	10.00
$L_{10} \times T_3$	-17.90*	-17.37*	-4.72	-13.50	3.73	-2.85	-2.63	-8.16	-4.92	-5.88	-35.90*	-30.95*	61.11*	52.22*
$L_{10} \times T_4$	-35.37*	-12.21*	-2.89	-17.15*	13.38*	-24.14*	15.79*	6.12	-4.92	-5.88	-22.12*	-21.43*	20.00*	40.67*
$L_{11} \times T_1$	-36.68*	-35.21*	-13.91*	-23.36*	26.54*	17.11*	18.42*	-14.29*	9.84	-17.65	-12.82	-13.39	10.78	11.11
$L_{11} \times T_2$	-12.23*	18.78*	-10.24*	-5.11	57.02*	8.56*	13.16*	-10.20*	-31.15*	-31.37*	-14.10*	-15.18	48.67*	37.78*
$L_{11} \times T_3$	-10.48*	-12.68*	-4.72	-1.09	18.42*	9.89*	31.58*	-2.04	-26.23*	-17.65	-5.13	-5.36	69.78*	44.44*
$L_{11} \times T_4$	-17.90*	-1.17	2.36	3.28	32.68*	-3.04	31.58*	-6.12	-31.15*	-37.25*	-3.21	-19.64*	20.00*	24.44*
$L_{12} \times T_1$	-5.68	14.55*	-7.61*	-22.26*	46.49*	2.66	10.53*	-14.29*	-21.31*	-25.49*	-7.69	-41.96*	47.67*	10.89
$L_{12} \times T_2$	-12.23*	5.63	-5.25	-17.52*	26.75*	-1.90	-15.79*	-20.41*	-26.23*	-25.49*	-38.46*	-42.86*	44.44*	11.11
$L_{12} \times T_3$	-18.78*	-4.23	3.67	-15.69*	41.67*	7.22	10.53*	-34.69*	21.31*	-31.37*	-2.56	-31.25*	59.22*	20.00*
$L_{12} \times T_4$	-17.03*	24.65*	12.60*	-12.77	55.04*	-6.84	26.32*	12.24*	0.00	25.49*	5.13	-4.46	63.44*	44.44*
$L_{13} \times T_1$	-23.14*	-7.51	-8.14*	3.28	65.13*	29.28*	21.05*	-20.41*	-11.48	-25.49*	-23.08*	-10.71	17.22*	27.78*
$L_{13} \times T_2$	-18.78*	2.82	-2.62	-1.46	34.43*	-0.95	31.58*	-14.29*	-16.39*	-11.76	-28.21*	-11.61	48.11*	53.33*
$L_{13} \times T_3$	-17.03	-15.02*	9.71*	22.99*	19.74*	33.84*	13.16*	10.20*	-4.92	5.88	8.97	-22.32*	22.22*	35.56*
$L_{13} \times T_4$	-27.95*	-32.16*	6.56*	20.07*	24.34*	15.02*	0.00	-4.08	14.75	-17.65	5.13	4.17	68.56*	77.78*
$L_{14} \times T_1$	-20.52*	-13.85*	-19.16*	-7.66	32.24*	8.75*	-7.89	-2.04	4.92	-11.76	-16.67*	-29.46*	16.67*	11.11
$L_{14} \times T_2$	16.59*	10.56*	-13.39*	-5.11	18.64*	15.02*	28.95*	-8.16	36.07*	-5.88	-21.79*	-4.46	9.56	55.56*
$L_{14} \times T_3$	-12.66*	-17.84*	-8.92*	-4.38	4.39	0.38	28.95*	-16.33*	0.00	-25.49*	-17.95*	-33.04*	42.56*	55.56*
$L_{14} \times T_4$	2.18	31.69*	-4.46	-14.60	32.02*	-6.84	13.16*	-18.37*	4.92	-5.88	-3.85	-22.92*	54.22*	22.22*
$L_{15} \times T_1$	-17.90*	-19.95*	-16.01*	-12.04	34.87*	22.62*	10.53*	-8.16	4.92	-5.88	-3.85	-12.20	58.33*	33.33*
$L_{15} \times T_2$	-20.09*	5.40	-7.35*	-3.65	70.61*	18.63*	23.68*	14.29*	-31.15*	-25.49*	-21.79*	-5.36	57.11*	55.56*
$L_{15} \times T_3$	-17.03*	14.55*	-5.51*	-1.46	28.73*	-5.32	10.53*	-14.29*	-42.62*	-43.14*	-20.51*	0.00	15.56*	22.22
$L_{15} \times T_4$	-17.03*	-9.39	-5.25	-2.55	55.92*	27.95*	10.53*	18.37*	4.92	0.00	-41.03*	-28.87*	55.56*	44.44*
S.E.	1.48	2.18	0.11	0.21	0.21	0.22	0.16	0.22	0.05	0.07	2.18	3.27	0.54	0.44

* Significant at 5% level AIS = Alcohol insoluble solids, TSS = Total soluble solids

T_1) for TSS, -42.62 (L_{15} x T_3) to 40.98% (L_6 x T_3) and -43.14 (L_{15} x T_3) to 45.10% (L_1 x T_2) for titratable acidity in E_1 and E_2, respectively. In the main-season, Dhatt *et al.* (2001a) observed standard heterosis of 39.39 to 72.11% for number of locules, 0.80 to 49.50% for TSS, -48.05 to 40.93% for titratable acidity in main-season in F_1 hybrids involving *rin*, *nor* or *alc* alleles. Of sixty hybrids, significantly positive standard heterosis in both seasons was shown by 7 hybrids (L_1 x T_1, L_1 x T_3, L_2 x T_3, L_3 x T_2, L_3 x T_3, L_3 x T_4, L_{13} x T_3) for number of locules, by 7 hybrids (L_2 x T_1, L_4 x T_3, L_6 x T_1, L_{12} x T_4, L_{13} x T_3, L_{15} x T_2 and L_{15} x T_4) for TSS, by 3 hybrids (L_3 x T_1, L_4 x T_2 and L_6 x T_1) for titratable acidity.

Ascorbic acid, an antioxidant, contributes to nutritional value of tomato (Ram, 1999). Another antioxidant, lycopene ($C_{40}H_{56}$) imparts red colour to the fruit and prevents human beings from atherosclerosis, cervical cancer and breast cancer (Kaur *et al.*, 2004). Here, significant and positive standard heterosis was exhibited by 10 and 9 hybrids for lycopene, and by 3 and none for ascorbic acid in E_1 and E_2, respectively (table 1). Standard heterosis ranged from -21.26 (L_{10} x T_1) to 30.71% (L_9 x T_4) and -27.01 (L_7 x T_1) to 40.15% (L_9 x T_4) for lycopene, and -60.26 (L_5 x T_2) to 17.95% (L_2 x T_4) and -48.21 (L_5 x T_2) to 8.04% (L_4 x T_3) for ascorbic acid in E_1 and E_2, respectively. The present results are in contrast to those of Dhatt *et al.* (2001a) who have reported standard heterosis up to 109.39% for ascorbic acid in main-season in hybrids involving ripening mutants. Significant and positive standard heterosis in both seasons was shown by eight hybrids (L_1 x T_4, L_4 x T_4, L_9 x T_1, L_9 x T_2, L_9 x T_3, L_9 x T_4, L_{13} x T_3 and L_{13} x T_4) for lycopene.

High dry matter improves the quality of the processed paste products (DePascale *et al.*, 2001). Alcohol insoluble solids (AIS) increase the viscosity of juice and consistency of the finished (processed) product (Stevens and Paulson, 1976). Significant and positive standard heterosis was shown by 44 and 29 hybrids for dry matter, by 11 and 11 hybrids for AIS in E_1 and E_2, respectively (table 1). The standard heterosis exhibited a range of -30.26 (L_{10} x T_2) to 70.61% (L_{15} x T_2) and -24.14 (L_{10} x T_4) to 33.84% (L_{13} x T_3) for dry matter, -48.03 (L_9 x T_2) to 29.69% (L_{10} x T_2) and -36.62 (L_2 x T_1) to 38.97% (L_7 x T_2) for AIS in E_1 and E_2, respectively. Dhatt *et al.* (2001a) had found standard heterosis of -9.39 to 42.53% in main-season for dry matter in hybrids involving *rin*, *nor* or *alc* alleles. Significantly positive standard heterosis in both seasons was shown by 25 hybrids for dry matter and by 3 three hybrids (L_4 x T_2, L_7 x T_2 and L_{14} x T_2) for AIS.

Shipping attributes: The cultivars having firm fruits, thick pericarp and extended shelf-life are desired for long distance transportation. In the present study, as firmness was measured as deformation of pericarp, negative values of heterosis were considered desirable. There was no hybrid showing significantly negative standard heterosis in any environment for shelf-life index (table 1). Significant and desirable standard heterosis was exhibited by 46 and 60 hybrids for pericarp thickness and by 42 and 39 hybrids for firmness index in E_1 and E_2, respectively. The magnitude of standard heterosis varied from 9.56 (L_{14} x T_2) to 77.78% (L_8 x T_3) and 10.00 (L_1 x T_1, L_{10} x T_2) to 77.78% (L_7 x T_4, L_{13} x T_4) for shelf life, -21.88 (L_3 x T_4) to 71.51% (L_{10} x T_2) and 22.06 (L_2 x T_2) to 126.47% (L_{10} x T_2) for pericarp thickness, and -43.33 (L_5 x T_2) to 38.89% (L_{15} x T_3) and -33.67 (L_8 x T_3) to 48.98% (L_{15} x T_3) for firmness index in E_1 and E_2, respectively. Significant and desirable standard heterosis in both seasons was exhibited by 40 hybrids for shelf life index, 46 for pericarp thickness and by 39 hybrids for firmness index. Dhatt *et al.* (2003) have reported standard heterosis up to 33.87% for shelf life at room temperature in F_1 hybrids involving ripening mutants. Standard heterosis ranging from -38.70 to 43.23% for pericarp thickness and -13.39 to 229.46% for firmness index in main-season in F_1 hybrids involving ripening mutants has also been reported earlier by Dhatt *et al.* (2001b). The F_1 hybrids involving ripening mutants contribute towards firmness due to a slower rate of fruit softening (Faria *et al.*, 2003).

Further perusal of table 1 shows that in main-season, significant and desirable standard heterosis was exhibited for a maximum of 9 traits (including total yield) by only 2 hybrids, *viz.*, L_1 x T_1 and L_9 x T_1 and for 8 traits by 2 cross-combinations, *viz.*, L_5 x T_1 and L_7 x T_1. In late-season, significant and desirable standard heterosis was exhibited for a maximum of 8 characters (including total yield) by only 2 hybrids, *viz.*, L_{11} x T_3 and L_{14} x T_2 and for 7 characters by 3 cross-combinations, *viz.*, L_2 x T_1, L_9 x T_1 and L_{11} x T_2. Therefore, it is recommended to further evaluate these promising hybrids in respective seasons to identify superior and stable hybrids for commercial release to increase the profit of tomato growers.

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