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Heterosis, dominance estimate and genetic control of yield and post harvest quality traits of tomato

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Abstract: Paucity of research on the development of tomato hybrid having desirable post harvest/or processing quality in the tropics compel to undertake this study. Therefore, the present investigation was undertaken to identify potential donors and crosses, to study the extent of heterosis and dominance behaviour, and to ascertain the genetic control of fifteen yield components and post harvest quality traits through line x tester mating design in tomato. Non-additive gene action controlled all characters studied, suggesting heterosis breeding for their improvement. Among parental lines, CLN2777-G' and 'FEB-2' were the best general combiners for yield and processing traits and could be utilized further in tomato breeding programme. Crosses ('CLN2768-A x A.C.AFT' and 'CLN2777-G x FEB-2') showing high specific combining ability and yield involved parents showing high general combining ability for fruit yield per plant and other horticultural traits. All 9 F_1 hybrids had significantly higher number of fruits per cluster and number of fruits per cluster over both mid-and better-parental values, while for the other traits, hybrids expressed average heterosis in both directions. The maximum extent of heterobeltiosis (53.56%) was found in lycopene content of fruit followed by number of fruits per cluster (32.59%) and fruit yield per plant (31.77%). The performances of the hybrids illustrated the presence of various degrees of dominance effects i.e., partial to over dominance /or no dominance. We could able to improve processing quality in spite of yield in the cross ('CLN2777-G x FEB-2') which can substantially make a dent for processing industry in the tropics.

Keywords: Combining ability, Dominance estimate, Gene action, Heterosis, Tomato

INTRODUCTION

Quality in vegetable crops, in contrast to field crops, is often more important than yield. In other words, good quality exists when the product complies with the requirements specified by the client. Breeding for post harvest traits, mainly transport quality, shelf life and cosmetic problems, is of increasing importance in vegetables and tomatoes are no exception. Quality of tomato depends on cultivar, growing condition and ripening on and off the vine. The physico-chemical characteristics of tomato also affect the quality of processed products (Chakraborty *et al.*, 2007). Nearly 80% of the fresh tomatoes are processed into various value added products in most of the advanced countries. However, very negligible amount (2.2 %) of the total produce in India is processed and the rest is marketed as fresh vegetables or subjected to huge post harvest losses (Anonymous, 2009). In our previous study, most of the public and private bred hybrids in India did not comply with good processing traits (Chattopadhyay *et al.*, 2013). High yield having good processing traits are of natural choice by the growers as well as the processors who often confronted with the problem of limited supply of processing tomatoes. Therefore, genetic enhancement of shelf life *vis-à-vis* processing quality of the crop seems to be the best option for the breeders.

Heterosis breeding provides an opportunity for achieving unique improvement in yield, quality and other desirable attributes in one generation that would more time taking and difficult with other conventional breeding methods. When genetically unlike parents are used, the yield of the hybrid will be, with fewer exceptions, substantially greater than those of the better-parent. The increased yield of hybrids could also be as a result of high yielding parents selected for hybridization. The combining ability analysis is a prerequisite in any sound breeding programme

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providing necessary information of choice of parents, and describing the nature and magnitude of gene action involved in the expression of desirable traits. Tomato has a degree of possible improvement through heterosis breeding which can further be utilized for development of desirable recombinants (Chattopadhyay *et al.,* 2011). Line x tester crossing is a useful tool for preliminary evaluation of genetic stock for use in hybridization programme with a view to identify good combiners. The need to develop tomato hybrids that will replace the existing public and private sector hybrids that are either not adaptable or poor in quality attributes particularly in major tomato growing parts of eastern India motivated this study. Thus, the present study aimed to determine the extent of heterosis, to estimate the dominance behaviour and to investigate the genetic control of the quantitative traits controlling fruit yield and post harvest quality in tomato.

MATERIALS AND METHODS

Plant material: The present investigation was undertaken during the autumn winter season of two consecutive years (2011-2012 and 2012-2013) at the research field of All India Coordinated Research Project on Vegetable Crops, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India. The experiment site is located at 22°56' N, 88°32' E, 9.75 m. a.s.l.

Development of F_1 hybrids and their field growing: Three tomato leaf curl virus (ToLCV) tolerant lines viz., CLN2777-G, CLN2764-A, and CLN2768-A collected from AVRDC, Taiwan and three testers FEB -2, A.C.AFT and BCT-115 (DG) obtained from Institute of Genetics, Bulgarian Academy of Science, Sofia, Bulgaria were used for the present study. Seedlings were raised under low cost poly house covered with 200 µm UV-stabilized polyethylene film to protect seedlings from rain and direct sunlight. Twenty-five days old seedlings were transplanted to the main field during the 3rd week of September, 2011. Lines and testers were planted separately in 4 rows spaced 60 × 45 cm apart in plots. Management practices for cultivation were followed as per Chattopadhyay *et al.* (2007).

During full boom, emasculation (afternoon hours) and pollination (morning hours) were carried out as per the methods described by Shende *et al.* (2012). Hybrid seeds were extracted by the fermentation method, dried and stored in desiccators for sowing in the next season. Again the seeds of six parents and nine hybrids were sown in the seed bed as described earlier in the 4th week of August, 2012. Twenty-five days old seedlings of 6 parental lines and 9 hybrids were transplanted in the 3rd week of September, 2012. The parents and hybrids were arranged in a randomized complete block design with 3 replications at 60 × 60 cm spacing in a 3.6 m × 3.6 m plot. Plant protection measures against whitefly (*Bemisia tabaci* Genn.) and leaf diseases were taken up as and when required to avoid the spread of ToLCV and blight diseases.

Observations recorded: The data were recorded for fifteen quantitative traits on days to 50% flowering (D50F); number of flower clusters per plant (NFCPP); number of fruits per cluster (NFPC); plant height (PH, cm); polar diameter (PD, cm); equatorial diameter (ED, cm); number of fruits per plant (NFPP); fruit weight (FW, g); pericarp thickness (PT, mm); locules number (LN), and fruit yield per plant (FYPP, kg plant $^{-1}$) from 10 competitive plants selected per replication. The nutritional constituents of fruit like total soluble solids (TSS, ^{0} brix) by digital hand refractometer, titratable acidity (TA, % anhydrous citric acid) by Sadasivam and Manickam (1996), ascorbic acid (AA, mg/100g fresh pulp) by AOAC (1990), and lycopene (LYP, mg/100g fresh pulp) by Davies (1976) have been estimated from the composite samples of ten fruits each of parents and hybrid per replication.

Statistical analysis: The data were analyzed with 3 × 3, line × tester model of genetic analysis (Kempthrone, 1957). Heterosis over the mid-parent (Relative heterosis) and better-parent (Heterobeltiosis) was determined according to Hayes *et al.* (1965). The dominance estimates (D.E.) were computed using "potence ratio" method as per Smith (1952).

D.E. = F_1-MP/ 0.5 x P_2-P_1,

Where, F_1 = mean value of the hybrid population; MP= Mid-parent; P_2= Mean of the highest parent; P_1= Mean of the lowest parent

Complete dominance was realized when D.E. = +1; while partial dominance is indicated when D.E. is between −1 and +1; D.E. = zero indicates absence of dominance. Over dominance was considered when D.E. exceeds ±1. The '+' and '–'signs indicate the direction of dominance of either parent. Combining ability variances and effects were worked out according to Griffing (1956). Statistical analyses were done using SPSS Professional Statistics version 7.5 (SPSS Inc., Chicago, Ill.).

RESULTS AND DISCUSSION

Analysis of variance for combining ability: The combining ability is the main criteria of rapid genetic assaying of the test genotypes under line x tester analysis. The variations among lines in respect of their general combining ability were significant for four characters, whereas variances among testers were significant for seven characters. However, the variances due to line x tester interaction were significant for all the characters studied indicating a predominance of non-additive gene action in the genetic control of all these characters (Table 1).

Genetic control for different characters: Additive variance (s^2D) and dominance variance (s^2H) were calculated at inbreeding coefficient, F=l (tomato being self pollinated crop) from gca and sca variances. A general trend of the genetic control of the characters

Table 1. Analysis of variance for combining ability.

Source of variation (d.f.)	Mean sum of square for parents and hybrids for the character														
	D50F	**NFCPP**	**NFPC**	**PH**	**PD**	**ED**	**NFPP**	**FW**	**PT**	**LN**	**TSS**	**TA**	**AA**	**LYP**	**FYPP**
Replication (2)	12.6889**	0.0060^{NS}	0.0038^{NS}	53.32**	0.6565*	0.0528^{NS}	0.0626^{NS}	0.2940*	0.0265^{NS}	0.4201^{NS}	0.0329^{NS}	0.0000^{NS}	0.9941*	0.0002^{NS}	0.0000^{NS}
Lines (2)	30.0370^{NS}	3.9263^{NS}	0.1053^{NS}	818.08**	0.2654^{NS}	0.5836^{NS}	1.8526^{NS}	223.9004**	0.9692^{NS}	1.0040^{NS}	1.0726*	0.0037^{NS}	96.9776**	2.4270^{NS}	0.3172^{NS}
Testers (2)	24.9259^{NS}	12.0207**	0.3218*	12.78^{NS}	0.3170^{NS}	0.6509^{NS}	212.498**	42.2538^{NS}	1.6192^{NS}	0.0785^{NS}	1.1826*	0.0156**	26.6336*	1.2222^{NS}	0.6108*
Line vs. Tester (4)	16.0370**	1.8419**	0.0943**	22.10**	0.1803**	0.6225**	24.377**	23.8690**	0.6699**	0.5968**	0.3054**	0.0022**	6.6543**	0.9942**	0.1497**
Error (28)	2.3079	0.0475	0.0039	4.4441	0.020	0.0164	0.4604	0.0766	0.0388	0.1383	0.0250	0.0002	0.2362	0.0004	0.0017

D50F: Days to 50% flowering, NFCPP: Number of flower clusters per plant, NFPC: Number of fruits per cluster, PH: Plant height; (cm), PD: Polar diameter (cm), ED: Equatorial diameter (cm), NFPP: Number of fruits per plant, FW: Fruit weight (g), PT: Pericarp thickness (mm), LN: Locules number, TSS: Total soluble solids (^{0} brix), TA: Titratable Acidity (% anhydrous citric acid), AA: Ascorbic acid (mg 100 g^{-1} fresh pulp), LYP: Lycopene (mg 100 g^{-1} fresh pulp), FYPP: Fruit yield per plant (kg plant^{-1}); ^{NS}Non significant at the 0.05 level, ** **significant ($p < 0.001$) probability level; * **significant ($p < 0.005$) probability level

Table 2. Estimates of component of variance for fifteen quantitative traits.

Component of genetic variance	D50F[a]	NFCPP	NFPC	PH	PD	ED	NFPP	FW	PT	LN	TSS	TA	AA	LYP	FYPP
α^2 GCA	0.3179	0.1703	0.0033	10.9258	0.0031	-0.0001	2.2999	3.0336	0.0173	-0.0015	0.0228	0.0002	1.5320	0.0231	0.0087
α^2 D (2 x α^2 GCA)	0.6358	0.3406	0.0066	21.8516	0.0062	-0.0002	4.5998	6.0672	0.0346	-0.0030	0.0456	0.0004	3.0640	0.0462	0.0174
α^2 H (α^2 SCA)	6.4838	1.6201	0.0500	71.4400	0.0726	0.2012	21.7720	26.1322	0.3144	0.1436	0.2305	0.0019	11.3312	0.4697	0.1017
α^2 H + α^2 D	7.120	1.961	0.057	93.292	0.079	0.201	26.372	32.199	0.349	0.1406	0.276	0.002	14.395	0.516	0.119
Predictability Ratio α^2 D/ (α^2 H + α^2 D)	0.089	0.174	0.117	0.234	0.079	-0.001	0.174	0.188	0.099	-0.021	0.165	0.174	0.213	0.090	0.146

D50F: Days to 50% flowering, NFCPP: Number of flower clusters per plant, NFPC: Number of fruits per cluster, PH: Plant height (cm), PD: Polar diameter (cm), ED: Equatorial diameter (cm), NFPP: Number of fruits per plant, FW: Fruit weight (g), PT: Pericarp thickness (mm), LN: Locules number, TSS: Total soluble solids (^{0} brix), TA: Titratable Acidity (% anhydrous citric acid), AA: Ascorbic acid (mg 100 g^{-1} fresh pulp), LYP: Lycopene (mg 100 g^{-1} fresh pulp), FYPP: Fruit yield per plant (kg plant^{-1}).

can be ascertained from the estimates of additive and non-additive variance components. The relative importance of the additive and non-additive genetic effects for these characters can also be reflected by the predictability ratio i.e. additive genetic variance expressed as proportion of total genetic variance. The variance of gca includes additive and additive × additive portions, whereas sca includes non-additive genetic portion. The variances due to sca were much higher than sca variances and also showed wide range of variation for all the characters studied (Table 2). The predictability ratio for all the characters was found to be < 0.50, also an indicative of non-additive genetic controls of these characters, the use of selection will bring slow or no genetic improvement.

Identification of good general and specific combiners: No single line or tester was found to be a good general combiner for all the characters studied. However, the line '2777G' was considered as a good general combiner, as it exhibited significant gca effects in desired direction for plant height, days to 50% flowering, number of fruits per cluster, fruit weight, locules number, pericarp thickness, total soluble solids, titratable acidity, lycopene and fruit yield per plant. Among the testers, 'FEB-2' showed significant gca effects for eight characters namely, number of flower clusters per plant, number of fruits per cluster, number of fruits per plant, fruit weight, pericarp thickness, fruit acidity, lycopene and fruit yield per plant (Table 3). Therefore, two parents 'CLN2777-G' and 'FEB-2' can be picked up as potential donors for fruit yield per plant and other horticultural traits.

Similarly, no single cross was found to be a good specific combiner for all the characters studied. Nevertheless, the cross 'CLN2777-G x BCT-115 (DG)' was having high sca effects for yield per plant along with nine other traits, the next best cross 'CLN2764-A x FEB-2 showed good sca effects for eight characters including yield per plant and the third best cross 'CLN2768-A x BCT-115 (DG)' exhibited better sca effects for seven characters in desired direction. The cross 'CLN2777-G x FEB-2' also showed positive significant sca effects for fruit yield per plant and number of fruits per cluster, fruit weight, total soluble solids in the desired direction. Among these four crosses, the *per se* performance of the hybrid 'CLN2777-G x FEB-2' was the highest for fruit yield per plant. There was a reasonable ground to suggest that the heterotic expression for fruit yield per plant in cross combination 'CLN2777-G x FEB-2' was due to additive and additive x additive type of gene effects as the cross combination involved parents with high gca effects. Therefore, four crosses 'CLN2777-G x BCT-115', 'CLN2764-A x FEB-2', 'CLN2768-A x BCT-115 (DG)' and 'CLN2777-G x FEB-2' could be identified as potential specific combiners for their significant sca effects in desired direction for fruit yield per plant along with desirable horticultural traits.

In general, the crosses involving both parents with high (H) gca effects or having H (female) and L (male parent) gca values produced hybrids with overall high heterotic status. On the other hands, hybrids involving L x H gca status had overall low heterotic status except days to 50% flowering (Table 3).

Heterosis and potence ratio estimations of the F_1 hybrids: The estimates of heterosis expressed in percentage of increase or decrease of hybrids over mid -parental and better-parental values, and dominance estimates for fifteen characters have been described in table 4. Selection of hybrid showing negative heterosis over their better-parents for days to 50 % flowering may be useful for developing early commercial hybrids. The maximum negative heterobeltiosis for this character was observed in 'CLN2764-A x A.C.AFT' (-13.51%) followed by 'CLN2768-A x A.C.AFT' (-10.81%). For number of flower clusters per plant, the cross 'CLN2768-A x A.C.AFT' produced the maximum number of flower clusters with the highest positive heterosis of 22.37% and 8.25% over mid- and better-parent, respectively. All the nine hybrids expressed positive heterosis over both parents for number of fruits per cluster with the maximum hybrid vigour of 32.59% by the hybrid 'CLN2777-G x FEB-2'. None of the hybrids exhibited positive and significant heterobeltiosis for plant height and polar diameter of fruit, however two crosses for plant height and one cross for polar diameter of fruit expressed heterosis over mid parent. Positive heterosis over mid-parent for equatorial diameter was shown by three hybrids and one hybrid 'CLN2768-A x BCT-115 (DG)' exhibited 1.86% heterobeltiosis. All the nine hybrids revealed positive and significant heterosis over both mid-parent and better-parent for number of fruits per plant. The hybrid 'CLN2768-A x A.C.AFT' showed the highest positive heterosis of 53.37% and 38.90% over mid- and better-parent, respectively for this yield contributing character. No single hybrid expressed significant positive heterosis over both mid- and better-parent for average fruit weight. For pericarp thickness, significantly positive heterosis over mid-parent was shown by three crosses and over better -parent by two hybrids. The maximum heterosis over both mid-parent and better-parent was observed in 'CLN2777-G x FEB-2' with 40.47% and 26.00% heterosis, respectively. For locules number heterosis in negative direction is desirable and eight crosses showed significant negative heterosis over both mid-parent and better-parent, the maximum being in 'CLN 2777-G x A.C.AFT' (-26.14% over M.P. and -27.25% over B.P.). Only three crosses revealed positive and significant heterosis over both mid-parent and better-parent for total soluble solids content of fruit. The maximum significant positive heterosis over both mid-and better-parent exhibited by 'CLN2777-G x A.C.AFT' (19.23% and 13.14%, respectively). Positive and significant heterosis over mid-parent was

Table 3. Selected crosses with high heterobeltiosis, gca and sca effects and type of combinations.

Characters	Crosses with high heterobeltiosis in desired direction	Parents with gca effects	Crosses having sca effects with *per se* performance	Type of combinations
Days to 50% flowering	CLN2764-A x A.C.AFT (-13.513**)	CLN2764-A (1.3704*), A.C.AFT (-1.8519**), CLN2768-A (0.7037NS)	-1.704^{NS} (32.00)	L x H
	CLN2768-A x A.C.AFT (-10.810**)		-0.037^{NS} (33.00)	L x H
Number of flower clusters per plant	CLN2768-A x A.C.AFT (8.256**)	CLN2768-A (0.7581**), A.C.AFT (1.0604**)	0.611** (15.21)	H x H
Number of fruits per cluster	CLN2777-G x FEB-2 (32.586**)	CLN2777-G (0.0804**), FEB-2 (0.2026**), CLN2764-A (0.0426*)	0.096* (3.35)	H x H
	CLN2764-A x FEB-2 (29.067**)		0.011^{NS} (3.23)	H x H
Equatorial diameter (cm)	CLN2768-A x BCT-115 (DG) (1.864**)	CLN2768-A (0.0448NS), BCT-115 (DG) (0.3015**)	0.202* (5.83)	H x H
Number of fruits per plant	CLN2768-A x A.C.AFT (38.908**)	CLN2768-A (0.4967*), A.C.AFT (2.5711**), BCT-115 (DG) (-5.6044**)	0.513^{NS} (41.55)	H x H
	CLN2768-A x BCT-115 (DG) (33.226**)		1.549** (34.42)	H x L
Pericarp thickness (mm)	CLN2777-G x FEB-2 (26.000**)	CLN2777-G (0.3370**), FEB-2 (0.4815**)	0.285^{NS} (6.30)	H x H
Locules number	CLN2777-G × A.C.AFT (-27.248**)	CLN2777-G (-0.3456*), A.C.AFT (-0.0867NS), FEB-2 (0.0989NS)	-0.136^{NS} (2.67)	H x L
	CLN2777-G x FEB-2 (-18.256**)		0.012^{NS} (3.00)	H x L
Total soluble solids (0brix)	CLN2777-G × A.C.AFT (13.139**)	CLN2777-G (0.3852**), A.C.AFT (0.3963**)	0.059^{NS} (5.17)	H x H
Titratable Acidity (% anhydrous citric acid)	CLN2777-G x FEB-2 (17.021**)	CLN2777-G (0.0133**), FEB-2 (0.0467**), CLN2768-A (0.0100*), A.C.AFT (-0.0133**)	0.017^{NS} (0.55)	H x H
	CLN2768-A x FEB-2 (12.766**)		-0.000^{NS} (0.53)	H x H
	CLN2768-A x A.C.AFT (10.526**)		0.020** (0.49)	H x L
Ascorbic acid (mg 100 g -1 fresh pulp)	CLN2764-A x A.C.AFT (21.999**)	CLN2764-A (3.1693**), A.C.AFT (1.8504**), CLN2777-G (0.2159NS)	0.299^{NS} (25.10)	H x H
	CLN2777-G × A.C.AFT (10.335**)		0.852** (22.70)	H x H
Lycopene content (mg 100 g-1 fresh pulp)	CLN2777-G × BCT-115 (DG) (53.563**)	CLN2777-G (0.5979**), BCT-115 (DG) (0.2860**)	0.286** (5.54)	H x H
Fruit yield per plant (kg plant-1)	CLN2777-G x FEB-2 (23.759**)	CLN2768-A (0.0607**), A.C.AFT (0.0671**), CLN2777-G (0.1499**), FEB-2 (0.2204**), BCT-115 (DG) (-0.2875**)	0.090** (2.87)	H x H
	CLN2768-A x A.C.AFT (31.772**)		0.157** (2.69)	H x H
	CLN2777-G × BCT-115 (DG) (19.398**)		0.113** (2.38)	H x L

gca: general combining ability, sca: specific combining ability; ^{NS}Non significant at the 0.05 level, ** **significant ($p < 0.001$) probability level; , * **significant ($p < 0.005$) probability level

Table 4. Dominance estimates (D.E.) of fifteen quantitative traits in tomato.

Hybrids	D50F	NFCPP	NFPC	PH	PD	ED	NFPP	FW	PT	LN	TSS	TA	AA	LYP	FYPP
CLN2777-G x FEB-2	-0.33	0.23	42.00	-0.73	-1.59	-1.25	2.85	0.00	3.52	-13.18	-0.13	17.00	-0.94	1.12	3.62
CLN2777-G × A.C.AFT	-1.00	0.58	3.05	-0.21	-0.79	-0.19	5.39	-3.28	0.34	-17.18	3.55	-1.00	2.08	0.88	6.43
CLN2777-G × BCT-115 (DG)	-1.29	-0.03	1.94	0.32	0.44	0.70	160.80	-2.50	-0.17	-4.39	-3.20	1.67	-0.43	22.44	8.60
CLN2764-A x FEB-2	-1.00	1.04	147.00	-0.48	-0.54	0.75	3.67	-4.61	9.00	-3.73	-3.96	1.40	0.45	0.75	2.33
CLN2764-A x A.C.AFT	0.00	0.54	4.46	0.02	-1.03	-5.35	6.56	-4.30	0.00	-2.64	1.15	2.00	3.58	-0.33	7.75
CLN2764-A x BCT-115 (DG)	1.67	-0.74	1.51	0.62	-1.66	-5.67	119.00	-24.30	-1.39	-19.18	-6.88	-1.00	-0.35	2.47	-13.00
CLN2768-A x FEB-2	-0.73	1.00	4.75	-1.77	-1.55	-14.20	2.35	-4.47	-1.28	-7.18	-0.73	2.71	-1.76	-5.87	1.53
CLN2768-A x A.C.AFT	-3.67	1.72	9.17	-1.58	-0.87	-84.00	5.12	-2.31	-7.00	1.00	3.30	3.50	-1.54	0.00	6.20
CLN2768-A x BCT-115 (DG)	-7.00	-0.27	3.95	-0.31	-1.63	6.50	12.08	5.53	-1.67	-5.06	-0.31	1.00	-1.17	-0.58	3.38

D50F: Days to 50% flowering, NFCPP: Number of flower clusters per plant, NFPC: Number of fruits per cluster, PH: Plant height (cm), PD: Polar diameter (cm), ED: Equatorial diameter (cm), NFPP: Number of fruits per plant, FW: Fruit weight (g), PT: Pericarp thickness (mm), LN: Locules number, TSS: Total soluble solids (^{0} brix), TA: Titratable Acidity (% anhydrous citric acid), AA: Ascorbic acid (mg 100 g^{-1} fresh pulp), LYP: Lycopene (mg 100 g^{-1} fresh pulp), FYPP: Fruit yield per plant (kg plant^{-1}).

recorded by seven hybrids and five hybrids over better-parent for titratable acidity of fruit. The maximum positive heterosis over better-parent was shown by 'CLN2777-G x FEB-2' (17.02%). For ascorbic acid content of fruits, three hybrids exhibited positive significant heterosis over mid-parent and two crosses showed positive significant heterosis over better-parent. The cross 'CLN2764-A x A.C.AFT' exhibited the highest positive heterosis of 33.34% and 22.00% over both mid-parent and better-parent, respectively. Five hybrids exhibited positive significant heterosis over mid-parent and three hybrids showed heterobeltiosis in desired direction for lycopene content of fruit. The cross 'CLN2777-G x BCT-115 (DG)' exhibited the maximum heterosis over both mid - and better-parent with 57.38% and 53.56% heterosis, respectively. For fruit yield per plant, eight hybrids exhibited positive and significant heterosis over both mid- and better-parent. The hybrid 'CLN2768-A x A.C.AFT' showed the highest positive heterosis of 40.56% and 31.77% over mid- and better-parent, respectively.

The values of dominance estimates (Potence ratio) illustrated in nine F_1 crosses are presented in Table 4. In case of number of flower clusters per plant, number of fruits per plant and fruit yield per plant, all the crosses exhibited over-dominance (> $\pm$ 1) reaction. Potence ratio of other characters expressed equal magnitude of both partial and over-dominance in most of the crosses. No dominance (0.0) has also been found in days to 50% flowering, fruit weight and pericarp thickness in one cross combination each. The above results reflected various degrees of dominance; i.e., partial to over-dominance or absence of dominance which involved in the inheritance of characters studied. However, the preponderance of partial-dominance and over-dominance actions for most of the crosses in the inheritance of these traits has been recorded.

Results of the estimates of genetic variances of studied characters illustrated that non-additive gene effects were found to be more pronounced for their genetic control. These results thus indicated that tomato crosses can produce F_1 hybrids which may perform better; in one or more traits; than either of their parents. Non-additive gene action have been reported in regulating the inheritance of days to 50% flowering (Ahmad *et al.,* 2009); number of flower clusters per plant, polar diameter, equatorial diameter (Shende *et al.,* 2012); number of fruits per cluster (Makesh *et al.,* 2002); plant height (Izge and Garba, 2012); number of fruit per plant (Chattopadhyay *et al.,* 2011); average fruit weight, locules number (Farzane *et al.,* 2012); pericarp thickness (Naveen *et al.,* 2008); titratable acidity (Virupannavar *et al.,* 2010); lycopene content of fruit (Akhtar and Hazra, 2013); total soluble solids, ascorbic acid, and fruit yield per plant (Kumar *et al.,* 2013) irrespective of the parental materials, biometrical

techniques and growing conditions.

From the study of combining ability of parents and crosses, no single parent or cross were found to be good general or specific combiner for all the characters studied. The results implies that two parents 'CLN2777-G' and 'FEB-2' were good general combiner indicating their ability in transmitting additive genes in the desired direction to their progenies. On the other hand, four crosses 'CLN2777-G x BCT-115', 'CLN2764-A x FEB-2', 'CLN2768-A x BCT-115 (DG)' and 'CLN2777-G x FEB-2' were identified as superior specific combiners and parents involved in the in these cross combinations showed high gca effects and high *per se* performance for several characters studied. Nevertheless, the crosses 'CLN2777-G x FEB-2' and 'CLN2768-A x A.C.AFT' showed significant sca effects particularly for fruit yield per plant and the parents involved in these combinations recorded significantly positive gca effects and high *per se* performance for this character. It may be suggested that parents with H ´ H gca effects could produce desirable transgressive segregants in advance generation because additive genetic system present in the good combiner and complementary epistatic effect in F_1 may act in the same direction to maximize the desirable plant attributes. The results of type of cross combination clearly demonstrated that high heterotic hybrid could be obtained when utilize parents having high gca effects.

With regard to the study of heterosis, the number of crosses with significantly positive heterosis over mid-parent was more as compared to heterosis over better-parent for most of the characters excepting days to 50% flowering and locules number. It also emerged from the study that best two crosses 'CLN2768-A x A.C.AFT' and 'CLN2777-G x FEB-2' showed the maximum heterobeltiosis for fruit yield per plant *vis-à-vis* number of fruits per plant and number of fruits per cluster. Therefore, it appeared that heterosis for fruit yield per plant could be realized mainly to heterosis observed for number of fruits per plant and number of fruits per cluster. These two hybrids could be exploited commercially for table purpose because of both high number and weight of fruits along with high yield. Moreover, the hybrid 'CLN2777-G x FEB-2' could fulfill the basic requirements (low locule number, high TSS, titratable acidity and lycopene contents of the fruit) for processing as suggested by Adsule *et al.* (1980) and may also be recommended for processing purpose. Manifestation of heterosis over mid- and better-parent for the studied characters in desired direction had also been observed by many workers (Chattopadhyay *et al.*, 2011; Shende *et al.*, 2012; Farzane *et al.*, 2012; Solieman *et al.*, 2013). Absence of significant heterobeltiosis in most of the crosses for plant height, fruit weight and polar diameter of fruit could be explained by the internal cancellation of heterotic components. When significant heterobeltiosis is observed in majority of the crosses for any character indicates involvement of non-additive gene action in the genetic control of that particular trait. If assuming that epitasis is absent, the cause of heterosis can only be attributed to the dominance gene action. The results also demonstrated various degrees of dominance effects which involved in the genetic control of these characters. These findings were in agreement with previous workers (Singh and Asati, 2011; Solieman *et al.,* 2013) who found that predominance of non-additive component of variance for all the studied traits suggesting heterosis breeding as the best possible option for improving the above traits of tomato.

Conclusion

It was concluded that all the studied characters of tomato were conditioned by non-additive gene effects. Two parents 'CLN2777-G' and 'FEB-2' could be identified as potential donors for improvement of yield and post harvest quality in future breeding programme. Two promising hybrids ('CLN2768-A x A.C.AFT' and 'CLN2777-G x FEB-2') were selected on the basis of *per se* performance, heterosis manifested in them and relevance of sca effect for fruit yield and other component traits. Nevertheless, the cross 'CLN2777-G x FEB-2' which possessed better processing quality could be exploited commercially for different value added products of tomato.

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