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RESEARCH **P**APER

Heterosis breeding in tomato for yield and quality contributing trait

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In the present study of correlation which revealed that average fruit weight, number of fruits per plant, equatorial fruit diameter, polar fruit diameter, titratable acidity, ascorbic acid content possessed significant positive correlation with total fruit yield and days to 50 per cent flowering and days to first fruit set was having high significant negative correlation with total fruit yield. On the other hand total soluble solids content have high significant positive correlation with lycopene content, total carotenoids content, total phenol content and total antioxidant capacity and total soluble solids exerted high significant negative correlation towards titratable acidity and ascorbic acid content. This study revealed that large size tomato fruits are not just good yielder moreover, they are also nutritionally very rich in quality. Path analysis studies in this research work revealed high direct positive effect of number of fruits per plant, equatorial fruit diameter, polar fruit diameter, days to first flowering, days to first fruit set on total fruit yield and quality both. While high negative direct effect on total yield was expressed by days to 50 per cent flowering, average fruit weight, lycopene content, total carotenoids content. Hence, selection for number of fruits per plant, equatorial fruit diameter and polar fruit diameter can be effectively done for improving yield. While heterosis studies showed that cross Pusa Rohini x CLNB possessed high significant SH towards days to first flowering, days to 50 per cent flowering, days to first fruit set. Arka Alok x CLNB posessed high significant BPH and SH heterosis in the desirable direction for total fruit yield, while Pusa Rohini x Sel-12 was having high significant standard heterosis for total soluble solids, lycopene content and total carotenoids content , respectively. On the basis of combining ability studies we were able to identify the best parents and hybrids based on GCA and SCA analysis. So on GCA basis Kashi Vishesh was found to be the best general combiner in relation to fruit yield per plant and total fruit yield whereas Sel-12 was found to be the best general combiner in relation to earliness while Pusa Rohini was found to be the best in relation to important biochemical aspects. While on SCA basis cross Arka Alok x CLNB was found to be the best specific cross combination for fruit yield per plant and total fruit yield. Whereas Pusa Rohini x CLNR was found to be the best specific cross combination in relation to biochemical parameters *i.e.* for total soluble solids content, lycopene content, total carotenoids content, total antioxidant capacity and ascorbic acid content.

Key words : GCV, SCA, CLNB, CLNR, DUS, PPV, FRA

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INTRODUCTION

Vegetables are the most important component of balance diet, it providing not only energy but also supplying vital protective nutrients like vitamins, minerals and antioxidants. The presence of antioxidants in some vegetables protects our body from adverse biological reaction involving oxygen. India is the second largest producer of vegetables only next to china under the area of 9.4 million hectare with a total production of 162.9

million tonnes with the productivity of 17.3 tonnes/ hectare. India is the second largest tomato producing country in the world followed by China. In India, tomato occupies an area of 1.20 million hectares and having the production of 19.40 million tonnes. However, the productivity is only 16.1 metric tonnes/ha. At present, India accounting for 11.5 per cent of the world's tomato production as well as second largest in terms of acreage. In India, tomato has wider coverage in comparison to other vegetables. The major tomato producing states are Utter Pradesh, Maharashtra, Haryana, Orissa, Karnataka and Bihar. The total global area under tomato is 48.15 lakh hectares and the global production is to the tune of 1630.29 lakh tonnes. The world wide tomato productivity is 33.9 metric tonnes/ha.Tomato (*Solanum lycopersicum* L.) is an important vegetable of Solanaceae family having chromosome number 2n=2x=24. It has originated from wild form in the Peru- Equador-Bolivia region of the Andes, South America and is grown in almost every corner of the world. Tomato is universally known as "protective food". It is a versatile vegetable for culinary purpose. Tomato is generally consumed as salad, cooked or as processed food. The unripe green fruits are used for making pickles and preserves and are consumed after cooking as vegetable. Tomato is a rich source of antioxidants (mainly lycopene and Vitamin A, Vitamin C and minerals like Ca, P and Fe. In tomato total antioxidant capacity ranges from 80 to 200. Lycopene is major antioxidantal pigmental, which is responsible for red color in tomato. Lycopene and their production plays important role in human health in order to reduce the risk of chronic diseases. Lycopene varies between 4.31 to 5.97mg/100g (Kaur *et al.,* 2013), total phenolic content ranges from 9.20- 22mg/100g, few ascorbic acid contents of tomatoes have been found to vary according to colour and it ranged from 23.21-40.44 and 24.38 - 33.87mg/100g in red and yellow cultivars, respectively (Singh *et al.,* 2010). A survey made by M. A. Stevens indicated that among the main fruits and vegetables tomato ranks 16th as the source of both vitamins A and C (Thamburaj and Singh, 2013). Tomato plants typically reach 1-3 meters in height and have a weak, woody stem that often vines over other plants. The leaves are 10-25cm long, odd pinnate, with 5-9 leaflets on petiole and each leaflet upto 8cm long, with a serrated margin; both the stem and leaves are densely glandular-hairy. The flowers are 1-2 cm across, yellow, with five pointed lobes on the corolla; they are borne in a cyme of 3-12 together. Tomato is typical day neutral plant and mainly self-pollinated, but a certain percentage of cross-pollination also occurs. It is a perennial, often grown outdoors in temperate climates as an annual. *S. lycopersicum* and near relatives are self fertile but the former is out crossed to a considerable extent in certain part of subtropical areas and its native region. The identification and selection of fixable parental lines are required to be used in any hybridization programme to produce potentially rewarding germplasm by assembling fixable gene effects more or less in a homozygous line. Information pertaining to different types of gene action, relative magnitude of genetic variance, and combining ability estimates are important and vital parameters to mould the genetic makeup of tomato crop. This important information could improve an essential strategy to tomato breeders in the screening of better parental combinations for further enhancement. Exploitation of heterosis is primarily dependent on the screening and selection of available germplasm that could be produced by better combinations of important agronomic characters. Heterosis can be defined as superiority or inferiority of F_1 hybrid over its parents. Heterosis can be measured over mid-parent value, better parent value and check parent. Heterosis leads to superiority in adaptation, yield, quality, disease resistance, maturity and general vigour over its parents. Generally, positive heterosis is considered as desirable, but in some cases negative heterosis is also desirable. Heterosis is confined only to the F_1 generation of a cross and it declines in F_2 and subsequent generations. The first incidence of heterosis in tomato was observed by Hedrick and Booth (1968) for increased yield and number of fruits in tomato. To obtain a high heterotic result, it is important that the parental lines should be genetically diverse. After the 2nd World War, heterosis breeding in tomato developed quickly in the Netherlands, England, France, USA, Japan and other countries. Hybrid can provide many advantages over non-hybrid cultivars, in addition to heterosis for yield and quality. Combining ability refers to the capacity or ability of a genotype to transmit superior performance to its crosses. It helps in the selection of suitable parents for hybridization and in identification of superior cross combinations. Average performance of a genotype in series of hybrid combination is the general combining ability (GCA), whereas average performance of a parent in specific cross combination is the specific combining ability (SCA). A knowledge of GCA and SCA helps in choice of parents or hybrids, while nature of gene action

helps in choosing an effective breeding methodology. India is known for diverse genotypes of tomato. Identification of superior genotypes among the existing germplasm becomes extremely important for future breeding programme and also for increasing production per unit area. The development of an effective improvement programme depends upon the existence of genetic variability and knowledge of genotypic and phenotypic correlation of yield and yield attributing components. Phenotypic and genotypic co-efficients of variation are useful in detecting amounts of variability present in genotypes. Heritability and genetic advance help in determining the influence of environment in expression of characters and the extent to which improvement is possible after selection. High heritability alone is not enough to make efficient selection in segregating generation and needs to be accompanied by a substantial amount of genetic advance. The correlation co-efficient measures the mutual relationship between two or more variable and gives an idea about the various associations existing between the yield and yield components. Correlation co-efficient between a pair of characters is either positive or negative and it may be high or low. Estimation of correlation co-efficient among the yield contributing variables is necessary to understand the direction of selection and to maximize yield in the shortest period of time. However, as the number of variables in the correlation study increases the direct and indirect association between yield and particular component character becomes complex. It only reveals the direction and magnitude of association between any two characters but the path co-efficient analysis helps in partitioning the correlation into direct and indirect effects of various yield components on yield. Therefore, correlation studies coupled with path co-efficient analysis are a powerful tool to study the character association and their final impact on yield, which help the selection procedure accordingly. Path co-efficient analysis which determines the cause and effect relationship has been found useful in splitting the correlation into its direct and indirect effects contributing to yield. The great extent of natural variation present in various characters among the genotypes of tomato suggests good scope of improvement in economic traits through conventional breeding techniques. During recent past, much breeding efforts have been put to develop promising tomato varieties possessing high yield and good quality keeping all above facts in consideration, the present investigation on heterosis breeding in tomato for yield and quality contributing traits has been framed with following objectives : To estimate the extent of genetic variability, heritability and genetic advance in tomato, to work out the extent of heterosis and combining ability for yield and quality contributing traits and to study the association of different characters and their direct and indirect effect with fruit yield and quality contributing traits.

RESEARCH METHODOLOGY

An experiment was carried out on heterosis breeding in tomato for yield and quality contributing traits during *Rabi* season 2015-17. Materials used, experimental procedures followed and techniques employed in the present investigation have been described in this chapter.

Plant materials:

During *Rabi* 2015-16 all the seven inbred lines were raised in a breeding nursery to derive all possible 21F1 single cross hybrids (SCH) in diallel fashion excluding reciprocals. In *Kharif* 2016, these 21 crosses along with seven parents and one check were evaluated in RBD design at vegetable research farm of Bhagwant University, Ajmer Rajasthan India.

Other materials:

Other materials consisting of field implements and tools, FYM, plant protection chemicals, pan balance, chemical balance, digital Vernier calliper, metre scale and different chemicals etc. were utilized as and when necessary.

Rising of seedlings in nursery:

Before sowing the seeds in nursery, the land was ploughed with the help of cultivator to a depth of 20-25 cm. At the time of first ploughing, well rotten farm yard manure (FYM) @ 25 t/ha was applied, mixed well and made soil to a fine tilth. A small size raised bed of 10m x lm prepared and it was divided into 27 small beds. Required quantity of nitrogen, phosphorus and potash was added to the soil in the nursery at the rate of 100, 60 and 60kg/ ha, respectively. Seed sowing was done on the 8th November 2016. Seed of all twenty nine genotypes, treated with carbendazim fungicide at the rate of 2g/kg of seed. Soon after sowing the seed bed irrigated lightly. Seeds germinated in a week. Regular watering and plant

protection measures were given till become ready for transplantin.

Field preparation:

The experimental plot was ploughed four times, followed by planking. Ploughing was given manually. Root stables, weeds and other crop residues were removed by harrowing. Land was properly leveled. Well rotten farm yard manure at the rate of 250q/ha was applied at the time of last ploughing. A fine tilth was then attained by through spading of the experimental plot.

Transplanting of seedlings:

Nursery bed was irrigated one day prior to transplanting in order to facilitate uprooting of seedlings. Healthy and uniform seedlings were uprooted in the evening hours and transplanted in their respective plots on the same day *i.e.*, the 17th December 2016 with proper spacing. Transplanting was followed by irrigation with the help of watering cane for 5 days in the morning till the plants established properly. Row to row and plant to plant distance were kept 70cm and 60cm, respectively.

Gap filling:

The plants were carefully observed from the second day of transplanting. The sign of permanent wilting and the advent of new growth were considered as indications of mortality and survival, respectively. Very few gaps filling was done by transplanting uniform, healthy and well developed seedling of same age in each plot with same line and sufficient care was taken for their proper establishment. However, plants transplanted later in the gaps were not included for detailed study.

Irrigation and intercultural operations:

Furrow irrigation was given to the plot after one week of transplanting. Subsequent irrigation, hoeing and weeding were provided throughout the cropping season as and when required.

Manures and fertilizers:

Organic manure in the form of well rotten farm yard manure was applied in the experimental plot at the time of field preparation. A dose of fertilizers at the rate of 100kg N_2, 60kg P_2O_5 and 60kg, 1/3rd dose the nitrogen and full dose of phosphorus and potash were applied after fifteen days of transplanting of seedling, 1/3rd dose of nitrogen was applied after thirty days and rest amount of nitrogen was applied after 45 days of transplanting of seedlings and earthing up was completed.

Plant protection measures:

Against pests and diseases plant protection measures were provided throughout the growing season. The crop was sprayed with 0.03 per cent dimethoate (Rogar) 30EC before flowering and with imidachlorprid at the rate of lml/litre of water after flowering and fruiting. Dithane M-45 (Mancozeb) was sprayed at the rate of 2 kg/ha twice at an interval of 15 days against fungal diseases.

Tagging of plants for studies:

For the sake of recording the data, 3 plants were randomly selected in each plot excluding the border in each replication and they were tagged and numbered. Observations were then recorded at different intervals on the following aspects.

Collection of data and recording of observations:

Five plants in each entry were selected randomly and were tagged. These tagged plants were used for recording observations for the following characters.

Morphological characters studies:

The morphological observations were taken with the help of guidelines for the conduct of test for distinctiveness, uniformity and stability (DUS) on tomato by protection of plant varieties and farmers' rights authority (PPV and FRA), Government of India.

Days to first flowering:

It is total number of days from the date of transplanting to days to first anthesis.

Days to 50 per cent flowering:

It is total number of days from the date of transplanting to 50 per cent of plants flowered.

Days to first fruit setting:

It is total number of days counted from the day of transplanting to fruit bud differentiation stage *i.e.* pea stage of fruits.

Plant height (cm):

The plant height was measured in centimeter from

the base to the top of plant at time of last picking of the fruits by a meter scale.

Average fruit weight (g):

Fruit yield (*q/ha*):

Total yield per plant was worked out by adding yield of all harvests and was expressed in kilogram (kg) per plant and converted in per hectare yield (q/ha).

Plant type:

Mainly tomato plant is characterized by two types of growth habits, *viz*.,determinate and indeterminate type.

Nature of stigma :

Five marketable fruits were weighed and the average fruit weight was worked out and expressed in grams (g).

Equatorial fruit diameter (mm):

Fruit equatorial diameter was measured from fruit breadth at highest bulged portion of the fruit by using Vernier callipers.

Polar fruit diameter (mm):

Fruit polar diameter was measured from stalk end to blossom end by using Vernier callipers.

Number of fruits per plant:

Number of fruit per plant at each harvest was accounted and average was worked out.

Number of locules per fruit:

The fruits were halved transversely and the locule numbers were counted from the five fruits. The average was worked out.

Yield per plant (g):

The weight of fruits from each picking was recorded from the five labeled plants of each experimental plot. Total yield per plant was worked out by adding yield of all harvests and was expressed in gram (g) per plant. According to position of stigma, classified into inserted or exerted type of stigma.

Biochemical analysis :

Total soluble solids content of fruit (%):

Tomato juice was collected from red ripe fruits. A drop of juice was placed over the prism of digital refractometer and value was noted in per cent.

Titratable acidity (%):

Titratable acidity was determined by using titration method (A.O.A.C., 2000). For this 2 g of fruit sample was weighed and crushed. The homogenate was diluted upto 100 ml with distilled water. The solution was then filtered and two drops of 1 per cent phenolphthalein solution was added to 10ml of filtrate solution. Finally, it was titrated against 0.1N NaOH solutions till pink colour appeared.The observed titre value was used for calculating acidity from the following formula and the results were expressed as percentage of citric acid. Titre value x normality of alkali x vol. made up x 64 x100. Titratable acidity (%) =Volume of sample taken x wt. of sample taken x 1000.

Ascorbic acid content (mg/100g):

Ascorbic acid content of the juice was determined by titrating freshly extracted juice against 2,6-dichlorophenol indophenols dye (A.0.A.C., 1975). For its determination 2g pulp was crushed with 3.00 per cent metaphosphoric acid (MPA) solution and volume made upto 100 ml with 3 per cent MPA in a volumetric flask. After 10 min. aliquot of filtrate was titrated against standard 0.025 per cent 2, 6-dichlorophenol indophenols dye solution. The end point was marked by the appearance of pink colour which persisted for 15 second. The content of ascorbic acid was expressed as mg/100g of pulp.

Total phenolics content (mg GAE/100g):

Total phenolics content of tomato fruit was determined by the method of Singleton *et al.* (1999). 2g fruit was crushed in 10 ml 80 per cent ethanol. After that centrifuged the sample homogenate at 10,000 rpm for 20 min. at 4°C. In a small test tube 2.7 ml of distilled water 3000 sample and 0.5ml 2N Folin-ciocalteau reagents added. After 3 min. 2ml of 20 per cent of sodium carbonate solution added on the above sample solution.Taken absorbance at 760nm in a spectrophotometer after sometime till solution colour became blue-black in colour.

Total antioxidant capacity (pmol/g):

Total antioxidant capacity of tomato fruit was estimated following cupric method (Apak *et al.*, 2008). 2g fruit was crushed in 10ml 80 per cent ethanol. After

that centrifuged the sample homogenate at 10,000 rpm for 20 min at 4°C. After that 1ml of neocuproine, 1ml copper chloride, 1ml ammonium acetate solution and 1ml distilled water added in a small test tube with 1000 supernatant sample, in case of blank 1000 distilled water added instead of sample. Then absorbance has been taken at 450nm in a spectrophotometer.

Total carotenoids content (mg/100g):

Total carotenoids content of tomato fruit was determined by the method of Roy (1973) with some modifications. 5g of tomato pulp was crushed in acetone, till it became colorless. Then the extracted solution was poured into a separating funnel. Then added petroleum ether and small amount of sodium sulphate and shaken rigorously for mixing well. Then the separating funnel was kept undisturbed to separate the carotenoids from acetone to petroleum ether layer. After that, coloured solution was separated in a 50ml volumetric flask and the volume was adjusted with petroleum ether. Finally, the sample absorbance was measured at 452 nm in a spectrophotometer, using petroleum ether as blank. The results expressed as mg 100g' FW (fresh weight) basis.3.857 x absorbance x vol. made up x dilution x 100. Total carotenoids (mg carotene/100g)-Weight of sample x 1000.

Total lycopene content (mg/100g):

Total lycopene content of tomato fruit was determined by the method of Lee (2001) with some modifications. With the help of mortar and pestle 5g of tomato pulp was crushed in acetone, till it became colorless. Then the extracted solution was poured into a separating funnel. Then added petroleum ether and small amount of sodium sulphate and shaken rigorously for mixing well. Then the separating funnel was kept undisturbed to separate the lycopene pigment from acetone to petroleum ether layer. After that, coloured solution was separated in a 50ml volumetric flask and the volume was adjusted with petroleum ether. Finally, the sample absorbance was measured at 503nm in a spectrophotometer, using petroleum ether as blank. The results expressed as mg 100g1 FW (fresh weight) basis.3.1206 x absorbance x vol. made up x dilution x 100. Lycopene content (mg /100g) =Weight of sample x 1000.

Statistical analysis:

The data collected for various characters were statistically analysis adopting analysis of variance procedures in case of Randomized Complete Block Design, as suggested by Fisher (1948). Variability, heritability, genetic advance, correlation and path analysis were measured and their significance expressed at 1 per cent and 5 per cent levels.

Analysis of variance:

The analysis of variance for design of experiment was done for partitioning the variance into treatments and replications according to procedure given by Panse and Sukhatme (1967) in the following manner. This statistic is generally used to judge the precision of the experiment. The values less than 25 per cent are usually accepted as normal.

Biometrical analysis:

Biometrical analysis of quantitative traits was done under the following heads: Estimation of correlation co-efficient, path co-efficient analysis and combining ability analysis.

Correlation co-efficient analysis:

Correlation co-efficient is the mutual association between variables without implying any cause and effect relationship. Single correlation co-efficients were computed at genotypic and phenotypic levels between pair of characters adopting following formula given by Johnson *et al.* (1955) and Al-Jibouri *et al.* (1958).

Genotypic correlation between traits X and Y:

where, cr22 (xy) 1 = Genotypic covariance between X and Y (72 6,(X) = Genotypic variance for X, G-22 (y) = Genotypic variance for Y.

Phenotypic correlation between traits X and Y:

2 p CRY) Rxy (13) 410'2 (x) g^2p (y), where,0-2p(xy)= Phenotypic covariance between X and Y.

Genetic advance:

Genetic advance is the improvement in mean genotypic value of selected plants over the parental population. The estimates of genetic advance were obtained by the formula given by Lush (1949) and Johnson *et al.* (1955). GA = K. ap. H. where, K= Constant selection differential at 5 per cent level intensity (2.06) ar= Phenotypic standard deviation.

Path co-efficient analysis:

The path co-efficient analysis is simply the standardized partial regression co-efficient, which splits the correlation co-efficient into the measures of direct and indirect effects of independent variables on the dependent variables. The concept of path analysis was originally developed by Wright (1921), but this technique was firstly used for plant selection by Dewey and Lu (1959). Path analysis was worked out by using the estimates of correlation co-efficient in all possible combinations among the dependent variables.

Estimation of heterosis:

The magnitude of heterosis was studied using information on various quantitative characters. Heterosis expressed as per cent increase or decrease in the mean values of Fi's (hybrid) over better-parent (heterobeltiosis) and standard variety was calculated according to method suggested by Hayes *et al.* (1955).

RESEARCH FINDINGS AND ANALYSIS

The result obtained from the data of present investigation which was carried out to access genetic variability, heritability and genetic advance, heterosis, combining ability, correlation and path co-efficient among tomato genotypes including check varieties are given and discussed under the following heads:

Analysis of variance:

Mean data for 20 characters were subjected to analysis of variance for the design of experiment. The mean sum of square due to treatments was highly significant for all the characters under study at 1 per cent and 5 per cent level of significance, which indicated that considerable amount of variability, were present in the genotypes included in the study. Hence, there is ample scope for selection of promising genotypes in breeding programme for yield and its component characters (Table 1).

Genetic variability, heritability and genetic advance:

In general a wide range of mean values between the genotypes were found for the respective characters. Character wise mean performance of the genotypes are being discussed here:

Table 1 : Analysis of variance for 19 characters for the design of experiment in tomato

Sr. No.	Characters	Mean sum of squares					
		Replication (df=2)	Treatment (df=27)	Parents (df=6)	Hybrids (df=1)	Parents vs. hybrids (df=1)	Error (df=54)
1.	Days to first flowering	1.94	81.40**	78.44**	85.82**	10.73	3.78
2.	Days to 50% flowering	0.32	76.63**	59.27**	81.62**	81.15**	3.82
3.	Days to first fruit set	6.44	73.23**	46.86**	70.86**	278.67**	3.97
4.	Plant height (cm)	6.29	1210.75**	464.16**	1436.03**	1184.73**	7.75
5.	Polar fruit diameter (mm)	3.36	79.66**	26.41**	83.82**	315.88**	2.27
6.	Equatorial fruit diameter (mm)	6.74	64.17**	45.58**	61.76**	223.82**	2.80
7.	Average fruit weight (g)	1.48	606.51**	620.98**	581.66**	1016.66**	7.01
8.	Number of fruits/ plant	0.44	224.31**	389.41**	172.64**	267.16**	9.25
9.	Fruit yield/ plant (g)	1096.4	683785.69**	541279.50**	589602.50**	3422486.25**	12477.2
10.	Total fruit yield (q/ha)	62.18	38732.42**	30660.15**	33397.56**	193863.22**	706.75
11.	Locules/ fruit	0.02	2.35**	1.03**	2.84**	0.34	0.09
12.	Pericarp thickness	0.27	2.16**	2.03**	2.24**	1.36*	0.16
13.	TSS	0.03	0.42**	0.25**	0.44**	1.05	0.01
14.	TA	0.00*	0.02**	0.02**	0.02**	0.00**	0.00
15.	AA	0.02	87.77**	186.08**	61.27**	27.98**	0.04
16.	TPC	0.02	144.19**	184.43**	134.23**	101.85**	0.05
17.	T. Aox	0.0	1.01**	0.73**	1.13**	0.21**	0.00
18.	LC	0.01	1.89**	2.23**	1.83**	1.20**	0.01
19.	T.C.	0.0	1.62**	2.30**	1.47**	0.41**	0.00

*and ** indicate significance of values at P=0.05 and 0.01, respectively

Characters: Total soluble solid (TSS), Ascorbic acid content (AA), Titrable acidity (TA), Total phenol content (TPC) and Total antioxidant capacity (TAox), lycopene content (LC), Total carotenoids (TC)

Growth characters:

Plant height (*cm*):

Plant height was highest in Sel-12 x Pusa-120 followed by Sel-12 x CLNR and lowest in Pusa Rohini x CLNB with mean value 75.22. The phenotypic and genotypic co-efficient of variation was 27.82 and 27.56, respectively. The heritability in broad sense as well as genetic advance in per cent of mean was high.

Reproductive characters:

Days to first flowering:

The data for this trait revealed that days to first flowering ranged from 46.67 days to 64.33 days with over all mean value of 57.22 days (Table 2). Pusa Rohini x CLNB has taken minimum days for flowering which was at par with H-86 x Arka Alok, H-86 x CLNB, Pusa Rohini x Sel-12. The phenotypic and genotypic co-efficient of variation was 9.49 and 8.87, respectively. The heritability in broad sense was very high for this trait. However, the genetic advance in per cent of mean was moderate.

Days to 50 per cent flowering:

Days to 50 per cent flowering ranged from 56.00 days to 74.33 days with mean value of 67.40 days. Pusa Rohini x CLNB taken minimum days for 50 per cent flowering that is at par with H-86 x Arka Alok, H-86 x CLNB. The phenotypic and genotypic co-efficient of variation was 7.83 and 7.27, respectively. The heritability in broad sense was very high. However, the genetic advance in per cent of mean was moderate.

Days to first fruit set:

Days to first fruit setting ranged from 56.33 to 78.67 days with mean value of 68.26 days. Pusa Rohini x CLNB taken minimum days for first fruiting that was at par with H-86 x Arka Alok. The phenotypic and genotypic co-efficient of variation was 7.63 and 7.05, respectively. The heritability in broad sense was very high. However, the genetic advance in per cent of mean was moderate.

Fruit morphological characters:

Equatorial fruit diameter (*mm*):

Equatorial fruit diameter was highest in H-86 x Pusa Rohini followed by H-86 x CLNR and Sel-12 x CLNR. Lowest equatorial fruit diameter was observed in CLNB with mean value of. The phenotypic and genotypic co-efficient of variation was 11.21 and 10.50, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Table 2 : Genetic performance of 29 genotypes of tomato

Characters	General mean	GCV (%)	PCV (%)	h^2 (Broad sense) %	Gen. adv as % of mean 5%	Exp mean next generation
Days to first flowering	57.22	8.87	9.49	87.29	17.07	66.99
Days to 50% flowering	67.40	7.27	7.83	86.30	13.92	76.78
Days to first fruit setting	68.26	7.05	7.63	85.54	13.44	77.44
Fruits/ plant	38.06	22.25	23.61	88.77	43.18	54.50
Fruit yield/ plant (g)	1586.36	29.59	30.40	94.75	59.33	2527.58
Fruit yield (q/ha)	377.55	29.59	30.40	94.75	59.33	601.56
Average fruit weight (g)	42.92	32.34	32.91	96.58	65.48	71.03
Plant height (cm)	75.22	27.56	27.82	98.15	56.25	117.53
Polar fruit diameter (mm)	36.86	14.06	14.64	92.27	27.83	47.12
Equatorial fruit diameter (mm)	42.37	10.50	11.21	87.66	20.24	50.95
Locules/ fruit	3.10	27.78	29.40	89.30	54.08	4.78
Pericarp thickness	5.75	14.16	15.70	81.40	26.32	7.26
TSS (°Brix)	4.62	7.91	8.26	91.83	15.62	5.34
Titratable acidity (%)	0.63	12.12	12.13	99.95	24.97	0.79
Ascorbic acid content (mg/100g Fw)	38.88	13.66	13.67	99.86	28.12	49.81
Total phenolics content (mg catechol equivalent/100g Fw)	70.16	10.13	10.13	99.90	20.85	84.79
Total antioxidant capacity (i.t Mol/Te/G)	2.57	22.16	22.18	99.87	45.63	3.74
Lycopene content (mg/100g Fw)	2.79	28.12	28.39	98.07	57.36	4.39

Polar fruit diameter (mm):

Polar fruit diameter was highest in H-86 x CLNR followed by Pusa Rohini x CLNR. Lowest polar fruit diameter was found in CLNB with mean value of 36.86. The phenotypic and genotypic co-efficient of variation was 14.64 and 14.06, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Number of locules per fruit:

Number of locules per fruit ranged from 5.27, to 2.0 with over all mean value of 3.10. The phenotypic and genotypic co-efficient of variation was 29.40 and 27.78, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Pericarp thickness (mm):

The highest pericarp thickness was found in Sel-12 x Pusa-120 followed by, H-86 x CLNR, H-86 x Pusa-120 and lowest pericarp thickness was observed in CLNB x Pusa-120. The overall mean value of pericarp thickness was 5.75. The phenotypic and genotypic co-efficient of variation was 15.70 and 14.16, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Average fruit weight (g):

Average fruit weight was highest in H-86 x Arka Alok which was at par with H-86, H-86 x Pusa Rohini, H-86 x Sel-12, H-86 x Pusa-120 and lowest fruit weight was found in CLNB with mean value of 42.92. The phenotypic and genotypic co-efficient of variation was 32.91 and 32.34, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Fruit yield characters:

Number of fruits per plant :

Number of fruits per plant was highest in CLNB followed by CLNB x Pusa-120 and lowest in Pusa Rohini with mean value of 38.06. The phenotypic and genotypic co-efficient of variation was 23.61 and 22.25,respectively. The heritability in broad sense as well as genetic advance in per cent of mean was high.

Yield per plant (g):

Yield per plant was highest in Arka Alok x CLNB followed by H- 86 x Arka Alok, H-86 x Sel-12, H-86 x CLNB and lowest yield per plant was found in Pusa-120. The overall mean value of yield per plant was 1586.36. The phenotypic and genotypic co-efficient of variation was 30.40 and 29.59, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Fruit yield (q/ha):

Highest fruit yield was found in Arka Alok x CLNB (567.31) followed by H-86 x Arka Alok, H-86 x Set-12, H-86 x CLNB and lowest fruit yield was found in Pusa-120. The overall mean value of yield per plant was 377.55q/ha. The phenotypic and genotypic co-efficient of variation was 30.40 and 29.59, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Biochemical characters:

Total soluble solids (*%*):

The highest total soluble solids were found in Pusa Rohini x Set-12 followed by, Sel-12 x CLNB and Pusa Rohini x CLNR. The lowest total soluble solids were observed in H-86 x Pusa Rohini. The overall mean value of total soluble solids was 4.62 per cent. The phenotypic and genotypic co-efficient of variation was 8.26 and 7.91, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Titratable acidity (%):

The highest titratable acidity was observed in H-86, followed by, H-86 x Pusa Rohini, H-86xCLNB, CLNR x Pusa-120. The lowest titratable acidity was found in Sel-12. The overall mean value of total soluble solids was 0.63 per cent. The phenotypic and genotypic co-efficient of variation was 12.13 and 12.12 per cent, respectively. The heritability in broad sense (99.95%) as well as the genetic advance in per cent of mean was high.

Ascorbic acid content (mg/100g):

The highest ascorbic acid content was observed in H-86 x Pusa Rohini followed by Sel-12 and Pusa Rohini x Sel-12. The lowest ascorbic acid content was observed in CLNB. The overall mean value of ascorbic acid content was 38.88mg/100g. The phenotypic and genotypic co-efficient of variation was 13.67 and 13.66, respectively. The heritability in broad sense as well as the genetic

advance in per cent of mean was high.

Lycopene content (mg/100g):

The highest lycopene content was observed in Pusa Rohini x Arka Alok followed by Arka Alok x CLNB and Arka Alok. The lowest lycopene content was found in H-86 x Pusa-120. The overall mean value of lycopene content was 2.79mg/100g. The phenotypic and genotypic co-efficient of variation was 28.39 and 28.12, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Total carotenoids content (mg/100g):

The highest total carotenoids content was found in Pusa Rohini x Arka Alok followed by Arka Alok and Arka Alok x CLNR. The lowest total carotenoids content was found in H-86. The overall mean value of total carotenoids content was 3.45mg/100g. The phenotypic and genotypic co-efficient of variation was 20.89 and 20.88, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Total phenolics content (mg GAE/100g):

The highest total phenolics content was found in Set-12 (83.26) followed by Sel-12 x CLNB, Sel-12 x Arka Alok and H-86 x Sel-12. The lowest total phenolics content was found in Arka Alok x Pusa-120. The overall mean value of total phenolics content was 70.16 lig GE/g. The phenotypic and genotypic co-efficient of variation was 10.13 and 10.13, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Total antioxidant capacity (pmol /g):

The highest total antioxidant content was found in Arka Alok x CLNB followed by Sel-12 x CLNB and Pusa Rohin x Set-12. The lowest total antioxidant content was found in Arka Alok x Pusa-120. The overall mean value of total antioxidant content was 2.57gmol TE/g. The phenotypic and genotypic co-efficient of variation was 22.18 and 22.16, respectively. The heritability in broad sense as well as the genetic advance in per cent of mean was high.

Estimation of heterosis:

Growth characters:

Plant height (cm):

The range of standard variety heterosis for plant height was from -61.66 per cent to 5.24 per cent and that of mid parent heterosis was from -36.80 per cent to 74.46 per cent whereas for better parent heterosis ranged from -43.67 per cent to 61.79 per cent. Maximum positive heterosis over the standard variety has been found in Sel-12 x CLNR, whereas, nine hybrids were found to contain highly significant positive heterosis in desirable direction over mid parent and seven showed significant positive heterosis over the better parent.

Reproductive characters:

Days to first flowering:

For days to first flowering, the range of heterosis varied from -24.73 per cent to 3.76 per cent over standard variety. The range of heterosis varied from -18.84 per cent to 14.46 per cent over the mid parent. While heterosis ranged from -23.16 per cent to 12.27 per cent over better parent. Among the 21F1 hybrids, none of them showed negative significant heterosis in desirable direction over standard variety. While only three hybrids showed highly significant negative heterosis in desirable direction over mid parent and one hybrid namely H-86 x Pusa Rohini showed significant negative heterosis in desirable direction over the better parent.

Days to 50 per cent flowering:

For days to 50 per cent flowering, the standard variety heterosis range varied from -21.86 per cent to 3.72 per cent the mid parent for this trait ranged between -18.10 per cent to 8.50 per cent. While the better parent heterosis varied from -22.22 per cent to 6.03 per cent Out of the 21F1 hybrids, none of them showed significantly high negative heterosis in desirable direction over standard variety and better parent while only 1 hybrid namely Set-12 x CLNR showed significant negative heterosis over mid parent.

Days to first fruit set:

The range value for this character varied from -23.18 per cent to 1.36 per cent over the standard variety, while it ranged between-20.09 per cent to 5.77 per cent over the mid parent. Whereas the better parent heterosis varied between-21.03 per cent to 4.27 per cent. From all the 21F1 hybrids, none of them showed significantly high negative heterosis in desirable direction over standard variety and better parent while only 1 hybrid namely Se1-12 x CLNR showed significant negative heterosis over mid parent.

Fruit morphological characters:

Equatorial fruit diameter (*mm*):

For this trait, the extent of standard variety heterosis varied from -14.05 per cent to 21.38 per cent. Heterosis over mid parent ranged from -3.28 per cent to 26.18 per cent while over better parent this trait ranged from -9.92 per cent to 19.88 per cent. Out of the 21F1 hybrids, only five hybrids were found to contain highly significant positive heterosis in desirable direction over standard variety, while all except nine hybrids were found to contain highly significant positive heterosis in desirable direction over mid parent, whereas six hybrids were found to have positive significant heterosis in desirable direction over better parent.

Polar fruit diameter (mm):

For this trait, the extent of standard variety heterosis varied from 22.67 per cent to -26.38 per cent. Heterosis over mid parent ranged from 53.42 per cent to -8.84 per cent. While better parent heterosis for this trait ranged between 48.60 per cent to -11.75 per cent. Out of the 21F1 hybrids, only two hybrid namely H-86 x CLNR and Pusa Rohini x CLNR was found to contain highly significant positive heterosis in desirable direction over standard variety, while all except one hybrid was found to contain highly significant positive heterosis in desirable direction over mid parent whereas eight hybrids was found to have positive significant heterosis in desirable direction over better parent.

Number of locules per fruit:

The range value for this character varied from -16.67 per cent to 119.44 per cent over the standard variety while it ranged between-40.68 per cent to 66.32 per cent over the mid parent. Whereas, the better parent heterosis varied from -40.68 per cent to 58 per cent. From all the 21F1 hybrids, none of them showed significantly high negative heterosis in desirable direction over standard variety. While 10 hybrid showed highly significant negative heterosis in desirable direction over mid parent and 11 hybrids showed significant negative heterosis in desirable direction over the better parent.

Pericarp thickness:

The range value for this character varied from -34.95 per cent to 22.06 per cent over the standard variety, while it ranges between -18.61 per cent to 27.60 per cent over the mid parent. Whereas the better parent heterosis varied between -26.28 per cent to 16.64 per cent. From all the 21F1 hybrids, only one hybrid namely Arka Alok x CLNB showed highly significant heterosis in desirable direction over standard variety. While 5 hybrid showed highly significant positive heterosis in desirable direction over mid parent and 2 hybrids showed significant positive heterosis in desirable direction over the better parent.

Average fruit weight (g):

For this trait, the extent of standard variety heterosis varied from -36.90 per cent to 62.25 per cent. Heterosis over mid parent ranged from -9.85 per cent to 26.18 per cent while over better parent this trait ranged from -9.92 per cent to 19.88 per cent. Out of the 21F1 hybrids, nine hybrids was found to contain highly significant positive heterosis in desirable direction over standard variety, while all except seven hybrid were found to contain highly significant positive heterosis in desirable direction over mid parent, whereas only two hybrids was found to have positive significant heterosis in desirable direction over better parent.

Fruit yield characters:

Number of fruits per plant:

For this trait, the extent of standard variety heterosis varied from -40.09 per cent to 21.65 per cent. Heterosis over mid parent ranged from-11.18 per cent to 35.54 per cent. While over better parent this trait ranged from -33.73 per cent to 15.89 per cent. Out of the 21F1 hybrids, only one hybrid namely CLNB x Pusa-120 was found to contain highly significant positive heterosis in desirable direction over standard variety, while five hybrids had significant positive heterosis over mid parent, whereas only one hybrids was found to have positive significant heterosis in desirable direction over better parent.

Fruit yield per plant (g):

For this trait, the extent of standard variety heterosis varied from -42.66 per cent to 22.94 per cent. Heterosis over mid parent ranged from -3.93 per cent to 65.52 per cent. While over better parent this trait ranged from -29.03 per cent to 39.01 per cent. Out of the 21F1 hybrids, five hybrids were found to contain highly significant positive heterosis in desirable direction over standard variety, while all hybrids except three were found highly significant positive heterosis over mid parent, whereas 12 hybrids were found to have positive significant

heterosis in desirable direction over better parent.

Biochemical characters:

Total soluble solids (%):

For total soluble solids content in tomato, the extent of standard variety, heterosis varied from -7.63 per cent to 25.95 per cent. The mid parent heterosis for this trait ranged from -6.56 per cent to 22.48 per cent. While over better parent this trait ranged from -11.64 per cent to 19.70 per cent. Out of the 21F1 hybrids 13 hybrids were found to contain highly significant positive heterosis in desirable direction over standard variety, while 12 hybrids were found to contain highly significant positive heterosis over mid parent whereas only 7 hybrid were found to contain highly significant positive heterosis in desirable direction over better parent.

Titrable acidity (%):

For titrable acidity, the range of heterosis varied from -28.86 per cent to 6.94 per cent over standard variety. The range of heterosis varied from -14.09 per cent to 13.02 per cent over the mid parent. While heterosis ranged from -21.76 per cent to 10.28 per cent over better parent. Among the 21F1 hybrids, the entire hybrids except four showed negative significant heterosis in desirable direction over standard variety. While 11 hybrids showed highly significant negative heterosis in desirable direction over mid parent and the entire hybrids except 3 showed highly significant negative heterosis in desirable direction over the better parent.

Ascorbic acid content (mg/100g fw):

For ascorbic acid content in tomato, the extent of standard variety, heterosis varied from -23.08 per cent to 23.53 per cent. The mid parent heterosis for this trait ranged from -8.60 per cent to 30.54 per cent. While over better parent this trait ranged from -24.11 per cent to 29.16 per cent. Out of the 21F1 hybrids 8 hybrids were found to contain highly significant positive heterosis in desirable direction over standard variety, while 8 hybrids were found to contain highly significant positive heterosis over mid parent whereas only 3 hybrids were found to contain highly significant positive heterosis in desirable direction over better parent.

Total phenol content (mg/gallic acid equivalent/ 100g fw):

For total phenol content in tomato, the extent of standard variety, heterosis varied from -0.14 per cent to 38.79 per cent. The mid parent heterosis in this trait ranged from -8.84 per cent to 10.74 per cent. While over better parent this trait ranged from -16.89 per cent to 10.17 per cent. Out of the 21F1 hybrids all hybrids except Arka Alok x Pusa-120 were found to contain highly significant positive heterosis in the desirable direction over standard variety, also the 16 hybrids were found to contain highly significant positive heterosis in the desirable direction over mid parent, while 7 hybrids were found to contain significant positive heterosis in desirable direction over better parent.

Lycopene content (mg/100g):

For total lycopene content the extent of standard variety, heterosis varied from -36.37 per cent to 46.49 per cent. The mid parent heterosis in this trait ranged from -28.39 per cent to 43.67 per cent. While over better parent this trait ranged from -37.26 per cent to 25.68 per cent. Out of the 21F1 hybrids 13 hybrids showed highly significant positive heterosis in the desirable direction over standard variety, also the 13 hybrids were found to contain highly significant positive heterosis in the desirable direction over mid parent, while 5 hybrids were found to contain significant positive heterosis in desirable direction over better parent.

Total carotenoid content (mg/100g):

For total carotenoids content the extent of standard variety, heterosis varied from -66.04 per cent to 25.95 per cent. The mid parent heterosis in this trait ranged from -33.66 per cent to 42.70 per cent. While over better parent this trait ranged from -39.99 per cent to 25.12 per cent. Out of the 21F1 hybrids 3 hybrids showed highly significant positive heterosis in the desirable direction over standard variety and 10 hybrids were found to contain highly significant positive heterosis in the desirable direction over mid parent, while 5 hybrids were found to contain significant positive heterosis in desirable direction over better parent.

Total antioxidant activity (pg/trollox equivalent/ 100g fw):

For total antioxidant activity, the extent of standard variety, heterosis varied from -41.03 per cent to 29.53 per cent. The mid parent heterosis in this trait ranged from -26.83 per cent to 33.60 per cent while over better parent this trait ranged from -34.79 per cent to 10.42 per

cent. Out of the 21F1 hybrids, 9 hybrids were found to contain highly significant positive heterosis in the desirable direction over standard variety, also the 13 hybrids were found to contain highly significant positive heterosis in the desirable direction over mid parent, while 5 hybrids were found to contain significant positive heterosis in desirable direction over better parent.

Estimation of combining ability:

General combining ability (GCA) effect of parents:

The combining ability effects revealed the genetic worth of different parents. The estimate of effect provides a measure of general combining ability of each parent. The effect based on GCA is of great importance in plant breeding programme.

Growth characters:

Plant height (*cm*):

Among parents, the positive and significant effect was displayed by Sel-12 and Pusa 120 whereas Pusa Rohini Arka Alok and CLNB showed negative significant GCA effect.

Days to first flowering:

Reproductive characters:

For this characters three parental lines *viz.*, H-86, Pusa Rohini and Sel-12 showed negative significant GCA effects in desirable direction.

Days to 50 per cent flowering:

For this characters three parental lines *viz.*, H-86, Pusa Rohini and Set-12 showed negative significant GCA effects in desirable direction.

Days to first fruit setting:

Earliness for days to first fruit harvest is most important character in tomato. For this characters three parental lines *viz.*, H-86, Pusa Rohini and Sel-12 showed negative significant GCA effects in desirable direction.

Fruit morphological characters:

Equatorial fruit diameter (*mm*):

Among seven parents H-86, Sel-12 and CLNR displayed significant positive GCA effect. Whereas Arka Alok, CLNB and Pusa 120 showed negative significant GCA effect.

Polar fruit diameter (mm):

The positive and highly significant GCA effect was expressed by H-86 Sel-12 and CLNR whereas CLNB and Pusa 120 showed negative significant GCA effect.

Number of locules per fruit:

Out of seven parental lines only two lines *viz.,* Pusa Rohini and CLNB were found as good general combiners for number of locules. While parent H-86 were identified as poor general combiners for number of locules per fruit.

Pericarp thickness (mm):

For pericarp thickness, estimates of positive GCA effect values are considered desirable. Three parental lines H-86 Pusa Rohini and Sel-12 exhibited this trend and were classified as the good general combiners.

Average fruit weight (g):

Significant GCA effects in positive direction was observed in parents H-86 followed by Arka Alok which showed good general combining ability whereas, Pusa Rohini, Arka Alok, CLNR, CLNB and Pusa 120 were poor general combiners with negative GCA effects.

Fruit yield characters:

Number of fruits per plant:

Among parents, CLNB showed significant GCA effect for number of fruits per plant, whereas H-86, Pusa Rohini, Pusa 120 were poor combiner for this character.

Fruit yield per plant (*g*):

The positive and highly significant GCA effect was expressed by H-86 Arka Alok and CLNB whereas Pusa Rohini Sel-12 CLNR and Pusa 120 showed negative significant GCA effect.

Yield per hectare (q/ha):

The positive and highly significant GCA effect was expressed by H-86 Arka Alok and CLNB whereas Pusa Rohini Sel-12 CLNR and Pusa 120 showed negative significant GCA effect.

Biochemical characters:

T.S.S. (°*Brix*):

Only three parent *viz.*, Pusa Rohini Sel-12 and CLNB were good combiner for this character.

Titrable acidity (%):

Out of seven parental lines only two lines *viz.*, Sel-12 and CLNB were found as good general combiners for titrable acidity. While parent H-86 were identified as poor general combiners.

Ascorbic acid content (mg/100gFW):

Significant GCA effects in positive direction was observed in parents H-86 followed by Pusa Rohini and Sel-12 which showed good general combining ability.

Lycopene content (mg/100g FW):

Significant GCA effects in positive direction was observed in parents Arka Alok followed by Pusa Rohini and CLNB which showed good general combining ability.

Total carotenoids content (mg/100g FW):

Significant GCA effects in positive direction was observed in parents Arka Alok followed by Pusa Rohini and CLNB which showed good general combining ability.

Total phenolics content (mg C.E./100g FW):

Significant GCA effects in positive direction was observed in parents Set-12 followed by CLNB which showed good general combining ability.

Total antioxidant capacity (ft mol/Te/G):

Significant GCA effects in positive direction was observed in parents CLNB followed by Sel-12 and Pusa Rohini which showed good general combining ability.

Specific combining ability effects:

The estimates of SCA effects of 21F1 crosses and their standard errors for different comparisons were studied for twenty metric traits. The SCA effects in negative direction was considered desirable for maturity traits *viz.*, days to first flowering, days to 50 per cent flowering and days to first fruit harvest. The character wise results are described as under.

Growth characters:

Plant height (*cm*):

The significant SCA effects were manifested in eight hybrids. The hybrid Sel-12 x Pusa-120 showed the maximum positive SCA effects followed by H-86 x Arka Alok and Sel-12 x CLNR for plant height.

Reproductive characters:

Days to first flowering:

The significant negative SCA effects for earliness were observed in fourteen cross combinations. The top three value of negative SCA effects were recorded by the crosses H-86 x Arka Alok followed by Pusa Rohini x CLNB and H-86 x CLNB. Four hybrids showed positive and significant values of SCA effects for this character.

Days to 50 per cent flowering :

Among the 21 F1 hybrids, four showed significant and negative SCA effects in desirable direction. The crosses H-86xArka Alok followed by Pusa Rohini x CLNB and H-86 x CLNB were found as the top three specific combiners for earliest days to 50 per cent flowering.

Days to first fruit setting:

The SCA estimates were significantly negative and desirable in six hybrids. The best three promising crosses in order of performance for earliness were Pusa Rohini x CLNB, H-86 x Arka Alok and 1-1-86 x CLNB. The significant and positive SCA effects for lateness were also observed in three F_1 hybrids with maximum value for H-86 x Pusa Rohini.

Fruit morphological characters:

Equatorial fruit diameter (*mm*):

Among the 21 crosses combinations, the values of SCA effects revealed that six crosses exhibited positive and significant SCA effects.Three crosses namely H-86 x Pusa Rohini, Se1-12xPusa-120 and Pusa Rohini x CLNR possessed significant positive SCA effects in order of merit. Cross Pusa Rohini x Pusa 120 was found as the best negative specific combination for equatorial fruit diameter.

Polar fruit diameter (mm):

The significant SCA effects were manifested in five hybrids. The hybrid H-86 x CLNR showed the maximum positive SCA effects followed by Pusa Rohini x CLNR and Se1-12xPusa-120 for polar fruit diameter. Cross H-86 x Pusa 120 was found as the best specific combination for shorter fruit length.

Number of locules per fruit:

Total eight crosses displayed positive and significant

SCA effect ranged from 0.45 to 1.72. H-86xCLNR exhibited the maximum positive SCA effect followed by Arka AlokxPusa-120, Sel-12 x Arka Alok. The negative and significant SCA effect varied from H-86 x Arka Alok to Arka x CLNB.

Pericarp thickness:

Total five crosses displayed positive and significant SCA effect, Sel-12 x Pusa-120 exhibited maximum positive SCA effect followed by H-86xCLNR, Arka AlokxPusa-120.

Average fruit weight (g):

The estimates of SCA effects indicated that six cross combinations showed significant values for higher fruit weight.On the other hand six crosses showed negative estimates of SCA effects with significant values. Crosses H-86x Sel-12, H-86xPusa-120 and Arka Alok x CLNR were identified top three specific combiner for average fruit weight.

Fruit yield characters:

Number of fruits per plant:

For fruits per plant, the significant values of positive and negative SCA effects were manifested in three hybrids. The hybrid CLNBxPusa-120, H-86xPusa Rohini and CLNRxPusa-120 were identified as three top specific combiners for higher number of fruits (Table 2).

Fruit yield per plant (g):

Out of 21F1 hybrids, eight showed positive significant SCA effects. Crosses Arka Alok x CLNB, H-86xPusa Rohini and H-86xSe1-12 were the most promising combinations for fruit yield. On the other hand, two crosses showed negative estimates of SCA effects with significant values. The highest negative estimates of SCA effects was observed in cross Pusa Rohini x Arka Alok.

Fruit yield (q/ha):

Out of 21F1 hybrids, eight showed positive significant SCA effects. Crosses Arka Alok x CLNB, H-86xPusa Rohini and H-86 x Se1-12 were the most promising combinations for fruit yield. On the other hand, two crosses showed negative estimates of SCA effects with significant values. The highest negative estimates of SCA effects was observed in cross Pusa Rohini x Arka Alok.

Biochemical characters:

T.S.S (*°Brix*):

The significant and positive SCA effect ranged from 0.26 to 0.61. Highest significant and positive SCA effects were exhibited by Pusa Rohini x CLNR followed by Pusa Rohini x Sel-12, and Sel-12xCLNB.

Titrable acidity (%):

The significant negative SCA effects for titrable acidity were observed in ten cross combinations. The top three value of negative SCA effects were recorded by the crosses H-86xPusa-120 followed by H-86 x CLNR and Pusa RohinixCLNR. Ten hybrids showed positive and significant values of SCA effects for this character.

Ascorbic acid content (mg/100gFW):

The estimates of SCA effects indicated that nine cross combinations showed significant values for higher ascorbic acid content. On the other hand nine crosses showed negative estimates of SCA effects with significant values. Crosses CLNR x CLNB, Pusa Rohini x CLNR and Arka Alok x CLNB were identified top three specific combiner for ascorbic acid content.

Lycopene content (mg/100g FW):

The estimates of SCA effects indicated that nine cross combinations showed significant values for higher lycopene content. On the other hand five crosses showed negative estimates of SCA effects with significant values. Crosses Pusa Rohini x Pusa-120, H-86 x Arka Alok and Pusa Rohini x CLNR were identified top three specific combiner for lycopene content.

Total carotenoids content (mg/100g FW):

The estimates of SCA effects indicated that 12 cross combinations showed significant values for high total carotenoids content. On the other hand nine crosses showed negative estimates of SCA effects with significant values. Crosses Pusa Rohini x CLNR, Arka Alok x CLNR and H-86 x Pusa Rohini were identified top three specific combiner for total carotenoids content.

Total phenolics content (mg C.E./100g FW):

The estimates of SCA effects indicated that sixteen cross combinations showed significant values for higher total phenolics content. On the other hand five crosses

showed negative estimates of SCA effects with significant values. Crosses Sel-12 x Pusa-120, H-86 x CLNR and Set-12 x Arka Alok were identified top three specific combiner for ascorbic acid content.

Total antioxidant capacity (11, mol/Te/G):

The estimates of SCA effects indicated that eleven cross combinations showed significant values for higher total antioxidant. On the other hand ten crosses showed negative estimates of SCA effects with significant values. Crosses Pusa Rohini x CLNR, Arka Alok x CLNB and CLNR x Pusa-120 were identified top three specific combiner for total antioxidant.

Inter-relationship studies:

Correlation studies for yield and quality attributing traits:

Days to first flowering had shown high significant positive correlation with days to days to 50 per cent flowering, days to 1st fruit set number of fruit per plant and it also showed significant positive correlation with plant height and number of locules per fruit. It had high significant but negative correlation with pericarp thickness, total soluble solids, ascorbic acid content, total phenolic content, total antioxidant and lycopene content. Days to 50 per cent flowering had shown high significant positive correlation with days to 1st fruit set number of fruit per plant and it also showed significant positive correlation with number of locules per fruit. It had high significant but negative correlation with pericarp thickness, total soluble solids, ascorbic acid content, total phenolic content, total antioxidant and lycopene content. Days to first fruit setting had shown non-significant positive correlation with number of fruit per plant, plant height and number of locules per fruit. It had high significant but negative correlation with fruit yield per plant, total fruit yield, average fruit weight, pericarp thickness, total soluble solids, ascorbic acid content, total phenolic content, total antioxidant and lycopene content. Number of fruits per plant had highly significant positive correlation with total soluble solids, total phenolic content, total antioxidant and it also showed significant with fruit yield per plant total, fruit yield. It had high significant but negative correlation with average fruit weight, equatorial fruit diameter, number of locules per fruit, pericarp thickness, titrable acidity and ascorbic acid content. Fruit yield per plant had highly significant positive correlation with average fruit weight primary branches per plant titrable acidity and it also showed significant with polar fruit diameter, equatorial fruit diameter, ascorbic acid content. Average fruit weight had highly significant positive correlation with polar fruit diameter, equatorial fruit diameter and number of locules per fruit, pericarp thickness, titrable acidity and ascorbic acid content. It had high significant but negative correlation with total soluble solids. Correlation studies revealed that plant height showed high significant and positive correlation with polar fruit diameter, equatorial fruit diameter pericarp thickness and significant with ascorbic acid content. Polar fruit diameter had highly significant positive correlation with equatorial fruit diameter, number of locules per fruit, pericarp thickness and significant with ascorbic acid content. Equatorial fruit diameter had highly significant positive correlation with number of locules per fruit, pericarp thickness, titrable acidity and ascorbic acid content. It had high significant but negative correlation with lycopene content. Number of locule per fruit had highly significant positive correlation with pericarp thickness and it had high significant but negative correlation with total antioxidant and lycopene content. Pericarp thickness had highly significant positive correlation with ascorbic acid content and it had significant but negative correlation with total antioxidant content, lycopene content and total carotenoid content. Total soluble solids had highly significant positive correlation with total phenolic content, total antioxidant, lycopene content and total carotenoid content. It had high significant but negative correlation with titrable acidity. Titrable acidity had highly significant negative correlation with total phenolic content, total antioxidant, lycopene content and total carotenoid content. It had non-significant but positive correlation with ascorbic acid content. Ascorbic acidity had highly significant positive correlation with total phenolic content, total antioxidant, lycopene content and total carotenoid content and it had significant positive correlation with lycopene content. Total phenolic content had highly significant positive correlation with total antioxidant, lycopene content and total carotenoid content. Total antioxidant content had highly significant positive correlation with lycopene content and total carotenoid content. Lycopene content had highly significant positive correlation with total carotenoid content.

Path co-efficient analysis:

Direct effect:

The data revealed that out of twenty characters, only one character average fruit weight had very high positive direct effect on fruit yield per plant at both genotypic and phenotypic level. The characters which had positive high direct effect were number of fruits per plant, days to first fruit setting and equatorial fruit diameter while it showed positive moderate direct effect with days to first flowering, low direct effect with total soluble solids and lycopene content, very low direct effect with number of locule per fruit. However, days to 50 per cent flowering, plant height, polar fruit diameter, pericarp thickness, titrable acidity, ascorbic acid content, total phenolic content, total antioxidant, total carotenoid content showed negative direct effect on fruit yield per plant.

Indirect effect:

Fruit yield per plant, TSS and plant height influenced the fruit yield per plant positively and indirectly at both phenotypic and genotypic levels. However, the indirect negative effect on fruit yield per plant was exhibited by days to first fruit set.

Residual effect:

The residual effect appeared too small *i.e.*, 06.73 per cent which indicated that 93.27 per cent yield attributing characters had been account. This research was conducted at research farm of Department of Horticulture, Bhagwant University, Ajmer Rajasthan during *Rabi* season, 2015-17. The present study contained evaluation of 21 tomato hybrids including two checks *viz.*, BSS-488. The observations were recorded for 18 important morphological traits, bioactive compound. The quantitative traits were days to first flowering, days to 50 per cent flowering, first fruit setting, plant height average fruit weight equatorial fruit diameter, polar fruit diameter, number of fruits per plant, number of locules per fruit, yield per plant fruit yield. Plant type, nature of stigma, fruit shape and fruit colour. Biochemical traits were total soluble solids, titratable acidity, ascorbic acid content, lycopene content, total carotenoids content, total phenolics content total and antioxidant capacity.

Genetic variability, heritability and genetic advance:

The knowledge of heritability of character is important to the breeder since it indicates the possibility and extant to which improvement is possible through selection. High heritability alone is not enough to make efficient selection in the advanced generations unless accompanied by substantial amount of genetic advance. Genetic advance is another important selection parameter, which is although independent and presents the expected genetic advance under selection. In this study phenotypic coefficient of variation was slightly higher than its corresponding genotypic co-efficient of variations. Highest GCV and PCV value observed in average fruit weight and fruit yield per plant, plant height, respectively. GCV and PCV for total soluble solids were 7.91 and 8.26 per cent, respectively. High phenotypic co-efficient of variation for number of locules per fruit was noticed.

Heterosis and combining ability:

Heterosis:

The results of heterosis attained and range of mean values of parents, F_1 hybrids and range of heterosis indicating three best F_1 hybrids and the three most heterotic crosses with respect to important economic traits of interest have been discussed in following paragraphs. The nature and magnitude of heterosis differed for different traits in various hybrid combinations. A close examination of heterotic values of the 3 maturity traits for earliness *viz.*, days to first flowering, days to 50 per cent flowering and days to first fruit set, revealed that only a few F_1 hybrids exhibited significant but very low level of heterosis in desirable direction for all these characters. For maturity traits, negative heterosis is usually desirable, because this will cause the hybrids to produce first fruits earlier as compared to parents, thereby increasing the productivity per day per unit area. The best performing F_1 hybrid regarding earliness based on performance over both better parent and standard parent was Pusa Rohini x CLNB for days to first flowering was -23.08 per cent and -24.73 per cent, respectively while desirable heterosis for days to first fruit set of this best performing F_1 hybrid was -21.03 per cent and -23.18 per cent, respectively. Another cross *i.e.* H-86 x Arka Alok, H-86 x CLNB also found to be having heterosis in desirable direction over better parent for days to first flowering, 50 per cent flowering, respectively while over standard parent it was having a low positive value which also denotes the at par nature of this hybrid. Therefore, it can surely be concluded that any of the three best parents *i.e.*, Sel-12, Pusa Rohini and H-86 may be a better choice in heterosis breeding programme intended to breed for early hybrids. Fruits per plant are one of the

most important components of fruit yield in respect of which hybrids with positive heterosis are desirable. The findings of the present study revealed that cross *i.e.*, CLNB x Pusa-120 expressed high significant heterosis in desirable direction over standard variety. While 5 crosses showed very strong heterosis for number of fruit per plant over the mid parent CLNB x Pusa-120, H-86 x Pusa Rohini, H-86 x Pusa-120, Sel-12 x Pusa-120, Sel-12 x Pusa-120 and CLNR x Pusa-120. In general, the hybrids with significant heterosis for yield also expressed significant heterosis either for fruit weight or for fruits per plant. Along with the fruit yield, fruit quality is also equally important for enhancing the appearance and nutritive value of a crop so the present study also focuses on quality aspect in tomato as it is also a rich source of many important metabolites which is required for a healthy diet. The improvement in heterosis for quality component may not necessarily be reflected in increased yield so we have to compromise yield so to get a good quality of tomato crop. Standard heterosis for quality traits of high value *viz.*, total soluble solids, ascorbic acid content, total phenolic content, total antioxidant capacity, lycopene content and also total carotenoids content were found to be having high significant over the best standard check variety BSS-488, thereby depicting superiority of F_1 hybrids over the best standard check for all the above mentioned quality traits. Considering the heterosis over standard variety, the top ranking Fi hybrids for the above mentioned quality characters are as follows Pusa Rohini x Sel-12 for total soluble solids content, H-86 x Pusa Rohini for ascorbic acid content, Set-12 x CLNB for total phenolic content, Arka Alok x CLNB for total antioxidant capacity, Pusa Rohini x Arka Alok for lycopene content as well as for total carotenoids content. While none of the crosses showed significant positive heterosis in desirable direction over standard variety for titrable acidity. The above finding indicated that some parental lines have strong heterotic capability compared to other ones during hybridization process. This may be due to diverse parent and favourable cross combination. As the performance of hybrids developed upon the heterotic capability of the parents involved, from economic point of view it will be useful to select and utilize the parental lines with strong heterotic capability for important traits associated with yield in order to achieve higher fruit yield in F_1 hybrids through exploitation of heterosis. Since earliness, biochemical characters and desirable fruit shape are the important considerations for choice of elite high quality F_1 hybrids, so the decision for final selection of a hybrid for commercial cultivation should also take into account the earlier two factors *i.e* earliness along with the latter *i.e.* high fruit quality so to exploit an ideal Fi hybrid in tomato that can suit not only for our countries market in general but can also suits according to the international market demand for export. Out of all the 21 hybrids so generated the overall best performing hybrid in terms of both total fruit yield and quality basis was Arka Alok x CLNB which can be considered the best based on present market demand.

Combining ability:

The concept of combining ability has gained prominence in plant breeding as it provides a means of understanding the nature of gene action for selecting suitable breeding procedure. It is especially a useful testing procedure, which is used to study and compare the performance of genotypes in hybrid combinations. The information obtained is useful in selecting the parental lines for future breeding programmes and to decide the breeding procedures to be adopted. The combining ability effects reveal the genetic worth of different parents. The estimates of GCA effects provide a measure of general combining ability of each parent. The effects based on GCA are of great importance in plant breeding programmes. The effects based on SCA are non-fixable and high value of SCA indicates that the combination did relatively better than other. Specific combining ability reveals, on the other hand, the best cross combination among the genotypes that could be used for developing hybrids with high vigour for the respective traits. The SCA effects are found to be significant yield components. For all the 19 characters studied, the crosses with significant SCA effects involved parents with high x high, high x low, low x high or low x low GCA effects. In general, the hybrids with significant SCA effects in the desired direction involve parents with either high x high or high x low or low x low GCA effects, indicating high performance of these crosses due to additive, dominance or epistatic gene interaction. The ideal cross combination to be exploited is one where high magnitude of SCA is present in addition to high GCA in both or at least one of the parents.

General combining ability:

A perusal of the general combining ability (GCA) effects for parents revealed that, none of the parents

was good general combiner for all the characters. However, for earliness characters parents like Sel-12 and Pusa Rohini proved to be good general combiners for the characters like days to first flowering and days to 50 per cent flowering, respectively, while for days to first fruiting H-86 proved to be earlier. Whereas H-86 found to be good general combiner in terms of average fruit weight, polar fruit diameter, equatorial fruit diameter, fruit yield per plant. While CLNB and Sel-12 found to be the best general combiner for number of fruit per plant. If we talk about the bio-chemical characters then Sel-12 and Pusa Rohini proved to be the best general combiner for both total soluble solids and ascorbic acid content. Sel-12 also for total phenol content, CLNB for total antioxidant capacity, Arka Alok found best for both lycopene content and total carotenoids content. Hence, these two parents CLNB, Arka Alok, may be used extensively in breeding programme aimed at the development of high yielding with quality tomato hybrids.

Specific combining ability:

In the present study, the entire cross combinations showed significant and positive SCA effect for most of the characters. However, all the crosses displayed significant positive SCA effect in desirable direction for one or few traits. Out of 21 crosses it was concluded that Sel-12 x Pusa-120 was good specific combiner for plant height while CLNR x Pusa-120 produced good combining effect for number of primary branches, CLNB x Pusa-120 for number of fruits per plant, H-86 x Sel-12 for average fruit weight, H-86 x CLNR for polar fruit diameter, H-86 x Pusa Rohini for equatorial fruit diameter and Pusa Rohini x CLNR for TSS. On the basis of specific combining ability effect across seven characters, CLNB x Pusa-120, H-86 x Se1-12and Pusa Rohini x CLNR could be considered as most promising parent, as it has been good specific combiner for most of the characters.

Correlation co-efficient:

The knowledge of association of various characters related to yield is important for future improvement in a complex polygenic character through selection. The present study discloses that in general, genotypic correlation co-efficient were higher than their phenotypic ones. The genetic improvement in fruit yield is not possible without bringing an improvement in the yield component characters. The inclusion of various component characters in a selection scheme is obviously not practicable and under these situations, knowledge with respect to relationship of various traits with fruit yield and quality parameters would be of great help in formulating an effective and efficient selection. Genotypic and phenotypic correlation co-efficients were calculated by standard procedures. Fruit yield showed positive significant association with average fruit weight polar fruit diameter, number of locules per fruit, at 1 per cent and 5 per cent level of significance. Fruit yield showed negative significant association with fruit setting per cent, total antioxidant capacity, lycopene content, at 1 per cent level of significance while, total carotenoids content at 5 per cent level of significance. Characters like days to first flowering, days to 50 per cent flowering, number of fruits per plant, total soluble solids, titratable acidity, ascorbic acid and total phenolics content showed non-significant correlation with fruit yield. Moreover, average fruit weight had highly significant positive correlation with equatorial fruit diameter. Equatorial fruit diameter exhibited highly significant positive correlation with polar fruit diameter.

Path co-efficient analysis:

Path co-efficient analysis facilitates the partitioning of correlation co-efficients into direct and indirect effects of various characters on yield its attributing traits and quality. Therefore, information on the cause and effect of various yield and quality attributes and the relative importance of their direct and indirect effects on yield and quality in tomato are essential in crop improvement programme. Correlation studies in conjunction with path co-efficient analysis revealed a better picture of the cause and effect relationship of different attributes.

Path co-efficient analysis in relation to total fruit yield (q/ha):

Total fruit yield is the product of interaction of components traits. Path analysis is important to obtain information about different ways in which component characters influence yield. Direct effects of any character on yield gives idea about how reliable selection can be made for particular character to bring improvement in yield, if a correlation between a causal factor and direct effect is more or less of equal magnitude, it explain true relationship between character and direct selection through this trait will be effective. In the present study, the path co-efficients analysis indicated that number of fruits per plant expressed high positive direct influences

on yield at both genotypic and phenotypic levels. Based on direct and indirect effects of different yield components on total fruit yield, it appears that weight of fruit had high high heritability with genetic advance and high direct contribution towards yield at both genotypic and phenotypic levels. But on genotypic level, path co-efficient analysis revealed that number of fruits per plant, days to 1st harvest, number of primary branches per plant and fruit length expressed direct positive influences on yield but days to 1st harvest, days to first flowering, plant height and days to 50 per cent flowering had direct negative effect on yield. The residual effect *i.e.* unexplained variations for genotypic path in relation to total yield were 0.0673, by this value it is envisaged that 93.7 per cent variation in total fruit yield at phenotypic level had been determined It further spokes about presence of some factors, which were not considered here and need to include specifying the variation in total fruit yield of tomato.

Path co-efficient analysis in relation to total antioxidant capacity:

At both genotypic and phenotypic level, path co-efficient analysis revealed that total soluble solids expressed direct positive influences on ascorbic acid, total phenol content, total antioxidant capacity, lycopene content and total carotenoids content but titrable acidity had direct negative effect on total soluble solids. From this study, fruits yield per plant and lycopene content emerged as the most important trait in relation to total soluble solids in tomato and these characters may be used as important selection parameters because of their probable conditioning by additive gene action.

Conclusion :

Half diallel analysis was carried out using seven parents with a view to study the genetic variability, heritability, genetic advance, heterosis, combining ability, correlation and path analysis of 21 tomato hybrids along with 2 checks that were being evaluated during *Rabi* 2016-17. The seedling was transplanted on 17th October, 2016 in the Randomized Block Design with three replications. The observations were recorded for 19 characters namely days to first flowering, days to 50 per cent flowering, days to first fruit set, plant height average fruit weight equatorial fruit diameter polar fruit diameter no. of fruits per plant, number of locules per fruit, fruit yield per plant, total fruit yield, total soluble solids, titratable acidity ascorbic acid content, lycopene content, total carotenoids content total phenol content and total antioxidant capacity. The analysis of variance for design of experiment, mean performance of crosses, parents and checks, studies on correlation and path analysis in relation to total yield and total soluble solids, estimation of heterosis, estimation of GCA and SCA effects, studies were done for above mentioned characters.

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