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GENETIC VARIABILITY AND CHARACTER ASSOCIATION IN TOMATO (*SOLANUM LYCOPERSICUM* L.)

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Abstract

The genetic variability and character association among important yield and attributing traits was studied in 20 genotypes of tomato. The magnus of the phenotypic coefficient of variation (PCV) for all characteristics was higher than the magnitude of the genotypic coefficient of variation (GCV). High PCV, GCV, and heritability accompanied by high genetic advance as per cent of mean was recorded for the number of fruits per plant, average fruit weight, number of flower clusters/plant, number of fruits per cluster, plant height, number of flowers per cluster and locule number, polar diameter, equatorial diameter, pericarp thickness, fruit yield/plant. Therefore, selection in early generations would be effective in the improvement of these traits. The trait inter-relationship studies revealed that for aiming at high-yielding tomato genotypes, selection based on average fruit weight, number of fruits per plant, polar and equatorial diameter, plant height, number of primary branches, days to 50% flowering, and days to the first harvest would be effective.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most essential solanaceous vegetable crops widely grown for its edible fruits all over the world. With the chromosome number 2n = 2x = 24, it is a native of Peru. In India, it is known as the poor man's orange, while in England, it is known as the love of apple. Tomatoes are day-neutral annual herbaceous plants that are highly self-pollinated in nature due to chasmogamy. Cultivated tomatoes are said to have originated in Mexico, whereas wild tomatoes are said to have originated in the Peru-Ecuador area (Jenkins 1948). The Solanaceae genealogical taxonomy has recently been amended, with the genus *Lycopersicon* being reintegrated into the *Solanum* genus with its new classification and cultivar *Solanum lycopersicum* L. (Peralta *et al.* 2008).

Tomato is a versatile crop that may be used in a variety of ways in the kitchen. Ripe fresh tomatoes are eaten raw in salads and used in a variety of processed foods such as ketchup, puree, paste, chutney, and pickles. It is a good supplier of lycopene and ascorbic acid, antioxidants, and chemo-protective chemicals; therefore, it may be called functional food (Akhtar and Hazra 2013). Tomatoes come in two types: determinate and indeterminate, and they may be grown in both open fields and greenhouses. There are around 3000 species in the *Solanum* genus, and tomatoes are the lycopene producing species among them. The only cultivated species of tomato, *Solanum lycopersicum*, is included in Section *Lycopersicum,* along with a dozen additional wild relatives (Kalloo 2012).

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India is second only to China in terms of area (809 thousand ha) and production (19697 MT) of tomato, but its productivity (24.36 ton/ha) is far lower than that of several other major producing countries. Andhra Pradesh, Madhya Pradesh, Karnataka, Telangana, and Gujarat are the leading tomato-producing states in India. Tomatoes are mostly exported from India to Pakistan, the United Arab Emirates, and Bangladesh (Anonymous 2017). Tomatoes are one of the most important vegetables produced in Bihar, with a total area of 46.27 thousand hectares, a production of 1011 metric tonnes, and a productivity of 21.85 tonnes per hectare (Anonymous 2017). In Bihar, tomato is mainly grown in Patna, Bhojpur, Bhagalpur, Aurangabad, Nalanda, Purbi Champaran Muzaffarpur, and Madhubani (Anonymous 2017).

Variability among the genotypes is the pre-requisite of any breeding program. High variability among yield and yield-attributing traits and quality parameters favors selection of elite genotypes. Moreover, high heritability along with high genetic gain as per cent of mean gives a clearer picture of selection procedure as it directs towards the contribution of the additive gene in the expression of any trait. In the current investigation, genetic variability was studied in 20 tomato genotypes and the trait inter-relationship among twenty-one yield and quality attributing traits was also investigated.

Materials and Methods

Twenty tomato genotypes were grown in the autumn-winter season of 2019-20 and 2020-21 at the Vegetable Research Farm, Bihar Agricultural University in randomized block design with three replications. The details of the plant materials used are presented in Table 1. Twenty-one yield and attributing traits and quality parameters were recorded. The yield-attributing traits included plant height, number of primary branches/plant, days to first flowering, days to 50% flowering, days to first fruit setting, days to first harvest, number of flower cluster/plant, number of flowers per cluster, number of fruits per cluster, number of fruit per plant, average fruit weight, polar diameter, equatorial diameter, fruit shape index, locule number, pericarp thickness, and fruit yield per plant. The quality parameters included total soluble solids (TSS), lycopene, beta-carotene, and total carotenoid content of the fruits. The genotypic coefficient of variance (GCV) and phenotypic coefficient of variance (PCV) were estimated according to Comstock and Robinson (1952). On the other hand, the estimation of heritability was done according to Lush (1940) and predicted genetic advance as per the method suggested by Lush (1949) and Johnson *et al.* (1955). The correlation analysis was done as per Al-Jibouri *et al.* (1958) and the path analysis was according to Dewey and Lu (1959).

Results and Discussion

The genetic variability estimates for different traits are genetic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, genetic advance and genetic advance as a per cent of mean which have been depicted in Table 2. The coefficient of genotypic and phenotypic variability is a useful tool for determining the degree of variability in a given characteristic. They also serve as a metric for comparing the degree of variability among distinct quantitative features. The magnitude of the phenotypic coefficient of variation (PCV) for all characteristics was larger than the magnitude of the genotypic coefficient of variation (GCV) (Table 2). Ahirwar *et al.* (2013), Kumar *et al.* (2016) and Pandey *et al.* (2018) also reported higher values of PCV compared to GCV. The higher PCV values in comparison to the GCV values suggested that there was some influence of environment on all the traits under study as reported previously by Dar and Sharma (2011).

Table 1. List of tomato genotypes used with their sources.

Sl. No.	Genotypes	Source
01	H-86	IIVR, Varanasi
02	BRDT-1	BAU, Sabour
03	Superbug SPS	IIVR, Varanasi
04	Arka Vikas	IIHR, Bengaluru
05	Arka Alok	IIHR, Bengaluru
06	CLNB	BCKV, WB
07	CLN1621L	IIVR, Varanasi
08	SEL-18	IIVR, Varanasi
09	Sun Cherry	IIVR, Varanasi
10	IIHR 2614	IIHR, Bengaluru
11	IIHR 2612	IIHR, Bengaluru
12	Kashi Aman	IIVR, Varanasi
13	Pusa Rohini	IIVR, Varanasi
14	Kashi Chayan	IIVR, Varanasi
15	VRTOLCV-16	IIVR, Varanasi
16	VRTOLCV-32	IIVR, Varanasi
17	H-88-78-1	IIVR, Varanasi
18	2017/TODVAR-05	AICRP-VC, BAU, Sabour
19	2017/TODVAR-07	AICRP-VC, BAU, Sabour
20	2017/TODVAR-10	AICRP-VC, BAU, Sabour

Table 2. Estimates of genetic variability for different characters.

Sl. No.	Characters	GCV (%)	PCV (%)	Estimated heritability (h^2bs) (%)	GA	GAV %
01.	Plant height (cm)	24.86	25.32	96.39	48.50	50.28
02.	Number of primary branches/plant	16.26	20.40	63.48	2.27	26.68
03.	Days to first flowering	17.56	19.02	85.16	9.80	33.37
04.	Days to 50% flowering	14.62	15.48	89.16	10.63	28.43
05.	Days to first fruit setting	9.96	10.97	82.34	7.42	18.61
06.	Days to first harvest	8.75	9.86	78.86	16.36	16.01
07.	Number of flower cluster/plant	42.17	42.81	97.04	44.25	85.58
08.	Number of flowers per cluster	27.52	31.09	78.33	3.94	50.17
09.	Number of fruits per cluster	40.70	42.10	93.44	4.53	81.04
10.	Number of fruit per plant	72.78	73.01	99.37	63.37	149.45
11.	Average fruit weight (g)	42.51	42.65	99.34	48.66	87.28
12.	Polar diameter (mm)	22.47	22.71	97.99	21.40	45.83
13.	Equatorial diameter (mm)	22.36	22.89	95.42	20.71	44.99
14.	Fruit shape index	18.12	18.96	91.33	0.37	35.68
15.	Locule number	25.44	28.04	82.36	1.31	47.57
16.	Pericarp thickness (mm)	22.28	22.80	95.44	2.23	44.83
17.	Total Soluble Solids (°Brix)	6.66	7.67	75.28	0.63	11.90
18.	Lycopene content (mg/100g FW)	19.59	21.46	83.29	1.45	36.83
19.	β-carotene (mg/100g FW)	24.23	25.97	87.00	0.35	46.55
20.	Carotenoid (mg/100g FW)	19.04	20.52	86.07	1.90	36.39
21.	Fruit yield/plant (g)	15.14	15.78	92.05	537.40	29.92

GCV (Genotypic Coefficient of Variations), PCV (Phenotypic Coefficient of Variations), GA (Genetic Advance), GAV (Genetic Advance value % means).

Sivasubramanyan and Madhavamenon (1973) classified GCV and PCV into low when less than 10%, moderate when 10-20%, and high when greater than 20%. Both PCV and GCV were high for fruit per plant, average fruit weight (g), number of flower cluster/plant, number of fruits per cluster, number of flowers per cluster and locule number, plant height, β-carotene, polar diameter, equatorial diameter, and pericarp thickness; PCV was high and GCV was moderate for lycopene content, total carotenoids and number of primary branches; moderate PCV and GCV were observed for fruit shape index, days to first flowering, fruit yield/plant and days to 50% flowering; both were low for TSS, and days to first harvest; moderate PCV and low GCV was observed for days to first fruit setting. Dar and Sharma (2011) previously observed high values of GCV and PCV for fruit number/plant, total yield, and beta-carotene, while Prema *et al.* (2011) observed the same for lycopene content, polar diameter, and equatorial diameter of fruits, TSS of fruit.

Heritability and genetic advance were regarded as important selection parameters. Genetic variation along with heritability estimate would give a better idea about the efficiency of the selection. Estimation of heritability becomes important when genotypic coefficients of variation offer information about the amount of variation present for a certain trait among genotypes. The heritability of a character is the proportion of its variability that is passed on to offspring. Heritability estimates were classified into low, when less than 30%, moderate when 30-60%, and high when greater than 60% as per Johnson *et al.* (1955). Heritability was high for all the traits under study suggesting a predominance of additive gene action for the traits. Ara *et al.* (2009), Agarwal *et al.* (2014), Bhandari *et al.* (2017) also reported similar findings earlier.

When the estimate of genetic advance accompanies heritability, then the prediction of genetic gain under selection is more accurate (Johnson *et al.* 1955). The classification of genetic advance as per cent of mean has been given by Johnson *et al.* (1955) as low, when less than 10%, moderate when 10-20% and high when greater than 20%. Except days to first fruit setting, days to first fruit harvest, and TSS which exhibited moderate values for genetic advance as percent of mean, it was high for all traits (Table 2). When high heritability is accompanied with high genetic advance, it suggests preponderance of additive gene action and in such case selection would be effective. On the other hand, high heritability along with low genetic advance is resultant of non-additive gene action and the selection would be ineffective. Low heritability coupled with high genetic advance suggests additive gene effect in governance of the trait, but high interference of environment in expression of the trait and therefore selection in early generation would be ineffective. However, selection in the later generations might be effective in such cases. If low heritability is observed along with low genetic advance, then the character is predisposed to environmental effects leading to ineffective selection. Burton and De Vane (1953) proposed that genetic coefficients of variability, together with heritability estimates, may be used to predict the degree of improvement predicted by selection. High PCV, GCV, heritability accompanied with high genetic advance as percent of mean was recorded for number of fruit per plant, average fruit weight, number of flower cluster/plant, number of fruits per cluster, plant height, number of flowers per cluster and locule number, polar diameter, equatorial diameter, pericarp thickness, fruit yield/plant (Table 2). In these traits Singh *et al.* (2018) also observed high PCV and GCV with high heritability and genetic gain for number of fruits/plant, locule number and average fruit weight. High heritability for fruit weight, number of locules/fruit and yield of fruit was previously observed by Golani *et al.* (2007). Rai *et al.* (2016) noticed high heritability with high genetic gain for number of fruits per plant, average fruit weight, fruit yield per plant and lycopene content. Thus, selection in early generations would be effective in improvement of these traits.

The knowledge of the nature and magnitude of inter-relationship among yield and its components is very important for the simultaneous improvement of the characters and thus become necessary for effective and successful breeding program. An understanding of the correlation between contributing traits and their relative contribution to yield is essential to bring a rational improvement in desirable traits. In the present study the phenotypic and genotypic correlation coefficients were worked out in respect of twenty characters in all possible combinations and have been shown in Tables 3 and 4, respectively. In general, it was found that genotypic correlation coefficients were higher in magnitude than their corresponding phenotypic values. The values of genotypic correlation coefficients were higher than phenotypic correlation

Table 3. Phenotypic correlation among twenty-one characters in twenty tomato genotypes.

Ch	NPB	DFF	D50F	DFS	DFH	NFCPP	NFPC	NFrPC	NFPP	AFW
PH	0.407**	-0.351**	-0.367**	-0.426**	-0.414**	0.714**	0.524**	0.584**	0.791**	-0.494**
NPB		-0.402**	-0.461**	-0.330**	-0.445**	0.353**	0.321*	0.360**	0.523**	-0.605**
DFF			0.920**	0.863**	0.852**	-0.525**	-0.568**	-0.571**	-0.682**	0.731**
D50F				0.821**	0.854**	-0.410**	-0.607**	-0.580**	-0.698**	0.825**
DFS					0.753**	-0.475**	-0.555**	-0.564**	-0.677**	0.721**
DFH						-0.519**	-0.557**	-0.561**	-0.673**	0.741**
NFCP							0.634**	0.765**	0.817**	-0.498**
NFPC								0.907**	0.734**	-0.671**
NFrPC									0.815**	-0.699**
NFPP										-0.814**
AFW										
PD										
ED										
FrSI										
LC										
PT										
TSS										
LYC										
BC										

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PD	ED	P/E	LC	PT	TSS	LYC	BC	Caro	FYPP
-0.669**	-0.532**	-0.241^{NS}	-0.139^{NS}	-0.709**	0.295*	0.349**	0.233^{NS}	0.337**	-0.459**
-0.646**	-0.499**	-0.265*	-0.154^{NS}	-0.495**	0.181^{NS}	0.190^{NS}	0.167^{NS}	0.194^{NS}	-0.395**
0.529**	0.620**	-0.110^{NS}	0.289*	0.400**	-0.162^{NS}	-0.116^{NS}	0.073^{NS}	-0.078^{NS}	0.221^{NS}
0.555**	0.689**	-0.141^{NS}	0.438**	0.511**	-0.302*	-0.120^{NS}	0.017^{NS}	-0.094^{NS}	0.300*
0.516**	0.601**	-0.093^{NS}	0.262*	0.426**	-0.132^{NS}	-0.186^{NS}	-0.051^{NS}	-0.158^{NS}	0.135^{NS}
0.528**	0.629**	-0.102^{NS}	0.244^{NS}	0.493**	-0.216^{NS}	-0.013^{NS}	-0.011^{NS}	-0.004^{NS}	0.270*
-0.554**	-0.528**	-0.056^{NS}	-0.174^{NS}	-0.610**	0.083^{NS}	0.289*	0.032^{NS}	0.249^{NS}	-0.315*
-0.532**	-0.644**	0.106^{NS}	-0.539**	-0.536**	0.293*	0.239^{NS}	-0.042^{NS}	0.186^{NS}	-0.332**
-0.586**	-0.677**	0.060^{NS}	-0.560**	-0.580**	0.211^{NS}	0.220^{NS}	-0.094^{NS}	0.161^{NS}	-0.262*
-0.782**	-0.762**	-0.093^{NS}	-0.412**	-0.833**	0.220^{NS}	0.304*	0.090^{NS}	0.270*	-0.416**
0.711**	0.854**	-0.125^{NS}	0.546**	0.734**	-0.318*	-0.235^{NS}	-0.064^{NS}	-0.200^{NS}	0.496**
	0.737**	0.423**	0.166^{NS}	0.775**	-0.164^{NS}	-0.334**	-0.316*	-0.341**	0.371**
		-0.291*	0.583**	0.779**	-0.205^{NS}	-0.343**	-0.155^{NS}	-0.315*	0.563**
			-0.477**	0.081^{NS}	0.023^{NS}	0.032^{NS}	-0.190^{NS}	-0.012^{NS}	-0.241^{NS}
				0.423**	-0.193^{NS}	-0.012^{NS}	0.293*	0.050^{NS}	0.275*
					-0.309*	-0.287*	-0.262*	-0.287*	0.526**
						0.177^{NS}	0.086^{NS}	0.166^{NS}	-0.211^{NS}
							0.621**	0.985**	-0.255*
								0.733**	-0.344**

Characters and their abbreviation in parenthesis: Characters (Ch.), Plant height (PH), Number of primary branches / plant (NPB), Days to first flowering (DFF), Days to 50% flowering (D50F), Days to first fruit setting (DFS), Days to first harvest (DFH), Number of flower cluster/plant (NFCP), Number of flowers per cluster (NFPC), Number of fruits per cluster (NFrPC), Number of fruit per plant (NFPP), Average fruit weight (AFW), Polar diameter (PD),Equatorial diameter (ED), Fruit shape index (FrSI), Locule number(LN), Pericarp thickness(PT), TSS (Total Soluble Solids), Lycopene content (LYC), β-Carotene (BC), Carotenoid (Caro).

* and ** depict significance at 5% and 1% levels of probability respectively.

Table 4. Genotypic correlation among twenty-one characters in twenty tomato genotypes.

	NPB	DFF	D50F	DFS	DFH	NFCPP	NFPC	NFrPC	NFPP	AFW
PH	0.507**	-0.391**	-0.398**	-0.467**	-0.473**	0.736**	0.633**	0.623**	0.808**	-0.507**
NPB		-0.646**	-0.674**	-0.554**	-0.671**	0.421**	0.505**	0.471**	0.674**	-0.765**
DFF			0.936**	0.942**	0.970**	-0.567**	-0.674**	-0.673**	-0.738**	0.790**
D50F				0.896**	0.977**	-0.429**	-0.709**	-0.643**	-0.739**	0.873**
DFS					0.941**	-0.541**	-0.657**	-0.666**	-0.739**	0.791**
DFH						-0.563**	-0.742**	-0.702**	-0.758**	0.829**
NFCPP							0.765**	0.810**	0.836**	-0.509**
NFPC								0.999**	0.816**	-0.757**
NFrPC									0.845**	-0.730**
NFPP										-0.814**
AFW										
PD										
ED										
FrSI										
LC										
PT										
TSS										
LYC										
BC										
Caro										

Right side of the table

PD	ED	FrSI	LC	PT	TSS	LYC	BC	Caro	FYPP
-0.683**	-0.550**	-0.255*	-0.155^{NS}	-0.751**	0.357**	0.391**	0.265*	0.373**	-0.493**
-0.830**	-0.622**	-0.382**	-0.187^{NS}	-0.600**	0.359**	0.290*	0.204^{NS}	0.278*	-0.463**
0.564**	0.698**	-0.146^{NS}	0.368**	0.460**	-0.202^{NS}	-0.111^{NS}	0.084^{NS}	-0.070^{NS}	0.265*
0.588**	0.740**	-0.149^{NS}	0.518**	0.568**	-0.379**	-0.100^{NS}	0.017^{NS}	-0.074^{NS}	0.345**
0.562**	0.669**	-0.108^{NS}	0.319*	0.495**	-0.196^{NS}	-0.215^{NS}	-0.070^{NS}	-0.181^{NS}	0.197^{NS}
0.602**	0.752**	-0.154^{NS}	0.447**	0.568**	-0.262*	-0.069^{NS}	-0.032^{NS}	-0.053^{NS}	0.353**
-0.573**	-0.547**	-0.066^{NS}	-0.199^{NS}	-0.636**	0.113^{NS}	0.302*	0.032^{NS}	0.256*	-0.343**
-0.588**	-0.762**	0.173^{NS}	-0.672**	-0.592**	0.277*	0.304*	-0.048^{NS}	0.247^{NS}	-0.397**
-0.609**	-0.707**	0.066^{NS}	-0.609**	-0.612**	0.220^{NS}	0.210^{NS}	-0.133^{NS}	0.145^{NS}	-0.283*
-0.792**	-0.783**	-0.097^{NS}	-0.463**	-0.854**	0.243^{NS}	0.332**	0.105^{NS}	0.292*	-0.450**
0.724**	0.879**	-0.130^{NS}	0.615**	0.750**	-0.365**	-0.257*	-0.073^{NS}	-0.215^{NS}	0.526**
	0.756**	0.429**	0.171^{NS}	0.804**	-0.174^{NS}	-0.368**	-0.333**	-0.369**	0.391**
		-0.261*	0.626**	0.825**	-0.224^{NS}	-0.360**	-0.153^{NS}	-0.321*	0.601**
			-0.529**	0.075^{NS}	0.031^{NS}	0.008^{NS}	-0.227^{NS}	-0.043^{NS}	-0.258*
				0.481**	-0.256*	0.014^{NS}	0.370**	0.091^{NS}	0.298*
					-0.337**	-0.340**	-0.291*	-0.332**	0.554**
						0.218^{NS}	0.141^{NS}	0.213^{NS}	-0.254^{NS}
							0.680**	0.990**	-0.298*
								0.778**	-0.355**
									-0.319**

Characters and their abbreviation in parenthesis: Characters (Ch.), Plant height (PH), Number of primary branches / plant (NPB), Days to first flowering (DFF), Days to 50% flowering (D50F), Days to first fruit setting (DFS), Days to first harvest (DFH), Number of flower cluster/plant (NFCP), Number of flowers per cluster (NFPC), Number of fruits per cluster (NFrPC), Number of fruit per plant (NFPP), Average fruit weight (AFW), Polar diameter (PD),Equatorial diameter (ED), Fruit shape index (FrSI), Locule number(LN), Pericarp thickness(PT), TSS (Total Soluble Solids), Lycopene content (LYC), β-Carotene (BC), Carotenoid (Caro)

* and ** depict significance at 5% and 1% levels of probability respectively.

coefficients which suggested that there was inherent relationship between the traits under study, despite the fact that phenotypic manifestation was hampered by environmental factors between the traits under study and environment had not played much role in reducing their actual association. It was noted that there was significant positive association of days to 50% flowering, days to first harvest, average fruit weight, polar diameter, equatorial diameter, locule number, pericarp thickness and significant negative association of plant height, number of primary branches, number of flowers per cluster, number of fruits per cluster, total number of flower clusters per plant, number of fruits per plant, lycopene, beta-carotene and total carotenoids with yield at both genotypic and phenotypic level. On the other hand, TSS had significant negative correlation with fruit yield per plant at genotypic level only, and its association at phenotypic level though negative was not significant. Ullah *et al.* (2013) had also observed the significant positive genotypic and phenotypic correlation with fruits per plant, fruit weight, fruit diameter and locule number per fruit with fruit yield per plant. Kumar *et al.* (2013) previously observed that yield showed a positive correlation with number of fruits per cluster. Ahirwar *et al.* (2013) reported highly significant negative correlation of yield with days to 50% flowering, number of flowers per truss, and locule number. The studies of Meena and Bahadur (2015) revealed that number of flowers per plant, number of fruits per plant and fruit weight was significantly and positively correlated with fruit yield. Similar findings in tomato were also reported by Haydar *et al.* (2007), Singh *et al.* (2002), Singh *et al.* (2004), Prashanth *et al.* (2008), Meitei *et al.* (2014).

Correlation studies only give an idea about the linear relationship about two traits. The direct and indirect effect of different traits influencing a certain trait like yield is elucidated by path coefficient analysis, where yield is considered dependent variable. Path coefficient values in the range of 0.00-0.09 were classified as negligible, 0.10-0.29 as low, 0.20-0.29 as moderate, 0.30-1.00 as high and more than 1.00 as very high (Lenka and Mishra 1973).

The genotypic path matrix (Table 5), with yield per plant as dependent variable, showed high positive direct effects of number of fruits per cluster, days to 50% flowering, average fruit weight, number of fruits per plant, low positive direct effects of equatorial diameter and polar diameter while high negative direct effects of number of flower cluster per plant, days to first fruit harvest, number of flower per cluster, plant height, fruit shape index, number of primary branches per plant, while moderate negative direct effect of days to first flowering and pericarp thickness on fruit yield per plant. High positive indirect effect of average fruit weight via number of primary branches, days to 50% flowering, number of flower clusters per plant and number of flowers per cluster, while high negative effect of average fruit weight via days to first fruit set, days to first fruit harvest, number of fruits per cluster, number of fruits per plant were noted. The residual was 0.2097 depicting that the unexplained variances were 20.97%.

The phenotypic path matrix (Table 6), with yield per plant as dependent variable, showed high positive direct effects of average fruit weight, number of fruits/cluster, polar diameter, number of fruits per plant, while high negative direct effects of plant height, number of flowers/cluster, equatorial diameter, moderate direct negative effect of number of flower cluster/plant, days to first fruit harvest were observed on fruit yield per plant.

Average fruit weight showed high positive indirect effects via equatorial diameter, days to 50 % flowering, days to first fruit harvest, pericarp thickness, polar diameter and number of locules while high negative indirect effects via number of fruits/plant, number of fruits/cluster, number of flowers/cluster, number of primary branches/plant, number of flower cluster/plant and plant height were observed on fruit yield per plant.

Table 5. Genotypic path analysis (dependent variable yield per plant).

Ch.	PH	NPB	DFF	D50F	DFS	DFH	NFCPP	NFPC
PH	**-0.584**	-0.210	0.096	-0.343	0.183	0.345	-0.544	-0.391
NPB	-0.296	**-0.413**	0.159	-0.581	0.217	0.489	-0.312	-0.312
DFF	0.228	0.267	**-0.246**	0.807	-0.369	-0.708	0.419	0.416
D50F	0.232	0.278	-0.230	**0.863**	-0.351	-0.713	0.318	0.438
DFS	0.272	0.229	-0.232	0.773	**-0.391**	-0.686	0.401	0.405
DFH	0.276	0.277	-0.239	0.843	-0.368	**-0.730**	0.417	0.458
NFCPP	-0.429	-0.174	0.139	-0.370	0.212	0.411	**-0.740**	-0.472
NFPC	-0.369	-0.209	0.166	-0.612	0.257	0.542	-0.566	**-0.617**
NFrPC	-0.364	-0.195	0.166	-0.555	0.261	0.512	-0.599	-0.616
NFPP	-0.471	-0.278	0.182	-0.637	0.289	0.553	-0.619	-0.503
AFW	0.296	0.316	-0.194	0.753	-0.310	-0.605	0.377	0.467
PD	0.399	0.343	-0.139	0.507	-0.220	-0.440	0.424	0.363
ED	0.321	0.257	-0.172	0.639	-0.262	-0.549	0.405	0.470
FrSI	0.149	0.158	0.036	-0.129	0.042	0.112	0.049	-0.107
LC	0.090	0.077	-0.091	0.447	-0.125	-0.326	0.147	0.414
PT	0.438	0.248	-0.113	0.490	-0.194	-0.415	0.470	0.365

Right side of the table

NFrPC	NFPP	AFW	PD	ED	FrSI	LN	PT	r_g FYPP
0.765	0.328	-0.259	-0.111	-0.092	0.147	0.007	0.169	-0.493^{**}
0.578	0.274	-0.391	-0.135	-0.104	0.220	0.008	0.135	-0.463^{**}
-0.826	-0.300	0.404	0.092	0.116	0.084	-0.016	-0.103	0.265^{*}
-0.789	-0.300	0.446	0.096	0.123	0.086	-0.023	-0.127	0.345^{**}
-0.818	-0.300	0.404	0.092	0.112	0.063	-0.014	-0.111	0.197^{NS}
-0.862	-0.308	0.424	0.098	0.125	0.089	-0.020	-0.128	0.353^{**}
0.995	0.340	-0.260	-0.093	-0.091	0.038	0.009	0.143	-0.343^{**}
1.226	0.332	-0.387	-0.096	-0.127	-0.100	0.030	0.133	-0.397^{**}
1.228	0.343	-0.373	-0.099	-0.118	-0.038	0.027	0.137	-0.283^{*}
1.037	**0.406**	-0.416	-0.129	-0.131	0.056	0.020	0.192	-0.450^{**}
-0.896	-0.331	**0.511**	0.118	0.147	0.075	-0.027	-0.168	0.526^{**}
-0.747	-0.322	0.370	**0.163**	0.126	-0.247	-0.008	-0.180	0.391^{**}
-0.867	-0.318	0.449	0.123	**0.167**	0.151	-0.028	-0.185	0.601^{**}
0.081	-0.039	-0.066	0.070	-0.044	**-0.577**	0.023	-0.017	-0.258^{*}
-0.747	-0.188	0.314	0.028	0.104	0.305	**-0.044**	-0.108	0.298^{*}
-0.752	-0.347	0.383	0.131	0.138	-0.043	-0.021	**-0.224**	0.554^{**}

Residual effect = 0.2097. * and ** depict significance at 5% and 1% levels of probability respectively. r_g FYPP is the genotypic correlation coefficient of different traits on fruit yield per plant.

Characters and their abbreviation in parenthesis: Characters (Ch.), Plant height (PH), Number of primary branches / plant (NPB), Days to first flowering (DFF), Days to 50% flowering (D50F), Days to first fruit setting (DFS), Days to first harvest (DFH), Number of flower cluster/plant (NFCP), Number of flowers per cluster (NFPC), Number of fruits per cluster (NFrPC), Number of fruit per plant (NFPP), Average fruit weight (AFW), Polar diameter (PD),Equatorial diameter (ED), Fruit shape index (FrSI), Locule number(LN), Pericarp thickness(PT), TSS (Total Soluble Solids), Lycopene content (LYC), β-Carotene (BC), Carotenoid (Caro)

High direct positive effect of number of flowers per inflorescence, number of locules per fruit, fruit diameter on yield were earlier reported by Singh *et al.* (2018) and for fruit diameter and plant height by Kumar *et al.* (2014). High direct positive effect of fruit per plant on yield per plant was observed by Rani *et al.* (2008) and Islam *et al.* (2010). The work of Reddy *et al.* (2013), Shankar *et al.* (2014) were also in accordance of this study.

Table 6. Phenotypic path analysis (dependent variable yield per plant).

Ch.	PH	NPB	DFF	D50F	DFS	DFH	NFCPP	NFPC
PH	**-0.600**	-0.049	-0.092	-0.003	0.252	0.089	-0.164	-0.236
NPB	-0.244	**-0.119**	-0.106	-0.004	0.196	0.096	-0.081	-0.145
DFF	0.210	0.048	**0.263**	0.009	-0.511	-0.183	0.121	0.256
D50F	0.220	0.055	0.242	**0.009**	-0.486	-0.184	0.094	0.274
DFS	0.255	0.039	0.227	0.008	**-0.592**	-0.162	0.109	0.250
DFH	0.248	0.053	0.224	0.008	-0.446	**-0.215**	0.119	0.251
NFCPP	-0.428	-0.042	-0.138	-0.004	0.281	0.112	**-0.230**	-0.286
NFPC	-0.314	-0.038	-0.149	-0.006	0.329	0.120	-0.146	**-0.451**
NFrPC	-0.350	-0.043	-0.150	-0.005	0.334	0.121	-0.176	-0.409
NFPP	-0.474	-0.062	-0.179	-0.006	0.401	0.145	-0.188	-0.331
AFW	0.296	0.072	0.192	0.008	-0.427	-0.160	0.115	0.302
PD	0.401	0.077	0.139	0.005	-0.306	-0.114	0.127	0.240
ED	0.319	0.060	0.163	0.006	-0.356	-0.135	0.121	0.290
FrSI	0.144	0.032	-0.029	-0.001	0.055	0.022	0.013	-0.048
LC	0.084	0.018	0.076	0.004	-0.155	-0.052	0.040	0.243
PT	0.425	0.059	0.105	0.005	-0.252	-0.106	0.140	0.242

Right side of the table

NFrPC	NFPP	AFW	PD	ED	FrSI	LN	PT	r_p FYPP
0.421	0.339	-0.395	-0.363	0.215	0.173	0.010	-0.054	-0.459^{**}
0.260	0.224	-0.484	-0.351	0.201	0.191	0.011	-0.038	-0.395^{**}
-0.411	-0.292	0.585	0.287	-0.250	0.079	-0.020	0.031	0.221^{NS}
-0.418	-0.299	0.660	0.301	-0.278	0.102	-0.031	0.039	0.300^{*}
-0.406	-0.290	0.577	0.280	-0.243	0.067	-0.019	0.033	0.135^{NS}
-0.404	-0.288	0.593	0.287	-0.254	0.073	-0.017	0.038	0.270^{*}
0.551	0.350	-0.398	-0.301	0.213	0.040	0.012	-0.047	-0.315^{*}
0.654	0.315	-0.537	-0.289	0.260	-0.076	0.038	-0.041	-0.332^{**}
0.720	0.349	-0.559	-0.318	0.273	-0.043	0.039	-0.044	-0.262^{*}
0.587	**0.428**	-0.651	-0.425	0.308	0.067	0.029	-0.064	-0.416^{**}
-0.503	-0.348	**0.800**	0.386	-0.345	0.090	-0.039	0.056	0.496^{**}
-0.422	-0.335	0.569	**0.543**	-0.297	-0.305	-0.012	0.059	0.371^{**}
-0.488	-0.326	0.683	0.400	**-0.403**	0.210	-0.041	0.060	0.563^{**}
0.043	-0.040	-0.100	0.230	0.117	**-0.720**	0.034	0.006	-0.241^{NS}
-0.403	-0.177	0.437	0.090	-0.235	0.343	**-0.071**	0.032	0.275^{*}
-0.418	-0.357	0.588	0.421	-0.314	-0.058	-0.030	**0.077**	0.526^{**}

Residual effect = 0.3335. * and ** depict significance at 5% and 1% levels of probability respectively. r_p FYPP is the phenotypic correlation coefficient of different traits on fruit yield per plant.

Characters and their abbreviation in parenthesis: Characters (Ch.), Plant height (PH), Number of primary branches / plant (NPB), Days to first flowering (DFF), Days to 50% flowering (D50F), Days to first fruit setting (DFS), Days to first harvest (DFH), Number of flower cluster/plant (NFCP), Number of flowers per cluster (NFPC), Number of fruits per cluster (NFrPC), Number of fruit per plant (NFPP), Average fruit weight (AFW), Polar diameter (PD),Equatorial diameter (ED), Fruit shape index (FrSI), Locule number(LN), Pericarp thickness(PT), Fruit yield per plant (FYPP).

The trait inter-relationship studies revealed that for aiming at high yielding tomato genotypes, selection based on average fruit weight, number of fruits per plant, polar and equatorial diameter, plant height, number of primary branches, days to 50% flowering, days to first harvest would be effective. The ideotype of high yielding tomato genotype would be moderate plant height (60 to 70 cm), moderate number of primary branches/plant (6 to 7 branches), moderate number of flower/cluster (6 to 7 flower/cluster), moderate number of flower cluster/plant (20 to 30 flower cluster/plant), moderate number of fruits/plant (40 to 50 fruits/plant), high fruit weight (60 to 80 g), high pericarp thickness (>5 mm).

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