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Article

Genetic association analysis in advance tomato (*Solanum lycopersicum* L.) lines for horticultural and yield contributing traits

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Abstract: Twenty-two tomato (*Solanum lycopersicum* L.) genotypes were examined for correlation and path analysis in the randomized block design under open field conditions. Total fruit yield showed a significant positive correlation with the number of fruits per plant, average fruit weight, lycopene content, and percent seedling survival in the field at both the genotypic and phenotypic levels. A strong correlation between these characters revealed that selection based on these characters would consequently improve the total fruit yield. Path analysis showed that the number of fruits per plant, average fruit weight, percent seedling survival in the nursery, and number of locules per fruit exhibited high positive direct phenotypic effects on total fruit yield, whereas the number of fruits per plant, average fruit weight, percent seedling survival in the field, and pollen viability had very high positive direct genotypic effects. Therefore, to increase the yield, it would be profitable to prioritize these traits in the selection program.

Keywords: correlation; genetic association; path analysis; tomato

1. Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable grown all over the world and belongs to the Solanaceae family. Due to its nutritional benefits, it is considered a protective food and is sometimes referred to as the “poor man’s orange”. Tomatoes are a rich source of lycopene, Vitamin B, and ascorbic acid. Recent studies have shown that consuming tomatoes and tomato-related products can lower the risk of developing prostate and digestive tract cancers [1]. Tomato has an excellent appetizing property, and its soup is recommended for patients suffering from constipation due to its laxative properties [2]. Tomato was originally grown in the Andes Mountains, which spanned across Peru, Chile, and Ecuador. Nowadays, tomato is widely cultivated in countries such as China, India, Italy, Turkey, and Egypt. The relationship between yield and its components is crucial for the selection of breeding programs. Correlation helps determine the degree and direction of the relationship between two or more traits. Path analysis allows the correlation coefficient (r) to be divided into direct and indirect effects on yield and other attributes [3]. Therefore, this study aims to analyze the correlation and path coefficient analysis.

2. Material and methods

2.1. Experimental material

The current research was carried out at the Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana, Punjab, India, from

2021 to 2022. The study trial is situated 247 meters above mean sea level at 30°55′ north latitude and 75°54′ east longitude. It is situated in a humid subtropical climate zone. The current investigation used twenty diverse lines, viz., RS-15, RS-11, RS-19, RS-65, RS-211, PVB-45, PVB-172, RS-191, NLLR-1, NLLR-6, NLLR-12, PDRT-91, PDRT-57, NLLR-2, NLLR-7, NLLR-9, RS-210, RS-212, RS-60, and RS-67, including two standard checks, namely Punjab Chhuhara and PVB-4 (Punjab Varkha Bahar-4), developed by Punjab Agricultural University, Ludhiana. The genotypes were evaluated in the Randomized Block Design (RBD) in open-field conditions. The seedlings were transplanted at four compound leaf stages in three replications at a spacing of 120 × 30 cm. The recommended package of practices was followed to raise a healthy crop [4].

2.2. Observations recorded

In each row of each replication, five plants were chosen at random and the plants in the border were omitted for data recording. The observations were recorded on 18 parameters viz. percent seedling survival in the nursery (%), percent seedling survival in the field (%), pollen viability (%), number of days to first anthesis, plant height (cm), days from transplanting to first harvest, harvesting span (days), number of fruits per plant, average fruit weight (g), total fruit yield (kg/plant), number of locules per fruit, pericarp thickness (mm), polar/equatorial (P/E) ratio, total soluble solids of fruit (°Brix), dry matter content (%), lycopene content (mg/100 g of fresh weight), titratable acidity (mg/100 mL of fruit juice) and tomato leaf curl disease (TOLCD) incidence (%).

2.3. Statistical analysis

The data was analyzed using SPSS software (version 27).

3. Results and discussion

3.1. Correlation analysis

Correlation coefficients were calculated at genotypic and phenotypic levels for every possible combination of the eighteen characters (**Table 1**). The genotypic association of fruit yield with studied traits was presented in **Figure 1**. The correlation coefficient findings from the current study on tomato genotypes showed that total fruit yield showed high significant and positive phenotypic correlation with number of fruits per plant (0.909), lycopene content (0.789), percent seedling survival in the field (0.718), average fruit weight (0.688), pericarp thickness (0.490) and pollen viability (0.393). Similar findings for number of fruits per plant and average fruit weight were reported by Sunilkumar et al. [5], Sushma et al. [6], Maurya et al. [7], Sharma et al. [8], and Nevani and Sridevi [9]. Total fruit yield was also positively and significantly correlated with number of locules per fruit (0.276). The non-significant positive correlation of fruit yield per plant was observed with percent seedling survival in the nursery (0.226), harvesting span (0.171) and titratable acidity (0.134). Fruit yield per plant showed highly significant and negative correlation with days from transplanting to first harvest (−0.646), dry matter content (−0.558), number of days to first anthesis

(−0.491), total soluble solids of fruit (−0.467), tomato leaf curl diseases incidence (−0.236) and polar/equatorial ratio (−0.387). The total fruit yield was reported to be highly significant and negative correlated with days from transplanting to first harvest by Sushma et al. [6], Nevani and Sridevi [9] and number of days to first anthesis by Sharma et al. [8]. Whereas, negative and non-significant correlation was found with plant height (−0.024).

Percent seedling survival in nursery showed highly significant and positive correlation with percent seedling survival in the field (0.530), plant height (0.492), polar equatorial ratio (0.455), tomato leaf curl diseases incidence (0.382) and pollen viability (0.396) while the highly significant and negative correlation was observed with number of days to first anthesis (−0.487). There was positive and high significant correlation of percent seedling survival in the field with number of fruits per plant (0.834), total fruit yield (0.718), pollen viability (0.650), lycopene content (0.507), pericarp thickness (0.391) and plant height (0.328). In contrast a highly significant and negative correlation was found with number of days to first anthesis (−0.775) and days from transplanting to first harvest (−0.659). Pollen viability presented a highly significant and positive correlation with number of fruits per plant (0.496), total fruit yield (0.393) and lycopene content (0.346) while highly significant and negative correlation was with number of days to first anthesis (−0.465) and days from transplanting to first harvest (−0.449). The number of days to first anthesis was found to be highly significant and positively correlated with days from transplanting to first harvest (0.575) and number of locules per fruit (0.340), while highly significant and negative correlation of number of days to first anthesis was observed with number of fruits per plant (−0.643), fruit yield (−0.491) and lycopene content (−0.351).

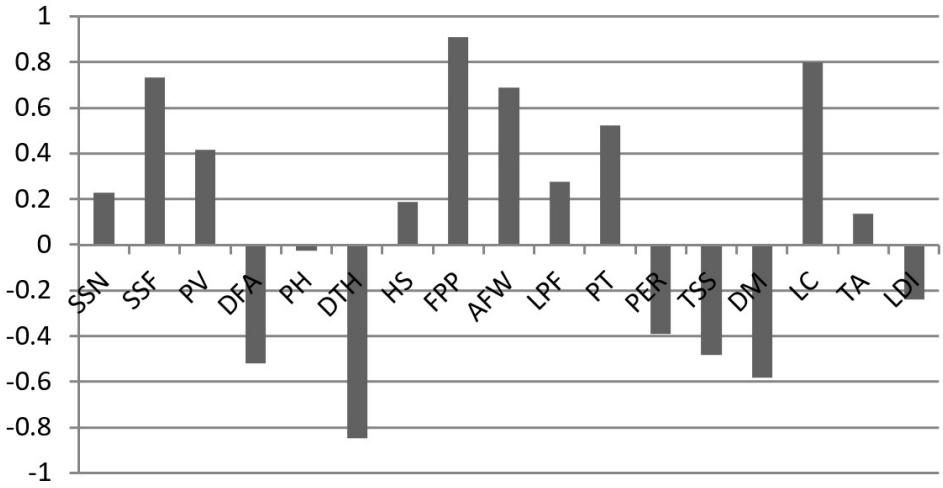

Figure 1. Genotypic association of fruit yield with important traits in tomato.

Plant height was found to be highly significant and positively correlated with total soluble solids (0.481), polar equatorial ratio (0.410) and dry matter content (0.398) whereas the highly significant and negative correlation of plant height was observed with harvesting span (−0.328) while negative and significant correlation with average fruit weight (−0.291) and number of locules per fruit (−0.277). Similar results were recorded by Maurya et al. [7]. Days from transplanting to first harvest showed highly significant and positive phenotypic correlation with dry matter content (0.336) while

the highly significant and negative correlation was observed with number of fruits per plant (−0.661), total fruit yield (−0.646), lycopene content (−0.524), harvesting span (−0.395), pericarp thickness (−0.379) and average fruit weight (−0.364) while significant and negative correlation with titratable acidity (−0.292). Sushma et al. [6] also observed negative correlation of days from transplanting to first harvest with fruit yield. Harvesting span was found to be highly significant and negatively correlated with total soluble solids (−0.388) and dry matter content (−0.314) showed negative and significant correlation. Number of fruits per plant showed highly significant positive correlation with fruit yield/plant (0.909), lycopene content (0.659), pericarp thickness (0.400) and average fruit weight (0.364). Nevani and Sridevi [9] also recorded positive association with pericarp thickness. In contrast, the negative association was found with number of fruits per plant by Sunilkumar et al. [5] and Sharma et al. [8]. Whereas, negative and highly significant correlation was found with dry matter content (−0.405) and total soluble solids (−0.357). Average fruit weight presented highly significant and positive correlation with the number of locules per fruit (0.765), lycopene content (0.701), fruit yield (0.688), pericarp thickness (0.513) and titratable acidity (0.339) while highly significant and negative correlation was found with polar equatorial ratio (−0.714), dry matter content (−0.611), total soluble solids (−0.452) and tomato leaf curl diseases incidence (−0.337). Nevani and Sridevi [9] found positive correlation of average fruit weight with number of locules per fruit and pericarp thickness. Number of locules per fruit had high significant and positive correlation with lycopene content (0.445) and titratable acidity (0.443) whilst negative and highly significant correlation was observed with polar equatorial ratio (−0.589), dry matter content (−0.405) and tomato leaf curl diseases incidence (−0.261). There was positive and high significant correlation of pericarp thickness with lycopene content (0.679) and total fruit yield (0.490) while highly significant and negative correlation was found with dry matter content (−0.531). Polar equatorial ratio had positive and highly significant correlation with tomato leaf curl disease incidence (0.749) and dry matter content (0.373) while highly significant and negative correlation was observed with lycopene content (−0.459) and total fruit yield (−0.387). Nevani and Sridevi [9] also recorded positive and high significant correlation of pericarp thickness with fruit yield.

Total soluble solids was found to be positive and highly significant correlation with dry matter content (0.779) while highly significant and negative correlation was observed with lycopene content (−0.478) and total fruit yield (−0.467). Dry matter content presented highly significant and negative correlation with lycopene content (−0.709), total fruit yield (−0.558) and titratable acidity (−0.339). Lycopene content had positive and highly significant correlation with total fruit yield (0.789) while significant and negative correlation was observed with tomato leaf curl disease incidence (−0.294).

Table 1. Phenotypic (P) and genotypic (G) correlation coefficients among different characters in tomato.

Trait		SSN	SSF	PV	DFA	PH	DTH	HS	FPP	AFW	LPF	PT	PER	TSS	DM	LC	TA	LDI
SSF	P	0.530**	1.000**															
	G	0.539**																
PV	P	0.396**	0.650**	1.000**														
	G	0.441*	0.731**															
DFA	P	−0.487**	−0.775**	–0.465**	1.000**													
	G	−0.507*	−0.810**	–0.531*														
PH	P	0.492**	0.328**	0.278*	–0.125	1.000**												
	G	0.501*	0.346	0.329	–0.126													
DTH	P	−0.204	−0.659**	–0.449**	0.575**	0.003	1.000**											
	G	−0.246	−0.850**	–0.613**	0.786**	–0.037												
HS	P	−0.172	0.245*	0.274*	–0.219	–0.328**	–0.395**	1.000**										
	G	−0.207	0.27	0.342	–0.245	–0.351	–0.443*											
FPP	P	0.287*	0.834**	0.496**	–0.643**	0.142	–0.661**	0.136	1.000**									
	G	0.29	0.853**	0.526*	–0.676**	0.145	–0.869**	0.153										
AFW	P	−0.122	0.120	–0.049	0.037	–0.291*	–0.364**	0.151	0.364**	1.000**								
	G	−0.124	0.123	–0.053	0.039	–0.300	–0.479*	0.169	0.365									
LPF	P	−0.071	−0.205	−0.154	0.340**	–0.277*	–0.064	0.103	–0.056	0.765**	1.000**							
	G	−0.072	−0.21	−0.164	0.354	–0.284	–0.086	0.121	–0.055	0.771**								
PT	P	0.025	0.391**	0.286*	–0.175	0.174	–0.379**	0.084	0.400**	0.513**	0.191	1.000**						
	G	0.02	0.407	0.349	–0.196	0.195	–0.451*	0.078	0.425*	0.546**	0.207							
PER	P	0.455**	0.153	0.077	–0.273*	0.410**	0.168	–0.07	–0.116	–0.714**	–0.589**	–0.266*	1.000**					
	G	0.463*	0.154	0.086	–0.280	0.425*	0.215	–0.07	–0.115	–0.721**	–0.597**	–0.285						
TSS	P	0.155	−0.181	0.079	0.258*	0.481**	0.17	–0.388**	–0.357**	–0.452**	–0.209	–0.263*	0.301*	1.000**				
	G	0.161	−0.186	0.085	0.306	0.514*	0.249	–0.431*	–0.367	–0.467*	–0.222	–0.263	0.312					
DM	P	0.081	−0.247*	−0.119	0.204	0.398**	0.336**	–0.314*	–0.405**	–0.611**	–0.405**	–0.531**	0.373**	0.779**	1.000**			

Table 1. (*Continued*).

Trait		SSN	SSF	PV	DFA	PH	DTH	HS	FPP	AFW	LPF	PT	PER	TSS	DM	LC	TA	LDI
LC	G	0.086	−0.267	−0.126	0.233	0.414	0.398	–0.369	–0.42	–0.634**	–0.416	–0.567**	0.39	0.854**				
	P	0.148	0.507**	0.346**	–0.351**	–0.082	–0.524**	0.15	0.659**	0.701**	0.445**	0.679**	–0.459**	–0.478**	–0.709**	1.000**		
	G	0.151	0.521*	0.371	–0.371	–0.09	–0.698**	0.154	0.668**	0.711**	0.454*	0.721**	–0.470*	–0.495*	–0.732**			
TA	P	0.250*	0.039	0.05	–0.187	–0.188	–0.292*	0.159	0.057	0.339**	0.443**	0.124	0.011	–0.077	–0.339**	0.247*	1.000**	
	G	0.258	0.044	0.053	–0.212	–0.193	–0.39	0.196	0.06	0.344	0.449*	0.142	0.007	–0.083	–0.358	0.255		
LDI	P	0.382**	0.049	−0.084	–0.167	0.119	–0.009	–0.01	–0.105	–0.337**	–0.261*	–0.265*	0.749**	0.252*	0.158	–0.294*	0.375**	1.000**
	G	0.393	0.056	−0.094	–0.171	0.125	–0.008	–0.005	–0.108	–0.342	–0.264	–0.280	0.757**	0.268	0.163	–0.299	0.379	
FY	P	0.226	0.718**	0.393**	–0.491**	–0.024	–0.646**	0.171	0.909**	0.688**	0.276*	0.490**	–0.387**	–0.467**	–0.558**	0.789**	0.134	–0.236
	G	0.228	0.733**	0.416	–0.518*	–0.026	–0.846**	0.189	0.910**	0.688**	0.277	0.522*	–0.39	–0.484*	–0.581**	0.800**	0.135	–0.240

* Significant at 5% level of significance; ** Significant at 1% level of significance.

SSN—Percent seedling survival in the nursery; SSF—Percent seedling survival in the field; PV—Pollen viability; DFA—Number of days to first anthesis; PH—Plant height; DTH—Days from transplanting to first harvest; HS—Harvesting span; FPP—Number of fruits per plant; AFW—Average fruit weight; LPF—Number of locules per fruit; PT—Pericarp thickness; PER—Polar/equatorial ratio; TSS—Total soluble solids of fruit; DM—Dry matter content; LC—Lycopene content; TA—Titratable acidity; LDI—Tomato leaf curl diseases incidence; FY—Total fruit yield.

The characters that showed strong correlations between them at the phenotypic level would also show substantial correlation at the genotypic level relating total fruit yield per plant except from pollen viability (0.416), number of locules per fruit (0.277) and polar equatorial ratio (−0.390) which showed non-significant association at the genotypic level. A non-significant association of polar equatorial ratio with total fruit yield at genotypic level was also observed by Khapte and Jansirani [1].

3.2. Path analysis

Path analysis approach enables the partitioning of interactions in these situations into particular effects of the causal variables Guler et al. [10]. Pooled path analysis explained the direct and indirect effects in the current investigation (**Table 2**). Total fruit yield (kg/plant) was chosen as the dependent variable on the other traits and the genotypic and phenotypic pathways were examined.

The results presented that out of 17 traits, ten traits had positive and direct effect on total fruit yield at phenotypic level as shown in **Table 2**. The characters such as number of fruits per plant (0.700), average fruit weight (0.432), percent seedling survival in the nursery (0.134) and number of locules per fruit (0.106) had low to high positive effects on total fruit yield, while traits namely leaf curl disease incidence (0.088), pollen viability (0.054), percent seedling survival in the field (0.037), pericarp thickness (0.028), total soluble solids (0.023), days from transplanting to first harvest (0.017) had lesser positive effects. Direct and high influence of number of fruits per plant and average fruit weight on total fruit yield was observed by Sushma et al. [6], Maurya et al. [7], Kumar et al. [11], Sharma et al. [8], Nevani and Sridevi [9]. The highest negative and direct effect on total fruit yield was shown by titratable acidity (−0.196) followed by lycopene content (−0.133), polar equatorial ratio (−0.101), number of days to first anthesis (−0.084), plant height (−0.084), dry matter content (−0.067), and harvesting span (−0.007). Negative and direct effect of plant height on total fruit yield was also recorded by Maurya et al. [7], Sharma et al. [8] and Nevani and Sridevi [9].

At phenotypic level, number of fruits per plant imparted highest positive and indirect effect on total fruit yield per plant via average fruit weight (0.157) followed by number of days to first anthesis (0.054), percent seedling survival in the nursery (0.038), percent seedling survival in the field (0.031), dry matter content (0.027), pollen viability (0.027), polar equatorial ratio (0.012) and pericarp thickness (0.011). Its indirect effect was negative through lycopene content (−0.088), titratable acidity (−0.013), days from transplanting to first harvest (−0.012), plant height (−0.012), tomato leaf curl diseases incidence (−0.009), total soluble solids (−0.008), number of locules per fruit (−0.006) and harvesting span (−0.001). Similar results were obtained by Namdev and Dongre [12]. Average fruit weight imparted positive indirect effect on total fruit yield per plant via number of fruits per plant (0.255) followed by number of locules per fruit (0.081), polar equatorial ratio (0.072), dry matter content (0.041), plant height (0.024), pericarp thickness (0.014) and percent seedling survival in the field (0.004). Its indirect effect was negative through lycopene content (−0.094), titratable acidity (−0.072), tomato leaf curl diseases incidence (−0.030), percent seedling survival in the nursery (−0.016), total soluble solids (−0.011), number of days

to first anthesis (−0.003), pollen viability (−0.003) and harvesting span (−0.001). Similar results were obtained by Nevani and Sridevi [9].

Percent seedling survival in the nursery expressed positive indirect effect on total fruit yield per plant via number of fruits per plant (0.201), number of days to first anthesis (0.041), tomato leaf curl diseases incidence (0.034), pollen viability (0.021), percent seedling survival in the field (0.020), total soluble solids (0.004), harvesting span (0.001) and pericarp thickness (0.001). Its indirect effect was negative through titratable acidity (−0.053), average fruit weight (−0.053), polar equatorial ratio (−0.046), plant height (−0.041), lycopene content (−0.020), number of locules per fruit (−0.008) and dry matter content (−0.005). Number of locules per fruit imparted positive indirect effect on total fruit yield per plant via average fruit weight (0.331) followed by polar equatorial ratio (0.060), dry matter content (0.027), plant height (0.023) and pericarp thickness (0.005). Its indirect effect was negative through titratable acidity (−0.096), lycopene content (−0.060), number of fruits per plant (−0.039), number of days to first anthesis (−0.029), tomato leaf curl diseases incidence (-0.023), percent seedling survival in the nursery (−0.010), pollen viability (−0.008), percent seedling survival in the field (−0.008), total soluble solids (−0.005) and harvesting span (−0.001). The results are in congruence with the findings of Maurya et al. [7].

Titratable acidity expressed positive indirect effect on total fruit yield per plant through average fruit weight (0.145), number of locules per fruit (0.047), number of fruits per plant (0.041), percent seedling survival in the nursery (0.033), tomato leaf curl diseases incidence (0.033), dry matter content (0.022), plant height (0.016), number of days to first anthesis (0.016), pericarp thickness (0.004), pollen viability (0.003) and percent seedling survival in the field (0.001). Its indirect effect was negative through total soluble solids (−0.002) and harvesting span (−0.001). Lycopene content expressed positive indirect effect on total fruit yield per plant through number of fruits per plant (0.461), average fruit weight (0.303), number of locules per fruit (0.047), dry matter content (0.047), polar equatorial ratio (0.046), number of days to first anthesis (0.030), percent seedling survival in the nursery (0.020), pericarp thickness (0.019), percent seedling survival in the field (0.019), pollen viability (0.019) and plant height (0.007). Its indirect effect was negative through tomato leaf curl diseases incidence (−0.026) and total soluble solids (−0.011). Rest of the traits had negligible indirect effects. Similar results were obtained by Sushma et al. [6].

The results presented that out of 17 traits, ten traits had positive and direct effect on total fruit yield at genotypic level as shown in **Table 2**. The characters such as number of fruits per plant (0.550), average fruit weight (0.531), percent seedling survival in the field (0.203) and pollen viability (0.121) had low to high positive effects for total fruit yield, while traits namely leaf curl disease incidence (0.031), dry matter content (0.024), percent seedling survival in the nursery (0.032), number of locules per fruit (0.031), number of days to first anthesis (0.012) and polar equatorial ratio (0.006) had lesser positive effects. Direct and high influence of number of fruits per plant and average fruit weight on total fruit yield was observed by Sunilkumar [5], Sushma et al. [6], Maurya et al. [7], Kumar et al. [11], Sharma et al. [8], Nevani and Sridevi [9]. The highest negative and direct effect on total fruit yield was presented by harvesting span (−0.104) followed by titratable acidity (−0.103), total soluble solids

(−0.089), plant height (−0.084), pericarp thickness (−0.055), lycopene content (−0.053) and days from transplanting to first harvest (−0.006).

At genotypic level, number of fruits per plant imparted highest positive and indirect effect on total fruit yield per plant via average fruit weight (0.193) followed by percent seedling survival in the field (0.173), pollen viability (0.064), total soluble solids (0.033), percent seedling survival in the nursery (0.009) and days from transplanting to first harvest (0.005). Its indirect effect was negative through lycopene content (−0.036), pericarp thickness (−0.023), harvesting span (−0.016), plant height (−0.012), dry matter content (−0.010), number of days to first anthesis (−0.008), titratable acidity (−0.006), tomato leaf curl diseases incidence (−0.003), number of locules per fruit (−0.002) and polar equatorial ratio (−0.001). Average fruit weight imparted positive indirect effect on total fruit yield per plant via number of fruits per plant (0.201) followed by total soluble solids (0.041), plant height (0.025), and percent seedling survival in the field (0.025), number of locules per fruit (0.024) and days from transplanting to first harvest (0.003). Its indirect effect was negative through lycopene content (−0.038), titratable acidity (−0.035), pericarp thickness (−0.030), harvesting span (−0.018), dry matter content (−0.015), tomato leaf curl diseases incidence (−0.011), pollen viability (−0.006), percent seedling survival in nursery (−0.004) and polar equatorial ratio (−0.004). The results are in congruence with the findings of Sharma et al. [8]. Percent seedling survival in the field imparted positive indirect effect on total fruit yield per plant via number of fruits per plant (0.469) followed by pollen viability (0.088), average fruit weight (0.065), total soluble solids (0.017), percent seedling survival in nursery (0.017), days from transplanting to first harvest (0.005), tomato leaf curl diseases incidence (0.002) and polar equatorial ratio (0.001). Its indirect effect was negative through plant height (−0.029), harvesting span (−0.028), lycopene content (−0.028), pericarp thickness (−0.022), number of days to first anthesis (−0.010), number of locules per fruit (−0.006), dry matter content (−0.006) and titratable acidity (−0.005). Harvesting span expressed positive indirect effect on total fruit yield per plant through average fruit weight (0.090), number of fruits per plant (0.084), percent seedling survival in the field (0.055), pollen viability (0.041), total soluble solids (0.038), plant height (0.029), number of locules per fruit (0.004) and days from transplanting to first harvest.

Table 2. Direct and indirect phenotypic (P) and genotypic (G) effect of characters on fruit yield (kg/plant).

Trait		SSN	SSF	PV	DFA	PH	DTH	HS	FPP	AFW	LPF	PT	PER	TSS	DM	LC	TA	LDI	Correlation with FY (kg/plant)
SSN	P	**0.134**	0.020	0.021	0.041	–0.041	–0.004	0.001	0.201	–0.053	–0.008	0.001	–0.046	0.004	–0.005	–0.020	–0.053	0.034	0.226
	G	**0.032**	0.109	0.053	–0.006	–0.042	0.001	0.022	0.160	–0.066	–0.002	–0.001	0.003	–0.014	0.002	–0.008	–0.026	0.012	0.228
SSF	P	0.071	**0.037**	0.035	0.065	–0.028	–0.011	–0.002	0.584	0.052	–0.022	0.011	–0.015	–0.004	0.016	–0.068	–0.008	0.004	0.718**
	G	0.017	**0.203**	0.088	–0.010	–0.029	0.005	–0.028	0.469	0.065	–0.006	–0.022	0.001	0.017	–0.006	–0.028	–0.005	0.002	0.733**
PV	P	0.053	0.024	**0.054**	0.039	–0.023	–0.008	–0.002	0.348	–0.021	–0.016	0.008	–0.008	0.002	0.008	–0.046	–0.011	–0.007	0.393**
	G	0.014	0.149	**0.121**	–0.006	–0.028	0.004	–0.036	0.289	–0.028	–0.005	–0.019	0.001	–0.008	–0.003	–0.020	–0.005	–0.003	0.416
DFA	P	–0.065	–0.029	–0.025	**–0.084**	0.011	0.010	0.001	–0.450	0.016	0.036	–0.005	0.028	0.006	–0.014	0.047	0.040	–0.015	–0.491**
	G	–0.016	–0.165	–0.064	**0.012**	0.011	–0.005	0.026	–0.372	0.021	0.011	0.011	–0.002	–0.027	0.006	0.020	0.022	–0.005	–0.518*
PH	P	0.066	0.012	0.015	0.011	**–0.084**	0.000	0.002	0.099	–0.126	–0.029	0.005	–0.042	0.011	–0.026	0.011	0.040	0.010	–0.024
	G	0.016	0.070	0.040	–0.002	**–0.084**	0.000	0.037	0.080	–0.159	–0.009	–0.011	0.002	–0.046	0.010	0.005	0.020	0.004	–0.026
DTH	P	–0.027	–0.024	–0.024	–0.048	0.000	**0.017**	0.003	–0.463	–0.157	–0.007	–0.011	–0.017	0.004	–0.022	0.070	0.062	–0.001	–0.646**
	G	–0.008	–0.173	–0.074	0.009	0.003	**–0.006**	0.046	–0.478	–0.254	–0.003	0.025	0.001	–0.022	0.010	0.037	0.040	0.000	–0.846**
HS	P	–0.023	0.009	0.015	0.018	0.028	–0.007	**–0.007**	0.095	0.065	0.011	0.002	0.007	–0.009	0.021	–0.020	–0.034	–0.001	0.171
	G	–0.007	0.055	0.041	–0.003	0.029	0.003	**–0.104**	0.084	0.090	0.004	–0.004	0.000	0.038	–0.009	–0.008	–0.020	0.000	0.189
FPP	P	0.038	0.031	0.027	0.054	–0.012	–0.012	–0.001	**0.700**	0.157	–0.006	0.011	0.012	–0.008	0.027	–0.088	–0.013	–0.009	0.909**
	G	0.009	0.173	0.064	–0.008	–0.012	0.005	–0.016	**0.550**	0.193	–0.002	–0.023	–0.001	0.033	–0.010	–0.036	–0.006	–0.003	0.910**
AFW	P	–0.016	0.004	–0.003	–0.003	0.024	–0.006	–0.001	0.255	**0.432**	0.081	0.014	0.072	–0.011	0.041	–0.094	–0.072	–0.030	0.688**
	G	–0.004	0.025	–0.006	0.000	0.025	0.003	–0.018	0.201	**0.531**	0.024	–0.030	–0.004	0.041	–0.015	–0.038	–0.035	–0.011	0.688**
LPF	P	–0.010	–0.008	–0.008	–0.029	0.023	–0.001	–0.001	–0.039	0.331	**0.106**	0.005	0.060	–0.005	0.027	–0.060	–0.096	–0.023	0.276*
	G	–0.002	–0.043	–0.020	0.004	0.024	0.001	–0.013	–0.030	0.409	**0.031**	–0.011	–0.004	0.020	–0.010	–0.024	–0.046	–0.008	0.277
PT	P	0.003	0.014	0.016	0.015	–0.015	–0.007	–0.001	0.280	0.222	0.020	**0.028**	0.027	–0.006	0.036	–0.091	–0.028	–0.023	0.490**
	G	0.001	0.083	0.042	–0.002	–0.016	0.003	–0.008	0.233	0.290	0.006	**–0.055**	–0.002	0.023	–0.014	–0.038	–0.015	–0.009	0.522*
PER	P	0.061	0.006	0.004	0.023	–0.034	0.003	0.000	–0.082	–0.308	–0.062	–0.008	**–0.101**	0.007	–0.025	0.061	0.000	0.066	–0.387**
	G	0.015	0.031	0.010	–0.003	–0.036	–0.001	0.007	–0.064	–0.383	–0.018	0.016	**0.006**	–0.028	0.009	0.025	–0.001	0.024	–0.39
TSS	P	0.021	–0.007	0.004	–0.022	–0.040	0.003	0.003	–0.250	–0.195	–0.022	–0.007	–0.030	**0.023**	–0.052	0.064	0.018	0.022	–0.467**

Table 2. (*Continued*).

Trait		SSN	SSF	PV	DFA	PH	DTH	HS	FPP	AFW	LPF	PT	PER	TSS	DM	LC	TA	LDI	Correlation with FY (kg/plant)
DM	G	0.005	–0.038	0.010	0.004	–0.043	–0.001	0.045	–0.202	–0.248	–0.007	0.015	0.002	**–0.089**	0.020	0.026	0.009	0.008	–0.484*
	P	0.011	–0.009	–0.006	–0.017	–0.033	0.006	0.002	–0.283	–0.264	–0.043	–0.015	–0.038	0.018	**–0.067**	0.095	0.072	0.014	–0.558**
LC	G	0.003	–0.054	–0.015	0.003	–0.035	–0.002	0.038	–0.231	–0.337	–0.013	0.031	0.002	–0.076	**0.024**	0.039	0.037	0.005	–0.581**
	P	0.020	0.019	0.019	0.030	0.007	–0.009	–0.001	0.461	0.303	0.047	0.019	0.046	–0.011	0.047	**–0.133**	–0.050	–0.026	0.789**
TA	G	0.005	0.106	0.045	–0.004	0.008	0.004	–0.016	0.367	0.377	0.014	–0.040	–0.003	0.044	–0.018	**–0.053**	–0.026	–0.009	0.8**
	P	0.033	0.001	0.003	0.016	0.016	–0.005	–0.001	0.041	0.145	0.047	0.004	0.000	–0.002	0.022	–0.031	**–0.196**	0.033	0.134
LDI	G	0.008	0.009	0.006	–0.003	0.016	0.002	–0.020	0.033	0.183	0.014	–0.008	0.000	0.007	–0.009	–0.014	**–0.103**	0.012	0.135
	P	0.051	0.002	–0.005	0.014	–0.010	0.000	0.000	–0.074	–0.146	–0.028	–0.007	–0.076	0.006	–0.011	0.039	–0.081	**0.088**	–0.236
	G	0.013	0.011	–0.011	–0.002	–0.010	0.000	0.001	–0.059	–0.182	–0.008	0.015	0.004	–0.024	0.004	0.016	–0.039	**0.031**	–0.24

***** Significant at 5% level of significance; ** Significant at 1% level of significance.

SSN—Percent seedling survival in the nursery; SSF—Percent seedling survival in the field; PV—Pollen viability; DFA—Number of days to first anthesis; PH—Plant height; DTH—Days from transplanting to first harvest; HS—Harvesting span; FPP—Number of fruits per plant; AFW—Average fruit weight; LPF—Number of locules per fruit; PT—Pericarp thickness; PER—Polar/equatorial ratio; TSS—Total soluble solids of fruit; DM—Dry matter content; LC—Lycopene content; TA—Titratable acidity; LDI—Tomato leaf curl diseases incidence; FY—Total fruit yield

Its indirect effect was negative through titratable acidity (−0.020), dry matter content (−0.009), lycopene content (−0.008), percent seedling survival in the nursery (−0.007), pericarp thickness (−0.004) and number of days to first anthesis (−0.003). Titratable acidity expressed positive indirect effect on total fruit yield per plant through average fruit weight (0.183), number of fruits per plant (0.033), plant height (0.016), number of locules per fruit (0.014), percent seedling survival in the field (0.009) and percent seedling survival in the nursery (0.008), total soluble solids (0.007), pollen viability (0.006) and days from transplanting to first harvest (0.002). Its indirect effect was negative through tomato leaf curl diseases incidence (−0.103), harvesting span (−0.020), lycopene content (−0.014), dry matter content (−0.009), pericarp thickness (−0.008) and number of days to first anthesis (−0.003). Similar results for indirect effects of economic traits on yield were also observed by Sunilkumar [5], Sushma et al. [6], Maurya et al. [7], Kumar et al. [11], Sharma et al. [8], Nevani and Sridevi [9].

4. Conclusion

Total fruit yield showed a positive and significant correlation with the number of fruits per plant, lycopene content, percent seedling survival in the field, and average fruit weight at both the genotypic and phenotypic levels. Hence, it was concluded that strong correlations of total fruit yield with these traits showed that selection based on these parameters will ultimately increase total fruit yield, and it is also proposed that hybridizing genotypes with combinations of these traits is the most effective way to produce the desired high-yielder segregants. Path-coefficient analysis disclosed that the number of fruits per plant and average fruit weight had the highest positive direct effect on fruit yield both at phenotypic and genotypic levels. Hence, it would be rewarding to place stress on these characters in selection programmes to increase yield. It would therefore be fruitful to emphasize these traits in selection programmes in order to increase yield.

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