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Correlation and Path Coefficient Analysis for Fruit Yield and Its Component Traits among Bacterial Wilt Resistant F_4 Progenies of Tomato (*Solanum lycopersicum* L.)

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A B S T R A C T

An experiment was conducted using 18 F_4 progenies of tomato along with two bacterial wilt resistant varieties as checks (Palam Pink and Palam Pride) to determine the inter-relationship among component traits and their direct and indirect contribution on marketable fruit yield. The trial was laid out in Randomized Complete Block Design with three replications at Vegetable Research Farm, Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during summer-rainy season of 2016. Two susceptible checks, Roma and Marglobe, were planted at every alternate 11^{th} row in the experiment to establish the severity of the disease. Estimates of correlation coefficient revealed that marketable yield per plant was positively and significantly correlated with total and marketable fruits per plant, gross yield per plant and pericarp thickness indicating that selection based on these characters either in combination or alone will result in identifying the genotypes having high yield potential. Path coefficient analysis showed that marketable fruits per plant and average fruit weight had the maximum positive contribution (direct and indirect) towards marketable yield per plant; hence these traits require special attention to improve upon marketable yield and other component traits.

Introduction

Tomato (*Solanum lycopersicum* L.) is a member of the family *Solanaceae* and significant vegetable crop of special economic importance in the horticultural industry worldwide (He *et al.,* 2003). Ripe tomato fruits are consumed fresh as salad and utilized in the preparation of range of processed products. Tomatoes are important source of lycopene (antioxidant), vitamin A, vitamin C and minerals (Singh *et al.,* 2014). It is extensively grown as an off-season vegetable crop during summer-rainy season in mid hills of Himachal Pradesh, fetches high prices in the markets located in the plains. Though it is a remunerative crop, but is highly susceptible to various biotic and abiotic stresses. Among biotic stresses, bacterial wilt is one of the most important restraints in humid tropical, subtropical and mild temperate areas due to which huge losses occur. The race 1 biovar III of *Ralstonia solanacearum* Smith is prevalent in Himachal Pradesh (Kalha and Sood, 1994). Hence, identification and development of new improved disease resistant cultivars is required merely to further boost up the production and productivity of the crop in wilt prone areas of Himachal Pradesh. Being a complex character, selection for yield and yield components deserves considerable attention. A crop breeding programme, aimed at increasing the plant productivity requires deliberation not only of yield but also of its components that have direct or indirect bearing on yield. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection can be based for improvement in yield. The correlation coefficient provides information regarding the association of different characters among themselves, whereas better insight into the cause of the association is provided by the path coefficient analysis. It allows the partition of the correlation coefficients into direct and indirect effects of the traits contributing towards the dependent variable. The present research was therefore undertaken to ascertain magnitude and extent of correlation and path coefficient analysis among F_4 progenies of tomato.

Materials and Methods

The present research was carried out with 18 bacterial wilt resistant F_4 progenies of tomato viz., (Palam Pride × BWR-5)-1-15, (Palam Pride × BWR-5)-1-16, (Palam Pride × BWR-5)-2-3, (Palam Pride × BWR-5)-2-6, (Hawaii 7998 × Palam Pride)-2-7, (Hawaii 7998 × BWR-5)-3-1, (CLN2070B-1 × 12-1)-2-8, (CLN2070B-1 × 12-1)-2-16, (CLN2123A-1 × BWR-5)-3-6, Avtaar-1-3, Avtaar-1-13, Avtaar-1-15, (12-1 × BWR-5)-1-7, (12-1 × BWR-5)-2-2, (12-1 × BWR-5)-2-13, (12-1 × BWR-5)-2-14, (12-1 × BWR-5)-2-18 and (12-1 × BWR-5)-2-19; which had been developed in the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur along with two bacterial wilt resistant checks (Palam Pink and Palam Pride). Roma and Marglobe were grown at every alternate 11^{th} row as susceptible checks to examine the disease incidence. These genotypes were evaluated in Randomized Complete Block Design with three replications during summer-rainy season of 2016 with intra and inter-row spacing of 70 cm× 45 cm. Observations were recorded on 10 competitive plants from each genotype and replication for different yield and quality traits viz., plant survival (%), days to 50 per cent flowering, days to first harvest, average fruit weight (g), fruit shape index (polar : equatorial diameter ratio), pericarp thickness (mm), locules per fruit, plant height (cm), duration of fruit harvest, total fruits per plant, marketable fruits per plant, marketable yield per plant (kg), gross yield per plant (kg), TSS (°Brix), lycopene content (mg/100g), titrable acidity (%) and ascorbic acid (mg/100g). The recorded data were analyzed as per the given formula for correlation coefficient (Al-Jibouri *et al.*, 1958) and path coefficient analysis (Dewey and Lu, 1959). The statistical analysis was carried out by using OPSTAT software.

Results and Discussion

Tomato breeding programs have been traditionally focused on developing varieties with improved agronomic performance particularly traits related to yield and fruit quality. Therefore, expanding knowledge about the nature and magnitude of correlations between traits of interest is of utmost importance. Selection for a particular trait may either increase or reduce the expression of another trait, depending on the genetic correlation between them. In present investigation, genotypic correlations were observed higher than the corresponding phenotypic ones (Table 1), indicating predominant role of heritable factors. Marketable yield per plant exhibited significant and positive phenotypic and genotypic correlations with gross yield per plant (0.930 and 0.982), marketable fruits per plant (0.693 and 0.691), total fruits per plant (0.652 and 0.696) and pericarp thickness (0.329 and 0.609), respectively. The results revealed that gross yield per plant, marketable fruits per plant; total fruits per plant and pericarp thickness were the major traits contributing towards marketable yield per plant in tomato. The positive association also indicated that the selection should be oriented towards high gross yield per plant, marketable fruits per plant, total fruits per plant and pericarp thickness for obtaining higher marketable yield per plant. Earlier researchers have also found similar results for gross yield per plant (Chadha and Bhushan, 2013; Chadha and Walia, 2016), marketable fruits per plant (Chadha *et al.,* 2009), total fruits per plant (Kumar *et al.*, 2013; Chadha and Walia, 2016) and pericarp thickness (Thapa *et al.*, 2016).

Positive and significant correlations at the phenotypic and genotypic level were observed between total fruits per plant and marketable fruits per plant (0.947 and 0.986), marketable fruits per plant and gross yield per plant (0.683 and 0.713), total fruits per plant and gross yield per plant (0.702 and 0.735), pericarp thickness and gross yield per plant (0.329 and 0.673), days to 50 per cent flowering and days to first harvest (0.733 and 0.943), days to 50 per cent flowering and fruit shape index (0.448 and 0.680), days to 50 per cent flowering and average fruit weight (0.430 and 0.483), days to 50 per cent flowering and plant height (0.428 and 0.575), days to first harvest and fruit shape index (0.494 and 0.715), days to first harvest and average fruit weight (0.396 and 0.500), days to first harvest and plant height (0.373 and 0.469), fruit shape index and plant height (0.268 and 0.342), pericarp thickness and marketable fruits per plant (0.375 and 0.483), pericarp thickness and total fruits per plant (0.318 and 0.453), duration of fruit harvest and ascorbic acid (0.417 and 0.555), TSS and lycopene content (0.260 and 0.497), titrable acidity and ascorbic acid content (0.259 and 0.426), respectively. Positive and significant correlations were also observed for days to 50 per cent flowering with titrable acidity (0.447), TSS (0.442) and pericarp thickness (0.333); days to first harvest with titrable acidity (0.403), pericarp thickness (0.334) and TSS (0.287); average fruit weight and TSS (0.432); fruit shape index and duration of fruit harvest (0.320); pericarp thickness and duration of fruit harvest (0.276); duration of fruit harvest with marketable fruits per plant (0.350) and total fruits per plant (0.294); locules per fruit and plant height with TSS (0.443 and 0.510, respectively), and TSS and titrable acidity (0.624) at genotypic level only. This suggested that effective improvement in tomato yield through these characters could be achieved by simple recurrent selection. Various researchers in the past had worked on this aspect in tomato and reported associations between different parameters at phenotypic levels. Positive and significant correlations at phenotypic level were also reported between days to 50 per cent flowering with days to first harvest and fruit shape index (Sharma *et al.*, 2013), average fruit weight (Kumar, 2010), and plant height (Prajapati *et al.,* 2015); days to first harvest with average fruit weight and fruit shape index (Chadha and Walia, 2016); total fruits per plant with marketable fruits per plant and gross yield per plant (Chadha and Walia, 2016); TSS with lycopene content (Rani *et al.*, 2010), and titrable acidity with ascorbic acid content (Rani *et al.,* 2010). Marketable yield per plant registered significant and negative correlation with days to 50 per cent flowering (-0.293), locules per fruit (-0.356), plant height (-0.257) and TSS (-0.483) at genotypic level only.

Table.1 Estimates of correlation at phenotypic (P) and genotypic (G) levels among different traits of tomato

		Days to first harvest	Average fruit weight (g)	Fruit shape index	Pericarp thickness (mm)	Locules per fruit	Plant height (cm)	Duration of fruit harvest (days)	Total fruits per plant	Marketable fruits per plant	Gross yield per plant (kg)	Total soluble solids (°Brix)	Lycopene content (mg/100g)	Titrable acidity (%)	Ascorbic acid (mg/100g)	Marketable yield per plant (kg)
Days to 50 per cent flowering	P	0.733**	0.430**	0.448**	0.126	-0.159	0.428**	0.002	-0.479**	-0.489**	-0.058	0.217	-0.112	0.208	0.064	-0.121
	G	0.943**	0.483**	0.680**	0.333**	-0.336**	0.575**	0.195	-0.670**	-0.657**	-0.249	0.442**	-0.175	0.447**	0.130	-0.293*
Days to first harvest	P		0.396**	0.494**	0.034	-0.103	0.373**	-0.035	-0.363**	-0.373**	0.053	0.003	-0.238	0.248	0.020	-0.011
	G		0.500**	0.715**	0.334**	-0.235	0.469**	0.059	-0.555**	-0.537**	-0.062	0.287*	-0.360**	0.403**	0.077	-0.110
Average fruit weight (g)	P			0.114	-0.261*	0.219	0.191	-0.360**	-0.639**	-0.643**	-0.050	0.242	-0.304*	-0.086	-0.250	0.062
	G			0.198	-0.261*	0.218	0.174	-0.507**	-0.727**	-0.720**	-0.129	0.432**	-0.336**	-0.087	-0.322*	-0.034
Fruit shape index	P				0.093	-0.520**	0.268*	0.225	-0.157	-0.124	0.048	-0.271*	-0.317*	0.043	-0.005	0.002
	G				0.106	-0.607**	0.342**	0.320*	-0.234	-0.219	-0.003	-0.573**	-0.396**	0.048	-0.082	-0.047
Pericarp thickness (mm)	P					-0.440**	0.134	0.221	0.318*	0.375**	0.329*	-0.055	0.064	0.123	-0.010	0.329*
	G					-0.530**	0.113	0.276*	0.453**	0.483**	0.673**	0.092	0.102	0.187	-0.022	0.609**
Locules per fruit	P						-0.151	-0.426**	-0.180	-0.300*	-0.169	0.250	0.036	-0.124	-0.127	-0.218
	G						-0.159	-0.597**	-0.250	-0.343**	-0.299*	0.443**	0.058	-0.273*	-0.135	-0.356**
Plant height (cm)	P							0.133	-0.342**	-0.341**	-0.122	0.114	0.222	0.019	0.148	-0.163
	G							0.165	-0.383**	-0.418**	-0.110	0.510**	0.232	-0.049	0.234	-0.257*
Duration of fruit harvest (days)	P								0.216	0.200	0.020	-0.056	-0.204	0.004	0.417**	-0.025
	G								0.294*	0.350**	0.149	-0.299*	-0.242	-0.036	0.555**	0.088
Total fruits per plant	P									0.947**	0.702**	-0.238	0.085	-0.031	0.200	0.652**
	G									0.986**	0.735**	-0.642**	0.097	-0.023	0.247	0.696**
Marketable fruits per plant	P										0.683**	-0.348**	0.046	-0.022	0.193	0.693**
	G										0.713**	-0.717**	0.058	-0.022	0.236	0.691**
Gross yield per plant (kg)	P											-0.109	-0.099	-0.117	0.121	0.930**
	G											-0.483**	-0.109	-0.049	0.176	0.982**
Total soluble solids (°Brix)	P												0.260*	-0.013	0.020	-0.158
	G												0.497**	0.624**	-0.124	-0.483**
Lycopene content (mg/100g)	P													0.163	0.015	-0.157
	G													0.211	0.068	-0.186
Titrable acidity (%)	P														0.259*	-0.074
	G														0.426**	-0.048
Ascorbic acid (mg/100g)	P															0.073
	G															0.097

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

Table.2 Direct and indirect effects of component traits on marketable yield of tomato at phenotypic and genotypic level

Traits		Days to 50 per cent flowering	Days to first harvest	Average fruit weight (g)	Fruit shape index	Pericarp thickness (mm)	Locules per fruit	Plant height (cm)	Duration of fruit harvest (days)	Total fruits per plant	Marketable fruits per plant	Gross yield per plant (kg)	Total soluble solids (°Brix)	Lycopene content (mg/100g)	Titrable acidity (%)	Ascorbic acid (mg/100g)	Correlation with Marketable yield per plant
Days to 50 per cent flowering	P	**-0.005**	0.012	0.256	-0.002	0.004	0.001	0.008	0.000	0.055	-0.434	-0.025	0.005	-0.003	0.007	-0.000	-0.121
	G	**0.299**	-0.314	0.483	0.188	0.009	-0.125	0.048	0.047	0.120	-1.045	-0.077	0.031	-0.018	0.076	-0.017	-0.293*
Days to first harvest	P	-0.004	**0.016**	0.236	-0.002	0.001	0.001	0.007	-0.001	0.041	-0.332	0.023	0.000	-0.006	0.008	-0.000	-0.011
	G	0.282	**-0.333**	0.499	0.198	0.009	-0.087	0.039	0.014	0.100	-0.855	-0.019	0.020	-0.037	0.069	-0.010	-0.110
Average fruit weight (g)	P	-0.002	0.006	**0.596**	-0.001	-0.008	-0.002	0.004	-0.008	0.073	-0.571	-0.021	0.006	-0.008	-0.003	0.000	0.062
	G	0.145	-0.166	**0.999**	0.055	-0.007	0.081	0.015	-0.122	0.131	-1.146	-0.040	0.031	-0.034	-0.015	0.042	-0.034
Fruit shape index	P	-0.002	0.008	0.068	**-0.005**	0.003	0.004	0.005	0.005	0.018	-0.110	0.021	-0.006	-0.008	0.001	0.000	0.002
	G	0.203	-0.238	0.197	**0.277**	0.003	-0.226	0.029	0.077	0.042	-0.349	-0.001	-0.041	-0.041	0.008	0.011	-0.047
Pericarp thickness (mm)	P	-0.001	0.001	-0.156	-0.000	**0.031**	0.003	0.003	0.005	-0.036	0.333	0.142	-0.001	0.002	0.004	0.000	0.329*
	G	0.100	-0.111	-0.261	0.029	**0.026**	-0.197	0.009	0.067	-0.081	0.769	0.207	0.006	0.010	0.032	0.003	0.609**
Locules per fruit	P	0.001	-0.002	0.130	0.002	-0.014	**-0.007**	-0.003	-0.010	0.021	-0.267	-0.073	0.006	0.001	-0.004	-0.000	-0.218
	G	-0.101	0.078	0.218	-0.168	-0.014	**0.372**	-0.013	-0.144	0.045	-0.545	-0.092	0.031	0.006	-0.047	0.018	-0.356**
Plant height (cm)	P	-0.002	0.006	0.114	-0.001	0.004	0.001	**0.020**	0.003	0.039	-0.303	-0.053	0.003	0.005	0.001	-0.000	-0.163
	G	0.172	-0.156	0.174	0.095	0.003	-0.059	**0.084**	0.040	0.069	-0.666	-0.034	0.036	0.024	-0.008	-0.030	-0.257*
Duration of fruit harvest (days)	P	-0.000	-0.001	-0.215	-0.001	0.007	0.003	0.003	**0.023**	-0.025	0.178	0.009	-0.001	-0.005	0.000	-0.000	-0.025
	G	0.058	-0.020	-0.507	0.089	0.007	-0.222	0.014	**0.241**	-0.053	0.558	0.046	-0.021	-0.025	-0.006	-0.072	0.088
Total fruits/ plant	P	0.002	-0.006	-0.381	0.001	0.010	0.001	-0.007	0.005	**-0.114**	0.842	0.303	-0.006	0.002	-0.001	-0.000	0.652**
	G	-0.200	0.185	-0.726	-0.065	0.012	-0.093	-0.032	0.071	**-0.180**	1.569	0.226	-0.045	0.010	-0.004	-0.032	0.696**
Marketable fruits per plant	P	0.002	-0.006	-0.383	0.001	0.012	0.002	-0.007	0.005	-0.108	**0.888**	0.295	-0.008	0.001	-0.001	-0.000	0.693**
	G	-0.196	0.179	-0.720	-0.061	0.013	-0.127	-0.035	0.085	-0.177	**1.591**	0.219	-0.051	0.006	-0.004	-0.031	0.691**
Gross yield/ plant (kg)	P	0.000	0.001	-0.030	-0.000	0.010	0.001	-0.002	0.000	-0.080	0.607	**0.432**	-0.003	-0.002	-0.004	-0.000	0.930**
	G	-0.075	0.021	-0.129	-0.001	0.018	-0.111	-0.009	0.036	-0.132	1.134	**0.307**	-0.034	-0.011	-0.008	-0.023	0.982**
Total soluble solids(°Brix)	P	-0.001	0.000	0.144	0.001	-0.002	-0.002	0.002	-0.001	0.027	-0.309	-0.047	**0.024**	0.006	-0.000	-0.000	-0.158
	G	0.132	-0.095	0.432	-0.159	0.002	0.165	0.043	-0.072	0.115	-1.141	-0.148	**0.071**	0.051	0.106	0.016	-0.483**
Lycopene content (mg/100g)	P	0.001	-0.004	-0.181	0.001	0.002	-0.000	0.004	-0.005	-0.010	0.041	-0.043	0.006	**0.025**	0.005	-0.000	-0.157
	G	-0.052	0.120	-0.335	-0.110	0.003	0.022	0.019	-0.058	-0.017	0.093	-0.033	0.035	**0.103**	0.035	-0.009	-0.186
Titrable acidity (%)	P	-0.001	0.004	-0.051	-0.000	0.004	0.001	0.000	0.000	0.004	-0.019	-0.051	-0.000	0.004	**0.032**	-0.000	-0.074
	G	0.134	-0.134	-0.086	0.013	0.005	-0.102	-0.004	-0.009	0.004	-0.035	-0.015	0.044	0.022	**0.170**	0.055	-0.048
Ascorbic acid (mg/100g)	P	-0.000	0.000	-0.149	0.000	-0.000	0.001	0.003	0.010	-0.023	0.172	0.052	0.000	0.000	0.008	**-0.001**	0.073
	G	0.039	-0.025	-0.322	-0.023	-0.001	-0.050	0.020	0.134	-0.044	0.375	0.054	-0.009	0.007	0.072	**-0.130**	0.097

*Significant at 5% level of significance; Residual effect (R) 0.012; **Significant at 1% level of significance; Underlined va lues indicate direct effects

Similar findings were reported for days to 50 per cent flowering and locules per fruit (Kumar, 2005), and for plant height (Mohanty, 2002, 2003).

The correlation coefficients provide information regarding the association of different characters among themselves, whereas better insight into the cause of the association is provided by the path coefficient analysis. It allows the partition of the correlation coefficients into direct and indirect effects of the traits contributing towards the dependent variable. The phenotypic path-coefficient analysis for different component traits is presented in (Table 2). It is evident from the present investigation that marketable yield per plant showed highest positive direct effect on marketable fruits per plant [0.888(P) and 1.591(G)] followed by average fruit weight [0.596(P) and 0.999(G)], gross yield per plant [0.432(P) and 0.307(G)], titrable acidity [0.032(P) and 0.170(G)], pericarp thickness [0.031(P) and 0.026(G)], lycopene content [0.025(P) and 0.103(G)], TSS [0.024(P) and 0.071(G)], duration of fruit harvest [0.023(P)], plant height [0.020(P) and 0.084(G)] and days to first harvest [0.016(P)]. Positive direct effects of marketable fruits per plant and average fruit weight on marketable yield per plant were also reported by various researchers (Kumar, 2010; Chadha and Walia, 2016). On the other hand, direct negative effects were exhibited by total fruits per plant [-0.114(P) and -0.180(G)], locules per fruit [-0.007(P)], days to 50 per cent flowering [-0.005(P)], fruit shape index [-0.005(P)] and ascorbic acid [-0.001(P) and -0.130(G)]. Negative direct effect of ascorbic acid on fruit yield per plant was also reported in various findings (Rani *et al.,* 2010; Meena and Bahadur, 2015). In contrary to our results, negative direct effects on fruit yield per plant were exhibited by harvest duration (Kumar, 2010; Patil *et al.,* 2013; Chadha and Walia, 2016) and pericarp thickness (Sharma *et al.,* 2013). The characters showing high direct effect on marketable yield per plant indicated that direct selection for these traits might be effective and there is possibility of improving marketable yield per plant through selection based on these characters.

Many component traits showed pronounced indirect effect mainly via marketable fruits per plant and average fruit weight (either positive or negative) towards marketable yield per plant, however the overall effect towards marketable yield was nullified resulting in non-significant correlations of these traits with marketable yield per plant. The results pertaining to indirect effect of different component traits are discussed hereunder by ignoring their significance of correlation with marketable yield per plant. Positive indirect effects at phenotypic (P) and genotypic (G) levels were observed for pericarp thickness via marketable fruits per plant [0.333(P) and 0.769(G)], total fruits per plant via marketable fruits per plant [0.842(P) and 1.569(G)], marketable fruits per plant via gross yield per plant [0.295(P) and 0.219(G)], and for gross yield per plant via marketable fruits per plant [0.607(P) and 1.134(G)]. Negative indirect effects were observed at genotypic (G) level for TSS via marketable fruits per plant (-1.141), days to 50 per cent flowering via marketable fruits per plant (-1.045), plant height via marketable fruits per plant (-0.666) and locules per fruit via marketable fruits per plant (-0.545). A critical observation of indirect effects, it was noticed that most of the traits contributed towards marketable yield per plant via marketable fruits per plant and average fruit weight. Therefore, marketable fruits per plant and average fruit weight are the two most important characters which are required to be considered to improve upon marketable yield per plant and other horticultural traits. However, marketable fruits per plant and average fruit weight are negatively associated with each other.

Therefore, a compromise with average fruit weight mostly preferred by consumers (60-100g) along with high number of marketable fruits per plant has to be made for maximizing the marketable yield potential. The residual effect of other factors (0.012) on marketable yield per plant was found negligible, thereby, suggested that no major yield component is left over.

In present investigation, marketable fruits per plant showed significant positive correlation and high positive and direct effect with marketable yield per plant followed by average fruit weight. Therefore, higher number of fruits and average fruit weight should be considered in selection criteria for increasing marketable yield per plant. However, number of marketable fruits per plant and average fruit weight had significant negative correlation with each other. Therefore the present study suggested that more emphasis should be given to selecting genotypes with more number of fruits per plant with acceptable fruit size from consumers' perspective.

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