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Character association studies in polyhouse tomato [*Solanum lycopersicum* L.] accessions for fruit, yield and quality parameters

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Abstract
A comprehensive analysis involving correlation and path coefficients was conducted on a collection of thirty-three tomato genotypes. The objective of this study was to examine the nature and strength of relationship between the yield of tomato plants and the various contributing factors. These genotypes were cultivated using a randomized block design in two replicates at the PG Research Block, located within a naturally ventilated polyhouse at the College of Horticulture, Rajendranagar, Hyderabad, during the year 2022-23 *Rabi* season. Observations were recorded for ten distinct parameters related to tomato fruit, yield and quality traits. The correlation coefficients demonstrated a significantly positive association with fruit yield per plant at both the genotypic and phenotypic levels for several factors, including the fruit length, fruit diameter and average fruit weight. Furthermore, there was a positive significant association at the genotypic level for pericarp thickness, ascorbic acid content and shelf life while negative correlation with total soluble solids. The results obtained from the path analysis unveiled that the fruit diameter, total soluble solids exerted a direct and positive influence on fruit yield per plant both at genotypic and phenotypic level whereas fruit length and number of locules per fruit exerted a direct and negative influence.

Keywords: Polyhouse tomato, *Solanum lycopersicum* L., fruit, yield, parameters

Introduction
The tomato (*Solanum lycopersicum* L.) is a flowering plant belonging to the nightshade family (Solanaceae), featuring a chromosome count of 2n=24. It is extensively cultivated for its delectable fruits and holds the second position in global importance, following only the potato. Yield, a complex trait resulting from the interplay of numerous contributing factors and their interactions, is subject to polygenic inheritance. Thus, comprehending the associations between these factors and their interaction with the environment is crucial for the success of any crop improvement program.

Correlation coefficient analysis is a bivariate approach for quantifying the strength and direction of the relationship between two variables. It is broadly categorized into genotypic and phenotypic correlation coefficients. The genotypic correlation coefficient assesses the interdependence of two traits in expressing genetic characteristics, thus guiding breeding programs towards the most pertinent traits. Path analysis, in simpler terms, involves multiple regression analysis that examines the relationship between a dependent variable (in this study, yield per plant) and the independent variables represented by various plant characteristics.

Selecting traits solely based on correlation coefficients may not be suitable, as yield depends on numerous factors. Path analysis is essential because it can assess the relative importance of multiple traits that collectively contribute to yield. In more straightforward language, path analysis breaks down the strength of associations between traits into direct and indirect effects. Consequently, correlation and path coefficients help breeders simultaneously select the most effective traits for desired improvement and allocate resources effectively within crop improvement or selection programs, leading them in the desired direction.

Material and Methods
The current research was conducted at the PG Research Block, situated within a naturally ventilated greenhouse at the College of Horticulture, Rajendranagar, Hyderabad, during the *Rabi* season of 2022-23.

Furthermore, the analysis of fruit quality took place within the laboratories of the Department of Vegetable Science, also located at the College of Horticulture in Rajendranagar.
The selected germplasm encompassed a total of thirty-two different genotypes, in addition to one standard check variety, which were sourced from various origins. The crops were sown using a randomized block design with two replications. This investigation involved the observation and recording of ten (10) distinct parameters. For each genotype in every replication, five plants were randomly chosen for the recording of various plant characteristics. Similarly, ten (10) fruits were randomly selected and recorded to assess fruit characteristics.
The data collected for these various traits underwent statistical analysis to determine the nature and extent of their associations. Genotypic and phenotypic correlation coefficients were computed using variance and covariance components, as per the methodology suggested by Al-Jibouri *et al*. in 1958 [1]. Additionally, path coefficient analysis was performed following the procedure outlined by Dewey and Lu in 1959 [4].

Results and Discussion

Correlation coefficients were calculated for all the studied characteristics, both at the genotypic and phenotypic levels, including fruit yield per plant and relationships between these characteristics themselves (as shown in Table-1 and Table-2). When comparing these values, it became apparent that the genotypic correlation coefficient estimates were consistently higher than their phenotypic counterparts for nearly all the characteristics. This observation suggests that environmental factors mitigate the phenotypic expression, even when there is a strong inherent association between these characteristics. These findings align with previous research conducted by Reddy *et al.* (2013) [14], Buhroy *et al.* (2017), Gopinath and Vethamoni (2017) [6], Gillani *et al.* (2019) [5], Sharma *et al.* (2019) [15], Maurya *et al.* (2020) [9], Nevani and Sridevi (2021) [11], Patel and Kumar (2021) [13], Vijaya Laxmi *et al.* (2021), and *Shubha et al.* (2023) [16]. They indicate a robust genetic relationship between these characteristics, despite the fact that their observable (phenotypic) expression is influenced by environmental conditions.
Furthermore, the study's results highlight that the nature and direction of genotypic and phenotypic correlation coefficients remained consistent across all the considered traits. For instance, fruit yield per plant displayed a significant positive correlation with the fruit length (0.491 genotypic, 0.485 phenotypic), fruit diameter (0.660 genotypic, 0.651 phenotypic), and average fruit weight (0.636 genotypic, 0.634 phenotypic) at both genotypic and phenotypic levels. Additionally, characteristics like pericarp thickness (0.313), ascorbic acid content (0.352) and shelf life (0.243) showed significant positive associations with yield per plant at the genotypic level.
Fruit length was notably negatively associated with total soluble solids (TSS) at both phenotypic and genotypic levels (-0.433 and -0.437, respectively). Conversely, it displayed significant positive associations with fruit diameter (0.680 and 0.690, respectively), average fruit weight (0.616 and 0.623, respectively), pericarp thickness (0.731 and 0.750, respectively), and shelf life (0.454 and 0.475, respectively) at both phenotypic and genotypic levels. At the genotypic level, same trait was exhibited a negative correlation (-0.258) with titrable acidity. Fruit diameter exhibited a significant negative association with TSS (-0.534 and -0.539, respectively) at both phenotypic and genotypic levels, but showed a positive correlation with the number of locules per fruit (0.341) at the genotypic level. Additionally, fruit diameter displayed significant positive associations with pericarp thickness (0.371 and 0.379, respectively), average fruit weight (0.630 and 0.635, respectively), and shelf life (0.382 and 0.398, respectively) at both phenotypic and genotypic levels.
The number of locules per fruit had a significant negative association with TSS (-0.297 and -0.302, respectively) at both phenotypic and genotypic levels, while it exhibited a significant positive correlation with average fruit weight (0.384 and 0.387, respectively) at both phenotypic and genotypic levels. Pericarp thickness showed a significant negative association with TSS (-0.267) at the genotypic level but displayed significant positive associations with average fruit weight per plant (0.452 and 0.458, respectively) and shelf life (0.471 and 0.491, respectively) at both at phenotypic and genotypic levels.
Average fruit weight had a significant negative association with TSS (-0.296) at the genotypic level but exhibited significant positive associations with shelf life (0.288 and 0.296, respectively) at the phenotypic and genotypic levels. Ascorbic acid content was significantly negatively associated with TSS (-0.365) and displayed a significant positive association with titrable acidity (0.316) at the genotypic level. Shelf life had significant negative associations with TSS (-0.332) and titrable acidity (-0.286) at the genotypic level.
Path analysis is a statistical technique that assesses the standardized partial regression coefficients to measure how one variable affects another. It helps break down correlation coefficients into direct and indirect effects of different characteristics on attributes like crop yield. In this study, path coefficients were calculated using genotypic correlation values, treating yield per plant as the dependent variable and the other characteristics as independent variables. This allowed for the quantification of both direct and indirect effects on yield per plant, as shown in Table-3 and Table-4. The findings align with previous research, such as Shubha *et al.* (2023) [16] for fruit length and fruit diameter, Nevani and Sridevi (2021) [11] for pericarp thickness, Patel and Kumar (2021) [13] for average fruit weight, Namdev *et al.* (2018) [10] and Kumar *et al.* (2013) [8] for Total Soluble Solids (TSS), Reddy *et al.* (2013) [14] for ascorbic acid content, Buckseth *et al.* (2012) [2] for shelf life, and Panchbhai *et al.* (2023) [12] for the number of locules per fruit.
In terms of direct effects on yield per plant, the analysis revealed that average fruit weight had the most substantial positive impact (0.8390 genotypically and 0.7376 phenotypically), followed by fruit diameter (0.2776 genotypically and 0.3861 phenotypically) and TSS (0.1626 genotypically and 0.1167 phenotypically). On the contrary, the highest negative direct effect on yield per plant was attributed to fruit length (-0.4631), followed by shelf life (-0.1032) at the genotypic level and pericarp thickness (-0.1386), followed by the number of locules per fruit (-0.0764), and fruit length (-0.0505) at the phenotypic level.
The analysis revealed several noteworthy findings regarding the interrelationships among various characteristics. Furthermore, the influence on fruit length was attributed to the low positive indirect effect of the TSS (0.2024 and 0.0219, respectively), along with the negative indirect effects

of fruit diameter (-0.3195 and -0.0343, respectively), pericarp thickness (-0.3471 and -0.0369, respectively), and average fruit weight (-0.2886 and -0.0311, respectively) at the genotypic and phenotypic levels.

Pericarp thickness demonstrated positive indirect effects on fruit length (0.0226), fruit diameter (0.0114), average fruit weight (0.0138) and shelf life (0.0148) at the genotypic level. Average fruit weight exhibited positive indirect effects on fruit length (0.5229 and 0.4542, respectively), fruit diameter (0.5329 and 0.4646, respectively), number of locules per fruit (0.3249 and 0.2834, respectively), pericarp thickness (0.3840 and 0.3330, respectively), but it had negative indirect effects on the TSS (-0.2487 and -0.2182, respectively) and titrable acidity (-0.1605 and -0.1311, respectively) at both genotypic and phenotypic levels.

The character "ascorbic acid" displayed a positive indirect effect on TSS (0.0217) at the genotypic level. In the case of "shelf life," the positive indirect effects were due to the number of TSS (0.0343) and titrable acidity (0.0295) at the genotypic level and fruit length (0.0272), fruit diameter (0.0229), pericarp thickness (0.0282), and average fruit weight (0.0173) at the phenotypic level. Conversely, it had negative indirect effects on fruit length (-0.0490) and fruit diameter (-0.0410) at the genotypic level, as well as on TSS (-0.0196) and titrable acidity (-0.0160) at the phenotypic level.

Table 1: Genotypic correlation coefficient for fruit, yield and quality parameters in indeterminate tomato accessions

Characters	Fruit length (cm)	Fruit diameter (cm)	Number of locules per fruit	Pericarp thickness (mm)	Average fruit weight (g)	Ascorbic acid content (mg/100g)	Shelf life (Days)	Total soluble solids (ºbrix)	Titrable acidity (%)	Fruit yield per plant (g)
Fruit length (cm)	1.000	0.690**	0.121	0.750**	0.623**	0.038	0.475**	-0.437**	-0.258*	0.491**
Fruit diameter (cm)		1.000	0.341**	0.379**	0.635**	0.106	0.398**	-0.539**	-0.183	0.660**
Number of locules per fruit			1.000	-0.010	0.387*	-0.007	0.182	-0.302*	-0.063	0.217
Pericarp thickness (mm)				1.000	0.458**	0.125	0.491**	-0.267*	-0.047	0.313*
Average fruit weight (g)					1.000	-0.103	0.296*	-0.296*	-0.191	0.636**
Ascorbic acid content (mg/100g)						1.000	0.119	-0.365**	0.316**	0.352**
Shelf life (Days)							1.000	-0.332**	-0.286*	0.243*
Total soluble solids (ºbrix)								1.000	0.023	-0.311*
Titrable acidity (%)									1.000	-0.179
Fruit yield per plant (g)										1.000

Critical r value at 1% =0.314 5% = 0.242
*Significant at 5%
** Significant at 1%

Table 2: Phenotypic correlation coefficient for fruit, yield and quality parameters in indeterminate tomato accessions

Characters	Fruit length (cm)	Fruit diameter (cm)	Number of locules per fruit	Pericarp thickness (mm)	Average fruit weight (g)	Ascorbic acid content (mg/100g)	Shelf life (Days)	Total soluble solids (ºbrix)	Titrable acidity (%)	Fruit yield per plant (g)
Fruit length (cm)	1.000	0.680**	0.113	0.731**	0.616**	0.005	0.454**	-0.433**	-0.228	0.485**
Fruit diameter (cm)		1.000	0.333	0.371*	0.630**	0.056	0.382*	-0.534**	-0.179	0.651**
Number of locules per fruit			1.000	-0.010	0.384*	-0.020	0.176	-0.297*	-0.073	0.213
Pericarp thickness (mm)				1.000	0.452**	0.092	0.471**	-0.266	-0.045	0.309
Average fruit weight (g)					1.000	-0.077	0.288*	-0.296	-0.178	0.634**
Ascorbic acid content (mg/100g)						1.000	0.092	-0.281	0.231	0.248
Shelf life (Days)							1.000	-0.326	-0.267	0.230
Total soluble solids (ºbrix)								1.000	0.015	-0.309
Titrable acidity (%)									1.000	-0.177
Fruit yield per plant (g)										1.000

Critical r value at 1% = 0.395 5%= 0.341
*Significant at 5%
** Significant at 1%

Table 3: Genotypic path coefficient analysis for fruit, yield and quality parameters in indeterminate tomato accessions

Characters	Fruit length (cm)	Fruit diameter (cm)	Number of locules per fruit	Pericarp thickness (mm)	Average fruit weight (g)	Ascorbic acid content (mg/100g)	Shelf life (Days)	Total soluble solids (ºbrix)	Titrable acidity (%)	r_g
Fruit length (cm)	-0.4631	-0.3195	-0.0560	-0.3471	-0.2886	-0.0175	-0.2200	0.2024	0.1198	0.4912**
Fruit diameter (cm)	0.1916	0.2776	0.0945	0.1051	0.1763	0.0295	0.1104	-0.1498	-0.0508	0.6569**
Number of locules per fruit	-0.0083	-0.0234	-0.0687	0.0007	-0.0266	0.0005	-0.0125	0.0207	0.0043	0.2166
Pericarp thickness (mm)	0.0226	0.0114	-0.0003	0.0302	0.0138	0.0038	0.0148	-0.0081	-0.0014	0.3126*
Average fruit weight (g)	0.5229	0.5329	0.3249	0.3840	0.8390	-0.0865	0.2486	-0.2487	-0.1605	0.6363**
Ascorbic acid content (mg/100g)	-0.0022	-0.0063	0.0005	-0.0074	0.0061	-0.0595	-0.0071	0.0217	-0.0188	0.3516*
Shelf life (Days)	-0.0490	-0.0410	-0.0188	-0.0506	-0.0306	-0.0123	-0.1032	0.0343	0.0295	0.2426*
Total soluble solids (ºbrix)	-0.0711	-0.0878	-0.0491	-0.0438	-0.0482	-0.0594	-0.0540	0.1626	0.0037	-0.3113*
Titrable acidity (%)	0.0229	0.0162	0.0056	0.0042	0.0169	-0.0280	0.0253	-0.0020	-0.0885	-0.1787

Diagonal indicates direct effect Critical r value at 1% = 0.314 5%= 0.242 *Significant at 5% ** Significant at 1% Residual= 0.07 r_g- Genotypic correlation with fruit yield per plant

Table 4: Phenotypic path coefficient analysis for fruit, yield and quality parameters in indeterminate tomato accessions

Characters	Fruit length (cm)	Fruit diameter (cm)	Number of locules per fruit	Pericarp thickness (mm)	Average fruit weight (g)	Ascorbic acid content (mg/100g)	Shelf life (Days)	Total soluble solids (ºbrix)	Titrable acidity (%)	r_P
Fruit length (cm)	-0.0505	-0.0343	-0.0057	-0.0369	-0.0311	-0.0002	-0.0229	0.0219	0.0115	0.4847**
Fruit diameter (cm)	0.2624	0.3861	0.1286	0.1433	0.2432	0.0215	0.1476	-0.2063	-0.0689	0.6512**
Number of locules per fruit	-0.0086	-0.0255	-0.0764	0.0008	-0.0294	0.0016	-0.0135	0.0227	0.0056	0.2126
Pericarp thickness (mm)	-0.1013	-0.0514	0.0014	-0.1386	-0.0626	-0.0127	-0.0652	0.0368	0.0062	0.3088
Average fruit weight (g)	0.4542	0.4646	0.2834	0.3330	0.7376	-0.0569	0.2121	-0.2182	-0.1311	0.6337**
Ascorbic acid content (mg/100g)	0.0002	0.0023	-0.0008	0.0037	-0.0031	0.0406	0.0037	-0.0114	0.0094	0.2478
Shelf life (Days)	0.0272	0.0229	0.0106	0.0282	0.0173	0.0055	0.0600	-0.0196	-0.0160	0.2304
Total soluble solids (ºbrix)	-0.0505	-0.0623	-0.0347	-0.0310	-0.0345	-0.0327	-0.0381	0.1167	0.0017	-0.3092
Titrable acidity (%)	-0.0106	-0.0083	-0.0034	-0.0021	-0.0083	0.0107	-0.0124	0.0007	0.0464	-0.1771

Diagonal indicates direct effect Critical r value at 1% = 0.395 5%= 0.341 *Significant at 5% ** Significant at 1%
Residual= 0.144 r_P - Phenotypic correlation with fruit yield per plant

Conclusion

The findings from this study unveiled a noteworthy presence of both favourable and unfavourable direct and indirect influences exerted by different traits on tomato fruit yield. Consequently, certain plant traits, such as average fruit weight, fruit length, and fruit diameter, exhibited substantial correlations and heritability, signifying their paramount importance in the selection process for enhancing tomato crops in any breeding program. Similarly, when it comes to fruit quality, attributes like pericarp thickness, ascorbic acid content, and fruit shelf life emerged as the most reliable indicators.

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