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Assessment of Genetic Variability and Trait Associations Among Yield Components in Tomato (*Solanum lycopersicum L.*)

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is one of the most economically important vegetable crops globally, ranking second after potato in production. Despite its significance, tomato yield in Pakistan remains low (≈ 9 t ha^{-1}) compared to global averages (~ 37 t ha^{-1}). This study aimed to evaluate genetic variability, heritability, and correlations among yield-related traits in thirteen tomato genotypes under field conditions. The experiment was conducted in a Randomized Complete Block Design (RCBD) with three replications. Data were collected for sixteen quantitative traits, including days to flowering, fruit weight, plant height, and yield per plant. Analysis of variance revealed significant genotypic differences for most traits. High genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for fruit weight, number of fruits per plant, and yield per plant, indicating substantial genetic variability. Broad-sense heritability estimates were high (>60%) for fruit weight, plant height, and pericarp thickness, suggesting additive gene action. Correlation analysis revealed that fruit weight and number of fruits per plant had a significant positive association with yield. The findings suggest that selection based on these traits could enhance tomato yield in breeding programs.

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1. Introduction

Tomato (*Solanum lycopersicum L.*) is the second most important vegetable worldwide after potato (Naveed et al., 2019). The tomato was first domesticated in western South America. The worldwide cultivated total area is ≈ 5 million ha, with an average yield of ≈ 38 t ha^{-1} with total production of 189,133,909 metric tonnes of tomatoes. China harvested about 1,140,716 ha of tomatoes, yielding 68 241 811 t in 2022 (≈ 59.8 t ha^{-1}). India harvested roughly 841,000 ha of tomatoes, producing 20,694,000 t in 2022 (≈ 24.6 t ha^{-1}). Pakistan harvested about 168,150 ha, producing 792,938 t of tomatoes in 2022 (≈ 9 t ha^{-1}). Tomato species has spread worldwide as a result of its wide adaptability to a variety of growing conditions (including greenhouses and open fields), as well as the versatility of its consumption, which can be used as fresh or processed (Distefano et al., 2022). A tomato plant from the *Solanaceae* family with chromosome number 2n=24. Lycopene is the most well-known phytochemical found in tomatoes. There are also other carotenoids like beta-carotene, phytoene, and phytofluene, phenolics like quercetin, rutin, and naringenin, and also trace amounts of ascorbic acid (antioxidant vitamin C) and vitamin E (tocopherol). The majority of lycopene is found in tomatoes and few vegetables and fruits of red color. Lycopene helps reduce the risk of prostate and other cancers. Moreover, lycopene protects against cardiovascular disease and supports eye health. The nutritional and economic importance of the plant has increased the interest of stakeholder (Distefano et al., 2022). The increased demand for this fruit has resulted from the awareness of the great nutritional and health benefits of tomatoes as well as their extensive use in a variety of cuisine. As a result, tomato farming must be increased to fulfill consumer demand (Behera et al., 2020). By volume of its consumption on a daily basis, it contributes significantly to the dietary intake of essential minerals, vitamins A and C (Fufa et al., 2009). Climate change is expected to significantly reduce future crop yields. It also has a substantial impact on reproductive and vegetative traits, including germination, plant height, leaf size, pollen viability, and fertility. These effects are largely due to sustained temperature increases that exceed optimal levels by just a few degrees. The ideal temperatures during daytime and evening are, as 21

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to 30°C and 18 to 21°C. Between 2050 and 2100, extreme heat and water shortage stress are predicted to have a substantial impact on growth of plant (Lee et al., 2022). Pakistan produces far less tomatoes than other countries due to a lack of improved cultivars (Rasheed et al., 2023). Numerous studies demonstrate that tomato yield is reduced but fruit quality is raised at certain levels of water scarcity (Chen et al., 2013). In Pakistan main factor in reduction of tomato production is lack of promising varieties with lacking of crop changing environment, against insect pests, and diseases (Bihon et al., 2022). Tomato has strong genetic base because high phenotypic and genotypic variability so recognized as the most significant vegetable crop. Genetic diversity in tomatoes is ideal for improving quality and production measures. Breeder priority the genetic diversity and heritability of the qualitative and quantitative traits while making their selections. One of the complex characteristics of tomato that connected to numerous other plant characteristics is yield (Hassan et al., 2021). Pakistan's tomato yield is incredibly poor when compare with the 33.6 t ha^{-1} in the average of world's major producing countries. Therefore, Pakistan has a huge demand for superior tomato cultivars with outclass performance (Aziz et al., 2021). Genetic variability is one of pre-requirements for successful breeding program of crop plants. Appropriate knowledge for the variability current for various characters in germplasm is vital for selection of promising genotypes from population (Srivastava et al., 2013). Phenotypic and genotypic coefficient of variation is beneficial in noticing the amount of variation in current genotypes (D. Kumar et al., 2013). Correlation study is necessary to find the association between traits for this purpose, it necessary to investigate the nature and magnitude of traits which are contributing to yield and individual plant yield. Genetic variability and correlation help to choose superior genotypes for establishing a new breeding program. Plant breeders may develop tomato cultivars with the use of the collected information. So precise characterization of genetic properties is vital to know and estimate the genetic variation, heritability and correlation. Correlation and analysis of variance showed that selection is helpful tool to select the excellent genotype of tomatoes. The primary aim of this research is to screen and select the most promising lines for future breeding programs. To achieve this, the study involved the evaluation of multiple tomato genotypes under field conditions, the estimation of genetic differences among these genotypes, and the measurement of associations between traits relevant to yield.

2. Methodology

The present research was conducted to assess the genetic variability and correlations among quantitative traits in tomato. The study was carried out at the research area of the University of Agriculture, Sub-Campus Depalpur Okara, during the spring season of 2022–2023. The nursery of thirteen tomato genotypes was raised in trays filled with peat moss as the growth medium. After 35 days, the seedlings were transplanted to the field. The experiment followed a randomized complete block design (RCBD) with three replications. Each replication included five plants per genotype, and the spacing between rows and plants was maintained at 45 cm and 60 cm, respectively. The thirteen genotypes used in this study—CLN-3252-D, TM-35, TM-12521, TM-1421, TM-2301, Naqir, Naqeeb, TMA-13221, Roma, TM-24, TM-12821, TMA-13721, and Pakit—were obtained from the Department of Plant Breeding and Genetics, University of Agriculture Faisalabad. Data was collected on various growth and yield-related parameters. These included days to first blooming (counted from sowing to first flower appearance), number of blooming flowers per plant (average number of flowers from start to end of flowering), and time to 50% flowering (number of days to reach half of total flowering, assessed every three days). Additional observations were made on the number of flower clusters per plant, number of flowers per cluster, days to fruit initiation (from sowing to the appearance of the first fruit), and the number of fruits per truss at maturity. Other traits recorded included the total number of fruits per plant (from first to last picking), days to first harvest (from sowing to the first picking), average fruit weight (measured from five randomly selected fruits per plant), fruit size (measured vertically using a vernier caliper), and fruit diameter (measured at the central portion of the fruit). Pericarp thickness was measured using vernier calipers at the widest cross-section of five mature fruits per plant. The number of locules was counted by cutting five fruits longitudinally and calculating the average. At maturity, plant height was recorded from the base to the apical bud using a measuring tape, and yield per plant was calculated by averaging the total fruit weight from five randomly selected plants per genotype. The collected data was subjected to analysis of variance (ANOVA) to determine the significance of differences among genotypes. Mean performance values were estimated, and comparisons were made using the Least Significant Difference (LSD) test at a 5% probability level. Pearson (1895)'s method was used to calculate correlation coefficients among the traits.

2.1 Estimation of Genetic Components

To evaluate the genetic parameters, components of variance such as genotypic variance, phenotypic variance, and environmental variance were calculated. The phenotypic variance was computed by dividing the mean square of genotypes by the number of replications. The genotypic and environmental variances were derived accordingly.

2.2 Coefficient of Variation

The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated to estimate the degree of variability present among the traits. These were computed using formulas based on the respective variance

values and the grand mean of each trait. As per the classification by Sivasubramaniam and Madhava Menon (1973), the coefficients were categorized into low (<10%), moderate (10–20%), and high (>20%) variation.

2.3 Heritability

Broad-sense heritability was estimated for each trait as the ratio of genotypic variance to phenotypic variance, following the method proposed by Johnson, Robinson and Comstock (1955). The values were interpreted as low (<30%), moderate (30–60%), or high (>60%) heritability.

2.4 Genetic Advance (%)

Genetic advance as a percentage of the mean was also computed using the formula suggested by Johnson et al. (1955). This calculation considered the standard deviation of phenotypic variance and a selection differential value (K = 2.06) at a selection intensity of 5%.

2.5 Estimation of Correlation Coefficients

Both genotypic and phenotypic correlation coefficients were estimated using the method described by Searle (1961). Genotypic correlation was computed using the covariance of genotypic values, while phenotypic correlation used phenotypic covariances and variances for the traits under study. These correlations provided insights into the relationship between various growth and yield attributes in tomato genotypes.

3. Results and Discussion

The research work was started to analyze genetic variability and relationship between different characters in thirteen genotypes of tomato in randomized complete block design (RCBD) at research area with three replications grown, University of Agriculture Sub-Campus Depalpur Okara in 2022-2023. The assessments of coefficient of variation calculate the efficiency in segregated generations for selection. Phenotypic and genotypic correlation coefficients were assessed according to Lawrence and McKenzie (2000).

3.1 Variability

Variability stated to the presence of variation among individual of crop population. It arises as a result of variations in either the environment in which people are raised or in the genetic make-up of an individual within a community. For agricultural improvement, genetic diversity is crucial, and wider adaptability is effective for selection of plants. Breeders need to have information of the scope of variability in order to launch a wise breeding program. Analysis of variance (ANOVA) showed significant differences among genotypes, point out at minimum one group varies from the other sets. In order to analyze the arrangement of variance among means, the ANOVA is often monitored by specific associations, and the most commonly used one includes relating two resources (the so called “pairwise comparisons”). The first pairwise association method was advanced by Fisher in 1935 and is named the minimum significant alteration (LSD) test. This method can be used only if the Fisher (F) value in ANOVA is significant. The core idea of the LSD test is to work out the minimum significant alteration amid any two means values. Analysis of variance and mean act of thirteen tomato genotypes for several quantitative traits are displayed. Mean values of all attributes are displayed in table 3.1(A), 3.1(B). The genetic component displayed in Table 3.2(A). Phenotypic correlation coefficient (PCV) and genotypic correlation coefficient (GCV) is displayed in Table 3.2(B). The final results are detailed as follows:

Table 3.1(A): Mean Values of Flowering and Fruit Morphological traits in Thirteen Tomato Genotypes

Genotype	DPSF (days)	DF50%	NFP	NCFP	FET	F/T	FD (cm)	FL (cm)	PT (cm)
TM-2301	24.46	88.33	69	12.26	3.93	3.6	4.7	5.06	7
ROMA	30.4	45.07	53.6	13.4	3.46	3.06	4	5.26	5.66
Naqir	30.2	117.27	38.8	8.11	4.11	2.25	4.83	5.16	5.66
Naqeeb	27.53	42.73	75.67	14	4.33	2.26	5	5.9	7.66
Pakit	28	43.07	71.67	13	4.53	2.26	4.43	4.26	6
TM-24	31	42.27	40.27	9.467	3.33	2.13	4.03	3.2	4.66
CLN-3252-D	33.46	48.93	246.93	28.33	7.46	5.66	2.36	2.3	2
TM-35	37.4	50	125.33	17.2	6.2	5.38	2.96	3.83	2.33
TM-12521	25.6	42.93	62	10.86	4.66	2.93	5	5.46	6.66
TM-1421	22.28	36.2	52	9.1	4.78	3.33	4.86	5.93	6.66
TM-12821	25.41	36.73	38.93	7.083	4.91	2.53	4.66	6.36	7
TMA-13721	28.38	40.53	50.27	9.117	4.78	3.25	4.56	5.56	6
TMA-13221	27.61	40.2	49.67	8.383	4.96	2.61	5.2	6.56	6.66

Note: DPSF = Days to First Flower; DF50% = Days to 50% Flowering; NFP = Number of Flowers Per plant; NCFP = Number of Flower Clusters per Plant; FET = Flowers Per Truss; F/T = Fruits Per Truss; FD = fruit diameter; FL = fruit length; PT = Pericarp Thickness.

Table 3.1(B): Mean Values of Yield and Yield-Related Traits in Thirteen Tomato Genotypes

Genotype	FW (g)	NL	PH (cm)	FI (days)	NFPP	FPT (days)	YPP (g/plant)
TM-2301	66.88	2	75.18	33.4	64	71	3931.7
ROMA	45.91	2.33	53.17	40.73	49.67	72.33	3328.9
Naqir	66.96	2	56.05	38.83	9	82	637.5
Naqeeb	87.57	2.33	70.61	37.26	31.33	72	1918.9
Pakit	48.41	3	58.5	37.13	51.67	70	2600.2
TM-24	28.83	2.66	61.98	42.6	77.33	75.33	2049.1
CLN-3252-D	10.45	2.33	96.69	45.2	322	69	1971.6
TM-35	15.34	2.33	107.36	48.13	169.67	69	1788.5
TM-12521	74.48	2.33	72.64	33.93	73.33	72	4107.5
TM-1421	79.34	2.33	105.66	30.08	57.67	69	3907.1
TM-12821	80.74	2.33	96.69	35.85	31.67	73	2219.8
TMA-13721	69.33	2.33	59.61	37.86	22	76.33	1357.5
TMA-13221	94.06	2.66	61.98	36.26	19.33	76.33	1323.1

Note: FW = Fruit Weight; NL = Number of Locules; PH = Plant Height; FI = Fruit Initiation; NFPP = Number of Fruits Per plant; FPT = First Picking Time; YPP = Yield Per Plant.

Table 3.2(A): Estimation of Genetic Components for Flowering and Fruit Morphological Traits in Thirteen Tomato Genotypes

	DPSF	DF50%	NFP	NCFP	FET	F/T	FD	FS	PT
Coefficient of Variation (CV, %)	11.12	81.42	57.89	48.99	15.64	26.57	10.85	16.05	24.39
Environmental Variance	10.121	63.901	1835.71	49.722	0.547	0.712	0.223	0.642	1.927
Genotypic Variance	12.569	837.557	2585.52	5.960	1.026	1.068	0.626	1.375	2.384
Phenotypic Variance	22.690	901.458	4421.24	55.683	1.574	1.781	0.850	2.017	4.312
Environmental Coefficient of Variance (ECV, %)	11.125	15.693	57.177	57.173	15.636	26.572	10.854	16.053	24.388
Genotypic Coefficient of Variance (GCV, %)	12.397	56.814	67.857	19.795	21.422	32.529	18.170	23.491	27.128
Phenotypic Coefficient of Variance (PCV, %)	16.657	58.942	88.735	60.503	26.522	42.002	21.165	28.452	36.479
Standard Error of Mean	1.836	4.615	24.736	4.071	0.427	0.487	0.273	0.462	0.801
Heritability (Broad Sense, %)	55.39	92.91	58.48	10.7	65.24	59.98	73.7	68.17	55.3
Genetic Advance as Percent of Mean (GAM, %)	19.007	112.814	106.898	13.341	35.644	51.898	32.134	39.955	41.557

Note: DPSF = Days to First Flowering; DF50% = Days to 50% Flowering; NFP = Number of Flowers Per Plant; NCFP = Number of Flower Clusters Per Plant; FET = Flowers Per Truss; F/T = Fruits Per Truss; FD = Fruit Diameter; FL = Fruit Length; PT = Pericarp Thickness.

Table 3.2(B): Estimation of Genetic Components for Yield and Yield-Related Traits in Thirteen Tomato Genotypes

	FW	NL	PH	FI	NFPP	FPT	YPP
Coefficient of Variation (CV, %)	28.39	27.75	16.62	11.17	78.96	5.06	18.53
Environmental Variance	281.574	0.0149	155.791	18.249	3533.594	13.621	1351440.81
Genotypic Variance	644.533	0.064	334.474	18.276	5958.299	9.784	777265.288
Phenotypic Variance	926.108	0.079	490.265	36.526	9491.893	23.406	2128706.098
Environmental Coefficient of Variance (ECV, %)	28.390	5.368	16.623	11.167	78.961	5.064	48.529
Genotypic Coefficient of Variance (GCV, %)	42.954	11.205	24.356	11.175	102.534	4.292	36.803
Phenotypic Coefficient of Variance (PCV, %)	51.488	12.426	29.488	15.798	129.415	6.639	60.906
Standard Error of Mean	9.688	0.070	7.206	2.466	34.32	2.130	671.178
Heritability (Broad Sense, %)	69.6	81.3	68.22	50.04	62.77	41.8	36.51
Genetic Advance as Percent of Mean (GAM, %)	73.818	20.811	41.443	16.285	167.348	5.717	45.812

Note: FW = Fruit Weight; NL = number of Locules; PH = Plant Height; FI = Fruit Initiation; NFPP = Number of Fruits Per plant; FPT = First Picking Time; YPP = Yield Per Plant.

3.2 Correlation

A statistical tool for determining the strength and direction of a relationship between two or more variables is the correlation coefficient. It is symbolized by “r”. The correlation between two traits may be positive or negative. Its values vary from -1 to +1. Correlation coefficient analysis, used in plant breeding, calculates the interrelationships between various plant traits and identifies the constituent traits that might be used in selection to increase yield genetically. It helps in identifying the traits in plant breeding that contribute to yield. Three types of correlation are genotypic, phenotypic, and environmental. Phenotypical correlation is the relationship between two immediately observable factors. It considers into account both genotypic and environmental impacts and, as a result, varies depending on the environment. The essential or transmissible association among two variables is called genotypic correlation. This type of association may result through linkage, pleiotropic effects of genes, or more likely from both. Pleiotropy, the term for multiple gene effects, is the primary genetic factor causing this correlation. It is evidence of pleiotropy if the relationship between two positive or negative traits remains constant in both parental and segregated generation. If it varies in the segregating generation, it is likely to be the

result of recombination across two genes caused by a broken linkage between two genes. Two favorable traits or one desirable and one objectionable trait are involved in the pleiotropy or linkage. The first condition promotes genetic development, whereas the second constrains it. Such a type of correlation is more reliable, and it is crucial for a breeder to choose the other traits in a pair that is heritable associated in order to strengthen the genetic makeup of one character. It was detected that phenotypic correlation coefficient was best as related to their consistent genotypic correlation coefficient which shows greater contribution of environment in the development of associations. Between all possible combinations of 16 quantitative traits, PCV and GCV were assessed and displayed in table 3.3. Correlation among different traits is shown in table and explained in the following paragraphs.

3.3 Trait–Yield Relationship Analysis

The correlation analysis between various traits and yield per plant revealed diverse relationships. Days prior to the start of flowering showed an undesirable and statistically significant genotypic correlation with yield per plant and also exhibited a highly significant and negative phenotypic association. Time to 50% flowering exhibited a non-significant but consistent genotypic and phenotypic correlation with yield, indicating that this trait had limited direct influence on final output. The number of flowers per plant revealed an undesirable and non-significant genotypic association with yield, while its phenotypic correlation was also non-significant yet stable. The number of flower clusters per plant demonstrated a non-significant but positive genotypic correlation with yield per plant, whereas the phenotypic correlation was non-significant and slightly negative. Similarly, the number of flowers per cluster showed an undesirable and non-significant relationship with yield, both at genotypic and phenotypic levels. Fruits per truss, fruit diameter, and fruit size all exhibited confident yet non-significant genotypic and phenotypic associations with yield, suggesting consistent but statistically insignificant trends. Pericarp thickness showed a positive, though non-significant, genotypic and phenotypic correlation with yield per plant. Fruit weight was also confidently but non-significantly correlated with yield at both genetic and phenotypic levels. Likewise, the number of locules per fruit revealed a consistent and non-significant genotypic and phenotypic association with yield. Plant height showed a confident and non-significant correlation with yield at both genotypic and phenotypic levels, though prior studies, such as Singh et al. (2017) have reported a positive association between plant height and final yield. Fruit initiation showed a significant and negative correlation with yield at both levels, indicating that earlier fruit setting may be associated with higher productivity. The number of fruits per plant had a positive but non-significant genotypic and phenotypic correlation with yield, suggesting that this trait could still be valuable for selection. In contrast, the first time to picking demonstrated a highly significant and undesirable correlation with yield at both the genotypic and phenotypic levels, indicating that delayed harvesting negatively impacts total yield.

3.4 Inter-Trait Correlation Analysis in Tomato

Correlation analysis revealed several significant relationships between key agronomic and yield-related traits in tomato. Days prior to the start of blooming exhibited a positive and highly significant genotypic association with the number of flower clusters per plant, fruit initiation, and the number of fruits per plant. Additionally, fruit per truss and fruit initiation showed a highly significant and favorable phenotypic correlation. Fruit diameter, fruit size, and fruit weight were positively and significantly associated, suggesting that larger fruits tend to be heavier. However, undesirable and highly significant associations were also noted between fruit width, size, pericarp thickness, and single fruit weight with final yield at the phenotypic level. These results indicate that while certain fruit dimensions correlate positively with one another, they may adversely affect overall yield. The remaining traits exhibited non-significant associations at both genotypic and phenotypic levels. These findings align with those of Golani et al. (2007) who reported that yield per plant had a positive and significant association with the number of locules per fruit, but a negative and significant correlation with plant height. Time to 50% flowering revealed a non-significant and positive genotypic and phenotypic relationship with traits such as the number of flowers per plant, flower clusters per plant, fruit per truss, fruit length, pericarp thickness, number of locules, plant height, and number of fruits per plant. Conversely, flowers per truss, fruit size, fruit weight, fruit initiation, and time to first picking were negatively and non-significantly correlated with time to 50% flowering. These results are supported by Srivastava et al. (2013) who also observed a significant and positive relationship between final yield and days to 50% flowering. The number of flowers per plant displayed highly significant and positive genotypic correlations with flower clusters per plant, flowers per truss, fruit per truss, fruit initiation, and the number of fruits per plant. At the phenotypic level, significant and positive associations were noted with flowers per truss, fruit per truss, plant height, days to fruit emergence, and number of fruits per plant. However, significant and negative associations were recorded for fruit diameter, fruit size, pericarp thickness, and fruit weight. Additionally, the genotypic correlation with first picking time was also negative and highly significant. Similar observations were reported by V. Kumar et al. (2013) who found strong relationships between fruit weight, fruits per plant, and overall yield. The number of flower clusters per plant showed highly significant and confident genotypic correlations with fruit per truss, fruit initiation, and number of fruits per plant, along with a significant phenotypic

association with fruit initiation. However, undesirable and significant genotypic associations were observed with fruit diameter, fruit size, pericarp thickness, and fruit weight. Ghosh et al. (2018) similarly reported positive associations between fruit yield and traits like plant length, flower number, and fruits per cluster. Debnath et al. (2021) also noted significant phenotypic associations with clusters per plant and fruit weight, but a negative correlation with days to 50% flowering. Flowers per truss exhibited highly significant genotypic and phenotypic correlations with fruit per truss, plant height, and number of fruits per plant. However, it showed a significant and negative relationship with fruit diameter and pericarp thickness. These findings are consistent with Solieman, El-Gabry and Abido (2013) who also identified strong associations between flower traits and yield performance. Fruit per truss revealed highly significant genotypic associations with fruit initiation and the number of fruits per plant. At the phenotypic level, it was significantly associated with plant height and fruit number, but negatively and significantly correlated with fruit diameter, pericarp thickness, fruit weight, fruit size, and first picking time. Mahapatra et al. (2013) similarly emphasized positive correlations of fruit yield with flower clusters, fruit number, fruit size, pericarp thickness, locules, and fruit weight. Fruit diameter showed strong and significant genotypic and phenotypic correlations with fruit size, pericarp thickness, and fruit weight. As fruit diameter increased, so did pericarp thickness and weight. However, a highly significant and negative correlation was observed with fruit initiation and number of fruits per plant, indicating that larger fruits may delay fruit setting or reduce fruit number. Bojarian, Asadi-Gharneh and Golabadi (2019) also reported similar trends for fruit size, pericarp thickness, and fruit breadth. Fruit size had significant and positive genotypic and phenotypic associations with pericarp thickness and fruit weight. However, it was negatively associated with days to fruit emergence and the number of fruits per plant. Tembe et al. (2018) also reported a strong relationship between fruit size and breadth. Pericarp thickness displayed strong genotypic and phenotypic associations with fruit weight, while showing a non-significant and negative association with fruit initiation and the number of fruits per plant. Manna and Paul (2012) highlighted that pericarp thickness, fruit length, fruit weight, and number of fruits per plant significantly influenced yield per plant. Fruit weight exhibited a significant and negative genotypic and phenotypic correlation with fruit initiation and number of fruits per plant. It had a non-significant but positive correlation with days to first picking and yield. These findings are supported by Ullah (2025), who found significant correlations between yield and traits like fruit number, fruit weight, fruit width, and locules. The number of locules per fruit was negatively and significantly correlated with time to first picking, both genotypically and phenotypically. Reddy et al. (2013) reported that yield was positively associated with traits such as fruit weight, fruit number, and flower clusters. Al-Aysh et al. (2012) also noted significant correlations of locule number and pericarp thickness with yield. Plant height exhibited a negative and significant association with time to first picking. However, a positive and significant genotypic and phenotypic relationship was noted with the number of fruits per plant. Nwosu et al. (2014) similarly observed a strong association between plant height and fruit number. Fruit initiation revealed positive and highly significant associations with the number of fruits per plant at both genotypic and phenotypic levels but was negatively and significantly correlated with yield. Ayele et al. noted that fruit weight, fruit number, and plant height were key contributors to overall yield (Ayele, Gailing, & Finkeldey, 2011). The number of fruits per plant had a significant negative genotypic correlation with time to first picking, along with a non-significant negative association with yield. Phenotypically, it was negatively and significantly correlated with first picking time, but positively (and non-significantly) correlated with yield. Madhurina Manna and Amitava Paul (2012) reported similar results, with positive correlations between yield and pericarp thickness, fruit length, fruit weight, and fruit number, and negative associations with time to flowering and plant height. Lastly, time to first picking exhibited a highly significant and negative association with yield at both the genotypic and phenotypic levels. These findings are in contrast to those of Mohanty and Sahoo, who found a positive correlation between yield and time to first picking (Mohanty & Sahoo, 2003). Parveen Sharma et al. (2013) however, supported the current findings by reporting a significant correlation between early harvest, plant height, locule number, and yield per plant.

4. Conclusion

The present study was conducted to evaluate the genetic variability, heritability, genetic advance, and correlation among yield-related traits in thirteen tomato genotypes. The analysis of variance revealed significant differences among the genotypes for most of the studied traits, indicating substantial genetic variability. Large phenotypic and genotypic coefficients of variation (PCV and GCV) were recorded for number of flowers per plant, number of fruits per plant, fruit weight and yield per plant, indicating exploitable diversity. Broad-sense heritability estimates were high for traits like fruit weight (69.6%), fruit diameter (68.17%), plant height (68.22%), and pericarp thickness (55.3%), indicating that these traits are less influenced by environmental factors and can be improved through selection. High heritability coupled with high genetic advance was observed for fruit weight, fruit size, and plant height, suggesting the predominance of additive gene action, making these traits more responsive to selection. Correlation analysis revealed that yield per plant had a positive but non-significant association with fruit weight, fruit size, and number of fruits per plant, indicating that indirect selection for these traits could improve yield. However, yield showed a significant negative correlation with days to first flowering

and first picking time, suggesting that early-maturing genotypes may be more favorable for higher productivity. Among the genotypes, CLN-3252-D exhibited the highest number of flowers and fruits per plant, while TMA-13221 showed the highest fruit weight and size. TM-12521 recorded the highest yield per plant, making it a promising candidate for future breeding programs. The findings suggest that selection based on fruit weight, fruit size, and number of fruits per plant could be effective for improving tomato yield.

5. Recommendations

1. CLN-3252-D and TM-12521 should be considered for hybridization programs due to their high yield potential and desirable fruit characteristics.
2. Traits such as fruit weight, pericarp thickness, and plant height, which exhibit high heritability and genetic advance, should be prioritized in selection programs.
3. Further molecular studies should be conducted to identify quantitative trait loci (QTLs) associated with high-yielding traits to facilitate marker-assisted selection.

This study provides valuable insights into the genetic variability and trait relationships in tomato, which can aid breeders in developing high-yielding and stress-resistant varieties to meet increasing global demand.

6. References

Al-Aysh, F., Kutma, H., Serhan, M., Al-Zoubai, A., Al-Naseer, M. A., & Village, D. (2012). Genetic analysis and correlation studies of yield and fruit quality traits in tomato (Solanum lycopersicum L.). *New York Science Journal*, *5*(10), 142-145.

Ayele, T. B., Gailing, O., & Finkeldey, R. (2011). Assessment and integration of genetic, morphological and demographic variation in Hagenia abyssinica (Bruce) JF Gmel to guide its conservation. *Journal for nature conservation*, *19*(1), 8-17.

Aziz, I., Khan, A. A., Khalofah, A., Tabasum, A., Bashir, M. A., Batool, M., Khan, K. A., Farooq, H., Alajmi, R. A., & Metwally, D. M. (2021). Estimation of genetic components and heterosis for nursery traits in tomato hybrids (Solanum esculentum, MILL). *Fres. Environ. Bull*, *30*, 3371-3376.

Behera, M., Jagadev, P., Das, S., Pradhan, K., & Sahoo, B. (2020). Assessment of genetic variability, heritability and genetic advance in Tomato. *Int. J. Chem. Stud*, *8*(4), 481-483.

Bihon, W., Ognakossan, K. E., Tignegre, J.-B., Hanson, P., Ndiaye, K., & Srinivasan, R. (2022). Evaluation of different tomato (Solanum lycopersicum L.) entries and varieties for performance and adaptation in Mali, West Africa. *Horticulturae*, *8*(7), 579.

Bojarian, M., Asadi-Gharneh, H. A., & Golabadi, M. (2019). Factor analysis, stepwise regression and path coefficient analyses of yield, yield-associated traits, and fruit quality in tomato. *International Journal of Vegetable Science*, *25*(6), 542-553.

Chen, J., Kang, S., Du, T., Qiu, R., Guo, P., & Chen, R. (2013). Quantitative response of greenhouse tomato yield and quality to water deficit at different growth stages. *Agricultural water management*, *129*, 152-162.

Debnath, A., Kumar, R., Prasad, S., & Sharma, N. (2021). Genetic variation and character association study among morphological and biochemical traits of tomato (Solanum lycopersicum L.) genotypes. *The Biosc*, *16*(1), 69-75.

Distefano, M., Mauro, R. P., Page, D., Giuffrida, F., Bertin, N., & Leonardi, C. (2022). Aroma volatiles in tomato fruits: The role of genetic, preharvest and postharvest factors. *Agronomy*, *12*(2), 376.

Fufa, F., Hanson, P., Dagnoko, S., & Dhaliwal, M. (2009). AVRDC-The World Vegetable Center tomato breeding in sub-Saharan Africa: Lessons from the past, present work, and future prospects. I All Africa Horticultural Congress 911,

Ghosh, T., Islam, S., Shahanaz, S., Biswas, S., & Tareq, M. (2018). Genetic variability and selection index evaluation of some selected tomato lines for their yield and yield components. *Bangladesh journal of environmental science, Dhaka*, *34*, 73-78.

Golani, I., Mehta, D., Purohit, V., Pandya, H., & Kanzariya, M. (2007). Genetic variability, correlation and path coefficient studies in tomato. *Indian journal of agricultural research*, *41*(2), 146-149.

Hassan, Z., Ul-Allah, S., Khan, A. A., Shahzad, U., Khurshid, M., Bakhsh, A., Amin, H., Jahan, M. S., Rehim, A., & Manzoor,

Z. (2021). Phenotypic characterization of exotic tomato germplasm: An excellent breeding resource. *PloS one*, *16*(6), e0253557.

Johnson, H. W., Robinson, H., & Comstock, R. (1955). Estimates of genetic and environmental variability in soybeans.

Kumar, D., Kumar, R., Kumar, S., Bhardwaj, M., Thakur, M., Kumar, R., Thakur, K. S., Dogra, B. S., Vikram, A., & Thakur, A. (2013). Genetic variability, correlation and path coefficient analysis in tomato. *International Journal of Vegetable Science*, *19*(4), 313-323.

Kumar, V., Nandan, R., Srivastava, K., Sharma, S., Kumar, R., & Kumar, A. (2013). Genetic parameters and correlation study for yield and quality traits in tomato (Solanum lycopersicum L.). *Plant Archives*, *13*(1), 463-467.

Lawrence, D., & McKenzie, R. (2000). The general application of significance editing. *Journal of official statistics*, *16*(3), 243.

Lee, K., Rajametov, S. N., Jeong, H.-B., Cho, M.-C., Lee, O.-J., Kim, S.-G., Yang, E.-Y., & Chae, W.-B. (2022). Comprehensive understanding of selecting traits for heat tolerance during vegetative and reproductive growth stages in tomato. *Agronomy*, *12*(4), 834.

Madhurina Manna, M. M., & Amitava Paul, A. P. (2012). Studies on genetic variability and characters association of fruit quality parameters in tomato.

Mahapatra, A., Singh, A. K., Vani, V. M., Ramanand Mishra, R. M., Harit Kumar, H. K., & Rajkumar, B. (2013). Inter-relationship for various components and path coefficient analysis in tomato (Lycopersicon esculentum Mill).

Manna, M., & Paul, A. (2012). Path analysis between fruit yield and some yield components in tomato (Lycopersicon esculeutum Mill). *Hortflora Research Spectrum*.

Mohanty, K., & Sahoo, N. (2003). *Prospects of mycorrhizae as potential nematode antagonist*. Scientific Publishers: India.

Naveed, M. S., Manzoor, A., Javed, A., & Tariq, M. A. (2019). In-vitro screening of different tomato genotypes against peg induced water stress. *World journal of biology and biotechnology*, *4*(3), 15-19.

Nwosu, D., Onakoya, O., Okere, A., Babatunde, A., & Popoola, A. (2014). Genetic variability and correlations in rainfed tomato (Solanum spp.) accessions in Ibadan, Nigeria. *Greener J. Agric. Sci*, *4*(5), 211-219.

Parveen Sharma, P. S., Yashi Sadhawi, Y. S., Vidyasagar, V., & Neelam Bhardwaj, N. B. (2013). Correlation and path-coefficient studies in tomato (Solanum lycopersicum L.) under protected environment.

Pearson, K. (1895). VII. Note on regression and inheritance in the case of two parents. *proceedings of the royal society of London*, *58*(347-352), 240-242.

Rasheed, A., Ilyas, M., Khan, T. N., Mahmood, A., Riaz, U., Chattha, M. B., Al Kashgry, N. A. T., Binothman, N., Hassan, M. U., & Wu, Z. (2023). Study of genetic variability, heritability, and genetic advance for yield-related traits in tomato (Solanum lycopersicon MILL.). *Frontiers in Genetics*, *13*, 1030309.

Reddy, B., Reddy, D., Reddaiah, K., & Sunil, N. (2013). Studies on genetic variability, heritability and genetic advance for yield and quality traits in tomato (Solanum lycopersicum L.).

Searle, S. (1961). Phenotypic, genetic and environmental correlations. *Biometrics*, *17*(3), 474-480.

Singh, A., Ram, C., Yadav, G., Srivastava, R., Deo, C., & Gautam, D. (2017). Studies on genetic variability, heritability and genetic advance in tomato (Solanum lycopersicum L.). *Int. J. Pure App*, *5*, 908-912.

Sivasubramaniam, S., & Madhava Menon, P. (1973). Genotypic and phenotypic variability in rice.

Solieman, T., El-Gabry, M., & Abido, A. (2013). Heterosis, potence ratio and correlation of some important characters in tomato (Solanum lycopersicum L.). *Scientia Horticulturae*, *150*, 25-30.

Srivastava, K., Kumari, K., Singh, S., & Kumar, R. (2013). Association studies for yield and its component traits in tomato (Solanum lycopersicum L.). *Plant Archives*, *13*(1), 105-112.

Tembe, K. O., Chemining'wa, G., Ambuko, J., & Owino, W. (2018). Evaluation of African tomato landraces (Solanum lycopersicum) based on morphological and horticultural traits. *Agriculture and Natural Resources*, *52*(6), 536-542.

Ullah, M. Z. (2025). Phenotypic Variability, Trait Association and Path Coefficient Analysis of Cherry Tomato (Solanum lycopersicum Var. Cerasiforme) Genotypes.

Table 3.3: Phenotypic and Genotypic Correlation for Thirteen Tomato Genotypes

		DPSF	DF50%	AFP	NCFP	FET	F/T	FD	FL	PT	FW	CV	PH	TEF	AFPP	FPT	YPP
DPSF	P	1 **															
	G	1 **															
DF50%	P	-0.18	1 **														
	G	-0.21	1 **														
AFP	P	0.39 *	0.03	1 **													
	G	0.66 *	0.07	1 **													
NFCP	P	0.27	0.02	-0.007	1 **												
	G	1.19 **	0.05	1.77 **	1 **												
FET	P	0.31	-0.15	0.76 **	0.007	1 **											
	G	0.52	-0.15	0.91 **	0.41	1 **											
F/T	P	0.42 **	0.18	0.79 **	-0.007	0.65 **	1 **										
	G	0.63 *	0.20	0.86 **	1.06 **	0.92 **	1 **										
	P	-0.57 **	0.01	-0.63 **	-0.38 *	-0.50 **	-0.67**	1 **									
FD	G	-0.95 **	0.01	-0.98 **	-1.13 **	-0.75 **	-0.91 **	1 **									
FL	P	-0.51 **	-0.06	-0.54 **	-0.26	-0.33 *	-0.41 **	0.77**	1 **								
	G	-0.81 **	-0.08	-0.82 **	-1.20 **	-0.44	-0.64 *	0.89 **	1 **								
PT0	P	-0.62 **	0.10	-0.58 **	-0.15	-0.53 **	-0.60 **	0.85 **	0.74 **	1 **							
	G	-1.07 **	0.13	-0.90 **	-1.12 **	-0.75 **	-0.92 **	1.01 **	0.92 **	1 **							
FW	P	-0.58 **	-0.01	-0.48 **	-0.31	-0.31	-0.50 **	0.91 **	0.86 **	0.86 **	1 **						
	G	-0.97 **	-0.02	-0.78 **	-1.20 **	-0.47	-0.74**	0.94 **	0.98 **	0.96 **	1 **						
NFL	P	-0.04	0.26	0.12	-0.04	0.25	0.21	-0.18	-0.05	-0.007	-0.09	1 **					
	G	0.03	0.30	0.30	-0.51	0.37	0.37	-0.23	-0.05	-0.10	-0.10	1 **					
PH	P	0.08	0.02	0.49 **	-0.18	0.61 **	0.62**	-0.36 *	-0.13	-0.35 *	-0.18	0.23	1 **				
	G	0.05	0.02	0.45	-0.04	0.69 **	0.67 *	-0.45	-0.16	-0.37	-0.25	0.43	1 **				
TEF	P	0.95**	-0.17	0.34 *	0.35 *	0.31	0.34 *	-0.59 **	-0.53 **	-0.63 **	-0.60 **	0.002	0.09	1 **			
	G	1.008 **	-0.19	0.76 **	1.14 **	0.51	0.70 **	-1.03 **	-0.88 **	-1.09 **	-1.02 **	0.11	0.09	1 **			
NFPP	P	0.42 **	0.055	0.87 **	-0.01	0.65 **	0.76 **	-0.70 **	-0.59 **	-0.66 **	-0.59 **	0.08	0.52 **	0.41 **	1 **		
	G	0.69 **	0.05	1.02 **	1.53 **	0.90 **	0.93 **	-1.01 **	-0.94 **	-0.98 **	-0.90 **	0.28	0.55 *	0.79 **	1 **		
FPT	P	0.151	-0.13	-0.35 *	-0.14	-0.29	-0.34 *	0.30	0.17	0.05	0.18	-0.39 *	-0.47 **	0.10	-0.41 **	1 **	
	G	-0.16	-0.25	-0.67 *	-0.34	-0.55 *	-0.76**	0.56 *	0.40	0.44	0.49	-0.74 **	-0.79 **	-0.20	-0.68 *	1 **	
YPP	P	-0.44**	0.28	0.05	-0.21	-0.08	0.08	0.11	0.11	0.15	0.10	0.01	0.30	-0.39 *	0.19	-0.54 **	1 **
	G	-0.63 *	0.52	-0.21	0.32	-0.34	0.02	0.16	0.08	0.43	0.08	0.16	0.12	-0.63 *	-0.16	-0.70 **	1 **

DPSF =Days to first Flower, NFCP=Number of flower cluster/plant, DF50%=Days to 50% Flowering, FET=Flower in every truss, NFP =No. of flower at each plant, F/T=Fruit/ Truss, FD=Fruit Diameter, FL=Fruit Length, PT= Pericarp Thickness, FW=Fruit weight, PH=Height of plant, NL=No. of locules, FI= Fruit initiation, NFPP=No. of fruit at each plant, FPT= First picking Time, YPP=Yield per Plant