Characterization of Tomato Genotypes
for Important Fruit Quality Traits

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Abstract:

An experiment was conducted using thirty-eight tomato genotypes to evaluate the performance of different morphological and biochemical traits and their genetic analysis. An analysis of variance showed a high level of variation among all genotypes. Chlorophyll content (1st leaf), number of seed/fruit, ascorbic acid content in red fruit, lycopene, and beta-carotene content in red fruit showed high heritability along with a high percentage of genetic advance, which indicates selection can improve these traits. Other traits show moderate heritability and a moderate GA%. For most characters, phenotypic coefficient variance is higher than genotypic coefficient variance, indicating the influence of the environment is greater than genetic influence. Red fruit weight shows a positive and significant correlation with yield/plant. Path coefficient analysis revealed that the soluble solid content of red fruit exocarp and endocarp had a direct positive effect on yield/plant. Principal component analysis showed six principal components contributing 77.45% of the total variability of different traits. Cluster analysis grouped 38 genotypes into five clusters, where clusters V and III had the maximum genotypes. The dendrogram showed cluster V had the highest amount of variation. Two-way cluster heat map showed five clusters for genotypes and two groups for variable. Mean performance showed genotype CL5915-153 D4-3-6-0 has the highest yield/plant and the highest weight of red fruit; genotype TC0277 has high soluble solid content in endocarp of red fruit; and genotypes Bupribig and Homeastid were superior for ascorbic acid, lycopene and beta-carotene content, which can be considered superior genotypes having important fruit quality traits.

Keywords: *Tomato (Solanum lycopersicum L), Characterization, quality traits, PCA analysis, Heatmap and Cluster analysis, Correlation and path analysis.*

Introduction

The world's most widely consumed vegetable, Solanum lycopersicum L., is a cultivated tomato that serves as a fundamental component in a wide range of raw, cooked, and processed meals.

It belongs to the Solanaceae family, which also contains a number of other commercially significant species. For domestic use or export, tomatoes are grown across the world. This crop plant can be perennial or semi-perennial under specific circumstances (such as rejuvenation

pruning, weeding, irrigation, and frost protection), but commercially it is considered an annual (Geisenberg and Stewart, 1986).

In 2014, the global area cultivated with tomato was 5 million hectares with a production of 171 million tons, the major tomato-producing countries being the People's Republic of China (hereafter "China") and India (FAOSTAT, 2017).

The principal tomato-producing nations are China, the United States, Italy, Turkey, India, and Egypt. China shares the highest percentage of tomato production (28%) in world. Tomatoes are considered to be one of the most economically important crops of all those that exist in the world. Fresh tomato production amounts to over 159 million tons yearly on a global basis. In 2013, the world's annual production was accounted for by the top nine producing nations (74.2%) (GOP, 2013).

Bangladesh is an agricultural nation where agriculture is regarded as the foundation of the national economy. Growing vegetables can assist farmers in generating cash, hence reducing poverty. Among the vegetables tomato (Solanum lycopersicum) is one of the most important vegetables in terms of acreage, production, yield, commercial use and consumption. In Jessore, the summer tomato yield was 50.41 t/ha on average in 2014. The calculated average gross return per acre was Tk. 1542300 (Hajong et al., 2018).

The tomato has been utilized as a model species for research into gene mapping, gene characterization (for example, plant pathogen resistance genes), and gene transfer techniques since it is one of the best studied farmed dicotyledonous plants at the molecular level. It is also useful to study other plant traits such as fruit ripening, hormone function and vitamin biosynthesis (Gebhardt et al., 1991).

To increase the yield and quality of tomato (Lycopersicum esculentum) is the main purpose of most tomato breeding programs (Lucatti et al., 2013). To increase the yield of tomato and to improve its fruit quality, many beneficial traits such as disease and pest resistance, high sugar content, tolerance to abiotic stresses, are selected (Prins., 2013).

Any breeding effort intended to increase quantitative features must take genetic variability into account while developing and carrying out its breeding strategy. Therefore, the presence of genetic variability in desired traits and the plant breeder's aptitude for selecting desirable features are necessary for the success of plant breeding (Adhikari et al., 2018). Phenotypic variability explains individual variances among a population brought on by genetic diversity and the environment in which they're developing (Sumanth et el, 2017).

Heritability is the genetically heritable portion of the total phenotypic variation for a trait. Genetic advance shows the improvement in the mean genotypic values of the selected population compared to the original population from which these were selected. Heritability estimations combined with genetic advances are found to be more reliable than heritability alone in predicting genetic gain under selection.

Furthermore, both direct and indirect trait selection to facilitate yield improvement depend on the connection between yield and yield-attributing traits (Aditya and Bhartiya, 2013). Information on inter-trait correlations, as well as the direct and indirect effects of each trait on yield, is useful in the selection process. Correlation determines the extent of the relationship between yield and its components, as well as the relative importance of their effects, allowing for a clear knowledge of their relationship with yield.

Therefore, the present investigation was undertaken with the aim of characterizing different tomato genotypes. In this study, we were able to identify the morphological and biochemical characters such as plant height, flower bunch/plant, flower/bunch, fruit/bunch, Chlorophyll content (1st leaf), No. of seeds/fruit, weight (red fruit), yield/plant, soluble solid (red exocarp and endocarp), pH, Ascorbic Acid (red fruit), Lycopene and Beta-carotene.

Materials and Methods

During the period from October 2018 to April 2019, an experiment was conducted at the Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh. The aim was to screen high yielding and nutritionally rich tomato genotypes among the present ones in Bangladesh. The experimental site, belonging to AEZ-9 (Old Brahmaputra Flood Plain), had a climate characterized by high temperatures and heavy rainfall. The soil type was sandy loam with a pH range of 6.5 to 6.7. The experimental layout followed a Randomized Complete Block Design with 114 plots (38 x 3), each measuring 6.25 m², and containing thirteen rows with five plants each. Row to row distance was 60 cm, and plant-plant distance was 40 cm.

Planting Materials

The study involved 38 local genotypes of tomato (Jaint Hybrid, Feridal(MCC) BINA Tomato-5, Combel-28F.R., Marglobe II, Burpibig, Hekuri, World Champion, Marglobe I, 1318, Homeastid, Bulgeria, Oxheart, Big Cherry, Pinkgiant, Okiton No-9, CL1131-0-0-13-0-6, CL5915-153 D4-3-6-0, 0001-20-36-29-44-0-0, TC003-109-21-11-2-4-0-0-5, TC0014-23-9-1-0-0-8, TC0014-7-22-36-22-22, TC0122-38-2-43-43-14, TC0131-41-12-14-13-0-6, TC0136-6-45-13-0-10-0, TC0210-9-46-18-0-9-0, TC182-55-35-34-0-14-0, TC0046-23-5-0-0-3-2, TC0277, Bahar, BINA Tomato-2, BINA Tomato-3, BINA Tomato-9, BINA Tomato-10, VI045786, VI06494, VI006015, Tm219, TC0266) collected from Bangladesh Institute of Nuclear Agriculture and the Genetics and Plant Breeding farm, Bangladesh Agricultural University, Mymensingh.

Methods

The experimental field was prepared by thorough ploughing and cross ploughing using a power tiller and country plough. Land preparation included weed and debris removal, laddering to achieve proper tilth and leveling. Sowing of seeds took place on October 10, 2018, followed by transplanting 30-day-old seedlings on November 10, 2018, with watering provided for a few days after transplanting. Intercultural operations involved applying fertilizers and manures based on standard recommendations. Flood irrigation was given after each top dressing of urea, and no pesticides were used due to minimal infestation. Fruits were individually collected at full ripeness, considering varying maturity times among genotypes.

Parameter Studied

A. Morphological parameters

1. Plant height (cm)

2. Fruit/ bunch

3. Chlorophyll content (SPAD Unit)

4. No. of seeds/ fruit

5. Yield/ plant (Kg)

B. Biochemical parameters

1. Soluble solids (% Brix)

2. pH

3. Ascorbic acid (mg/ 1g)

Data Analysis

The recorded data were analyzed to find out analysis of variance, mean performance, phenotypic and genotypic variance of different component, heritability of traits, genetic advance, correlation of morphological and biochemical properties with yield and co-efficient. Data management was done using MS Office Excel. For analyzing the data, MINITAB17 (Minitab Inc., State College, Pennsylvania, NZ); MSTATC and BASICA software's were used.

Results

Table 1. Analysis of Variance (ANOVA) for Different Studied Traits in Thirty-Eight Tomato Genotypes

Source of Variation	Df	Plant height	Fruit/ Bunch	Chlorophyll content (1st leaf)	No. of seed/fruit	Weight of Red Fruit	Yield/ plant
Replication	2	116.03	2.632	46.94	315.16	55.92	315.16
Genotype	37	2.2.58**	9.972**	1099.90**	3486.77**	543.41**	3486.77**
Error	74	43.24	1.415	15.46	88.56	11.02	88.56

Table 2. (Cont'd)

Source of Variation	Df	Soluble Solid of Red Endocarp	Ph	Ascorbic Acid of Red Fruit	Lycopene	Beta-Carotene
Replication	2	1.690	0.006	0.026	0.0009	0.00095
Genotype	37	4.642**	0.025**	0.112**	0.00168**	0.00151**
Error	74	2.097	0.010	0.003	0.00002	0.00005

Table 4. Genetic Parameters for Various Morphological Characteristics in 38 Tomato Genotypes

Sl. No.	Characters	Genotypic variance ($\sigma^2 g$)	Phenotypic variance ($\sigma^2 p$)	GCV (%)	PCV (%)	Heritability ($h^2 b$)	GA	GA (%)
1	Plant Height	53.11	96.35	14.54	19.59	55.12	11.15	22.24
2	Fruit/bunch	2.85	4.27	60.54	74.06	66.84	2.84	101.97
3	Chlorophyll content (1st Leaf)	361.48	376.94	39.81	40.65	95.90	38.35	80.31
4	No. of seed/fruit	1132.74	1221.30	63.83	66.28	92.75	66.77	126.63
5	Weight of Red Fruit	56.67	117.02	29.10	41.82	48.42	10.79	41.72
6	Yield/plant	1.27	1.89	24.17	29.54	66.93	1.90	40.73
7	Soluble Solid of Red Endocarp	0.73	3.18	83.50	74.50	22.90	0.84	82.30
8	Ph	0.005	0.015	114.67	98.62	33.33	0.08	85.38
9	Ascorbic Acid of Red Fruit	0.04	0.04	87.80	40.49	92.37	0.38	88.35
10	Lycopene	0.06	0.06	55.45	56.44	96.51	0.05	81.22
11	Beta-Carotene	0.05	0.05	54.65	57.39	90.68	0.04	84.20

In the analysis of variance, all the parameters indicated significant differences at the 0.1% level of probability (Table 3 – Appendix 1).

Plant height is heavily influenced by the environment, with significant phenotypic variance (96.35) surpassing genotypic variance (53.11). Despite Mitul et al.'s (2016) study noting a height range from 41.34cm to 138.29cm, variable heritability results arise. Moderate heritability (55.12%) and low genetic advance (11.15%) suggest a weak additive gene effect.

However, Singh et al. (2018) found high heritability, while Kumar et al. (2016) revealed contrasting results.

Similarly, fruit/bunch traits indicate environmental influence, as higher phenotypic variance (4.27) than genotypic variance (2.85) is observed. With moderate heritability (66.84%), moderate genetic advance, and consistent findings by Mohammad et al. (2012) and Saini et al. (2013), this trait's genetic control seems moderate.

Chlorophyll content exhibits high heritability (95.90%) and moderate genetic advance, findings supported by Behera et al. (2020). The number of seeds per plant presents very high heritability (92.75%) and moderately high genetic advance, corroborated by Venkadeswaran et al. (2020).

Conversely, red fruit weight reflects environmental influence, with low heritability (48.42%), low genetic advance, and significant phenotypic/genotypic variations. Yield per plant indicates high heritability (66.93%) but low genetic advance. Contrasting outcomes by Saini et al. (2013) point towards the additive gene action's role.

Soluble solid content's range diverges, while pH trait exhibits moderate heritability (33.33), low genetic advance, and Singh et al.'s (2018) discrepant findings. Ascorbic acid content is moderately heritable (92.37%) with low genetic advance, aligning with Dar et al.'s (2011) similar results.

Lycopene content varies extensively, with Dar et al.'s (2011) report differing from recorded values. Beta-carotene displays medium-high heritability (90.68), low genetic advance, and Dar et al.'s (2011) findings contradicting current observations.

Correlation Analysis

Correlation coefficients were calculated to assess the interrelationship among studied traits. Both phenotypic and genotypic correlation coefficients between yield and its component characters were compared. Genotypic correlations were notably higher, suggesting a strong inherent association between the traits.

In case of morphological characters, yield has positive and highly significant correlation with weight of red fruit and has positively correlated with percentage of pollen fertility, while has negative correlation with plant height, fruit per bunch, chlorophyll content of 1st leaf, and number of seed per fruit. Saini et al., (2013) reported positive and significant correlation of yield with weight of red fruit, which is similar to our finding. Mitul et al. (2015) found non-significant positive correlation between plant height and yield per plant which is not similar to our findings.

In case of biochemical characters, yield has positively correlated with beta-carotene content. Yield shows negative correlation with pH, ascorbic acid of red fruit and lycopene content.

Table 5. Correlation Analysis

	Fruit/bunch	Chlorophyll content (1st Leaf)	No. of seed/fruit	Weight of Red Fruit	Soluble Solid of Red Endocarp	Ph	Ascorbic Acid of Red Fruit	Lycopene	Beta-Carotene	Yield/Plant
Plant Height	0.113	0.010	-0.031	-0.148	-0.113	0.010	-0.015	0.209	0.042	-0.285
Fruit/bunch		0.003	0.178	-0.091	-0.038	-0.066	0.106	-0.013	-0.151	-0.137
Chlorophyll content (1st Leaf)			0.205	0.066	-0.027	-0.245	-0.057	0.118	-0.353	-0.033
No. of seed/fruit				-0.003	-0.121	-0.029	-0.032	-0.057	0.057	-0.220
Weight of Red Fruit					-0.051	-0.254	-0.273	-0.180	0.216	0.754
Soluble Solid of Red Endocarp						0.078	-0.020	-0.155	-0.234	-0.145

Characters											
Ph								0.243	0.179	0.069	-0.253
Ascorbic Acid of Red Fruit									0.203	-0.137	-0.301
Lycopene										0.073	-0.260
Beta-Carotene											0.047

Path Coefficient Analysis

Through the study of path coefficient detailed relationship between yield and soluble solids contributing characters were analyzed. Yield of fruits per plant was considered as a resultant variable and days to first branching, days to first flowering, days to first fruiting, days to first fruit maturity, fruit/bunch, fruit diameter, fruit weight, pH in red tomato, leaf chlorophyll content, total phenolic content were considered as causal variables (Table 6). On the other hand, soluble solid in red tomato was considered as a resultant variable days to first branching, days to first flowering, days to first fruit maturity, fruit/bunch, fruit diameter, fruit weight, pH in red tomato juice, leaf chlorophyll content, total phenolic content were considered as causal variables (Table 6).

Positive values showed indirect positive effect where negative values showed indirect negative effect.

Table 6. Partitioning Correlation into Direct (Bold) and Indirect Effects of 4 Characters on Yield/Plant in 38 Tomato Genotypes

Characters	Soluble Solid of Red Endocarp	Ph	Ascorbic Acid of Red Fruit	Lycopene	Beta-carotene	Yield/Plant
Soluble Solid of Red Endocarp	**-0.089**	-0.008	0.005	0.059	-0.004	0.145
Ph	-0.007	**-0.014**	-0.061	-0.062	0.006	-0.253
Ascorbic Acid of Red Fruit	0.002	-0.025	**-0.251**	-0.059	0.004	-0.301
Lycopene	0.016	-0.020	-0.045	**-0.329**	0.006	-0.338
Beta-carotene	0.011	-0.023	-0.034	-0.066	**0.028**	-0.068

Principal Component Analysis

The principal component analysis revealed that six principal components PC1, PC2, PC3, PC4, PC5 and PC6 with eigenvalues 20.56, 14.95, 13.1, 11.19, 9.27, 8.37 respectively have accounted for 77.45% of the total cumulative variability among genotypes.

The contribution of first PC towards variability was highest (20.56%). The results showed that Yield/plant (0.560), Weight of Red Fruit (0.499), Ph (0.359) and Lycopene content (0.348) had the highest loadings in PCl. The second principal component illustrated 14.95% of the total variability. The most important traits in this component were Beta-carotene (0.630), Weight of Red Fruit (0.374) and Lycopene (0.342) had more contribution to the total diversity. So, PC2 is a weighted average of these traits indicating their significant importance for this component. It is evident that Weight of Red Fruit and Lycopene content both are among the chief contributors of PC1 and PC2.

Table 7. Eigen Values and Percentage of Variance and Percentage of Cumulative Variance of the Principle Components

PCs	Eigen values	% Variance	% Cumulative variance
PC1	2.2615	20.56	20.56
PC2	1.6448	14.95	35.51
PC3	1.4411	13.1	48.61
PC4	1.2313	11.19	59.81
PC5	1.0203	9.27	69.08
PC6	0.9204	8.37	77.45

Table 8. Principal Components of 38 Genotypes for 11 Traits Related to Yield

Variables	PC1	PC2	PC3	PC4	PC5	PC6
PH = Ph	0.359	-0.161	0.248	-0.379	0.067	0.130
FB= Fruit/bunch	0.121	0.325	0.298	-0.137	0.169	-0.662
CC= Chlorophyll content (1st Leaf)	-0.043	0.094	0.478	0.351	-0.491	0.249
NF= No. of seed/fruit	0.014	-0.164	0.433	0.555	0.407	-0.087
WRF= Weight of Red Fruit	-0.499	-0.374	0.094	-0.101	0.043	0.020
YP= Yield/plant	-0.560	-0.037	-0.024	-0.342	-0.047	-0.015
SSRE= Soluble Solid of Red Endocarp	0.065	0.326	-0.388	0.266	0.235	0.447
PHH = Plant Height	0.303	-0.264	-0.427	0.089	0.053	-0.293
AA= Ascorbic Acid of Red Fruit	0.272	0.051	0.303	-0.437	0.298	0.426
LY=Lycopene	0.348	-0.342	-0.015	-0.031	-0.566	-0.033
BC=Beta-carotene	0.030	-0.630	0.006	0.095	0.299	0.081

Cluster Analysis

The Ward's clustering method using squared Euclidean distance classified the 38 tomato genotypes into five distinct clusters (Table 9). This indicated the presence of diversity among the tested genotypes. Chernet et al. (2014) studied tomato genotypes and six clusters were found by cluster analysis. Shashikanth et al., (2010) clustered 30 genotypes into 10 clusters using Mahalanobis distance. Ghosh et al., (2014) also grouped 40 segregating tomato hybrids into 6 distant clusters.

The dendrogram analysis revealed distinct clusters based on genotype variations. Clusters II and III exhibited low variation with five and twelve genotypes respectively. Cluster I displayed moderate variation with five genotypes. The highest variation was found in cluster IV and V with one and fifteen genotypes, respectively. (Figure 1)

YP contributes most in PC1 and BC contributes most in PC2.

Table 9. Number, Percent and Name of Genotypes in Different Cluster

| Cluster number	Number of genotypes	Percent (%)	Name of genotypes
I	5	13.16	Marglobe II, Hekuri, Bulgeria, CL5915-153 D4-3-6-0, VI06494
II	5	13.16	Feridal (MCC), BINA Tomato – 5, Oxheart, TC0014-7-22-36-22-22, TC0131-41-12-14-13-0-6, TC136-6-45-13-0-10-0
III	12	31.58	Jaint Hybrid, Marglobe I, Okiton No-9, CL1131-0-0-13-0-6, TC003-109-21-11-2-4-0-0-5, TC0014-23-9-1-0-0-8 TC0122-38-2-43-43-14, TC0046-23-5-0-0-3-2, Bahar BINA Tomato-2, BINA Tomato-10, TC0266
IV	1	2.63	Big Cherry
V	15	39.47	Combel – 28 F.R., Burpibig, World Champion, 1318, Homeastid, Pinkgiant, 0001-20-36-29-44-0-0, TC0210-9-46-18-0-9-0, TC182-55-35-34-0-14-0, TC0277, BINA Tomato-3, BINA Tomato-9, VI045786, VI006015, Tm219

PCA – Biplot
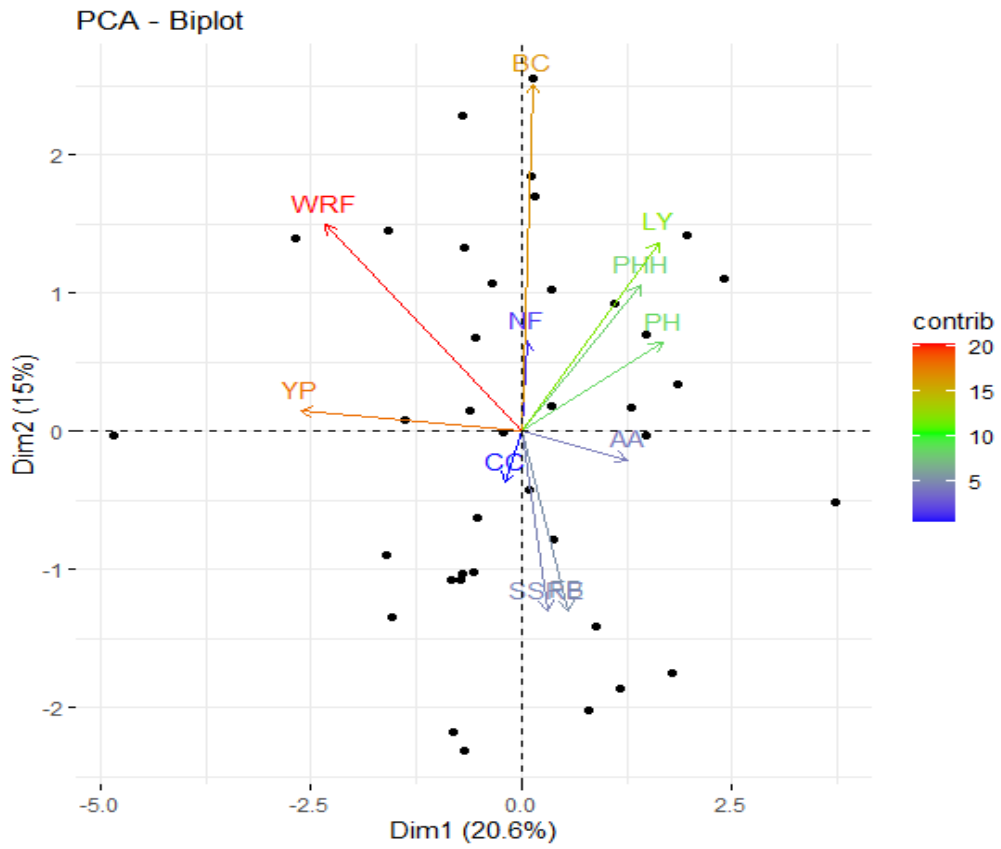
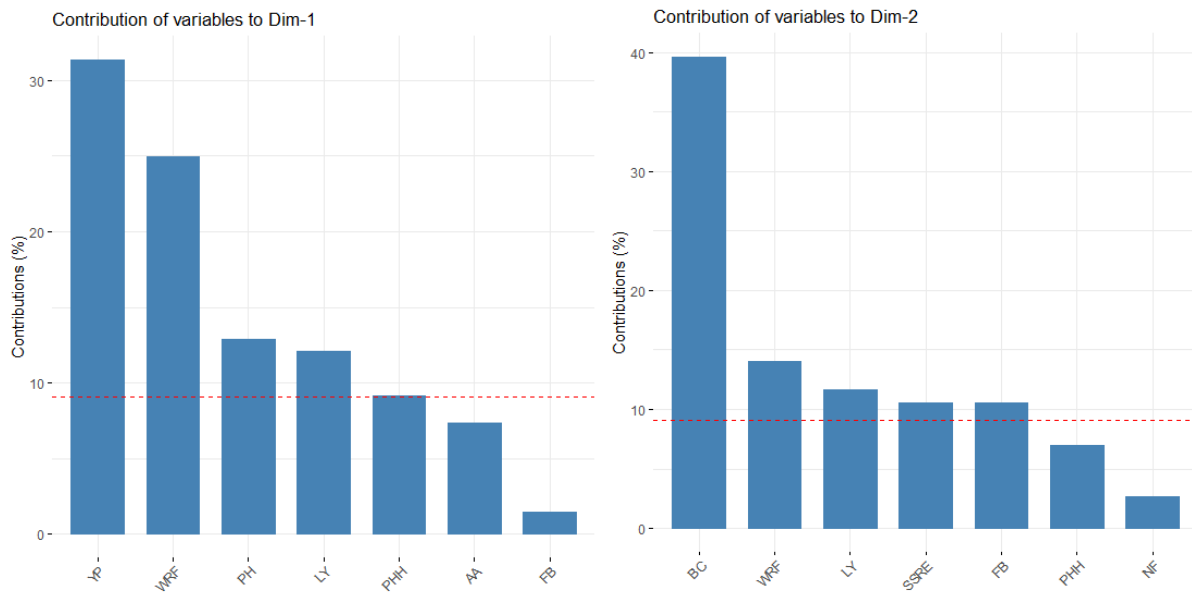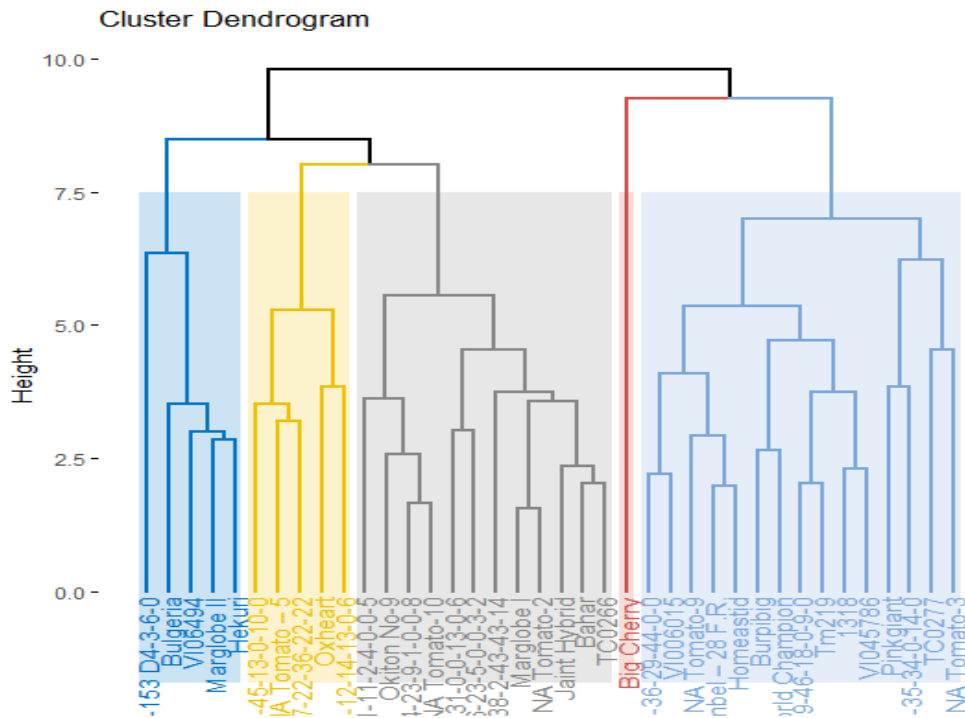**Figure 1. Biplot of Principal Component Analysis (PC1 and PC2)**

Figure 2. Contribution variables to PC1 and PC2

Figure 3. Dendrogram Based on Summarized Data on Differentiation Among 38 Landraces According to Ward's Method

Heatmap

PHH = Plant Height, LY=Lycopene, FB= Fruit/bunch, PH = Ph, AA= Ascorbic Acid of Red Fruit, WRF= Weight of Red Fruit, YP= Yield/plant, NF= No. of seed/fruit, BC=Beta-carotene, CC= Chlorophyll content (1st Leaf), SSRE= Soluble Solid of Red Endocarp

Five clusters were generated at the genotype level, and two groups were separated at the variable level and presented as a two-way cluster heatmap (Fig. 4). YP and WRF were placed in the variable group 1, whereas PHH, LY, NF, BC, PH, AA, SSRE, FB and CC were confined to group 2. Cluster V has the most tomato genotypes (15) among the row clusters, followed by clusters III (12). Generally, cluster I was determined primarily by the variables of group 1. In contrast, cluster V, IV and II were determined mainly by the parameters of group 2. However, the genotypes of cluster III exhibited a diverse pattern of variations among the variables of the two studied groups.

Discussion

The study was attempted to evaluate the performance of 38 genotypes of tomato to study the genetic diversity among these genotypes using different morphological and biochemical characters. The experiment was conducted following a Randomized Complete Block Design with three replication and data were collected on 11 different characters and analyzes statistically.

Analysis of variance for different yield contributing characters showed a high degree of variation among the genotypes used that indicated the presence of wide genetic diversity among all the genotypes and better scope of selection. Therefore, these genotypes could be used for further breeding program.

The highest plant height was observed in genotype Bupribig; maximum fruit per bunch was found in Pinkgiant; maximum chlorophyll content in first leaf was found in TC0131-41-12-14-13-0-6; maximum number of seed per fruit was found in Feridal (MCC) BINA Tomato - 5: maximum weight of red fruit was found in

CL5915-153 D4-3-6-0; maximum yield per plant was found in CL5915-153 D4-3-6-0; maximum soluble solid content in red endocarp was found in TC0277; maximum pH was found in Pinkgiant, BINA Tomato-3 and BINA Tomato-9; maximum ascorbic acid content in red fruit was found in VI006015; maximum lycopene content was found in TC182-55-35-34-0-14-0; maximum beta-carotene content was found in VI06494.
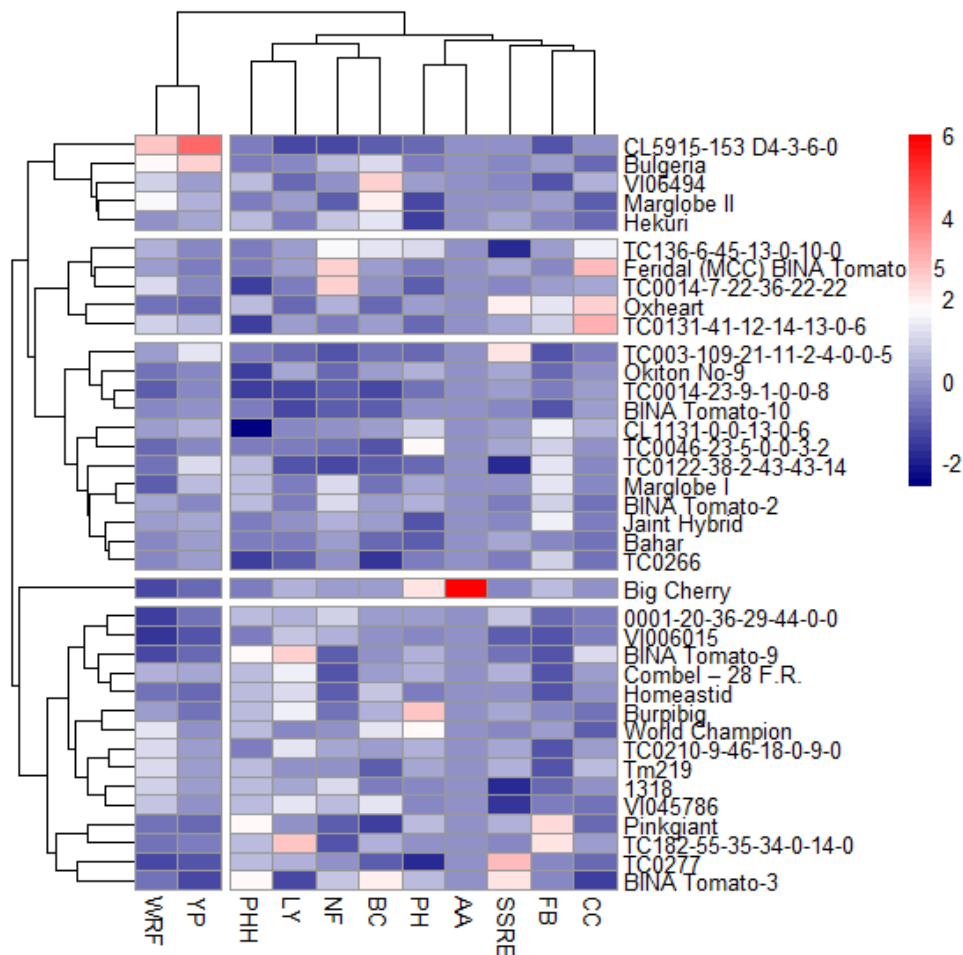
Fig 4. Cluster Heatmap Showing 38 Tomato Genotypes Based on Different Traits

The PCV was higher than GCV for all the traits studied indicating that they all have considerable environmental influences on their phenotypic expression. Among all the traits, individual fruit weight exhibited high estimates of GCV and soluble solid content in red endocarp exhibited high estimates of PCV followed by pH. Therefore, selection on the basis of phenotype alone can be effective for the improvement of the traits.

Chlorophyll content of 1st leaf, Number of seed per fruit, Ascorbic acid content of red fruit, Lycopene and Beta-carotene had high heritability along with high GA%. These traits can be improved through simple or progeny method. Plant height, Fruit/ bunch, Yield/ plant had moderate heritability along with moderate GA %. These traits can be improved by inter-mating with superior genotypes of segregating population which is developed through breeding.

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Correlation study estimated the relation among yield and fruit traits. Yield per plant was significantly correlated with weight (0.682) of red fruits. It is evident that CL5915-153 D4-3-6-0 has highest yield per plant along with highest weight of red fruit.

The Path Coefficient Analysis was done using genotypic correlation to find out the direct and indirect influence on selected 11 traits. The result showed that high positive direct effect was found in soluble solid of red endocarp which indicates their main contribution on yield.

Six principal components were found from Principal Component Analysis, and those explained 77.45% of total variation. PC1 and PC2 explained 20.56% and 14.95% of variation, respectively.

Cluster analysis was done and 38 genotypes were grouped into five cluster. Cluster V had maximum number of genotypes and dendrogram showed the highest variation among all other clusters. A heatmap illustration was done with 38 tomato genotypes clustered by traits; five genotypic and two variable clusters observed, revealing trait-based distinctions.

The results of the study showed that the characteristics were very diverse. This approach may prove useful for tomato breeding programs that use genotypes and effective selection to increase yield and nutritional quality. However, further research is encouraged to support our research's finding.

Conclusion

This research aimed to characterize tomato genotypes based on important fruit quality traits. The study evaluated 38 tomato genotypes for various morphological and biochemical characteristics, and their genetic analysis was performed. The analysis of variance showed significant variations among all genotypes for most traits. Traits such as chlorophyll content (1st leaf), number of seed/fruit, ascorbic acid content, lycopene, and beta-carotene content in red fruit exhibited high heritability and genetic advance, making them suitable for selection to

improve these traits. The study also identified the positive correlation of red fruit weight with yield/plant and revealed the direct positive effect of soluble solid content in red fruit on yield/plant. Principal component analysis contributed to understanding the variability of different traits. Cluster analysis grouped the genotypes into seven clusters, with certain genotypes standing out for specific traits. Genotypes CL5915-153 D4-3-6-0, TC0277, Bupribig, and Homeastid were identified as superior for important fruit quality traits. Overall, the research provides valuable insights into the genetic potential and potential breeding strategies for enhancing tomato yield and quality.

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Table 3. Mean Performance of 38 Tomato Genotypes for Different Morphological Trait

Genotype	Plant Height	Fruit/ bunch	Chlorophyll content (1st Leaf)	No. of seed/fruit	Weight of Red Fruit	Yield/plant	Soluble Solid of Red Endocarp	Ph	Ascorbic Acid of Red Fruit	Lycopene	Beta-Carotene
Jaint Hybrid	40.67	5.00	38.80	67.00	25.67	2.13	4.67	4.00	0.865	0.040	0.040
Feridal (MCC) BINA Tomato – 5	46.67	3.00	102.10	138.00	26.67	1.41	5.27	4.00	0.634	0.043	0.040
Combel – 28 F.R.	53.33	2.00	49.20	12.00	29.00	2.29	5.47	4.10	0.687	0.077	0.043
Marglobe II	39.00	3.33	28.80	19.00	39.33	2.43	4.90	4.00	0.714	0.043	0.083
Burpibig	72.33	3.00	35.50	30.00	27.00	1.21	5.23	4.10	0.989	0.077	0.050
Hekuri	37.33	3.00	33.40	78.33	24.67	2.13	5.27	4.10	0.893	0.030	0.067
World Champion	64.67	3.33	29.40	50.00	37.67	1.90	4.60	4.10	0.879	0.037	0.067
Marglobe I	52.33	4.67	42.10	92.00	18.00	2.58	4.80	4.10	0.508	0.030	0.027
1318	47.33	2.33	45.40	92.00	34.33	2.12	2.80	4.10	0.852	0.047	0.030
Homeastid	47.00	2.00	47.20	17.00	20.00	0.87	4.83	4.10	0.742	0.067	0.057
Bulgeria	45.67	3.33	32.90	73.00	41.67	4.87	4.67	4.00	0.687	0.037	0.063
Oxheart	51.00	4.67	96.60	68.00	21.00	0.94	7.37	4.10	1.016	0.023	0.023
Big Cherry	67.57	4.00	43.97	54.00	13.67	0.88	4.73	4.00	0728	0.053	0.043
Pinkgiant	55.00	6.00	32.70	21.00	19.67	0.95	5.57	4.20	1.058	0.040	0.006
Okiton No-9	53.67	2.33	46.50	26.67	20.67	1.58	5.27	3.90	0.508	0.047	0.040
CL1131-0-0-13-0-6	58.00	5.00	56.70	50.00	26.67	2.53	5.17	3.80	0.728	0.037	0.043
CL5915-153 D4-3-6-0	43.33	2.00	46.70	7.00	48.67	7.05	5.00	4.00	0.646	0.010	0.020
0001-20-36-29-44-0-0	50.67	2.33	40.00	84.00	13.00	1.08	5.93	4.10	1.128	0.053	0.040
TC003-109-21-11-2-4-0-0-5	43.33	2.00	39.50	14.00	26.33	3.50	7.70	4.00	0.797	0.023	0.027
TC0014-23-9-1-0-0-8	44.67	2.67	49.30	18.00	16.67	1.63	5.13	3.90	0.769	0.010	0.010
TC0014-7-22-36-22-22	42.33	3.33	50.60	135.00	35.67	1.57	4.67	3.90	0.755	0.033	0.037
TC0122-38-2-43-43-14	43.33	4.67	41.90	7.67	21.00	3.19	2.73	4.10	0.893	0.017	0.020
TC0131-41-12-14-13-0-6	43.67	4.33	104.30	38.00	34.00	2.67	5.37	3.90	0.769	0.043	0.040
TC136-6-45-13-0-10-0	59.33	3.33	76.30	110.00	28.67	1.52	2.70	4.00	0.824	0.043	0.067
TC0210-9-46-18-0-9-0	53.00	2.00	49.60	61.00	35.33	2.07	5.33	4.00	0.549	0.070	0.040
TC182-55-35-34-0-14-0	49.67	5.67	50.07	15.00	20.33	1.43	4.60	4.10	1.181	0.103	0.050
TC0046-23-5-0-0-3-2	65.00	4.33	45.50	32.00	19.33	1.68	5.23	4.00	0.508	0.030	0.017
TC0277	35.67	3.00	31.60	50.00	14.00	0.57	8.50	4.10	0.810	0.053	0.020
Bahar	42.00	3.00	34.50	53.00	22.67	1.97	5.27	4.00	0.673	0.030	0.023

BINA Tomato-2	54.00	4.33	37.20	91.00	27.33	1.58	4.53	4.10	0.659	0.030	0.040
BINA Tomato-3	55.33	3.00	18.90	76.00	21.00	0.40	7.67	4.20	0.769	0.010	0.083
BINA Tomato-9	53.67	2.00	67.20	19.00	14.33	0.96	4.17	4.20	0.701	0.100	0.037
BINA Tomato-10	49.33	2.00	48.60	21.00	22.67	1.91	4.63	4.00	0.714	0.010	0.020
VI045786	48.00	2.67	35.40	74.00	31.67	1.87	3.07	4.10	0.646	0.073	0.070
VI06494	51.00	2.00	54.20	49.00	34.33	1.99	4.77	4.10	1.044	0.023	0.097
VI006015	48.33	2.00	38.50	66.00	12.00	0.52	3.80	4.00	1.346	0.060	0.037
Tm219	51.33	2.00	58.40	49.00	35.67	2.07	5.60	4.10	0.508	0.040	0.020
TC0266	45.67	4.33	35.20	46.00	22.67	1.95	4.50	3.90	0.687	0.020	0.003
LSD$_{0.05}$	2.98	2.38	0.77	2.61	14.31	0.28	2.38	1.33	0.21	0.042	0.040
Mean	50.11	2.79	47.76	52.73	25.87	1.95	5.04	4.04	0.786	0.010	0.012
Standard Error	1.33	0.30	3.11	5.53	1.42	0.20	0.20	0.01	0.031	0.023	0.022
Standard Deviation	8.22	1.82	19.15	34.09	8.76	1.21	1.24	0.09	0.193	0.010	0.003
Minimum	35.67	2.00	18.90	7.00	12.00	0.40	2.70	3.80	0.508	0.010	0.006
Maximum	72.33	6.00	104.30	138.00	48.67	7.05	8.50	4.20	1.346	0.103	0.097
Level of sign.	**	**	**	**	**	**	**	**	**	**	**
CV%	13.12	42.65	8.23	17.85	30.03	40.62	31.09	2.42	6.71	9.53	16.90

Note: ** indicates significant at 0.01 probability level, * indicates significant at 0.05 probability level, NS = not significant