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Genetic variability studies in tomato (*Solanum lycopersicum* L.) under protected cultivation

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Abstract
In this study, the genetic diversity of 20 tomato genotypes was assessed under protected cultivation, focusing on 22 different characters. The analysis of variance revealed significant variation among the genotypes. Wide variation was observed for plant height, number of secondary branches, fruit length, fruit width, and fruit yield. The experimental results indicated that the genotype "Thingalur 1" is highly suitable for protected cultivation due to its desirable traits. It demonstrated superior performance in terms of fruit length, Fruit Shape Index (FSI), flowering time, fruit weight, total number of fruits per plant, lycopene content, and ascorbic acid levels. On the other hand, the genotype Kashi Amman exhibited the lowest fruit yield, as well as lower in plant height, secondary branches, number of clusters per plant, and total number of fruits per plant. Genetic parameters such as Genetic Coefficient of Variation (GCV), Phenotypic Coefficient of Variation (PCV), Genetic Advance, and Heritability revealed that the phenotypic coefficient of variation was slightly higher than the genotypic coefficient of variation for all the traits studied. High heritability and genetic gain were observed for traits such as days to maturity, days to first flowering, fruit width, fruit yield, secondary branches, fruit shape index, pericarp thickness, number of fruits per cluster, plant height, number of locules, seed weight, seeds per fruit, ascorbic acid content, number of clusters per plant, lycopene content, TSS, the total number of fruits per plant and fruit weight. Selection based on these characters will be effective to isolate superior genotypes.

Keywords: Variability, range, heritability, genetic advance, protected cultivation

Introduction
Tomato (*Solanum lycopersicum* L.), belongs to the Solanaceae family is one of the most important vegetables being widely grown both in open fields and under protected cultivation (Ja'afar *et al*. 2018) [6]. Tomatoes are self–pollinated crop and they are popularly known as ‘Love apple’. It is considered as a nutritional crop because it contains vitamin A and C, minerals, sugar, organic acids, and lycopene (Waiba *et al*. 2021) [25]. They are grown under protected cultivation, which is a focused and unique form of agriculture in which crops are controlled partially or entirely based on the needs of the plant species grown during the growth period (Lekshmi *et al*. 2017) [11]. The vegetable production under the protected cultivation system will result in efficient use of land resources, as well as the protection of vegetables during the production stage from adverse environmental conditions such as temperature, hail, heavy rain, snow, and frost (Narayan *et al*. 2020) [12]. Because the genetic variance of any quantitative trait is composed of additive variance (heritable) and non-additive variance, as well as dominance and epitasis (non-allelic interaction), it is critical to partition the estimated phenotypic variability into its heritable and non-heritable components using appropriate parameters such as genetic variance, phenotypic variance, genotypic coefficient of variation, phenotypic coefficient of variation, genetic advance, and heritability (Prakash *et al*. 2019) [13]. The present study was undertaken to investigate genetic variation, heritability and genetic advance, based on yield and yield attributing characters.

Materials and Methods
The present investigation was carried out in the polyhouse located at the North Instructional Farm of the School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore situated at 10.9362° N latitude and 76.7441° E longitude in the southern Western Ghats, in the Siruvani forest foothills. The twenty genotypes collected from different parts of India were used in this study (Table 1). The genotypes were grown under protected cultivation using Completely Randomized Block Design.

The seeds of each genotype were sown in fifteen polybags of size 40 x 40 cm filled with soil, sand, and cow dung in equal proportions (1:1:1). After germination and establishment one seedling was maintained in each bag and recommended package of practices were followed.

Table 1: List of the genotypes

Sl. No	Name of the genotypes	Source
1	Kashi Amman	IIVR, Uttar Pradesh
2	Thenganikotai	Thenganikottai, Karnataka
3	Thingalur– 2	Thanjavur, Tamil Nadu
4	Thingalur– 1	Thanjavur, Tamil Nadu
5	Kashi	Udupi, Karnataka
6	Thirupur -1	Kangeyam, Tamil Nadu
7	Muthurlocal	Coimbatore, Tamil Nadu
8	Thirupur - 2	Dharmapuri, Tamil Nadu
9	Kashi Adarsh	IIVR, Uttar Pradesh
10	Kumkumakesari	Mysore, Karnataka
11	Junnar	Pune, Maharashtra
12	CTRm - 2	Kerala
13	CTY	Mysore, Karnataka
14	CTR m	Kerala
15	Vetiyarpalayam	Krishnarayapurum, Tamil Nadu
16	FRPT	Mysore, Karnataka
17	Balaramapuram - 1	Balaramapuram, Trivandrum
18	Sujitha Kashi	Madurai, Tamil Nadu
19	PKM 1	TNAU
20	Pusa Rubi	Ricca seeds and garden, Pune

Observations were recorded on plant height (cm), number of primary branches, number of secondary branches, fruit length (mm), fruit width (mm), Fruit Shape Index (FSI), number of locules, pericarp thickness (mm), days to 50% flowering, days to first flowering, days to first harvest, days to maturity, number of seeds per fruit, 100-seed weight (g), fruit weight (g), number of clusters per plant, number of fruits per cluster, the total number of fruits per plant, ascorbic acid content, lycopene content, total soluble solids, and fruit yield (g).The analysis of variance (ANOVA) was performed to assess the significance of yield-related parameters, as proposed by Steel and Torrie (1960) [24].

The genetic parameters viz., Genetic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV) were estimated to assess the magnitude of variability. Genetic Advance and Heritability were estimated using the analysis method available in IBM SPSS software by the procedure produced by Rasheed *et al*. (2022) [17]. These analyses provide insights into the extent of genetic improvement that can be achieved for the traits under investigation and the proportion of phenotypic variation attributed to genetic factors. To evaluate the genetic diversity for yield and yield-related attributes among the 20 genotypes, Mahalanobis D^2 statistics were employed. Total soluble solids (TSS) were determined using a hand refractometer following the guidelines specified by AOAC (Association of Official Agricultural Chemists) in 1975. The measurement of TSS provides information about the sugar content in the sample.

Ascorbic acid content was analysed using the procedure developed by Sadasivam, S. in 1996 [18]. This method allows for the quantification of ascorbic acid, which is a key component of vitamin C and is important for assessing the nutritional quality of the sample. Lycopene content was determined using the procedure established by Alda in 2009 [1]. This method enables the measurement of lycopene, a pigment responsible for the red color in many fruits and vegetables. Lycopene is known for its antioxidant properties and is commonly associated with the health benefits of consuming tomatoes and tomato-based products.

Results and Discussion

The analysis of variance (ANOVA) for a Completely Randomized Design (CRD) revealed a significant variation among the 20 tomato genotypes in terms of yield and related traits (Table 2).

Table 2: Analysis of variance (ANOVA) for twenty two characters in tomato

S. No	Characters	Genotypes	Error
1	Plant height	1872.310**	0.660
2	Primary branches	0.100NS	0.054
3	Secondary branches	5.224**	0.292
4	Fruit length	26.744**	4.428
5	Fruit width	69.180**	5.080
6	Fruit shape index	0.077**	0.002
7	No. of locules	3.325**	0.050
8	Pericarp thickness	1.983**	0.042
9	Days to 50% flowering	62.330**	7.668
10	Days to first flowering	49.020**	1.193
11	First harvest	130.677**	0.453
12	Days to maturity	30.354**	0.425
13	Seeds per fruit	5949.000**	0.200
14	Seed weight	3.283**	0.027
15	Fruit weight	392.910**	0.080
16	Number of clusters	23.500**	0.163
17	Number of fruits per cluster	2.058**	0.023
18	Total no of fruits	1343.470**	6.090
19	Ascorbic acid	93.853**	0.007
20	Lycopene content	2.616**	0.004
21	Total soluble solid	1.624**	0.021
22	Yield	296115**	1254

Mean performance of the genotypes

Plant height ranged from 76.13 cm to 181.33 cm, with a mean value of 102.8 cm. Primary branches ranged from 2.93 to 3.6, with a mean value of 3.24. Secondary branches ranged from 3 to 8.27, with a mean value of 6.91. Fruit length ranged from 27.7 mm to 38.89 mm, with a mean value of 30.67 mm. Fruit width ranged from 23.11 mm to 41.19 mm, with a mean value of 35.51 mm. The Fruit Shape Index (FSI) ranged from 0.7 to 1.25, with a mean value of 0.89. The number of locules ranged from 2.21 to 5.64, with a mean value of 3.85. Pericarp thickness ranged from 2.99 mm to 5.75 mm, with a mean value of 4.31 mm. The number of days to 50% flowering ranged from 36.8 to 52.2, with a mean value of 45.26 days. The number of days to first flowering ranged from 28.05 to 40.85, with a mean value of 33.88 days. The first harvest ranged from 56.54 to 78.91, with a mean value of 68.36. Days to maturity ranged from 23.45 to 34.76, with a mean value of 29.35. The number of seeds per fruit ranged from 53.28 to 218.3, with a mean value of 128.25. Hundred seed weights ranged from 2.06 g to 5.72 g, with a mean value of 3.71 g. Fruit weight ranged from 7.94 g to 50.45 g, with a mean value of 26.27 g. The number of clusters per plant ranged from 3.42 to 16.1, with a mean value of 7.34. The number of fruits per cluster ranged from 3.01 to 5.67, with a mean value of 4.11. The total number of fruits per cluster ranged from 20.61 to 78.95, with a mean value of 48.73. The ascorbic acid content ranged from 9.25 to 28.16, with a mean value of 14.77. The lycopene content ranged from 0.08 to 3.95, with a mean value of 2.17. Total Soluble Solids (TSS) ranged from 3.92 to 7.76, with a mean value of 5.46.

Finally, the total fruit yield ranged from 438.91 g to 1466.28 g, with a mean value of 839.41 g. Based on the analysis of fruit yield, it was determined that Thingalur 1 had the highest fruit yield (1466.28 g), followed by Pusa rubi (1337.80 g) and CTR m-2 (1172.78 g). On the other hand, Kashi Amman exhibited the lowest fruit yield (438.91 g). Overall, the genotypes exhibited considerable variability in yield-related traits, highlighting the potential for selecting superior tomato varieties with desired characteristics for commercial cultivation or breeding programs.

Table 3: Mean performance of 20 genotypes

S. No	Genotypes	PH	PB	SB	FL	FW	FSI	NL	PT	DFF	DTFF	FH	DM	SPF	SW	WF	NC	NFC	TNF	AA	LC	TSS	FY
1	Kashi Amman	76.1	3.1	3.0	36.6	35.4	1.0	3.5	5.3	51.5	37.7	64.9	32.0	156.4	4.8	19.3	3.4	4.2	20.6	9.4	3.6	5.0	438.9
2	Thenganikotai	134.2	3.2	7.0	38.9	35.4	1.1	2.6	5.8	48.2	30.0	73.0	34.8	53.3	2.1	20.5	6.7	5.6	36.0	19.2	2.9	5.4	766.2
3	Thingalur - 2	104.9	3.3	5.0	32.6	38.5	0.9	5.0	3.5	36.8	28.9	78.9	31.5	140.8	3.0	21.2	5.8	3.8	24.8	13.2	2.2	5.5	548.5
4	Thingalur - 1	84.4	3.3	8.0	27.7	39.4	0.7	4.3	4.9	52.2	40.9	65.5	29.2	105.3	2.8	50.5	8.7	3.8	79.0	9.3	4.0	4.8	1466.3
5	Kashi tomato	96.9	3.2	7.0	28.1	35.7	0.8	3.6	3.8	49.7	38.7	57.6	28.7	104.7	3.1	21.9	7.4	3.3	29.0	9.5	1.8	5.5	668.6
6	Thirupur -1	83.3	2.9	7.1	31.4	41.2	0.8	5.6	4.3	48.1	36.2	69.8	29.9	130.6	3.1	36.0	8.7	3.5	68.9	22.6	1.2	5.2	1110.2
7	Muthur local	92.6	3.3	7.8	28.6	39.6	0.7	5.5	5.1	42.7	33.1	72.6	31.9	165.6	3.9	25.8	7.0	3.7	37.1	11.4	2.4	5.2	704.7
8	Thirupur - 2	101.9	3.2	7.5	28.3	37.0	0.8	3.9	4.5	43.9	31.8	71.6	30.9	140.5	3.7	33.9	5.4	3.4	34.6	17.0	2.0	5.3	739.2
9	Kashi Adarsh	102.3	3.5	7.5	29.0	35.5	0.8	4.6	4.0	49.3	35.6	64.1	27.1	90.8	4.3	24.7	6.5	4.4	56.3	11.7	3.4	6.0	953.7
10	Kumkuma Kesari	123.2	3.0	7.5	32.0	29.9	1.1	2.2	4.3	42.0	28.1	74.0	25.1	75.6	3.6	14.8	5.0	5.7	38.5	13.0	1.9	6.1	684.7
11	Junnar	87.7	3.6	6.8	29.4	39.7	0.7	3.9	3.5	38.3	30.4	76.7	30.1	160.4	5.5	46.0	8.8	3.2	75.0	15.2	2.2	5.5	1151.1
12	CTRm - 2	181.3	3.5	6.7	29.2	28.0	1.1	2.6	3.2	42.5	32.1	73.0	26.0	88.7	2.7	13.9	16.1	5.2	74.1	13.4	0.1	7.8	1172.8
13	CTY	104.5	3.4	7.8	31.0	39.3	0.8	3.0	5.6	43.4	29.0	60.4	33.0	115.1	3.4	21.2	4.1	3.0	24.1	26.3	2.9	5.2	510.5
14	CTR m	115.8	3.3	7.3	28.4	30.3	0.9	2.8	3.3	38.7	34.2	74.1	24.8	85.7	2.7	14.8	7.8	5.4	42.3	28.2	2.2	5.8	626.3
15	Vetiyarpalayam	77.7	3.3	7.6	28.8	36.1	0.8	5.4	5.0	44.8	35.6	60.2	32.9	218.3	5.7	34.8	9.5	3.4	73.4	9.4	1.8	5.2	1161.7
16	FRPT	121.7	3.4	8.3	28.6	23.1	1.2	2.4	3.0	50.2	39.5	74.8	30.5	105.3	3.0	7.9	9.9	4.6	63.1	11.3	2.1	5.5	500.7
17	Balaramapuram - 1	115.0	3.2	7.8	32.3	31.9	1.0	3.9	4.3	45.2	33.3	64.8	24.8	190.8	5.5	35.6	6.5	4.3	71.0	11.4	0.7	6.2	1123.6
18	Sujitha Kashi	77.3	3.0	4.8	30.2	41.1	0.7	4.3	4.1	49.9	39.0	56.5	30.4	110.4	3.0	19.8	4.0	3.5	28.1	13.4	2.1	5.0	554.2
19	PKM 1	93.0	3.3	5.7	28.8	39.1	0.7	4.5	3.7	41.3	28.1	71.2	23.5	210.2	4.7	21.5	6.3	3.6	26.5	18.9	1.4	5.2	568.6
20	Pusa Rubi	82.0	2.9	7.9	33.6	33.9	1.0	3.6	5.1	46.5	35.4	63.6	30.1	116.6	3.5	41.4	9.2	4.5	72.5	11.7	2.7	3.9	1337.8
	CD1%	1.8	0.5	1.2	4.7	5.0	0.1	0.5	0.5	6.1	2.4	1.5	1.4	0.9	0.4	0.6	0.9	0.3	5.5	0.2	0.1	0.3	78.4
	CD 5%	1.3	0.4	0.9	3.5	3.7	0.1	0.4	0.3	4.6	1.8	1.1	1.1	0.7	0.3	0.5	0.7	0.3	4.1	0.1	0.1	0.2	58.5
	Grand Mean	102.8	3.2	6.9	30.7	35.5	0.9	3.9	4.3	45.3	33.9	68.4	29.3	128.3	3.7	26.3	7.3	4.1	48.7	14.8	2.2	5.5	839.4

PH – Plant height, PB – Primary branches, SB – Secondary branches, FL – Fruit length, FW- Fruit width, FSI – Fruit Shape index, NL – No. of locules, PT – Pericarp thickness, DFF – Days to 50% flowering, DTFF – Days to first flowering, FH – First harvest, DM –Days to maturity, SPF – Seeds per fruit, SW – Seed weight, WF–Weight of fruit, NC- No. of clusters, NFC- No. of fruits per cluster, TNF- Total no. of fruits, AA- Ascorbic acid, LC- Lycopene content, TSS – Total Soluble Solids, FY- Fruit Yield per plant

Phenotypic and Genotypic coefficient of variation

The phenotypic coefficient of variation was higher than the corresponding genotypic coefficient of variation for all the traits (Table 4). High genotypic and phenotypic coefficients of variation are shown in plant height (24.29% and 24.31%), number of locules (27.11% and 27.75%), seed weight (28.03% and 28.48%), number of seeds per fruit (34.72 and 34.72), ascorbic acid (37.34% and 37.58%), lycopene content (37.86% and 37.87%), number of clusters per plant (37.9% and 38.3%), TSS (43% and 43.09%), the total number of fruits per plant (43.33% and 43.61%) and fruit weight (43.55% and 43.56%). Similar results were also reported by Golani (2007) [26], and Kumari *et al*. (2013) [27].

Moderate GCV and PCV were found for days to first flowering (11.77 and 12.24), fruit yield (13.39 and 13.64), fruit width (13.01 and 14.48), FSI (17.81 and 18.48), and pericarp thickness (18.67 and 19.25). This is in line with the results reported by Islam *et al*. (2012), Saleem *et al*. (2013) and Singh *et al*. (2014) [5, 20, 23]. However, the lowest GCV and PCV were observed for primary branches (3.8% and 8.11%), first harvest (9.63% and 9.68%), and days to maturity (10.76% and 10.98%). Overall, the phenotypic coefficient of variation (PCV) was greater than the genotypic coefficient of variation (GCV) for all the traits analyzed which indicated the role of environmental factors in the expression of these trais. Premalakshmi *et al*. (2014), Rai *et al*. (2016), Singh *et al*. (2019), and Kumar *et al*. (2017) [14, 15, 22, 9] also reported low heritability for these traits.

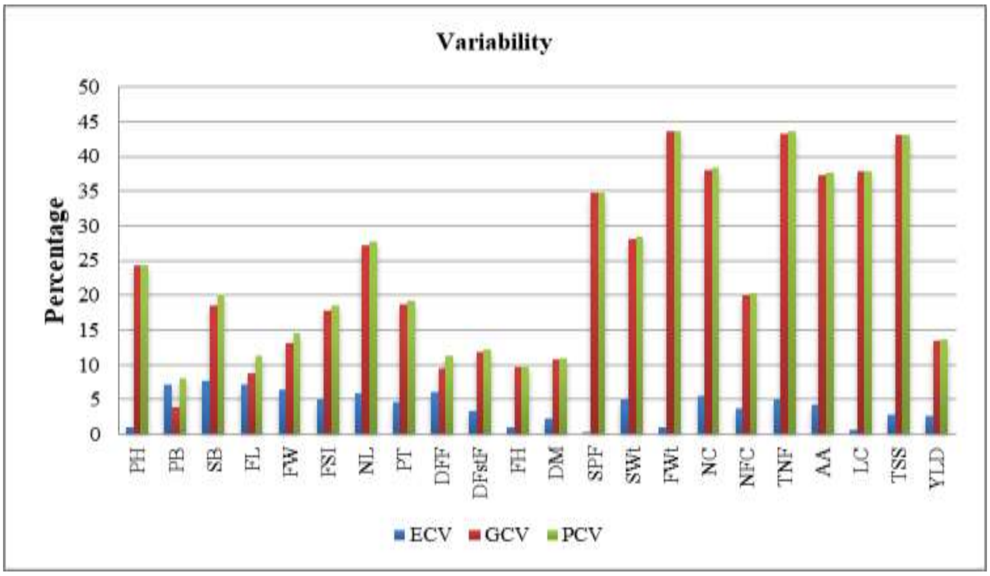

Fig 1: Phenotypic and Genotypic coefficient of variation

Heritability and Genetic Advance

Broad sense Heritability (h^2) estimates were high for all the characters except primary branches per plant (22.7%). The highest heritability was observed for seeds per fruit (99.99%) followed by lycopene content (99.98%), fruit weight (99.94%), plant height (99.84%), TSS (99.57%), first harvest (99.01%), ascorbic acid (98.75%), the total number of fruits per plant (98.71%), number of clusters per plant (97.99%), seed weight (96.86%), number of fruits per cluster (96.8%), fruit yield (96.31%), days to maturity (96.02%), number of locules (95.45%), pericarp thickness (94.08%), FSI (92.95%), days to first flowering (92.49%), secondary branches (85.32%), fruit width (80.77%), days to 50% flowering (70.54%) and fruit length (60.65%). This is in conformity with the findings of Meena *et al*. (2018) [28], and Kumar *et al*. (2022) [29]. Genetic gain refers to the increase in genetic performance or improvement achieved in a population, and it is quantified by expressing the genetic advance as a percentage of the population mean. In the present study, a genetic advance was high in fruit weight (89.69%) and the total number of fruits per plant (88.68%) followed by TSS (88.39%), lycopene content (77.99%), number of clusters per plant (77.46%), ascorbic acid (76.45%), seeds per fruit (71.52%), seed weight (56.84%), number of locules (54.57%), plant height (50%), number of fruits per cluster (40.62%), pericarp thickness (37.31%), FSI (35.39%), secondary branches (35.30%), fruit yield per plant (27.07%), fruit width (24.09%), days to first flowering (23.32%) and days to maturity (21.73%). Moderate genetic advance was observed in the first harvest (19.75%) followed by days to 50% flowering (16.32%) and fruit length (14.15%) where the lowest genetic advance was observed in primary branches (3.79%). Similar observations were also reported by and Sidhya *et al*. (2014) [21].

High heritability coupled with high genetic advance was observed for most of the characters in this study indicated the predominant role of the additive genes. Selection for these traits can be more effective. These results are in line with findings of Fahmida and Ahmad (2007), Ara *et al*. (2009), Chadha and Bhusan (2013), Sidhya *et al*. (2014), Khapte and Jansirani (2014), and Sahanur *et al*. (2012) [4, 2, 3, 21, 7, 19]. For characters with high heritability, the influence of the environment is minimal.

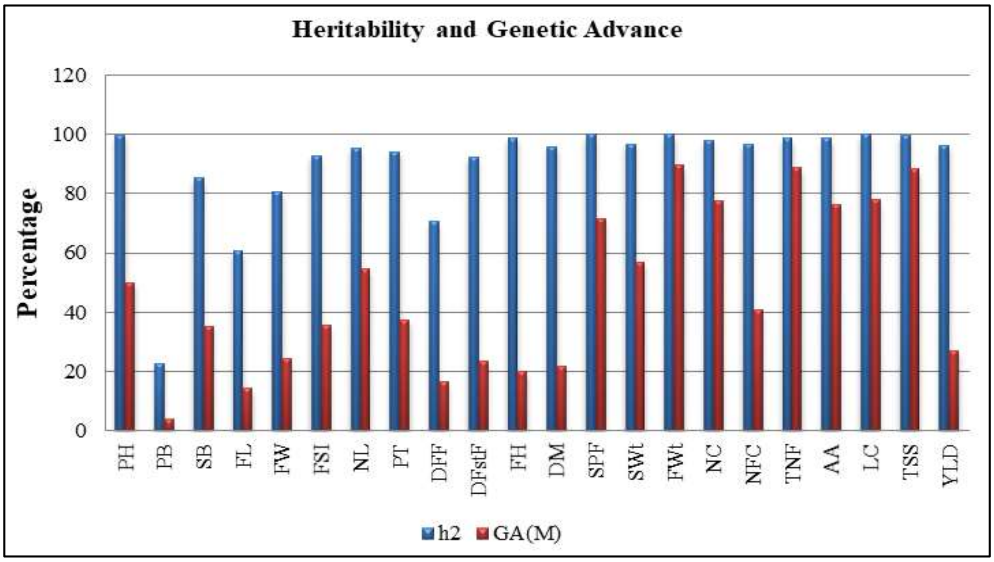

Fig 2: Heritability and Genetic advance

Table 4: Variability, heritability, and genetic advance for 12 characters in tomato

TRAITS	MEAN	RANGE		GCV	PCV	ECV	h^2	GA(M)
		MAX	MIN					
PH	102.80	181.33	76.13	24.30	24.31	0.97	0.998	50.01
PB	3.24	3.60	2.93	3.87	8.12	7.14	0.227	3.79
SB	6.91	8.27	3.00	18.55	20.09	7.70	0.853	35.30
FL	30.67	38.89	27.70	8.83	11.33	7.11	0.606	14.16
FW	35.51	41.19	23.11	13.02	14.48	6.35	0.808	24.10
FSI	0.89	1.25	0.70	17.82	18.48	4.91	0.930	35.39
NL	3.85	5.64	2.21	27.12	27.75	5.92	0.955	54.57
PT	4.31	5.75	2.99	18.67	19.25	4.68	0.941	37.31
DFF	45.26	52.20	36.80	9.44	11.23	6.10	0.705	16.33
DTFF	33.88	40.85	28.05	11.77	12.24	3.36	0.925	23.32
FH	68.36	78.91	56.54	9.64	9.69	0.96	0.990	19.76
DM	29.35	34.76	23.45	10.77	10.99	2.19	0.960	21.73
SPF	128.25	218.30	53.28	34.72	34.72	0.34	1.000	71.52
SW	3.71	5.72	2.06	28.04	28.49	5.05	0.969	56.84
WF	26.27	50.45	7.94	43.56	43.57	1.08	0.999	89.70
NC	7.34	16.10	3.42	37.99	38.38	5.44	0.980	77.47
NFC	4.11	5.67	3.01	20.04	20.37	3.64	0.968	40.62

TNF	48.73	78.95	20.61	43.33	43.61	4.95	0.987	88.68
AA	14.77	28.16	9.25	37.35	37.59	4.21	0.987	76.45
LC	2.17	3.95	0.08	37.87	37.87	0.59	1.000	77.99
TSS	5.46	7.76	3.92	43.00	43.09	2.81	0.996	88.40
FY	839.41	1466.28	438.91	13.39	13.65	2.62	0.963	27.07

PH – Plant height, PB – Primary branches, SB – Secondary branches, FL – Fruit length, FW – Fruit width, FSI – Fruit shape index, NL – No. of locules, PT – Pericarp thickness, DFF – Days to 50% flowering, DTFF – Days to first flowering, FH – First harvest, DM – Days to maturity, SPF – Seeds per fruit, SW – Seed weight, WF –Weight of the fruit, NC – Number of clusters, NFC – Number of fruits per cluster, TNF – Total no. of fruits, AA – Ascorbic acid, LC – Lycopene content, TSS – Total soluble solids, FY- Fruit Yield

Conclusion

The evaluation of 20 genotypes tomato revealed significant variability for yield and quality traits. The characters having high heritability and genetic advance can be improved based on simple selection procedures. The study revealed that plant height, number of locules, seed weight, ascorbic acid, lycopene content, TSS (Total Soluble Solids), number of clusters per plant, the total number of fruits per plant, individual fruit weight, days to first flowering, days to 50% flowering, fruit width, FSI (Fruit Shape Index), and pericarp thickness are the most crucial traits for which direct selection could lead to valuable improvements in identifying superior tomato genotypes. Protected cultivation offers several benefits, including protection against adverse weather conditions and effective management of pests and diseases. This cultivation method promotes healthier plant growth, resulting in increased yields and improved tomato quality. The findings from our analysis indicated that the genotype "Thingalur 1" was particularly well-suited for protected cultivation. Additionally, Thingalur 1 exhibited favorable characteristics such as increased fruit length, Fruit Shape Index (FSI), days to 50% flowering, days to first flowering, fruit weight, and total number of fruits per plant, lycopene content, and ascorbic acid. These findings highlight the potential of "Thingalur 1" for successful and productive tomato cultivation in protected environments followed by Pusarubi.

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