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Genotypic Variation in Tomato (Solanum lycopersicum) under Polyhouse-Grown Conditions: A Genetic Diversity Approach

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Abstract:

The present investigation was carried out during the 2021–2022 cropping season at Nalegaon, Maharashtra, India (latitude: 18.422146° N; longitude: 76.810104° E). The study aimed to assess the genetic variability and trait associations influencing yield and its contributing components in tomato (*Solanum lycopersicum*) genotypes. A total of six genotypes were evaluated, including four sourced from the Indian Institute of Horticultural Research (IIHR), Bangalore, and two obtained from the local market. Genetic relationships among the genotypes were analyzed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA), with a cophenetic correlation coefficient (r) of 0.845, indicating a strong representation of the dissimilarity matrix by the resulting dendrogram. Based on the pairwise Euclidean distance matrix, the greatest genetic dissimilarity was observed between the genotypes 'Lakshmi' and 'Vikas', while the highest similarity was noted between 'US440' and 'Alankar', as well as between 'Lakshmi' and 'Apeksha'. The analysis revealed significant genetic variability among the genotypes studied. Principal Component Analysis (PCA) identified plant height (cm), number of branches, number of fruits per plant, yield per plant (kg), pericarp thickness (mm), crop duration (days), and average fruit weight (g) as the most influential traits contributing to genotype differentiation. These findings highlight the existence of substantial genetic diversity and provide a basis for selecting promising genotypes for future tomato breeding programs.

Keyword: Alankar, US440, genetic diversity, tomato, polyhouse, yield/plant

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Introduction:

The present research was undertaken during the 2021–2022 cropping season at Nalegaon, located in Maharashtra, India, situated at 18.422146° N latitude and 76.810104° E longitude (GPS coordinates: 18°25'19.73" N, 76°48'36.37" E). The experimental material comprised six tomato (*Solanum lycopersicum*) genotypes—four sourced from the Indian Institute of Horticultural Research (IIHR), Bangalore, and two obtained from the local market. The primary aim of the study was to evaluate genetic variability and explore the association between yield and its component traits among these genotypes.

Tomato is a globally significant vegetable crop, belonging to the Solanaceae family, and is predominantly self-pollinated with a diploid chromosome number of 2n = 24 [1]. Its global demand continues to rise due to growing consumption of processed tomato products, increasing urbanization, and population growth. Nutritionally, tomatoes serve as a rich source of essential nutrients including potassium, folate, and vitamin E, and contain both soluble and insoluble dietary fibers. They are particularly notable for their high lycopene content (approximately 71.6%) and ascorbic acid (about 12%) [2].

Tomato plants follow a sympodial growth pattern, wherein the activity of stem cells plays a critical role in determining the plant's overall architecture, flowering time, inflorescence structure, fruit size, harvest index, and total fruit yield [3,4]. As per the Food and Agriculture Organization (FAO), global tomato production in 2020 was recorded at 182.05 million tons, cultivated over 5.06 million hectares, with a substantial share of this output contributed by developing Asian countries [5].

Given the rich genetic diversity present in India, it is essential to assess the compositional attributes of different tomato cultivars to identify genotypes with superior processing qualities. Such insights are vital for guiding breeding programs aimed at developing high-performing cultivars, particularly for large-scale processing and international market demands.

Tomato (*Solanum lycopersicum*) has gained recognition as a valuable functional food due to its nutrient-dense composition and widespread dietary use. Its regular consumption, particularly in processed forms, is associated with a reduced risk of several chronic lifestyle-related disorders, including cardiovascular diseases and various forms of cancer [6]. According to estimates from the United States Department of Agriculture (USDA), approximately 35% of raw tomato production is allocated to sauce production, 18% to tomato paste, 17% to canned tomatoes, 15% to juices, and the remaining 15% to ketchup (Canene-Adams et al., 2005).

In India, tomatoes have become an increasingly important commercial crop, widely cultivated by farmers due to their market demand and culinary versatility. They are a dietary staple featured in numerous Indian dishes and represent a significant component of daily food intake. Nutritionally, tomatoes are rich in potassium, folate, and vitamin E, and they contain both soluble and insoluble dietary fibers. Notably, they are a major source of lycopene (approximately 71.6%) and ascorbic acid (12%) [2].

Given the extensive genetic variability among Indian tomato cultivars, evaluating their chemical composition is essential for identifying genotypes with desirable processing attributes. Such information is crucial for guiding breeding programs aimed at developing superior varieties suitable for industrial processing and multinational markets.

The functional health benefits of tomatoes are primarily linked to their antioxidant capacity. With modern scientific interest increasingly focusing on the role of bioactive food components in disease prevention, tomatoes offer a promising avenue for improving public health through diet. Research examining the impact of production methods—organic versus conventional—on tomato quality has yielded mixed results. Some studies suggest that organically grown tomatoes may offer superior taste, higher vitamin C content, and elevated levels of other quality-related phytochemicals [7]. However, other research indicates either negligible differences or inferior quality parameters in organically grown crops compared to conventionally produced ones [8].

One of the primary constraints contributing to reduced yield in tomato cultivation is the limited genetic diversity and the absence of high-yielding cultivars [9–12]. Therefore, a thorough evaluation of genetic variability is crucial to facilitate the development of improved genotypes that combine favorable agronomic traits [13–15].

Materials and Methods

The study was carried out using a **Randomized Block Design (RBD)** with three replications over two consecutive growing seasons (2018–19 and 2019–20) at Nalegaon, Taluka Chakur, District Latur, Maharashtra, India. The experiment took place within a controlled polyhouse environment. The soil at the experimental site was classified as clay loam, and irrigation water with a pH of 7.25 and an electrical conductivity of 0.42 dS m^{-1} was applied regularly to maintain soil moisture at approximately 75% of the field capacity. Standard agronomic practices were followed for pest and disease management. After 45 days of nursery growth, tomato seedlings were transplanted into 6-liter black plastic pots, each filled with 5 kg of clay loam soil.

pH	Available Nutrients (mg/kg)			Coarse Sand %	Fine Sand %	Silt %	Clay %
	N	P	K				
7.55	113.9	10.5	238	3.6	36.4	29.3	39.1

Table 1. Chemical and physical properties of the soil used in the experiment.

The climate of the study area follows a distinct seasonal pattern. The monsoon season begins in mid-June and extends until the end of October, followed by the winter season from November to February, and summer from March to mid-June. During the rainy season, the atmosphere remains humid; in contrast, winter is characterized by dry and cold air, while summer is marked by dry and hot conditions. The average annual rainfall in the Latur district is approximately 801.04 mm, primarily contributed by the southwest monsoon. In the dry period, average maximum temperatures range from 41°C in March to 43°C in May, while the lowest temperatures dip to around 14°C in November.

The present study included six tomato genotypes, as detailed in Table 2. A total of twenty quantitative traits were analyzed, with particular attention to key agronomic characters such as plant height (cm), number of branches, number of fruits per plant, yield per plant (kg), pericarp thickness (mm), crop duration (days), and average fruit weight (g).

In polyhouse cultivation, **vertical growth techniques**, such as **trellising and string support systems**, are widely utilized to maximize vertical space and improve overall plant management in tomato production. These methods aid in enhancing plant vigor, **improving fruit quality**, and making **harvesting operations more efficient**. Optimal plant spacing is crucial for promoting healthy growth, ensuring adequate **air circulation**, and minimizing the risk of disease outbreaks. The spacing requirements may vary depending on the **varietal type** and the **design of the cultivation system**.

For successful transplantation and establishment of tomato seedlings within the polyhouse environment, a series of **well-defined agronomic practices** must be followed. The study systematically recorded data on key agronomic and yield-related parameters, including **plant height (m), number of fruits per plant, pericarp thickness (cm), fruit weight (g), total yield, and fruit quality traits**, following standardized experimental protocols.

The statistical analysis involved the computation of mean, variance, and standard deviation as outlined by Panse and Sukhatme [16]. Tomato plants were arranged in two rows per raised bed, maintaining a spacing of 115 cm × 40 cm. The trial was conducted using a Randomized Complete Block Design (RCBD) with three replications. In order to examine the relationships among growth, yield, and biochemical attributes, Pearson correlation coefficient analysis was employed. Genetic diversity among the genotypes was assessed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA). Additionally, fruit weight was precisely measured using digital weighing balances, and Principal Component Analysis (PCA) was performed using Euclidean distance coefficients as the metric for multivariate analysis [17].

Description of Tomato Genotypes Used in the Study

Six distinct tomato genotypes were evaluated for their morphological and yield-related attributes under controlled polyhouse conditions. These genotypes included three hybrids and three improved open-pollinated varieties sourced from IIHR, Bangalore, and local markets. The details of the genotypes are as follows:

1. **Arka Vikas-TFL (IIHR, Bangalore):** This variety is a pure line selection derived from the American cultivar ‘Tip-Top’. The fruits are medium to large in size (80–90 g), oblate in shape with light green shoulders, turning deep red upon ripening. It is primarily bred for fresh market consumption and is adaptable to both irrigated and rainfed conditions. The average yield is approximately 35 tonnes per hectare.
2. **Arka Rakshak F1 (IIHR, Bangalore):** A high-yielding F1 hybrid developed with triple disease resistance against Tomato Leaf Curl Virus (ToLCV), Bacterial Wilt (BW), and Early Blight. The fruits are square-round, large (90–100 g), deep red, and firm, making them suitable for both fresh consumption and processing. The hybrid performs optimally in Rabi and Kharif seasons, with a yield potential of 75–80 tonnes per hectare.
3. **Arka Apeksha F1 (IIHR, Bangalore):** A semi-determinate hybrid possessing resistance to Tomato Leaf Curl Disease (Ty1 + Ty2), Bacterial Wilt, and Early Blight. The plants have dark green foliage and produce deep red, oblong fruits (90–100 g) with a jointless pedicel (j2). The fruit characteristics make it ideal for processing, with notable TSS (4.7° Brix), acidity (0.36%), and lycopene content (14.15 mg/100g). It is recommended for cultivation in Summer, Kharif, and Rabi seasons with a yield range of 43–90 tonnes per hectare.
4. **Lakshmi:** This is a semi-determinate genotype with dark green foliage and round-oblate, firm fruits weighing approximately 90–100 g. It displays resistance to Tomato Leaf Curl Disease (Ty2 + Ty3), Bacterial Wilt, and Early Blight. This cultivar is suited for the fresh market and provides an average yield of 60–65 tonnes per hectare over a 140–150 day crop cycle.
5. **Alankar F1:** A determinate hybrid characterized by square-round fruits weighing around 100 g, exhibiting vivid red coloration and excellent fruit quality. This variety is high yielding and recommended for late Kharif and Rabi cultivation.
6. **US-440:** This variety shows intermediate resistance to Tomato Leaf Curl Virus. The fruits are flat-round, moderately firm, and weigh approximately 100 g. It is adaptable to year-round cultivation and delivers a moderate yield.

Table 2: Overall performance of hybrids for growth, yield and yield attributing characters.

Genotypes	Plant height (cm)	No of branches	Fruits per plant	Yield /plant (kg)	Pericarp thickness (mm)	Crop duration(Days)	Average fruit weight (g)
ARKA Vikas-TFL	50.1	6.2	35.6	3.73	5.99	124.5	60
Arka Rakshak F1	83.6	9.0	39.8	3.89	6.2	122.8	56.2
ARKA Apeksha F1	105.6	8.4	39.8	3.74	6.94	129.9	80.2
Lakshmi	91.62	7	49.6	4.21	5.98	125.0	72.5
Alankar F1	115.6	11	64.2	5.2	6.97	134.2	110.3
US-440	105.3	9	52.3	4.9	7.2	130.4	98.6

Plant Height (cm)

The genotypes under evaluation exhibited significant variability in plant height. The tallest plants were observed in **Alankar F1** (115.6 cm), followed by **Arka Apeksha F1** (105.6 cm). In contrast, **Arka Vikas-TFL** recorded the shortest plant height at 50.1 cm. Variations in plant height are largely influenced by the genetic makeup of the genotype as well as environmental factors, including the growth habit (determinate vs. indeterminate). These findings align with the results reported by **Muna et al. [18]** and **Kumar-Ch et al. [19]**, who demonstrated that hybrid plant height is sensitive to environmental and climatic conditions.

Number of Branches

Branch number is a critical trait that influences overall plant architecture and fruit-bearing potential. Among the studied genotypes, **Alankar F1** exhibited the highest number of branches (11), followed by **US-440** and **Arka Rakshak F1**, both with 9 branches. This substantial variation can be attributed to underlying **genetic differences**, **soil quality**, and **microclimatic factors** during growth.

Pericarp Thickness (mm)

Pericarp thickness is a crucial quality parameter, especially for processing and long-distance transportation. Tomatoes with thicker pericarps are generally preferred for enhanced **shelf life** and **structural integrity**. In this study, significant differences in pericarp thickness were observed among the genotypes. **US-440** recorded the highest pericarp thickness (7.2 mm), whereas **Lakshmi** had the lowest (5.98 mm). These findings emphasize the influence of genotype on pericarp development and its potential impact on post-harvest quality.

Crop Duration (Days)

Crop duration varied significantly across genotypes, ranging from 115.8 to 134.2 days. **Alankar F1** exhibited the longest duration (134.2 days), followed by **US-440** (130.4 days) and **Arka Apeksha F1** (129.9 days). Comparatively, **Lakshmi** (125 days), **Arka Vikas-TFL** (124.5 days), and **Arka Rakshak F1** (122.8 days) had shorter growing periods. **Arka Rakshak F1** recorded the shortest crop cycle. Extended crop duration is often linked to prolonged harvesting periods, which can enhance overall yield performance in high-performing hybrids.

Fruit Quality and Yield Performance of Tomato Hybrids

Average Fruit Weight (g)

Average fruit weight is a vital determinant of consumer preference and a major contributor to total yield. In the present study, significant variation was observed among the genotypes, with fruit weights ranging from 56.2 g to 110.3 g. The highest average fruit weight was recorded in Alankar F1 (110.3 g), followed closely by US-440 (98.6 g). This variation may be attributed to genetic diversity and differential nutrient utilization efficiencies among the hybrids.

Fruit Yield per Plant (kg)

Yield performance remains a key factor in cultivar selection for commercial cultivation. The tested hybrids exhibited notable differences in fruit yield per plant, ranging from 3.41 kg to 5.20 kg. Alankar F1 demonstrated the highest productivity with 5.2 kg per plant, followed by US-440 (4.9 kg/plant) and Lakshmi (4.21 kg/plant). The lowest yield was recorded in Arka Vikas-TFL (3.73 kg/plant). The results underscore the importance of genotype selection in enhancing productivity under controlled polyhouse conditions.

To assess overall hybrid performance, a composite ranking system was applied as described by Arunachalam and Bandyopadhyay [20]. The criteria included average fruit weight, fruit yield per plant, number of fruits per plant, and crop duration, enabling the identification of superior genotypes for future breeding and commercial production initiatives.

Table 3: Observations of Average fruit weight (g), Fruits per plant, Yield/plant (kg), Crop duration (Days) and Ranking for selection of hybrids.

Genotypes	Average fruit weight (g)	Fruits per plant	Yield /plant (kg)	Crop duration (Days)	Ranking
ARKA Vikas-TFL	60	35.6	3.73	124.5	6
Arka Rakshak F1	56.2	39.8	3.89	122.8	4
ARKA Apeksha [F1]	80.2	39.8	3.74	129.9	5
Lakshmi	72.5	49.6	4.21	125.0	3
Alankar F1	110.3	64.2	5.2	134.2	1
US-440	98.6	52.3	4.9	130.4	2

Multivariate Analysis for Genetic Diversity Assessment

Traditional approaches fall short in quantifying the extent of genetic variability among genotypes. To overcome this limitation while still examining pairwise genetic relationships, cluster analysis and principal component analysis (PCA) were employed. These multivariate techniques facilitated the grouping of tomato genotypes based on morphological similarities and differences. Analysis of six tomato genotypes revealed substantial variation across multiple traits, and genotypes sharing similar morphological characteristics were categorized within the same cluster.

Principal Component Analysis (PCA)

PCA was applied to identify key variables influencing yield performance and to reduce dimensionality in the dataset. Given that yield is influenced by numerous interrelated factors, correlation coefficient analysis was utilized to determine the strength and direction of relationships among these traits. Yield, being a composite trait, exhibited both positive and negative associations with other yield-contributing attributes. This analysis is essential for understanding the trait interdependence and for identifying key traits for selection in breeding programs.

Eigenvalues

Parameter	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7
Eigenvalue	5.5482	0.6546	0.4738	0.2112	0.1122	-1.853e-16	-1.278e-16
% of Variance	79.2597	9.3513	6.7682	3.0173	1.6035	-2.647e-15	-1.826e-15
Cumulative (%)	79.2597	88.611	95.3792	98.3965	100	100	100

Table4: Represents the Eigenvalues of principal components.

Scores

Series	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7
Vikas-TFL	-2.8366	0.267	-0.7852	-0.4795	-0.1563	-1.554e-15	-8.049e-15
Rakshak F1	-1.7098	-0.1046	1.2418	-0.2381	0.1058	-1.887e-15	-4.718e-15
Apeksha	0.119	-1.4359	-0.1687	0.3378	-0.2156	-5.412e-16	2.828e-15
Lakshmi	-0.9699	0.8893	-0.06966	0.7624	0.05504	-3.164e-15	1.33e-14
Alankar F1	3.4894	0.5556	0.1676	-0.2138	-0.3708	-1.887e-15	-2.998e-15
US-440	1.9079	-0.1714	-0.3858	-0.1687	0.5819	-1.665e-15	-4.274e-15

Table5: Represents the scores of principal components.

Table6: The standardized table

Series	Plant height (cm)	No of branches	Fruits per plant	Yield /plant (kg)	Pericarp thickness (mm)	Crop duration (Days)	Average fruit weight (g)
Vikas-TFL	-1.7869	-1.3218	-1.0622	-0.8709	-1.0123	-0.7537	-0.7541
Rakshak F1	-0.3572	0.3354	-0.6668	-0.6168	-0.6304	-1.1419	-1.3334
Apeksha	0.5817	-0.01973	-0.6668	-0.8551	0.7153	0.4796	0.09374
Lakshmi	-0.01494	-0.8483	0.2557	-0.1085	-1.0305	-0.6395	-0.2295
Alankar F1	1.0085	1.5191	1.6301	1.4639	0.7698	1.4617	1.3572
US-440	0.5689	0.3354	0.5099	0.9874	1.1881	0.5938	0.8661

Table7: Represents the covariance matrix.

Components	Plant height (cm)	No of branches	Fruits per plant	Yield /plant (kg)	Pericarp thickness (mm)	Crop duration (Days)	Average fruit weight (g)
Plant height (cm)	1	0.7932	0.7357	0.6638	0.7836	0.771	0.7486
No of branches	0.7932	1	0.7248	0.7217	0.7109	0.7132	0.6189
Fruits per plant	0.7357	0.7248	1	0.9537	0.5232	0.7528	0.8446
Yield /plant (kg)	0.6638	0.7217	0.9537	1	0.6142	0.7492	0.8532
Pericarp thickness (mm)	0.7836	0.7109	0.5232	0.6142	1	0.8631	0.7963
Crop duration (Days)	0.771	0.7132	0.7528	0.7492	0.8631	1	0.9561
Average fruit weight (g)	0.7486	0.6189	0.8446	0.8532	0.7963	0.9561	1

Table 8: Eigenvectors value

Vector2	Vector2	Vector3	Vector4	Vector5	Vector6	Vector7
0.3737	-0.2522	0.3427	0.772	0.1291	0.09514	-0.2398
0.3582	-0.1001	0.6931	-0.4553	-0.3001	-0.2773	-0.08343
0.378	0.5467	0.07474	0.1924	-0.09676	0.05311	0.7095
0.3793	0.4911	-0.02785	-0.2715	0.5009	0.2843	-0.4569

0.36	-0.5878	-0.1546	-0.2591	0.5106	0.03886	0.4144
0.3966	-0.1921	-0.3575	-0.09942	-0.6022	0.5393	-0.1211
0.398	0.06268	-0.494	0.09419	-0.09837	-0.7335	-0.1924

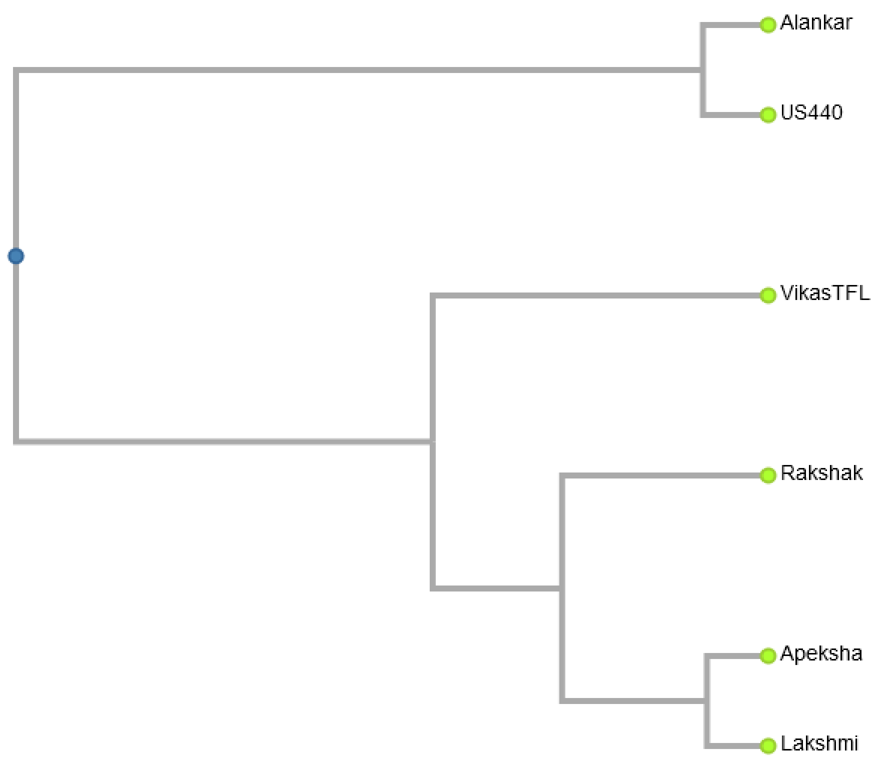

Fig 1 UPGMA dendrogram (based on Euclidean distance coefficient) of 06 genotypes generated by morphological characters. Cophenetic Correlation Coefficient (CP) = 0.84546399024385

Cophenetic Correlation and Principal Component Analysis

The **cophenetic correlation coefficient** obtained by comparing the UPGMA cluster analysis and the dissimilarity matrix yielded a value of **r = 0.845**, indicating a high degree of agreement and suggesting that the dendrogram provided a reliable representation of the original genetic distance data. The **pairwise Euclidean distance matrix** revealed the **greatest genetic dissimilarity** between the genotypes **Lakshmi and Vikas**, while **US440 and Alankar** exhibited the highest genetic similarity, as did **Lakshmi and Apeksha**, indicating potential genetic closeness.

In complement to clustering, **Principal Component Analysis (PCA)** was employed as an effective dimensionality reduction technique to identify the key traits contributing to genotype differentiation. Unlike cluster analysis, PCA also unveils underlying relationships between traits that may not be evident in hierarchical groupings. As suggested by Hair et al. [21], **eigenvalues greater than one** are typically considered significant, particularly in analyses involving a limited number of variables. Moreover, Guei et al. [22] emphasized that the **first three principal components** often capture the majority of variability among genotypes and are therefore most informative for trait-based differentiation.

Conclusion

The correlation analysis provided valuable insights into the interrelationships among the studied traits, offering a clearer understanding of each attribute's role in contributing to the genetic enhancement of tomato crops. The observed strong positive correlations between fruit yield and both the number of fruits per plant and average fruit weight underscore the importance of these traits as key selection criteria in future tomato breeding programs aimed at yield improvement [23].

The study revealed significant genetic variability among the six tomato genotypes, as demonstrated by both genetic distance and multivariate analyses. The genetic distance analysis effectively differentiated the genotypes, highlighting a dynamic range of diversity. Principal Component Analysis (PCA) identified plant height, number of branches, number of fruits per plant, yield per plant, pericarp thickness, crop duration, and fruit weight as the most influential traits contributing to genotype differentiation.

Among the genotypes assessed, Alankar emerged as particularly promising, exhibiting superior performance in terms of number of fruits per cluster, fruit weight, and total yield. This genotype holds strong potential for utilization in breeding programs focused on developing high-performing tomato cultivars suited for polyhouse cultivation.

Ultimately, understanding the genetic diversity among available genotypes supports not only their effective conservation and utilization but also strategic parental selection in hybridization efforts aimed at enhancing yield, disease resistance, and adaptability in controlled environments.

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