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RESEARCH ARTICLE

Genetic characterization for physiological, biochemical, and quality traits under high-temperature stress in tomato (*Solanum lycopersicum* L.)

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Abstract

This research aimed to assess how tomato plants and their hybrids react physiologically when exposed to high-temperature stress (HS). The research focused on exploring genetic diversity, heritability, and genetic advance in response to high-temperature stress at the Indian Council of Agricultural Research-Indian Institute of Vegetable Research (ICAR-IIVR), Varanasi, during the summer season of 2024 (February- May). In this investigation, a total of 23 distinct genotypes, comprising 8 parents and 15 crosses, were cultivated using a randomized block design. The results of the ANOVA indicate a notable level of genetic diversity among the selected genotypes concerning different traits. The phenotypic and genotypic coefficient of variation shows that the PCV is greater than the GCV across all traits studied, highlighting the significant influence of environmental factors. The combination of high heritability and genetic advances in traits like proline, sodium dismutase, and hydrogen peroxide suggests that additive gene effects influence these attributes and are more dependable for efficient selection.

Keywords: High-temperature stress, Physiological, Biochemical, Proline, Tomato.

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Introduction

Tomato is the predominant vegetable crop in India and is highly valued among various vegetables. Tomato, considered a "protective food," is extensively cultivated globally as an annual plant. They are primarily utilized for both fresh consumption and processing purposes. Tomato is a significant natural source of vitamins A, C, & lycopene. Additionally, they serve as an essential reservoir of β-carotene and ascorbic acid, which exhibit strong antioxidant properties (Kumar et al., 2017). In comparison to other vegetables, tomato is more widely grown in India. The growth and fruiting processes of tomatoes are significantly influenced by temperature, either independently or in conjunction with other environmental factors (Foolad, 2005). When the temperature exceeds 35°C, it has detrimental effects on various stages of the tomato plant's growth cycle, including seed germination, seedling development, vegetative growth, flowering, fruit set, and fruit ripening (Wahid et al., 2007). Elevated temperatures also impact the viability of pollen grains, osmotic pressure, fruit set, and overall crop yield (Firon et al., 2006; Saeed et al., 2007). An in-depth assessment of genetic diversity is essential before commencing any crop enhancement initiative and selecting suitable breeding methods (Dhanwani et al., 2013; Prasanna et al. 2023; Tiwari et al. 2023).

The evaluation of genetic diversity involves the analysis of genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and estimates of heritability. When predicting the outcomes of selection, the combination of heritability estimates and genetic advancements provides more comprehensive insights compared to solely relying on heritability estimates (Johnson et al., 1955). The primary objective of this study was to identify the range of variability in physiological and biochemical characteristics within a selected group of tomato genotypes.

Materials and Methods

The research was carried out at the Vegetable Research Farm of the Indian Institute of Vegetable Research (ICAR-IIVR) in Varanasi during the summer season (February-June) of 2024. The experimental site is situated near the Ganges River, at 82.52°E longitude and 25.10°N latitude, with an elevation of 128.93 m above mean sea level (MSL). The meteorological data for the season under study is showcased in Figure 1. For this study, a total of 8 distinct genotypes were selected. These 8 genotypes were employed to generate 15 crosses following a Line×Tester breeding scheme. The parental genotypes utilized in this investigation included VRT-06, EC-620402, Kashi Aman, Kashi Chayan, and Punjab Barkha Bahar-2 (PBB-2) as Lines, while Superbug, Vaibhav, and EC-620386 as Testers. The genotypes were studied for 13

Physiological and biochemical contributing traits such as Relative water content (%) (Barrs & Weatherly (1962), electrolyte leakage (%) (Sairam et al., 1997), total chlorophyll content (mg/g) (as described by Arnon 1949), proline (µg/g) (as described by Bates et al., 1973), TSS (°Brix), acidity (%), lycopene (mg/100g) and β-Carotene (mg/100g) (as described by Ranganna,1986), lipid peroxidation (µmol/g FW) (Mondal et al., 2003), hydrogen peroxide (µmol/g FW) (Rai et al., 2013), sodium dismutase (unit/mg protein) (as described by Shah et a*l*., 2001), superoxide ion (min/mg protein) (as described by Chaitanya and Naithani, 1994) and yield per plant (kg).

The ANOVA (analysis of variance) was carried out based on the experimental design to separate the variance into treatments and replications, following the methodology outlined by Panse and Sukhatme (1967). The genotypic and phenotypic coefficients of variance were computed using the method described by Burton and Devane (1953) based on genotypic and phenotypic variance estimates. The broad sense heritability (h^2bs) was determined following the methodology proposed by Weber & Moorthy (1952), while categorization of genetic advance as a percentage of the mean into low, moderate, and high groups was established, conferring to the guidelines provided by (Johnson et al., 1955).

Results and Discussion

High temperatures caused by elevated ambient temperatures pose a significant risk to agricultural productivity on a global scale. Variations in seasonal temperatures impact crop yields primarily by influencing phenological development processes. Heat resilience is commonly described as the plant's capacity to thrive and generate a profitable yield in high-temperature conditions. Opting for crops that exhibit tolerance to HS is suggested as the most effective and straightforward approach for breeding purposes. This research was conducted to assess the biochemical and physiological characteristics of parents and hybrids under high temperatures and stress conditions. Significant variation was noted across the genotypes for all physiological and biochemical characteristics (Table 1). These results indicate the existence of a notable degree of genetic diversity among the materials investigated.

Mean Performance

Significant variations were noted between the minimum and maximum mean values across all the analyzed traits (Table 2). The mean performance among the thirteen traits ranged between acidity (0.37%) to relative water content (64.81%) and remaining traits followed by hydrogen peroxide (64.23 µmol/g FW), proline (62.69 µg/g), electrolyte leakage (60.77%), sodium dismutase (45.28 unit/mg protein), TSS (4.87°Brix), lycopene (3.85 mg/100 g), lipid peroxidation (3.61 µmol/g FW), total chlorophyll content (1.63 mg/g), superoxide ion (1.43 min/mg protein), yield per plant (0.94 kg), and β-carotene (0.60 mg/100 g) highlighting their significant role in the overall variation seen in the tomato genotypes. The findings suggest that there is potential to improve desirable characteristics through targeted selection in the near future. The broad spectrum of diversity noted may be due to the inclusion of unique genetic profiles in the research.

Analysis of coefficient of variation

Diverse variations were present across all genotypes in terms of both phenotypic and genotypic coefficients of variability. The assessments of these coefficients highlighted the extent of variation within the germplasm under study (Table 2). In all the traits analyzed, the PCV was greater in extent than GCV, although there were slight differences in some instances. Opting for selection based on phenotypic performance is considered a more dependable strategy. The coefficient of variability is diverse in degree across different traits (ranging from low to high), suggesting a significant level of diversity.

Phenotypic coefficient of variation (PCV %)

The high PCV (> 20%) was estimated for traits *viz*., yield per plant (47.20) followed by superoxide ion (43.96), β-carotene (35.62), total chlorophyll content (29.14), proline

Table 1: ANOVA table for 15 different physiological, biochemical, and quality traits in 23 tomato genotypes including eight parent and fifteen hybrids

Characters	*DF*	*RWC (%)*	*EL (%)*	*TCC (mg/g)*	*Proline (µg/g)*	*TSS (°Brix)*	*Acidity (%)*	*Lycopene (mg/100 g)*	*β-Carotene (mg/100 g)*	*LPO (µmol/g FW)*	*HP (µmol/g FW)*	*SOD (unit/mg protein)*	*So_2 (min/mg protein)*	*Y/P (kg)*
Replication	2	0.53	5.06	0.01	3.43	0.39	0.002	0.05	0.01	0.04	0.40	4.39	0.01	0.01
Treatment	22	226.87**	169.32**	0.62**	845.90**	0.62**	0.013**	2.62**	0.13**	1.60**	305.06**	325.98**	1.18**	0.57**
Error	44	7.12	32.71	0.03	13.03	0.15	0.000	0.11	0.01	0.05	3.10	2.69	0.01	0.01
Total	68	78.02	76.09	0.22	282.21	0.31	0.005	0.92	0.04	0.55	100.71	107.33	0.38	0.19

Note: DF (degree of freedom), RWC (relative water content), EL (electrolyte leakage), TCC (total chlorophyll content), TSS (total soluble solids), LPO (Lipid peroxidation), HP (hydrogen peroxide), SOD (sodium dismutase), SO_2 (superoxide ion), Y/P (Yield per plant).

(27.20), lycopene (25.32), sodium dismutase (23.21), lipid peroxidation (20.79) whereas, moderate PCV (10–20%), reported in acidity (18.66) followed by hydrogen peroxide (15.86), electrolyte leakage (14.56), relative water content (13.83) and TSS (11.38). Kumar et al. (2017) similarly identified higher PCV% values for yield per plant, total chlorophyll content, and lycopene content during their investigation on the effects of HS on physiological and biochemical tomato genotypes.

Genotypic coefficient of variation (GCV%)

As phenotypic variability estimates cannot differentiate between genetic and environmental influences, focusing on genetic variability is crucial for isolating true genetic differences. High genotypic coefficients of variability suggest increased potential for improvement in the specific trait under scrutiny. The high genotypic coefficient of variation (> 20%) was estimated for traits *viz*., yield per plant (46.11) followed by superoxide ion (43.84), β-carotene (34.39), total chlorophyll content (27.27), proline (26.58), lycopene (23.74), sodium dismutase (22.93) whereas moderate GCV (10-20%) in lipid peroxidation (19.94), acidity (17.88), hydrogen peroxide (15.62), relative water content (13.21), electrolyte leakage (11.10), and lower GCV% observed only in TSS (8.15). as per our finding, Kumar et al., (2017)**,** Joshi et al., (2004) also reported the lower value of PCV and GCV for TSS. A thorough examination of the data revealed that hydrogen peroxide and superoxide ions displayed minimal differences in PCV and GCV, representing that the variability in these characteristics was predominantly attributable to genotypes, with a lesser impact on the environment. However, significant differences in PCV and GCV were observed in other traits, showing that the environment had a substantial impact on the total variability rather than the genotypes themselves. Similar findings were also reported by Kumar et al. (2013) and Khapte et al. (2014).

Heritability and Genetic advance

The concept of heritability offers valuable insights into the degree of trait inheritance; however, it does not directly measure the potential genetic advancement that would result from selecting the most superior individual. Therefore, an effective selection method must combine broad-sense heritability with significant genetic progress to be successfully implemented. Genetic advance, which assesses the genetic improvement gained through selection, is essential in evaluating the outcomes of selection strategies. The high heritability (more than 60%) was estimated for superoxide ion (99.41), followed by sodium dismutase (97.57), hydrogen peroxide (97.01), proline (95.52), acidity (91.77), yield per plant (95.44), β-carotene (93.20), lipid peroxidation (91.53), relative water content (91.14), lycopene (87.91), and total chlorophyll content (87.58). A similar record was also reported by (Kumar et al., 2017), Dar and Sharma (2011), and

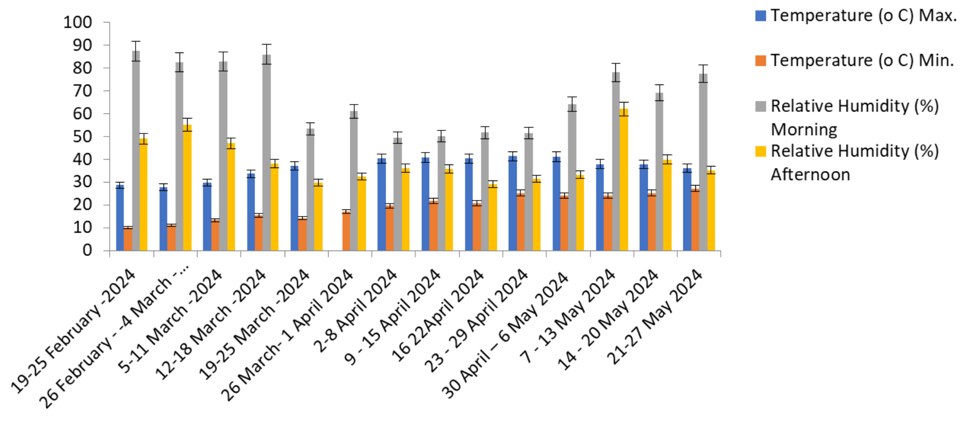

Figure 1: Standard meteorological weak weather data during the experiment

Table 3: Mean, range (minimum and maximum), GCV (%), and PCV (%), heritability (%), Genetic advance (GA) and genetic advance (%) over mean of physiological, biochemical, and quality traits of eight parent and fifteen hybrids of tomato under high temperature stress

Traits	*Mean*	*Minimum*	*Maximum*	*GCV (%)*	*PCV (%)*	*Heritability (%)*	*GA (%)*	*GA % over mean*
Yield/Plant (kg)	0.94	0.30	1.66	46.11	47.20	95.44	0.87	92.80
Relative Water content (%)	64.81	48.68	83.72	13.21	13.83	91.14	16.83	25.97
Electrolyte leakage (%)	60.77	48.33	71.67	11.10	14.56	58.20	10.60	17.45
Total chlorophyll content (mg/g)	1.63	0.96	2.40	27.27	29.14	87.58	0.86	52.58
Proline (µg/g)	62.69	37.62	97.51	26.58	27.20	95.52	33.55	53.51
TSS (°Brix)	4.87	4.13	5.73	8.15	11.38	51.30	0.59	12.03
Acidity (%)	0.37	0.24	0.54	17.88	18.66	91.77	0.13	35.28
Lycopene (mg/100g)	3.85	1.43	5.99	23.74	25.32	87.91	1.77	45.85
β-Carotene (mg/100g)	0.60	0.26	1.03	34.39	35.62	93.20	0.41	68.38
Lipid Peroxidation (µmol/g FW)	3.61	2.72	5.92	19.94	20.79	91.93	1.42	39.38
Hydrogen peroxide (µmol/g FW)	64.23	52.91	88.11	15.62	15.86	97.01	20.36	31.69
Sodium dismutase (unit/mg protein)	45.28	32.32	67.99	22.93	23.21	97.57	21.12	46.65
Superoxide ion (min/mg protein)	1.43	0.60	2.75	43.84	43.96	99.41	1.29	90.04

Kumar & Tewari (1999), whereas moderate heritability (31-60%) was reported in electrolyte leakage (58.20), and TSS (51.30). The high genetic advance (more than 20%) disclosed the best performance proline (33.55), sodium dismutase (21.12), and hydrogen peroxide (20.36), whereas moderate genetic advance (10–20%) was observed for relative water content (16.83), electrolyte leakage (10.60). The significant findings of high heritability and high genetic advance for traits such as proline, sodium dismutase, and hydrogen peroxide suggest that additive gene effects predominantly influence these characteristics. Consequently, these traits are considered more dependable for precise selection methods (Panse, 1957).

Conclusion

In this investigation, a significant amount of genetic variation was detected in the genotypes for various physiological, biochemical, and quality traits. The calculated variability demonstrates a notable PCV value for all the traits examined compared to their corresponding GCV, suggesting the environmental influence. High heritability was noted for all characters except electrolyte leakage and TSS, while traits such as proline, sodium dismutase, and hydrogen peroxide exhibited a substantial genetic advance. The combination of high heritability and genetic advances was observed for traits like proline, sodium dismutase, and hydrogen peroxide. Overall, our study suggests that these traits are governed by additive gene effects, implying that they can be enhanced effectively through the selection process.

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सारांश

इस षोध का उद्देष्य यह आकलन करना था कि टमाटर और उनके संकर उच्च तापमान तनाव के संपर्क में आने पर षारीरिक रूप से कैसे प्रतिक्रिया करते हैं। षोध ने 2024 (फरवरी-मई) के ग्रीश्म ऋतु के दौरान भारतीय कृशि अनुसंधान परिशद-भारतीय सब्जी अनुसंधान संस्थान, वाराणसी में उच्च तापमान तनाव के जवाब में आनुवंषिक विविधता, आनुवंषिकता और आनुवंषिक प्रगति की खोज पर ध्यान केंद्रित किया। इस जांच में, कुल 23 अलग-अलग जीनोटाइप, जिनमें 8 पैरेंट्स और 15 क्रॉस षामिल थे, जिसे रेंडमाइज्ड ब्लॉक डिज़ाइन का उपयोग करके उगाया गया था। जिसका परिणाम विभिन्न लक्षणों के संबंध में चयनित जीनोटाइप के बीच आनुवंषिक विविधता के उल्लेखनीय स्तर का संकेत देते हैं। भिन्नता के फिनोटिपिक और जीनोंटिपिक गुणांक से पता चलता है कि अध्ययन किए गए सभी ल क्षणों में फिनोटिपिक गुणांक भिन्नताए जीनोटाइपिक गुणांक भिन्नता से अधिक है, जो पर्यावरणीय कारकों के महत्वपूर्ण प्रभाव को उजागर करता है। प्रोलीन, सोडियम डिसम्यूटेस और हाइड्रोजन पेरोक्साइड जैसे लक्षणों में उच्च आनुवंषिकता और आनुवंषिक प्रगति का संयोजन बताता है कि ये विषेशताएँ योगात्मक जीन प्रभावों से प्रभावित हैं और कुषल चयन के लिए अधिक भरोसेमंद हैं।