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Estimates of Genetic Variability, Association Studies and *Per se* Performance of Tomato Genotypes for Growth and Yield Parameters Under Drought Stress Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. Author KGU conducted research, analyzed research data, and wrote the first draft of the manuscript. Author LTN was involved in planning, finalizing, and implementing the research program, providing technical guidance, and preparing the manuscript. Authors MBNN and DM managed the analysis of the study, provided guidance in carrying out the research, and corrected the draft copy. Authors VDG, SGG and SSN assisted in the finalization of the manuscript and statistical analysis of the data. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Drought tolerance is a complex phenomenon, influenced by the coordinated activity of many genes. Breeding for drought tolerance is the need for contemporary research under the present climate change scenario. Further, the estimates of variability and degree of association among the traits would facilitate the selection for yield under drought conditions as it is highly influenced by environmental factors. This study aimed for the enhancement of selection capacity for drought stress tolerance in tomato based on the measures of genetic variability parameters and extent of association among traits which in turn used to identify drought tolerant genotypes.

Methodology: The experiment was conducted with 39 tomato genotypes with 2 replications under normal and drought stress condition (15 days irrigation interval) following a Randomized Block Design during summer, 2020 at Department of Biotechnology and Crop Improvement, Kittur Rani Channamma College of Horticulture, Arabhavi.

Results: High heritability along with moderate to high GAM was recorded for all the characters under study in both control and drought stress condition, indicating predominance of additive gene action for these traits. Yield per plant had positive and strong association with plant height, stem girth, number of primary branches, number of fruits per plant and average fruit weight. Further, path analysis revealed high desirable direct effect of average fruit weight and number of fruits per plant on yield per plant. Thus, there is ample of scope for improving these traits through selection. The genotypes *viz.,* EC-634394, EC-638519 and Kashi Anupama shown superior performance for yield along with other yield attributing traits and also exhibited less percent reduction in these traits under drought condition.

Keywords: Tomato; drought; correlation; path coefficient; heritability; GAM.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L., 2n=24) is one among the important solanaceous vegetable crops used as a protective supplementary food and has gained significance from economic point of view owing to its higher yield potential within a short duration. It is the second largest growing vegetable crop in the world with an area of 5.51 million hectares and production of 186 million tons [1]. Tomato is generally grown as an irrigated crop and its cultivation as a rain fed crop has gained much importance especially in semi-arid areas [2]. However, tomato is highly sensitive to unfavorable environmental conditions such as drought, heat and salinity which adversely affect its growth and productivity [3,4]. Generally, majority of tomato genotypes are highly sensitive to several abiotic stresses [5]. Furthermore, the flowering and fruit development stages have been identified to be most sensitive to moisture deficits in tomato, [6,4].

Under the present climate change scenario, the prime requirement for extended tomato cultivation in semi-arid areas is the irrigation water, which is on the decline in most parts of the world. Thus, identification and utilization of the drought tolerant genotypes from the available germplasm in crop improvement programs is a promising approach towards the development of crop varieties that can alleviate the negative effects of stresses with enhanced water use efficiency and high productivity in vulnerable areas [7,8].

Environmental stress poses a significant challenge in achieving higher crop productivity in many parts of the world, more particularly water scarcity is a severe constraint on plant growth and yield [9]. It has been estimated that nearly 45% of the world's agricultural land area is subjected to drought [10]. So, dealing with the effects of water stress under a changing climate scenario is considered as the most viable option to increase the yield levels. The success of plant breeding program and the efficiency of selection and genetic improvement for a specific trait rely heavily on the nature and extent of genetic variability present within the germplasm for that trait. The total observable variability includes both genetic and environmental components. Thus, it is necessary to split the observed phenotypic variance into phenotypic and genotypic coefficients of variation. However, relying solely on information about these variability coefficients is insufficient to determine the effectiveness of selection, as it does not provide exact details about heritability and gene action. Heritability values along with the genetic advance are more helpful in predicting the genetic gain under selection than heritability estimates alone [11]. Heritability gives an idea about the extent to which genotypic value depends on phenotypic value and genetic advance estimates about the gene action involved in the expression of various polygenic traits. So, heritability and genetic advance in combination are more reliable as the important selection parameters.

Furthermore, drought tolerance is a complex phenomenon and is controlled by many genes. Breeding for drought tolerance is difficult and direct selection for yield under drought conditions may be misleading as it is highly influenced by environmental factors [12]. Hence, association studies among yield and yield attributes using correlation and path analysis under drought stress situations are very useful, while formulating the selection scheme to improve yield under drought stress. In this study, genetic variability parameters were estimated to quantify the extent of variability present among the evaluated set of tomato genotypes as well correlation and path coefficients were assessed to infer the associated set of traits to enhance the selection efficiency for yield under drought stress. Germplasm evaluation under drought stress helps to identify tomato genotypes with farmer-preferred traits and enhanced drought tolerance which would allow its expanded cultivation and elevated yields in marginal areas.

2. MATERIALS AND METHODS

This study was undertaken to screen the tomato genotypes for growth and yield parameters under normal and drought stress conditions at the Department of Biotechnology and Crop Improvement, Kittur Rani Channamma College of Horticulture, Arabhavi, which falls under the Northern dry zone of Karnataka, situated at an altitude of 612.03 meters above mean sea level. Geographically, it lies at 16°15' north latitude and 75°45' east longitude. The temperature during the experiment was 15.22° C to 36.66 ° C, while the humidity ranged between 60.33 and 79.32% (Table 1).

The experiment was conducted with 39 tomato genotypes evaluated under normal and drought stress conditions (15 days irrigation interval) following a Randomized Block Design with two replications during the summer of 2020. Four-week-old healthy seedlings were transplanted to a well-prepared main field in mid-February. Water stress was imposed after three weeks of transplanting to all the genotypes by withholding water for 15 days before rewatering. The stress was imposed up to the final harvest of the crop. The various traits *viz.,* plant height, stem girth, number of primary branches, days to 50 % flowering, number of fruits per plant, average fruit weight, and yield per plant were recorded from five randomly selected plants under both situations. The data recorded was subjected to genetic analysis using Gene stat software.

3. RESULTS AND DISCUSSION

Crop resilience to abiotic stresses is the prime need for sustainable food production [13]. This necessitates the quantification of phenotypic variability to identify morpho-physiological traits contributing and associated for drought stress. So far, there is limited knowledge on tomato phenotypic variability to water deficit. In this study, the response of a set of tomato germplasm screened for water stress was documented.

The results of evaluation of 39 genotypes of tomato indicated a large variability in response to water stress, as revealed through analysis of variance showing highly significant differences among the genotypes as well as the interaction effect between the genotypes and irrigation levels for all the traits studied (Table 2). The *per se* performance of 39 tomato accessions revealed a decreasing tendency for plant height, stem girth and number of primary branches under drought stress as compared to irrigated conditions [14,15,16]. Average plant height was highest under control condition (78.42 cm) as compared to drought stress condition (46.66 cm). Similarly, the mean stem girth of the genotypes was highest under the control condition (9.60 mm) compared to the drought stress condition (7.18 mm). Further, the mean number of primary branches in drought stress-imposed plants (6.74) was lower than in well-irrigated plants (8.31). These results indicated that these growth traits were significantly impacted when drought stress was imposed and reduced by 40.50%, 25.21%

Table 1. Monthly weather data during the experiment

Months (2020)	Temperature (° C)		Rain fall (mm)	RH (%)	Evaporation (mm)
	Min	Max			
February	17.08	31.24	--	60.33	4.5
March	15.22	31.43	--	75.90	5.5
April	22.04	32.08	12.04	72.06	6.0
May	21.83	36.66	83.80	79.32	6.3

and 18.89%, respectively. Reduced irrigation water significantly affected growth and yield parameters. However, the rate of response varied among different genotypes (Table 3). The decline in growth attributes (Plant height, stem girth and number of primary branches) under drought stress conditions could be attributed to reduced meristematic activity, including decreased cell division and cell enlargement due to reduced relative water content and turgor loss caused by drought [17]. Likewise, the evaluated genotypes flowered early under drought stress conditions (45.20 days to 50% flowering) when compared to the control condition (48.51 days), which was also revealed by Akter et al*.* [18] and Ilakiya et al. [19]. Plants accelerate phenological development through early flowering and fruiting to complete the life cycle under unfavorable environments [20].

Furthermore, a significant reduction in fruit yield traits was observed under stress conditions. The mean number of fruits per plant (20.53) average fruit weight (28.57 gm) and fruit yield per plant (0.73 kg) were considerably reduced when compared to well-irrigated conditions (31.64 fruits, 42.84 gm, and 1.36 kg, respectively) with a percent reduction of 35.11%, 33.31%, and 46.32%, respectively under drought stress. This decreasing trend for fruits per plant, average fruit weight and yield per plant was also reported by Sivakumar et al*.* [17] Prakash et al*.* [15] and Parveen et al. [16]. The reduction in fruit yield parameters under drought stress conditions is due to reduced water content in plants that adversely affects plant growth leading to reduced plant height and number of leaves [17], reduced photosynthetic efficiency, increased flower abscission, reduced pollen fertility [20] resulting in lower yields. Also, to maintain relative water content under drought and to avoid water loss through transpiration, the plant closes its stomata; it disrupts leaf gas exchange properties which limit the source size and activity (Photosynthesis) and partitioning of photo assimilates to fruits (sink size and activity) [15].

Comparative performance among the evaluated tomato genotypes under normal and water stress conditions identified few promising accessions that showed less percent reduction under stress conditions. Genotypes Hisar Arun (2.23 kg), Arka Rakshak (2.11 kg), EC-608269 (1.99 kg) and EC-631962 (1.80 kg) under control irrigation condition whereas Kashi Anupama (1.10 kg), EC-638519 (1.07 kg), EC-610652 (1.04 kg) and EC-610661 (1.02 kg) under drought stress condition exhibited higher fruit yield per plant. For average fruit weight, genotypes Hisar Arun (57.20 gm), EC-631962 (53.56 gm) and EC-608269 (51.68 gm) showed better performance under control conditions whereas Arka Rakshak (45.18) and Hisar Arun (41.61) recorded higher number of fruits per plant along with yield (Table 4). Genotypes EC-634394 and Kashi Anupama recorded higher plant height (64.70 cm & 59.87 cm respectively), stem girth (8.86 mm & 8.09 mm respectively), number of primary branches per plant (8.56 & 8.78 respectively) and number of fruits per plant (26.44 & 27.78 respectively) under drought stress condition. Among the genotypes, EC-638519 recorded high fruit yield under drought stress conditions with considerably high average fruit weight (35.73 gm) and plant height (61.62 cm). Kashi Anupama (-5.98%), EC-634394 (-10.83%) and EC-638519 (-14.71%) exhibited less reduction in yield and also for other yield attributing traits under drought stress conditions. Under control conditions, even though the genotypes, Hisar Arun, Arka Rakshak, and EC-608269 demonstrated higher yield and superior performance for other yield-attributing traits when subjected to drought stress, these genotypes experienced the maximum reduction in yield and yield attributing traits. Conversely, Kashi Anupama, EC-638519, and EC-634394 exhibited higher yield and better manifestation for other yield traits, with the least percent reduction under drought stress. Hisar Arun, Arka Rakshak, and EC-608269 can be considered promising genotypes for breeding high-yielding varieties and hybrids under normal growing conditions. However, for developing drought-tolerant varieties and hybrids, Kashi Anupama, EC-638519, and EC-634394 should be prioritized owing to their superior performance and minimal reduction in yield and yield attributing traits under drought stress.

Estimates of genetic variability parameters are presented in Table 5. A wide range of variation was observed among the 39 genotypes for seven quantitative characters and phenotypic variance was higher than the genotypic variances for plant height, stem girth, number of primary branches, days to 50% flowering, number of fruits per plant, average fruit weight and yield per plant, thus indicated the influences of environmental factor on these traits. However, the variability estimates would not offer the full scope of heritable variation. It can be found out with a greater degree of accuracy when variability measures are considered along with heritability and genetic advances realized.

Higher estimates of genotypic co-efficient of variability (GCV = 23.33% & 22.28%) along with high broad sense heritability (83.98% & 76.84%) and high genetic advance as percentage of mean (GAM) (44.04% & 40.23%) was observed for yield per plant under both and control condition respectively [21] and Sushma et al. [22]. This indicated the additive nature of genetic variation transmitted from the parents to the progeny. Thus, there is ample scope for improvement of yield through selection, thus selection would be rewarding in early generations [22]. However, the comparison of heritability for all the traits under drought stress and irrigated conditions, results indicated that for yield, heritability increases with better input conditions and environment. This is attributed to the influence of the environment on genotypes under drought-stress conditions [23]. Moderate GCV, but high heritability (> 60%) and high GAM (> 20%) were observed for average fruit weight under both situations. Further, under drought stress situations, moderate estimates of GCV coupled with high heritability and genetic advance were recorded for plant height, number of primary branches and number of fruits per plant. This implied that the available variability can be exploited gainfully through selection breeding. High broad sense heritability was noticed for plant height, and number of primary branches per plant under both control and drought stress conditions, whereas moderate GAM (10-20%) under control conditions and high GAM (>20%) under drought stress conditions for these traits. The number of fruits per plant demonstrated moderate heritability (56%) and high GAM (20.16%) under drought stress conditions whereas high broad sense heritability and GAM under control conditions.

However, under control conditions, low to moderate estimates of GCV (<20%) coupled with high broad sense heritability (> 60%) and moderate GAM (10- 20%) were noticed for plant height, stem girth and number of primary branches and days to flowering [15,24]. This indicated moderate variability in the studied accessions, but highly heritable variation owing to the additive gene action for these traits. The low variability estimates for these traits necessitate to inclusion of more diverse germplasm in the breeding programs.

To establish the degree of relationship among the yield component traits under drought stress, the genotypic correlation coefficients were analyzed and are shown in Table 6. Associations concerning yield per plant revealed that the trait's number of fruits per plant (0.823 & 0.804), average fruit weight (0.789 & 0.905), plant height (0.357 & 0.443) and number of primary branches (0.226 & 0.450) had significant positive association under normal condition and drought stress condition respectively. In addition, stem girth (0.437) also showed a strong positive association with yield per plant. When associations among yield component traits were compared, it was observed that under control conditions, plant height had a significant positive correlation with the number of fruits per plant (0.537), days to 50% flowering (0.441) and number of primary branches (0.409); while under drought stress condition, positive correlation was observed with stem girth (0.715), number of primary branches (0.601), number of fruits per plant (0.592) and average fruit weight (0.350). Further, stem girth revealed a significant negative correlation with days to 50% flowering (-0.316) and a positive correlation with several fruits per plant (0.234) in the control condition, while it showed a non-significant association with other characters. On the other hand, under drought stress conditions, stem girth had a positive correlation with several fruits per plant (0.796) and several primary branches (0.593). Several primary branches had a positive correlation with the number of fruits per plant of 0.273 and 0.693 under control conditions and drought stress conditions respectively. Likewise, several fruits per plant had a positive association with average fruit weight under control conditions (0.308) and drought stress conditions (0.265). The yield characteristic does not express independently; rather, it exists as a result of interaction with other component traits, resulting in a complex association that ultimately affects yield. This interaction or relationship might be positive or negative. Under both control and drought stress conditions, yield per plant had a positive and strong association with plant height, stem girth, number of primary branches, number of fruits per plant and average fruit weight. This revealed that the taller plants with more primary branches, thick stems, higher fruit weight and more number of fruits per plant would produce high yield per plant. Thus, these characteristics are important yield attributes to be considered in the selection criteria for improvement. Similar results were reported by Sushma et al. [22], Vijaylaxmi et al. [25], Srinivasulu et al. [26] and Sharma et al. [27].

The direction and magnitude of the correlation between yield and yield components are important for determining the important

Table 2. Analysis of variance for growth and yield parameters among tomato genotypes

Source	df	Plant height (cm)	Stem girth (mm)	No. of primary branches	Days to 50% flowering	No. of fruits per plant	Average fruit weight (g)	Yield per plant (kg)
Replication	1	30.61	0.01	0.05	1.44	15.71	0.77	0.03
Treatment	77	606.76*	4.15*	2.68*	33.08*	98.45*	156.04*	0.34*
Genotypes (G)	38	90.48*	1.30*	2.42*	54.51*	54.71*	75.36*	0.20*
Drought treatment (T)	1	39333.49*	227.38*	98.61*	422.21*	4815.19*	7939.40*	15.71*
GxT	38	103.91*	1.13*	0.41*	1.41*	18.06	31.89*	0.08*
Error	77	8.93	0.16	0.15	1.70	12.20	10.31	0.03

** and ** indicate significance of values at p=0.05 and p=0.01, respectively*

Table 3. Effect of irrigation interval on growth and yield traits of tomato genotypes

Traits		Range		Mean	% change over control
		Min.	Max.		
Plant height (cm)	T0	62.63	94.34	78.42	-
	T1	37.61	64.70	46.66	-40.50%
Stem girth (mm)	T0	7.62	11.19	9.60	-
	T1	6.14	8.86	7.18	-25.21%
No. of primary branches	T0	6.43	10.09	8.31	-
	T1	5.47	8.78	6.74	-18.89%
Days to 50% flowering	T0	40.03	55.43	48.51	-
	T1	39.19	51.77	45.20	-6.82%
No. of fruits per plant	T0	24.7	45.18	31.64	-
	T1	15.57	27.78	20.53	-35.11%
Average fruit weight (g)	T0	34.42	57.20	42.84	-
	T1	20.71	37.59	28.57	-33.31%
Yield per plant (kg)	T0	0.89	2.23	1.36	-
	T1	0.45	1.10	0.73	-46.32%

T0 Control condition T1 Drought stress condition

Table 4. *Per se* performance of selected Tomato genotypes for growth and yield parameters under control and drought stress condition

Sl. no.	Genotypes	Plant height (cm)		Stem girth (mm)		No. of primary branches		No. of fruits per plant		Average fruit weight (g)		Yield per plant (kg)	
		Control	15 days	Control	15 days	Control	15 days	Control	15 days	Control	15 days	Control	15 days
1	EC-608269	94.34	40.36	9.90	6.78	9.59	7.57	38.46	21.75	51.68	25.42	1.99	0.69
2	Hisar Arun	86.73	43.66	10.08	7.78	7.93	6.75	39.04	21.59	57.20	31.57	2.23	0.85
3	Kashi Anupama	76.52	59.87	9.58	8.09	9.29	8.78	30.99	27.78	37.89	32.07	1.17	1.10
4	EC-634394	80.41	64.70	10.16	8.86	9.45	8.56	28.42	26.44	35.93	31.27	1.02	0.87
5	EC-638519	78.96	61.62	9.50	8.59	9.30	7.99	29.69	24.12	40.58	35.73	1.20	1.07
6	Arka Rakshak	87.14	42.63	10.00	7.41	9.50	6.54	45.18	27.40	46.77	25.75	2.11	0.87

Table 5. Estimates of genetic variability parameters for growth and yield traits among tomato genotypes under control and drought stress condition

Traits		PCV %	GCV %	H^2 %	GA	GAM %
Plant height (cm)	T0	10.19	9.63	89.43	14.72	18.77
	T1	13.17	12.81	94.54	11.97	25.65
Stem girth (mm)	T0	9.76	9.09	86.82	1.67	17.45
	T1	9.05	8.52	88.83	1.19	16.55
No. of primary branches	T0	10.38	9.87	90.39	1.61	19.34
	T1	13.29	12.59	89.80	1.66	24.58
Days to 50% flowering	T0	8.23	8.03	95.20	7.83	16.14
	T1	7.93	7.65	93.05	6.87	15.21
No. of fruits per plant	T0	17.26	15.25	78.10	8.78	27.77
	T1	17.26	13.00	56.70	4.14	20.16
Average fruit weight (g)	T0	14.26	13.01	83.24	10.47	24.45
	T1	16.22	14.61	81.09	7.74	27.10
Yield per plant (kg)	T0	25.45	23.33	83.98	0.60	44.04
	T1	25.42	22.28	76.84	0.29	40.23

T0 Control condition T1 Drought stress condition

Table 6. Genotypic correlation coefficients for growth and yield parameters among tomato genotypes

	PH		SG		NPB		DFF		NFP		AFW		YP	
	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1
PH	1.000	1.000	0.037	0.715**	0.409**	0.601**	0.441**	-0.126	0.537**	0.592**	-0.038	0.350**	0.357**	0.443**
SG			1.000	1.00	0.070	0.593**	-0.316**	0.037	0.234*	0.796**	-0.059	0.162	0.113	0.437**
NPB					1.000	1.000	0.146	0.242*	0.273*	0.693**	0.078	0.138	0.226*	0.450**
DFF							1.000	1.000	0.099	0.027	0.031	-0.048	0.096	0.052
NFP									1.000	1.000	0.308**	0.265*	0.823**	0.804**
AFW											1.000	1.000	0.789**	0.905**
YP													1.000	1.000

** and ** indicate significance of values at p=0.05 and p=0.01, respectively. T0 Control condition and T1 - Drought stress condition* ***PH –*** *Plant height* ***SG –*** *Stem* ***NPB –****Number of primary branches* ***DFF*** *Days to 50% flowering* ***NFP*** *Number of fruits per plant* ***AFW –*** *Average fruit weight* ***YP*** *Yield per plant*

Table 7. Genotypic path coefficients for growth and yield parameters among tomato genotypes

		PH	SG	NPB	DFF	NFP	AFW	r_g	Partial R^2
PH	T0	0.062	0.0001	-0.005	-0.004	0.325	-0.023	0.357	0.022
	T1	-0.054	-0.292	-0.080	-0.013	0.625	0.256	0.443	-0.024
SG	T0	0.002	0.003	-0.001	0.003	0.142	-0.036	0.113	0.0003
	T1	-0.038	-0.408	-0.079	0.004	0.841	0.119	0.437	-0.179
NPB	T0	0.026	0.0002	-0.011	-0.001	0.166	0.048	0.226	-0.003
	T1	-0.032	-0.242	-0.134	0.024	0.732	0.101	0.450	-0.060
DFF	T0	0.027	-0.001	-0.002	-0.008	0.060	0.019	0.096	-0.001
	T1	0.007	-0.015	-0.032	0.099	0.029	-0.035	0.052	0.005
NFP	T0	0.033	0.001	-0.003	-0.001	0.606	0.187	0.823	0.499
	T1	-0.032	-0.325	-0.093	0.003	1.056	0.194	0.804	0.849
AFW	T0	-0.002	-0.0002	-0.001	-0.0002	0.186	0.607	0.789	0.479
	T1	-0.019	-0.066	-0.018	-0.005	0.280	0.733	0.905	0.664

** and ** indicate significance of values at p=0.05 and p=0.01, respectively. Diagonal indicates direct effects* ***Residual effect =*** *0.058 (T0 – Control condition) and 0.326 (T1 - Drought stress condition)* ***PH*** *Plant height* ***SG –*** *Stem girth* ***NPB –****Number of primary branches* ***DFF*** *Days to 50% flowering* ***NFP*** *Number of fruits per plant* ***AFW*** *Average fruit weight* r_g**=** *Genotypic correlation with yield per plant* characteristics that may be implemented in the breeding program as a crop enhancement approach, depending on selective breeding. A simple correlation metric does not accurately capture the characteristics contributing to yield. Path coefficient analysis is the most commonly used method for studying the interaction of various parameters with yield. A more detailed study of the relationships obtained by path analysis showed that the relation between yield and its components are somewhat different from that presented in the simple analysis of correlation (Table 7). Plant height had negligible direct positive effect (0.062) and negligible direct negative effect (-0.054) on yield per plant under normal irrigation and stress condition, respectively. But it was significantly correlated with yield. The high correlation revealed was due to its high indirect influence through number of fruits per plant (0.325) under control condition, whereas through number of fruits per plant (0.625) and average fruit weight (0.256) under 15 days irrigation interval. In control condition, stem girth had negligible direct positive effect on yield per plant whereas at 15 days irrigation interval, it shown a high negative direct effect (-0.408) on yield per plant. However, its association was significantly positive which was contributed by the high indirect positive effects through number of fruits per plant (0.841) and average fruit weight (0.119).

Furthermore, number of primary branches, even though was positively associated with yield per plant, its direct effect was negative along with indirect negative effect through stem girth (-0.242) under 15 days irrigation interval. So, the positive association (0.450) was due to its positive indirect effect through number of fruits per plant (0.732) and average fruit weight (0.101) under stress. The high degree of association as well as high direct positive effect (0.606) under control condition and stress condition (1.056) along with high indirect positive effect though average fruit weight (0.187 and 0.194) in spite of its negative indirect influence through stem girth (-0.325) was observed, indicating it as a significant yield contributing trait. Likewise, the trait average fruit weight had high correlation with yield which could be due to higher direct positive effect (0.607 & 0.733) on yield per plant and also due to high indirect positive effects through number of fruits per plant (0.280 & 0.186) under both control and stress conditions respectively.

Among the seven traits chosen for path analysis, plant height, stem girth, number fruits per plant and average fruit weight had positive direct effects on fruit yield per plant under normal irrigation. Hence direct selection for these traits is rewarding to improve fruit yield. Similar results were reported by Sharma et al. [28], Nevani and Sridevi [29] and Akhter et al. [30] However, under stress condition, days to 50% flowering, number of fruits per plant and average fruit weight had positive direct effects on yield per plant whereas plant height, stem girth, number of primary branches had negative direct effects. The true inherent positive association revealed among the traits could be considered for tomato yield improvement and direct selection for these traits is rewarding. Similar results were reported by Srinivasulu et al. [26], Nevani and Sridevi [29] and Sharma et al. [27]

The differential physiological and molecular responses under moisture stress has been deliberated in recent studies which would help in deployment of several drought stress mitigation strategies [31]. The efficiency of identified accessions to cope with the moisture stress needs to be focused in future studies. Furthermore, validation to be done in field trials under varied stressful conditions, contrasting pedoclimatic conditions and different experimental sites in order to quantify the genotype and environment interactions [32,33] like the role of soil type, leaching potential, water rentention capacity (Ayankojo et al. 2020) [34]. Earlier research on screening of tomato cultivars for drought tolerance has indicated the most sensitive parameters to reveal the impact of moisture stress on tomato plants (Sousaraei *et al*., 2021). The influence of unique environmental conditions of Latin America on the genetic variability and performance of tomato genotypes under drought stress was reported [35]. Previous research in Latin America has identified specific genotypes or genetic factors contributing to drought tolerance in potato [36]. This study contributes valuable insights into the genetic variability and trait associations governing drought tolerance in tomato genotypes. The findings provide a basis for targeted breeding strategies aimed at improving drought tolerance and ultimately enhancing tomato yield under challenging environmental conditions [37].

4. CONCLUSION

Drought stress is one of the major abiotic stresses under the present climate change scenario. The present study is a step towards exploring tomato variability and establishing association among traits contributing for better understanding and breeding of tomato for drought stress tolerance. The results have shown that the tomato genotypes evaluated harbored wide variability in response to moisture stress and serve as valuable gene pool to breed for abiotic stresses. High heritability along with moderate to high GAM observed for the studied traits under stress situation indicated the presence of additive gene action, which would enable the improvement of tomato for drought tolerance through effective selection programs. The identified drought tolerant genotypes EC-634394, EC-638519 and Kashi Anupama could be used in future breeding programs for the development of high yielding tomato varieties and hybrids. Moreover, molecular characterization and selection of the genotypes using linked markers with different drought tolerance responsive genes, would hasten the process of breeding. Direct selection is not effective for yield under drought stress owing to the complexity of yield as well as drought tolerance traits coupled with the influence of the environment. In this direction, the significant association among yield and drought sensitive parameters would enable their simultaneous improvement in breeding programs. In addition, the identified contrasting genotypes could be used to decipher the biochemical and molecular mechanisms underpinning the moisture stress tolerance which would in turn contribute for sustainable food production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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