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RESEARCH ARTICLE

The impact of induced drought stress on early seedling parameters and yield traits in tomato (*Solanum lycopersicon* L.) hybrids

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Abstract

Tomato is one of the most versatile vegetable crops, grown globally under diverse climatic conditions. Abiotic stresses, particularly drought, severely affect tomato productivity, causing yield losses of up to 70 % depending on stress duration and crop growth stage. Present study aimed to breed drought tolerant tomato hybrids by screening 13 parental lines and 30 hybrids along with one hybrid check under induced moisture stress. Early seedling screening using polyethylene glycol (PEG)-6000 revealed a reduction in germination percentage (-1.81 % and -15.60 %), shoot length (-7.28 % and -13.29 %) and seedling vigour index (-5.13 % and -17.55 %) with increasing PEG concentrations (8 % and 16 %) compared to the control. Field evaluation under different irrigation intervals showed significant reduction in plant height (-13.62 % and -28.16 %), total dry matter (-7.03 % and -16.13 %), leaf area (-8.55 % and -19.55 %) and yield (-26.86 % and -50.86 %), while root length (9.30 % and 17.15 %) and proline content (16.58 % and 42.68 %) increased under drought stress conditions (10 days and 20 days irrigation interval). The parental lines, EC-638519, Arka Meghali and Kashi Anupama and hybrids EC-608269 × Kashi Anupama, Arka Meghali × EC-634394 and Arka Saurabh × EC-638519 exhibited superior seedling vigour, yield performance and drought tolerance across early seedling, vegetative and reproductive stages. Molecular screening using 11 simple sequence repeat (SSR) markers resulted in monomorphic banding pattern indicating no detectable variation for these primers among the screened lines. Collectively, the study offers valuable opportunities for breeding hybrids adoptable to extreme drought conditions of marginal areas.

Keywords: heterosis; moisture stress; seedling vigour; simple sequence repeat markers

Introduction

Tomato (*Solanum lycopersicum* L., 2n=24) is one of the most versatile and commercially grown vegetable worldwide that belong to the Solanaceae family and is reported to originate from South America. Tomato is increasingly popular owing to its high nutritional value serving as a rich source of vitamin A, vitamin C as well as potassium, folate, dietary fiber and lycopene. Varied flavors, sweet and sour taste make it an important ingredient in numerous culinary dishes (1). Beyond culinary appeal, bioactive compounds, including lycopene and carotenoid pigment contribute to its antioxidant properties and potential health benefits (2, 3).

Globally, drought is the most detrimental and complex abiotic stress negatively impacting the crop plants both at molecular and physiological levels. Nearly 90 % of rural farmlands experience one or the other abiotic stress during the crop cycle, of this drought being the most predominant limiting factor for yield realization. Drought once considered as a distant threat, is now a global catastrophe exacerbated by climate change (4). By 2050, water scarcity significantly impedes crop plants on arable lands and affects nearly two-thirds of the global population (5). Prolonged water scarcity threatens food security, disrupts ecosystems and affects agricultural productivity worldwide. Tomato is highly sensitive to water scarcity and prolonged droughts restrict its commercial production (6). Drought stress has wide-ranging impacts on tomatoes, including delayed germination, reduced seedling vigour, impaired growth, disrupted nitrate reductase activity, altered carotenoid metabolism and reduced photosynthetic efficiency as well as fruit quality (7). Consequently, drought stress, especially during the early stages of crop establishment, can severely limit productivity in tomatoes.

Tomato germplasm represents as a valuable genetic resource for drought tolerance genes owing to their adaptation to diverse agro-ecological conditions, providing a unique opportunity to introduce resilience traits into modern hybrids and cultivars. The increasing reliance on genetically uniform hybrids has intensified genetic erosion and vulnerability to environmental stresses and hence genetic improvement for drought tolerance is often challenging due to the limited variability within cultivated tomato germplasm (8). In contrast, wild relatives such as *Solanum cheesmaniae* and *S. pennellii* possess superior drought tolerance traits and are cross-compatible with cultivated species, making them valuable resources for introgression breeding. Their conservation and utilization are vital in the context of increasing genetic erosion driven by the dominance of high yielding but genetically uniform hybrid cultivars (9).

In this context, to sustain the increasing demand for this vegetable crop under changing climate scenario, multiple strategies have been employed for the development of cultivars and hybrids with enhanced drought tolerance. These breeding strategies range from basic phenotypic screening of genetic resources and generated hybrids under induced stress to marker assisted selection to advanced genomic tools (8). In addition to genetic improvement, enhanced agronomic practices, such as the use of highly porous biochar can significantly improve soil water holding capacity and facilitate the retention of runoff water, thereby increasing water use efficiency and mitigating the adverse effects of drought stress on plants (10). Drought stress tolerance in tomato is a stage specific developmentally regulated phenomenon, tolerance at one stage of plant growth is independent of other stages (11). Several studies report that the germination and early seedling stages are among the most drought-sensitive, often restricting crop establishment. Moreover, drought stress during early growth stages can result in yield losses of up to 41 %, even when germination remains relatively unaffected under moderate stress (12). Likewise, drought during flowering, fruit development and ripening can severely reduce yield and compromise fruit quality (13). Hence, comprehensive screening at both early seedling and later vegetative/reproductive stages is crucial for identifying superior genotypes. Many efforts have been made and methods employed in the past (14) to screen tomato germplasm for drought tolerance at various critical stages. Among them, the most widely adopted approaches include screening at early seedling stage using polyethylene glycol (PEG) as an osmotic stress inducing agent (15) and at vegetative and reproductive stages under different field moisture stress regimes (16), which have proven to be very effective. Polyethylene glycol creates drought stress in the growth medium and highly effective in early-stage drought tolerance selection. Polyethylene glycol induced *in-vitro* screening offers a reliable approach to evaluate drought responses, as it induces water deficit without causing toxicity. Previous studies have shown that PEG-induced drought stress reduces germination, delays seedling emergence and restricts root and shoot growth in a genotype-dependent manner (11, 17).

Furthermore, plants have evolved complex drought tolerance strategies involving a set of biochemical, physiological and morphological adaptations, that include osmotic adjustment, reduction in water loss, enhanced water uptake and antioxidant defense systems to combat the drought induced adverse effects. Plants respond through morphological adaptive traits by regulating leaf wax thickness, pubescence and stomatal activity as well altering their root morphology (18). Considering the complexity of drought stress, no single mechanism operates to alleviate this stress and genes implicated in drought stress function differently in different plants and different species may rely on different sets of sub-traits to adapt to drought (18). So, owing to the high complexity of this trait confounded by the environmental influence, it is vital to augment field selection through marker assisted selection using markers linked to drought stress tolerance (19). Of the several markers screened, simple sequence repeats (SSR) being genome-wide and abundant provides a fast and easy approach in targeted selection for drought tolerance (20).

Considering these insights, the present study focused on the initial seedling screening of tomato under PEG induced stress, followed by field screening of parents and generated hybrids under controlled stress conditions as well as genotyping using drought stress associated SSR primers. This study would contribute to the broader understanding of the challenges posed by the increasing drought stress in tomato and to develop drought tolerant tomato cultivars and hybrids for farmer-preferred traits. Enhanced drought tolerance will allow its expanded cultivation and elevated yields in marginal areas under moisture stress conditions.

Materials and Methods

Plant material and growth conditions

The experiments involving the screening of tomato hybrids and their parents for induced moisture stress tolerance was conducted during summer season (Table 1) involving three drought tolerant tomato genotypes viz., EC-638519, EC-634394 and Kashi Anupama characterized previously as testers and crossed with other ten promising tomato lines in line × tester pattern to produce 30 single cross hybrids (21). These single cross hybrids along with their thirteen parents and one check (Arka Rakshak) were screened for induced moisture stress tolerance under laboratory condition using PEG-6000 as well as under greenhouse condition using controlled moisture stress regimes.

Early seedling screening using polyethylene glycol -6000

Tomato hybrids and the parents were screened under induced moisture stress using PEG-6000 in a completely randomized design (CRD) in 2 replications using 2 factors under the laboratory conditions. Factor A included the generated hybrids and their parents, whereas factor B consisted of 3 levels of drought stress artificially induced by desired strengths of PEG-6000. The PEG concentration was optimized through a series of experiments that included a range from 2 % to 20 % PEG. Distilled water was used as a control (T_0) and water deficit stress with osmotic potentials 8 % (T_1) and 16 % PEG (T_2) was created by adding PEG-6000 at 8 and 16 g per 100 mL distilled water respectively. The mixture was stirred to ensure that the PEG powder was dissolved completely and was continued until the solution appeared clear and homogenous.

Two replicates of 25 seeds of each of the generated hybrids and parents were surface sterilized with 70 % ethanol solution for a period of 5 min. The seeds were then thoroughly washed with sterilized distilled water for three times. Germination assays were performed by evenly distributing the seeds in a 10 cm diameter sterilized petri dishes with 2 layers of what man No. 1 filter paper. Three sets of petri dishes in each replication were maintained, 1 set for the control and 2 sets for PEG concentrations. Seeds primed in distilled water (control) as well in desired osmotic solutions of 8 % and 16 % PEG solutions that mimic drought stress were distributed

Table 1. Monthly mean weather parameters at the experimental site during crop growth period

Months -2021	Temperature (° C)		Rain falls (mm)	RH (%)	Evaporation (mm)
	Min	Max			
February	17.1	31.2	7.6	59.0	4.5
March	17.6	35.3	-	54.5	5.5
April	18.4	37.9	22.2	59.0	6.0
May	19.4	34.8	139.6	75.0	6.3

on moistened filter paper in petri dishes separately. The petri dishes were then placed in seed germinator at 25±5 °C and 80±1 % of relative humidity. The number of germinated seeds was recorded at 24 hr interval. Seeds were considered germinated when both plumule and radicle extended to more than 2 mm from the seeds. Thirteen days later, observations on number of seeds germinated, root length and shoot length were recorded and germination percentage, root to shoot ratio and seedling vigour index were calculated as per the following formulae.

Germination per cent: Germination percentage is an estimate of the viability of a population of seeds.

$$\text{Germination percentage} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

Root and shoot length (cm): At the end of germination test after 13 days, 10 seedlings from each replication were randomly selected for measuring root and shoot length using a scale in centimetres.

Root and shoot ratio (RS Ratio): This ratio was calculated by dividing the root length by shoot length.

RS ratio = Root length/Shoot length

Seedling vigour index: This was calculated using Germination percentage and Seedling length (22).

Seedling vigour index = Germination percentage × Seedling length

Screening under different moisture stress regimes under green house

All the 44 test entries comprising of 30 hybrids, 13 parents (10 lines and 3 testers) and 1 commercial check (Arka Rakshak) were screened under three irrigation regimes under greenhouse condition (growbag experiment) during summer, 2021. This experiment was laid out in a factorial randomized block design with 2 replications. The 25 days old healthy seedlings were transplanted to growbags filled with red soil and FYM as growth media in 2:1 ratio during mid-February. Five seeds per growbag were sown. After germination, three seedlings were retained per growbag and were kept in the green house of BCI department. Three test environments were created viz., normal irrigation as control (T_0) and 2 stressed treatments by withholding irrigation for 10 days (T_1) and 20 days (T_2) before rewatering. Moisture stress was induced from 4 weeks after transplanting to physiological maturity to simulate early, mid and terminal drought stress. Under induced stress, the parents and generated hybrids were assessed for their yield parameters namely, yield per plant (kg), plant height (cm) as well as drought related traits viz., root length (cm), total dry matter (g), leaf area (cm^2) and proline content in 3 moisture environments. Data was recorded on 5 randomly chosen plants in each of the test hybrid and parent in each of the replication (19). Roots and shoots were separated and washed properly with distilled water. The mean root length, shoot length and total dry matter was recorded in all the treatments.

Fruit yield per plant (kg) was recorded taking the weight of all the fruits harvested from the tagged plants of all the treatments in 2 replications. Plant height from basal region to the plant tip was recorded at 90 DAT. Root length was recorded from the collar region up to the root tip at the final harvest by uprooting the sample plants. Root and shoot dry matter (g) were taken at final harvest, wherein the plants were uprooted carefully and roots were washed thoroughly to remove adhered soil particles and then shoot and root portions were separated. Later, roots and shoots were dried in an oven at 80 °C until constant dry weights were obtained. Total dry matter (g) was obtained from root dry matter (g) and shoot dry matter (g). Leaf area (cm^2) was measured using leaf area meter and it is expressed in square centimetres.

Proline (µg/g of fresh leaf weight) content was estimated using 250 mg of leaf sample crushed with 10 mL of 3 % sulphosalicylic acid in pestle and mortar. Extract was filtered and extraction procedure was repeated. The 2 mL of extractant was pipetted out into a test tube and 2 mL of glacial acetic acid and 2 ml of acid ninhydrin was added, boiled in hot water bath for 1 hour at 100 °C. Later the test tubes were transferred to ice bath to terminate the reaction and the contents were transferred to the separating funnel and the pink coloured layer was collected by adding 4 mL of toluene and gently shaking the test tube. Using spectrophotometer the optical density (OD) at 520 nm of the extract was determined and toluene was used as blank (23).

$$\text{Proline content} = \frac{36.23 \times \text{optical density} \times \text{volume of aliquot taken}}{\text{Fresh weight of sample}}$$

Statistical analysis

The data recorded was subjected to statistical analysis and the analysis of variance (ANOVA) was performed to assess the amount of variability present among parents and hybrids under different stress environments using statistical analysis system (SAS software). The *per se* performances of parental lines and hybrids were compared using the critical difference at one and 5 % significance levels.

Simple sequence repeat genotyping of test genotypes (tomato parents and hybrids)

In addition, these parents and hybrids were also characterized using 11 SSR markers (Table 2), which have been reported to be associated with drought tolerance (24, 25). Genomic DNA was extracted from young healthy leaves of tomato parents and hybrids using a modified CTAB method (26) and subjected for polymerase chain reaction (PCR) amplification with SSR primers as per the standard procedure (Table 3). Polymerase chain reaction amplification included 15 µL reaction mixture consisted of 3.0 µL of each of primer pairs, 2.0 µL of each of dNTPs, 2 µL of 10X Taq buffer, 2.5 µL ddH$_2$O, 0.33 µL of Taq polymerase and 2.0 µL of template DNA. The amplified products were run on 3 % agarose gel using 1x TAE buffer stained with ethidium bromide. Electrophoresis was performed at 55–75 V for 3 hr, visualized the profile using UV trans illuminator and documented in a gel documentation system. The presence or absence of the bands was scored for each parent and hybrids and used for further analysis.

Results and Discussion

Early seedling screening of parents and hybrids using polyethylene glycol-6000

Table 2. List of SSR primers used for genotyping the test parents and hybrids of tomato for drought tolerance

Sl. No.	Primer name		Nucleotide sequence	Reference
1	SAL-3	F	GTGATGCAATGTCTCGGTGC	(21)
		R	CCGCCAAGTCTCTGATACGG	
2	SAL-16	F	GGCGAATTACATGGTCACGC	
		R	TCAACAAGTCCGAAGAGCCC	
3	SAL-17	F	GGAATGTACTGCCTCGCCTT	
		R	TCCTGAAGTGGGGTCCATCA	
4	SAL-18	F	TCAAGGCCGAGTACCCCATA	
		R	AGCGATCAACAACACGTCCT	
5	SAL-19	F	ATCGAACAACGGTCACCTGG	
		R	ACGCCTTCGCTCTACAACTT	
6	SAL-23	F	TGCTTGCAGGATCTCTCGTC	
		R	TGTGTGCGTCAGATCCCTTG	
7	SAL-24	F	CCACATGGAAAGTCGCTCCT	(20)
		R	CCATGGTTCGTCAGGACACA	
8	SAL-25	F	GAGCCCAAGTATGTAGGCCG	
		R	CCGATCAAGCCTCTCACGAA	
9	SAL-27	F	GGATCAGCTGACGTGAAGGT	
		R	TAGTTGGGCCCTCTTTTCGC	
10	SAL-28	F	TCTTCGACCTTACCATCGGC	
		R	CTCGGAAGTTCTCAGCGGTT	
11	ACT	F	GTCCTCTTCCAGCCATCC	
		R	ACCACTGAGCACAATGT	

Table 3. Polymerase chain reaction amplification protocol for genotyping with SSR primers in tomato parental lines and hybrids

Sl. No.	Steps	Temp. (°C)	Time (min)	Cycles
1	Initial denaturation	94.00	2:00	-
2	Denaturation	94.00	1:00	36
3	Annealing	54.00	2:00	
4	Primer extension	72.00	1:00	
5	Final extension	72.00	10:00	-

The combined analysis of variance (ANOVA) revealed highly significant variation among the tested tomato hybrids and parents along with 1 check hybrid. Significant variation was also implicated for different PEG concentrations (T_0=control; T_1=8 % and T_2=16 %) for the 5 early seedling parameters indicating the differential response of hybrids and parents to PEG induced moisture stress (Table 4). The mean comparison of early seedling parameters under different concentrations of PEG-6000 is given in Table 5 and the *per se* performance is presented in Fig. 1 and Supplementary table 1.

Germination percentage (%)

Seed germination rate and vigorous growth in early stages is most crucial in establishing good crop (27). Under moisture stress, seed germination becomes particularly important as it determines whether a plant can establish itself and withstand adverse conditions (28). In the study, the mean comparison of early seedling parameters revealed a significant reduction in seed germination percentage with the increase in PEG concentration (67.19 % at 16 % PEG concentration) compared to control (79.61 %). The *per se* performance (Fig. 1) indicated that the germination percentage was statistically consistent across control and 8 % PEG for the parents viz., EC-638519 (84.62 % and 83.49 % respectively) and Kashi Anupama (88.12 % and 85.03 % respectively), which showed their resilience to moderate moisture stress. But on further increase in PEG concentration (16 %), the germination

Table 4. Analysis of variance for early seedling parameters under polyethylene glycol induced drought stress among tomato parents and hybrids.

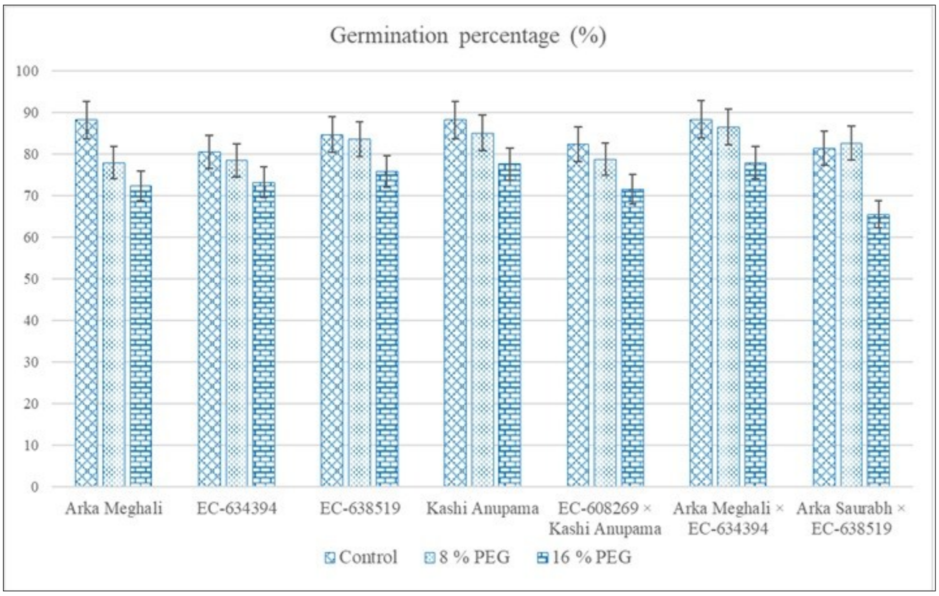
Source	df	Germination %	Root length (cm)	Shoot length (cm)	Root to shoot ratio	Seedling vigour index
Test genotypes	43	124.49 **	3.67 **	2.22 **	0.04 **	121.59 **
PEG treatment	2	4059.46 **	14.73 **	29.26 **	1.26 **	0.65 **
GxT	86	12.61 **	0.30 **	0.38 **	0.01 **	0.49
Error	132	4.01	0.27	0.22	0.01	2.69

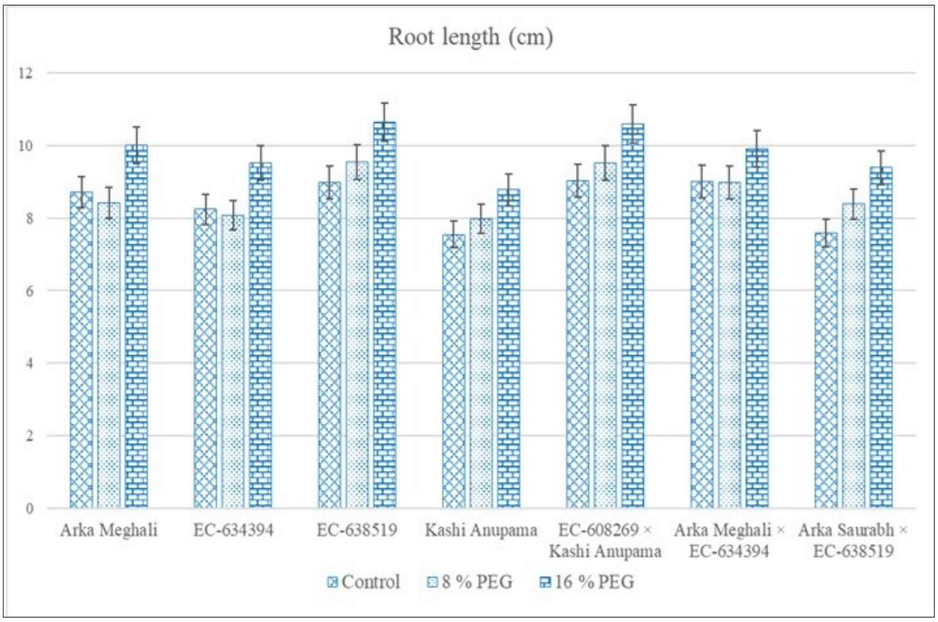
* and ** indicate significance of values at p=0.05 and p=0.01, respectively. Test genotypes included parental lines and generated hybrids of tomato.

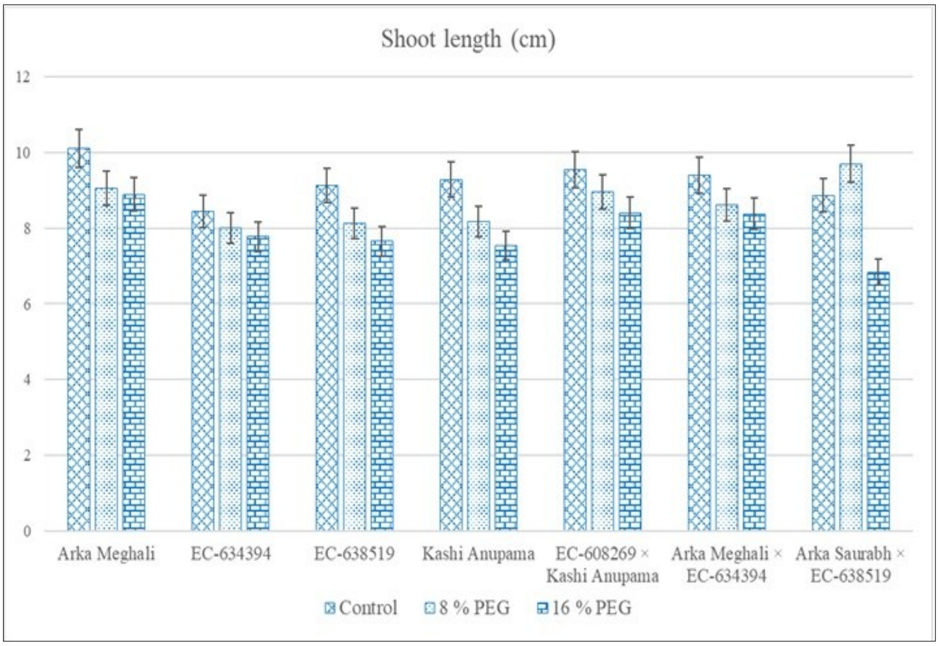
Table 5. Effect of polyethylene glycol (PEG) induced stress on early seedling parameters of tomato parents and hybrids

Sl. No.	Characters		Range	Mean	Change over control (%)
1	Germination (%)	T_0	71.96 - 88.3	79.61	-
		T_1	69.52 - 87.49	78.17	-1.81
		T_2	55.06 - 78.12	67.19	-15.60
2	Root length (cm)	T_0	6.27 - 9.37	7.72	-
		T_1	6.25 - 9.55	7.80	1.04
		T_2	6.43 - 10.65	8.47	9.71
3	Shoot length (cm)	T_0	6.51 - 10.29	8.65	-
		T_1	6.42 - 9.70	8.02	-7.28
		T_2	6.42 - 8.89	7.50	-13.29
4	Root to shoot ratio	T_0	0.71 - 1.10	0.90	-
		T_1	0.78 - 1.17	0.98	8.89
		T_2	0.84 - 1.43	1.13	25.56
5	Seedling vigour index	T_0	10.76 - 16.58	13.05	-
		T_1	10.36 - 15.21	12.38	-5.13
		T_2	7.90 - 14.24	10.76	-17.55

T_0: Control T_1: 8 % PEG concentration T_2: 16 % PEG concentration.


Germination percentage (%)
100
90
80
70
60
50
40
30
20
10
0
Arka Meghali
EC-634394
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
Arka Meghali × EC-634394
Arka Saurabh × EC-638519
Control
8 % PEG
16 % PEG


Root length (cm)
12
10
8
6
4
2
0
Arka Meghali
EC-634394
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
Arka Meghali × EC-634394
Arka Saurabh × EC-638519
Control
8 % PEG
16 % PEG


Shoot length (cm)
12
10
8
6
4
2
0
Arka Meghali
EC-634394
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
Arka Meghali × EC-634394
Arka Saurabh × EC-638519
Control
8 % PEG
16 % PEG

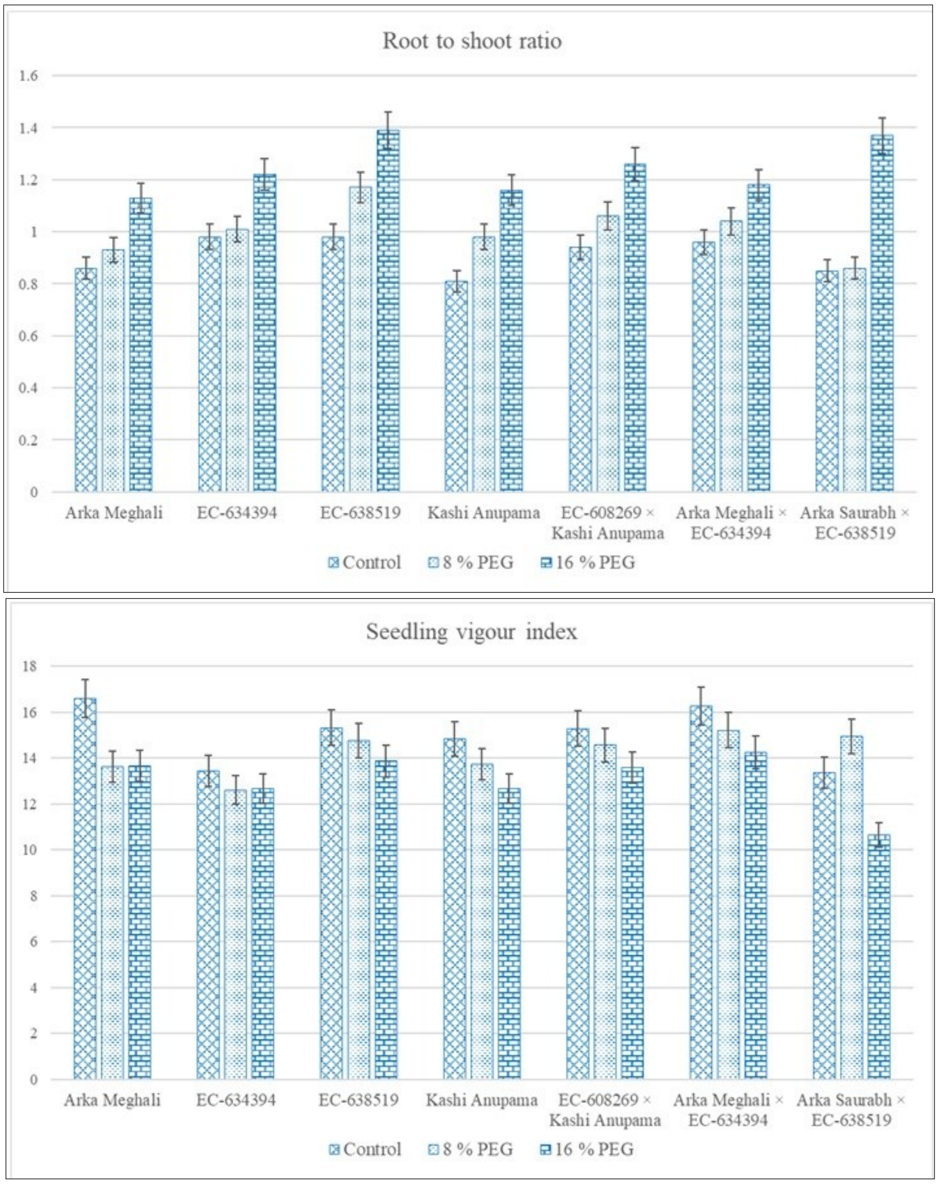


Fig. 1. *Per se* performance of selected tomato hybrids and parents for early seedling parameters under polyethylene glycol induced moisture stress.

percentage was drastically reduced to 75.59 % in EC-638519 and 77.56 % in Kashi Anupama, indicating sensitivity at higher stress levels. Similarly, among the hybrids, the cross Arka Meghali×EC-634394 showed less variation in germination percentage between control (88.30 %) and 8 % PEG concentra-tion (86.44 %) but drastically reduced at 16 % PEG (77.88 %). A sharp decline in germination rate under PEG induced stress in other hybrids and parents, confirmed their susceptibility and revealed that the germination rate is highly influenced by a genotype's capacity to absorb water under stress. The reduced germination rate was attributed to decreased water potential with ensuing low hydraulic conductivity under PEG stress. This makes the water unavailable to seeds, thereby affecting the imbibition process which is fundamental for germination (29). Reduced hydrolysis of seed reserves by PEG was also implicated (30).

Root and shoot length (cm)

Root length, another important parameter manifested against drought stress showed a significant increase in the average root length under 8 % and 16 % PEG concentrations (1.04 % and 9.71 % increase over control, respectively) (31). This demonstrated the possible drought avoidance mechanisms through deeper or more extensive rooting systems (32). Root length of parents Arka Meghali, EC-634394, EC-638519 and Kashi Anupama was consistent across control and 8 % PEG concentration but increased significantly at 16 % PEG. Contrastingly, shoot length was decreased with increasing PEG concentration (7.28 % and 13.29 % reduction under T_1 and T_2 compared to T_0). Mean shoot length was drastically decreased under 16 % PEG stress.

Root to shoot ratio

Lower root to shoot ratio under control (0.90) as compared to 8 % PEG (0.98) and 16 % PEG (1.13) was observed. Higher root to shoot ratios are associated with drought tolerance and are critical for survival in resource limited environments (11). Resource partitioning under stress tends to favour roots and facilitating water acquisition. Under 8 % and 16 % PEG treatment, the parental lines, EC-634394 (1.01 and 1.22, respectively) and EC-638519 (1.17 and 1.39, respectively) exhibited more than one root to shoot ratio and Kashi Anupama (1.16) and Arka Meghali (1.13) under 16 % PEG. Further, among the crosses, the combination of EC-608269 × Kashi Anupama showed root to shoot ratios of 1.06 and 1.26 under 8 % and 16 % PEG stress, respectively and the cross Arka Saurabh × EC-638519 (1.37) under the 16 % PEG treatment. The enhanced root to shoot ratio in these tolerant parents and crosses indicated a strategic shift in resource allocation to root systems for improved water uptake (33). Higher RS ratios are associated with drought tolerance and are critical for survival in resource limited environments.

Seedling vigour index (SVI)

The seedling vigour index measures the capacity of seedlings to withstand challenging environmental conditions, such as drought stress and is a useful index for screening seed vigour and potential drought tolerance. The lower SVI observed under 8 % PEG (12.38) and 16 % PEG (10.76) than in control (13.05) was due to its direct association with seedling length and germination which were significantly affected owing to low moisture availability under PEG stress (11). The parents, EC-634394 (13.43, 12.61 and 12.67, respectively), EC-638519 (15.32, 14.76 and 13.87, respectively), Kashi Anupama (14.83, 13.73 and 12.66) and Arka Meghali (16.58, 13.61 and 13.66) and the crosses Arka Meghali×EC-634394 (16.26, 15.21 and 14.24) and EC-608269×Kashi Anupama (15.28, 14.56 and 13.58) exhibited stable SVI, indicating better establishment potential under moisture stress.

The poor germination per cent, seedling length, seedling biomass and vigour index under moisture stress might be attributed to decrease in water uptake by the seeds as a result of low water potential of the germination medium, improper activation of enzymes (34), hindrance to the movement of inorganic nutrients to developing tissues, interruption of nitrogen metabolism (35), imbalance of plant growth regulators levels (36) and decrease in hydrolysis and utilization of food reserves. The parents EC-634394, EC-638519, Kashi Anupama and Arka Meghali, as well as the crosses Arka Saurabh×EC-638519, Arka Meghali×EC-634394 and EC-608269×Kashi Anupama exhibited better adaptability in terms of early seedling parameters when subjected to PEG treatment, indicating their potential as drought-tolerant varieties and hybrids. However, it should be noted that not all tomato lines maintained the same level of drought stress tolerance during later vegetative or reproductive growth stages. Therefore, it is important to further screen at the field level to determine their performance under field moisture.

Screening in greenhouse condition under different moisture stress regimes

Tested genotypes including tomato parents and hybrids varied significantly across different moisture stress regimes (T_0=control; T_1=10 days irrigation interval; T_2=10 days irrigation interval) for all the studied traits indicating their differential response to varied levels of moisture stress (Table 6). Reduced irrigation water led to a significant reduction in plant height, total dry matter, leaf area and yield and significant increase in root length and proline. However, the differential response among the parents and hybrids for the studied traits was indicated (Table 7).

Plant height (cm)

Plant height, a crucial determinant of growth was significantly affected with 13.62 % and 28.16 % reduction against control (87.99 cm) under enhanced stress conditions, i.e., T_1 (76.06 cm) and T_2 (63.21 cm) respectively (21, 37). Decline in the meristematic activity of cells due to low relative moisture content and turgor loss as well as the reduced photosynthate allocation to aerial parts significantly affected shoot elongation leading to slower growth rate under enhanced stresses in all the test genotypes (38).

Leaf area (cm^2)

Another stress implicated parameter, leaf area development was very sensitive to water deficit. Leaf area in drought stress-imposed plants was significantly lower (1652.45 cm^2 and 1446.53 cm^2, respectively) than well-irrigated plants (1807.00 cm^2) under T_1 and T_2,

Table 6. Analysis of variance for yield and drought implicated parameters under greenhouse induced moisture stress regimes among tomato parents and hybrids

Source of variation	DF	Plant height (cm)	Root length (cm)	Total dry matter (g)	Leaf area (cm^2)	Yield per plant (kg)	Proline (μg/g)
Replication	1	6.86*	17.45	69.05*	62.24	0.01	20.57
Test genotypes (V)	43	28.47**	138.93**	255.91**	231.76**	2.02**	266.61**
Drought treatment (T)	2	1368.13**	644.46**	58.71**	2142.10**	174.85**	17140.48**
Interaction V × T	86	2.62**	7.08	6.63	12.78	0.28	9.62**
Error	131	1.03	7.02	10.29	16	0.08	5.75

* and ** indicate significance of valvues at *p*=0.05 and *p*=0.01, respectively. Test genotypes included parental lines and generated hybrids of tomato.

Table 7. Mean performance of tomato parents and hybrids for yield and drought implicated parameters across different moisture stress regimes

Sl. No.	Characters		Range	Mean	Change over control (%)
1	Plant height (cm)	T_0	74.09 - 109.22	87.99	-
		T_1	61.51 - 88.50	76.01	-13.62 %
		T_2	46.83 - 76.74	63.21	-28.16 %
2	Root length (cm)	T_0	24.83 - 39.09	31.95	-
		T_1	24.55 - 45.92	34.92	9.30 %
		T_2	28.51 - 53.21	37.43	17.15 %
3	Total dry matter (gm)	T_0	42.03 - 62.98	52.81	-
		T_1	36.84 - 59.76	49.10	-7.03 %
		T_2	32.20 - 56.44	44.29	-16.13 %
4	Leaf area (cm^2)	T_0	1375.42 - 2251.70	1807.00	-
		T_1	1301.98 - 1989.76	1652.45	-8.55 %
		T_2	1054.68 - 1895.11	1446.53	-19.95 %
5	Yield per plant (kg)	T_0	1.32 - 2.24	1.75	-
		T_1	0.71 - 1.72	1.28	-26.86 %
		T_2	0.45 - 1.24	0.86	-50.86 %
6	Proline (μg/g)	T_0	173.10 - 253.69	205.62	-
		T_1	198.15 - 293.63	239.71	16.58 %
		T_2	236.55 - 357.76	293.38	42.68 %

T0 : control T1 : 10 days irrigation interval T2 : 20 days irrigation interval.

indicating a decrease of 8.55 % and 19.95 % respectively with increasing moisture stress (39). This might be an adoptive mechanism under drought for survival, by reducing transpiration rate (40).

Total dry matter (gm)

Total dry matter production was also reduced considerably under induced moisture stress, with a decrease of 7.03 % and 16.13 % over control (52.81 g) under T_1 (49.10 g) and T_2 (44.29 g), respectively, which was attributed to limited crop growth and leaf area, consequently reduced net photosynthesis (17, 39).

Root length (cm)

Roots are the lifeline of plants playing a critical role in absorption of water and minerals thereby contributing to the growth and development of plants (39). In the study, we observed a significant increase in root length of 9.30 % and 17.15 % under T_1 (34.92 cm) and T_2 (37.43 cm), respectively, as compared to normal irrigation schedule (31.95 cm). This increase was attributed to the continuous elongation of root cells as a survival mechanism employed by plants to develop roots faster than shoots under moisture stress conditions. This mechanism involves the translocation of more assimilates to the root and increased accumulation for the maintenance of a lower water potential than that of the soil water potential, so that the roots urge to search for water from deeper layers (41). Our findings are consistent with previous studies (38, 42) and an increase in root length and volume under moisture stress conditions has also been reported (43).

Yield per plant (kg)

Moisture stress critically affects the reproduction process by accelerating the phenological development and life cycle to escape the drought stress. As reported earlier, yield per plant decreased significantly under T_1 (1.28 kg) and T_2 (0.86 kg) stress regime showing a decline of 26.86 % and 50.86 %, respectively when compared with normal irrigation (1.75 kg), which is in consistent with earlier reports (37, 42, 44, 45). Under moisture stress regimes, flower shedding can negatively impact flower fertility and fruit formation in tomato plants (46). The closure of stomata to prevent water loss during drought stress reduces CO_2 entry into plants, which in turn affects the efficiency and rate of photosynthesis due to the reduced activity of the enzyme RUBISCO (47). This reduced photosynthesis further decreases the availability of assimilates to developing floral organs, leading to flower and bud abscission (13).

Proline (µg/g)

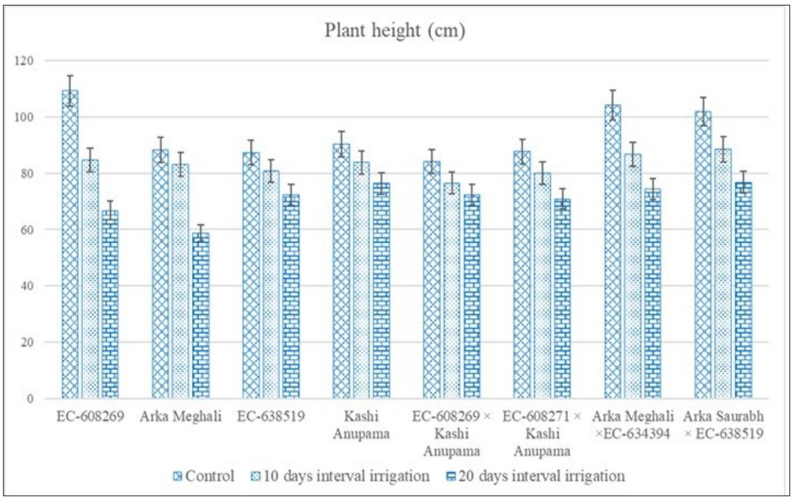
Accumulation of high proline content under moisture stress is implicated in the earlier studies. The findings of our study have also revealed higher proline levels under moisture stress conditions; T_1 (239.71 µg/g) and T_2 (293.38 µg/g) irrigation intervals, with an increase of 16.58 % and 42.68 %, respectively as compared to T_0 (205.62 µg/g). The accumulation of proline in the plant system reduces the plant's water potential relative to that of the soil, which in turn enables the root to absorb water from the soil. A positive correlation between proline accumulation and drought stress tolerance has been reported (38, 48).

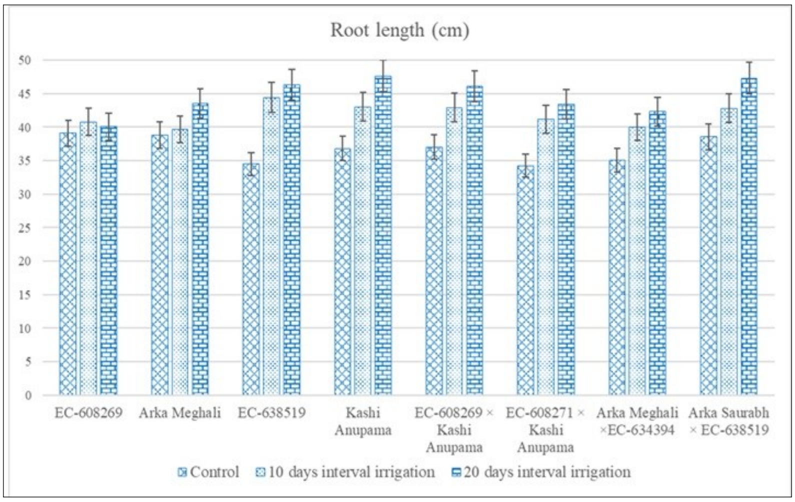
The current study identified promising parents and hybrids based on their consistent performance and minimal reduction under moisture stress conditions (Fig. 2 & Table S2). Parent EC-608269 exhibited better yield under T_0 (2.24 kg) and T_1 (1.41 kg) and revealed good root growth (39.09 cm, 40.76 cm and 40.06 cm), total dry matter (62.59 g, 57.00 g and 50.49 g), leaf area (2251.70 cm^2, 1980.61 cm^2 and 1691.38 cm^2) and proline (228.98 µg/g, 260.80 µg/g and 321.44 µg/g) under T_0, T_1 and T_2 respectively. Following which, the parent Arka Meghali also demonstrated comparatively better yield (1.99 kg, 1.34 kg and 0.89 kg), total dry matter (58.03 g, 57.08 g and 50.07 g) and increasing root length (38.82 cm, 39.71 cm and 43.55 cm) under T_0, T_1 and T_2, respectively. Similarly, EC-638519 and Kashi Anupama exhibited good performance under moisture stress regimes for yield, leaf area, root length and total dry matter as compared with the normal irrigation schedule.

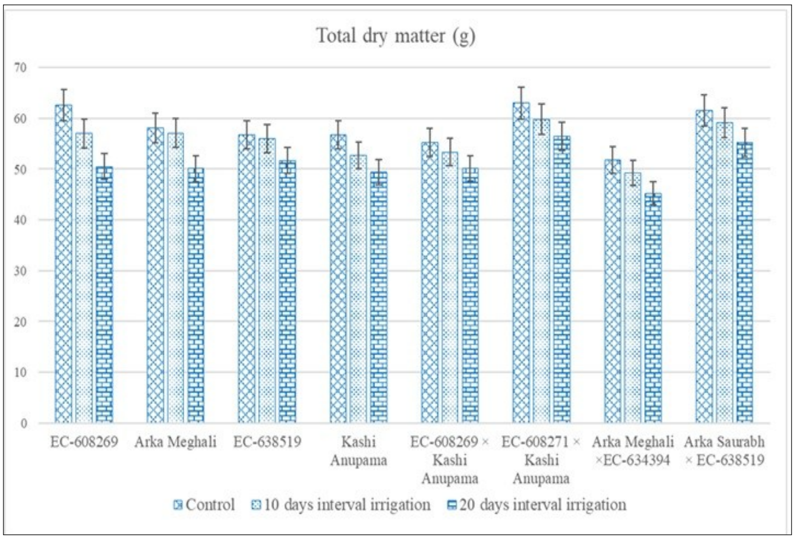
Among the various crosses, the Arka Saurabh × EC-638519 hybrid exhibited high yield (2.01 kg, 1.54 kg and 1.10 kg), plant height (101.84 cm, 88.50 cm and 76.74 cm), root length (38.57 cm, 42.81 cm and 47.28 cm), total dry matter (61.54 g, 59.13 g and 55.29 g) and leaf area (2173.13 cm^2, 1946.23 cm^2 and 1815.37 cm^2) under T_0 as well as T_1 and T_2 treatments. On the other hand, the EC-608269 × Kashi Anupama hybrid displayed good yield levels (1.71 kg and 1.13 kg, respectively) and proline content (258.06 µg/g and 331.61 µg/g, respectively) under moisture stress conditions, T_1 and T_2. This cross also displayed high leaf area (1929.88 cm^2 and 1799.22 cm^2) and root length (42.93 cm and 46.07 cm) under moisture stress conditions when compared with the normal irrigation schedule (leaf area of 2192.77 cm^2 and root length of 37.03 cm). Another hybrid, EC-608271 × Kashi Anupama cross maintained total dry matter under $T_1$and T_2 (59.76 g and 56.44 g, respectively) as against normal irrigation (62.98 g) and showed enhanced root length under T_1 (41.18 cm) and T_2 (43.44 cm) irrigation intervals. It is well established that the drought has a negative impact on many physiological processes. Stomatal closure under water stress affects leaf growth and net photosynthesis, production and translocation of assimilates (49). These results emphasise the significance of genotype specific screening under varied moisture stress intensities to identify stress resilient cultivars. The resilient parents and hybrids that performed consistently must be validated under realistic field stress conditions where interactions with soil and microclimate influence the stress responses.

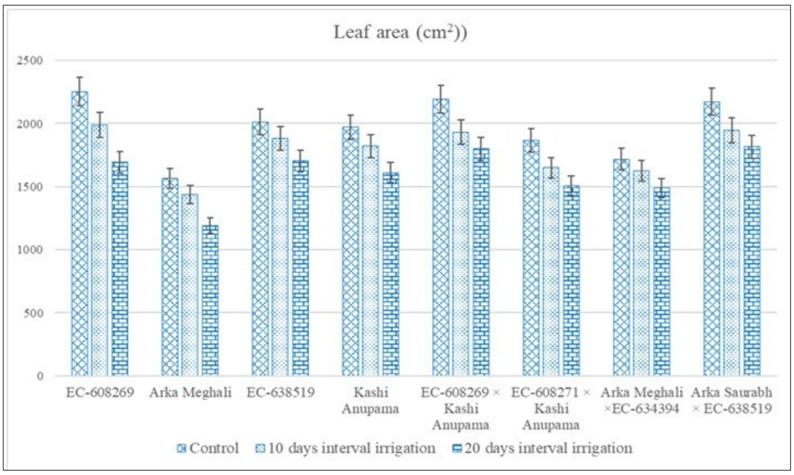
SSR genotyping of test genotypes (tomato parents and hybrids)

The SSR genotyping of 13 parents and 30 tomato hybrids was performed using PCR amplification of 11 SSR primers (24, 25). Among the selected 11 drought specific gene based SSR primers, 6 did not show any amplification pattern in any of the lines, testers and hybrids. Other 5 primers viz., SAL-17, SAL-18, SAL-19, SAL-23 and SAL -25 resulted in monomorphic bands, indicating the lack of collinearity between the primers and moisture stress tolerance. These SSR primers, despite their co-dominant and reproducible nature, were not effective in providing informative data for differentiating drought tolerant and susceptible genotypes in the evaluated set. This necessitates fine mapping of quantitative trait loci (QTLs) implicated in drought tolerance and development of additional drought-specific functional markers for effective selection in breeding. Additionally, it is also crucial to analyse the transcriptome of tomato for the differential expression of drought-specific genes through quantitative real-time polymerase chain


Plant height (cm)
120
100
80
60
40
20
0
EC-608269
Arka Meghali
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
EC-608271 × Kashi Anupama
Arka Meghali ×EC-634394
Arka Saurabh × EC-638519
Control
10 days interval irrigation
20 days interval irrigation


Root length (cm)
50
45
40
35
30
25
20
15
10
5
0
EC-608269
Arka Meghali
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
EC-608271 × Kashi Anupama
Arka Meghali ×EC-634394
Arka Saurabh × EC-638519
Control
10 days interval irrigation
20 days interval irrigation


Total dry matter (g)
70
60
50
40
30
20
10
0
EC-608269
Arka Meghali
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
EC-608271 × Kashi Anupama
Arka Meghali ×EC-634394
Arka Saurabh × EC-638519
Control
10 days interval irrigation
20 days interval irrigation


Leaf area (cm²))
2500
2000
1500
1000
500
0
EC-608269
Arka Meghali
EC-638519
Kashi Anupama
EC-608269 × Kashi Anupama
EC-608271 × Kashi Anupama
Arka Meghali ×EC-634394
Arka Saurabh × EC-638519
Control
10 days interval irrigation
20 days interval irrigation

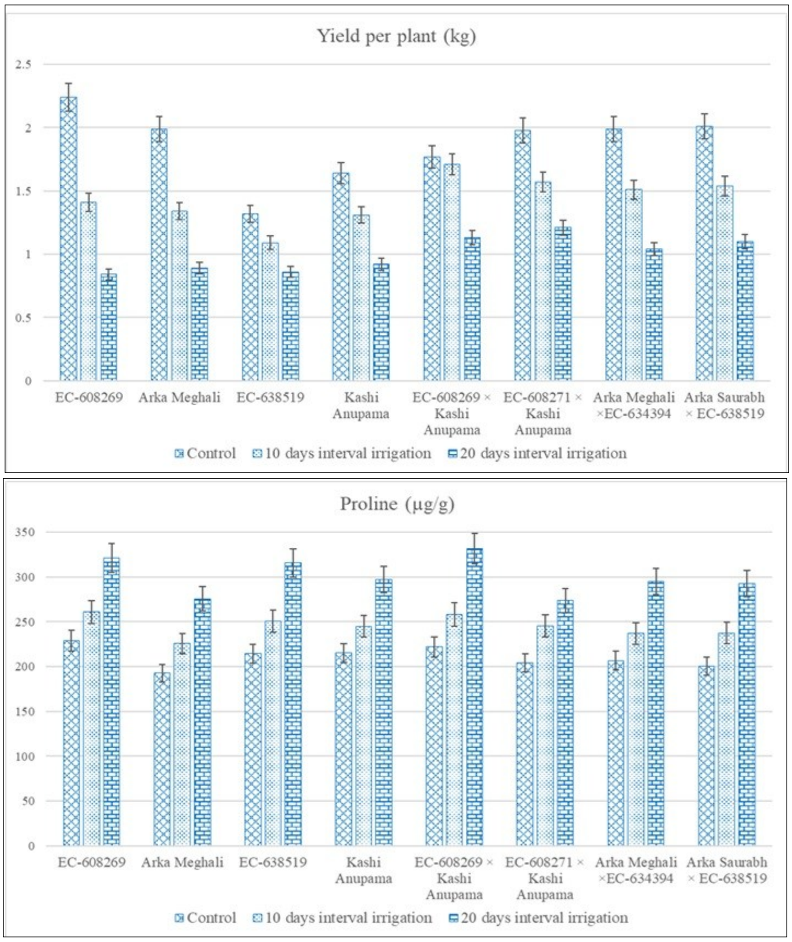


Fig. 2. *Per se* performance of selected tomato parents and hybrids for yield and drought implicated parameters across different moisture stress regimes.

reaction (qRT-PCR) studies to gain a better understanding of the genetic response to drought stress. These approaches will help to identify and differentiate between susceptible and tolerant genotypes, providing valuable insights for further research in drought stress tolerance breeding.

Conclusion

Drought tolerance in tomato is regulated by integrated and stage-independent adaptive traits rather than by single physiological responses. This study highlighted the differential response of tomato hybrids and parents to PEG induced stress as well is induced moisture stress under greenhouse conditions. The stable performance of specific parental lines and hybrids across varying moisture stress conditions confirmed that the drought resilience could be effectively improved through strategic parental selection and hybridization, even within the limited genetic diversity of cultivated tomato. The combined contribution of root system adaptation, sustained biomass partitioning and osmotic adjustment under water deficit identified as key drought associated traits as dependable indicators for selection in climate resilient breeding programs.

The identified genotypes offer a scalable and economically feasible option for stabilizing tomato productivity under water limited conditions, particularly in rainfed and marginal agro ecosystems. Their utilization can reduce irrigation requirements, minimize yield risk and improve resource use efficiency, supporting environmentally sustainable and climate-smart horticulture. Furthermore, the absence of detectable polymorphism with the SSR markers employed emphasizes the need to strengthen future breeding pipelines through functional genomics, high resolution molecular tools and transcript-based approaches to identify the drought tolerance implicated genes leading to accelerated genetic gains in tomato.

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Authors' contributions

LTN and KGU participated in the conceptualization of the research work, design of experiments, execution of field and laboratory experiments and data collection. KGU, LTN and MBN carried out the molecular genetic studies. DM, SGG and VDG conceived the study and participated in its design and manuscript preparation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Petro TM. Flavor of tomato and tomato products. Food Rev Int. 1986;2(3):309–51.https://doi.org/10.1080/87559128609540802
2. Chaudhary P, Sharma A, Singh B, Nagpal AK. Bioactivities of phytochemicals present in tomato. J Food Sci Technol. 2018;55:2833–49. https://doi.org/10.1007/s13197-018-3221-z
3. Seleiman MF, Al Suhaibani N, Ali N, Akmal M, Alotaibi M, Refay Y, et al. Drought stress impacts on plants and different approaches to alleviate its adverse effects. Plants. 2021;10(2):256-59. https://doi.org/10.3390/plants10020259
4. Iqbal MS, Singh AK, Ansari MI. Effect of drought stress on crop production. In: Rakshit A, Singh H, Singh A, Singh U, Fraceto L, editors. New frontiers in stress management for durable agriculture. Singapore: Springer; 2020. p. 35–47. https://doi.org/10.1007/978-981-15-1322-0_3
5. Naumann G, Alfieri L, Wyser K, Mentaschi L, Betts RA, Carrao H. Global changes in drought conditions under different levels of warming. Geophys Res Lett. 2018;45(7):3285–96. https://doi.org/10.1002/2017GL076521
6. Kumar L, Chhogyel N, Gopalakrishnan T, Hasan MK, Jayasinghe SL, Kariyawasam CS, et al. Climate change and future of agri-food production. In: Rajeev B, editor. Future foods: global trends, opportunities and sustainability challenges. Academic Press; 2022. p. 49–79. https://doi.org/10.1016/B978-0-323-91001-9.00009-8
7. Pervez MA, Ayub CM, Khan HA, Shahid MA, Ashraf I. Effect of drought stress on growth, yield and seed quality of tomato (*Lycopersicon esculentum* L.). Pak J Agr Sci. 2009;46(3):174–78.
8. Barrero LS, Tanksley SD. Evaluating the genetic basis of multiple-locule fruit in a broad cross section of tomato cultivars. Theor Appl Genet. 2004;109:669–79. https://doi.org/10.1007/s00122-004-1676-y
9. Maxim A, Sima R, Şandor M. Aspects regarding seed quality from local varieties of vegetables collected from different areas of Romania. Acta Univ Cibiniensis Agric Sci. 2008;1(1):27579.
10. Strunecky O, Shreedhar S, Kolar L, Marouskova A. Changes in soil water retention following biochar amendment. Energy Sources Part A. 2025;47(1):7145—52. https://doi.org/10.1080/15567036.2021.1916652
11. Kumar AP, Reddy NN, Lakshmi JN. PEG induced screening for drought tolerance in tomato genotypes. Int J Curr Microbiol App Sci. 2017;6(7):168–81. https://doi.org/10.20546/ijcmas.2017.607.020
12. Silva PO, Medina EF, Barros RS, Ribeiro DM. Germination of salt-stressed seeds as related to the ethylene biosynthesis ability in three Stylosanthes species. J Plant Physiol. 2014;171(1):14–22. https://doi.org/10.1016/j.jplph.2013.09.004
13. Sivakumar R, Srividhya S. Impact of drought on flowering, yield and quality parameters in diverse genotypes of tomato (*Solanum lycopersicum* L.). Adv Hort Sci. 2016;30(1):3–11.
14. Szira F, Balint AF, Borner A, Galiba G. Evaluation of drought-related traits and screening methods at different developmental stages in spring barley. J Agron Crop Sci. 2008;194(5):334–42. https://doi.org/10.1111/j.1439-037X.2008.00330.x
15. Almaghrabi OA. Impact of drought stress on germination and seedling growth parameters of some wheat cultivars. Life Sci J. 2012;9(1):590–98.
16. Kalloo G. Breeding for environmental stress resistance in tomato. In: Kalloo G, editor. Genetic improvement of tomato. Berlin: Springer; 1991. p. 153–65. https://doi.org/10.1007/978-3-642-84275-7_12
17. Brdar JM, Zdravkovic J. Germination of tomatoes under PEG induced drought stress. Field Veg Crops Res. 2015;52(3):108–13. https://doi.org/10.5937/ratpov52-8324
18. Ilyas M, Ahmad M, Hussain Z, Saeed A, Begum F, Khan MI, et al. Interactive effect of calcium and magnesium on the growth and yield of tomato (*Lycopersicon esculentum* L.). Pure Appl Biol. 2021;5(4):876–2. https://doi.org/10.19045/bspab.2016.50110
19. Foolad MR. Genome mapping and molecular breeding of tomato. Int J Plant Genomics. 2007;1:1–52. https://doi.org/10.1155/2007/64358
20. Kaur S, Panesar PS, Bera MB, Kaur V. Simple sequence repeats markers in genetic divergence, marker-assisted selection of rice cultivars. Crit Rev Food Sci Nutr. 2015;55(1):41–49. https://doi.org/10.1080/10408398.2011.646363
21. Prakash G. Physiological and genetical investigation for drought tolerance in tomato (*Solanum lycopersicum* L.) genotypes. Karnataka (IN): University of Horticultural Sciences; 2016.
22. Abdul BAA Anderson JD. Vigour determination in soybean seed by multiple criteria. Crop Sci. 1973;13(6):630–33. https://doi.org/10.2135/cropsci1973.0011183X001300060013x
23. Bates LS, Waldren RA, Teare ID. Rapid determination of free proline for water-stress studies. Plant Soil. 1973;39:205–07. https://doi.org/10.1007/BF00018060
24. Chen G, Wang H, Gai JY, Zhu YL, Yang LF, Liu QQ, et al. Construction and characterization of a full-length cDNA library, identification of genes involved in salinity stress in wild eggplant (*Solanum torvum*). Hortic Environ Biotechnol. 2012;53(2):158–16. https://doi.org/10.1007/s13580-012-0089-0
25. Rakshith M. Genetic variability for salt tolerance and expression analysis of salt responsive candidate genes. Karnataka (IN): University of Agricultural and Horticultural Sciences; 2020.
26. Gawel NJ, Jarret RL. A modified CTAB DNA extraction procedure for Musa and Ipomoea. Plant Mol Biol Rep. 1991;9:262–66. https://doi.org/10.1007/BF02672076
27. Dietz KJ, Zorb C, Geilfus CM. Drought and crop yield. Plant Biol. 2021;23(6):881–93. https://doi.org/10.1111/plb.13304
28. Turk MA, Rahman A, Tawaha MLKD, Lee KD. Seed germination and seedling growth of three lentil cultivars under moisture stress. Asian J Plant Sci. 2004;3(3):394–97. https://doi.org/10.3923/ajps.2004.394.397
29. Pirasteh AH, Ranjbar G, Pakniyat H, Emam Y. Physiological mechanisms of salt stress tolerance in plants. In: Mohamed MA, Parvaiz A, editors. Plant-environment interaction: responses and approaches to mitigate stress. 2016. p. 141–60. https://doi.org/10.1002/9781119081005.ch8
30. Aazami MA, Torabi M, Jalili E. In vitro response of promising tomato genotypes for tolerance to osmotic stress. Afr J Biotechnol. 2010;9(26):4014–17.
31. Kim YJ, Yun SJ, Park HK, Park MS. A simple method of seedling screening for drought tolerance in soybean. Korean J Crop Sci. 2001;46(4):284–88.
32. George S, Jatoi SA, Siddiqui SU. Genotypic differences against PEG simulated drought stress in tomato. Pak J Bot. 2013;45(5):1551–56.
33. Wilson JB. A review of evidence on the control of shoot:root ratio in relation to models. Ann Bot. 1988;61(4):433–49. https://doi.org/10.1093/oxfordjournals.aob.a087575
34. Ashraf M. Salt tolerance of cotton: some new advances. Crit Rev Plant Sci. 2002;21(1):1–30. https://doi.org/10.1080/0735-260291044160
35. Dell AA, Spada P. The effect of salinity stress upon protein synthesis of germinating wheat embryos. Ann Bot. 1993;72(2):97–101. https://doi.org/10.1006/anbo.1993.1085
36. Khan MA, Rizvi Y. Effect of salinity, temperature and growth regulators on the germination and early seedling growth of Atriplex griffithii var. stocksii. Can J Bot. 1994;72(4):475–79. https://doi.org/10.1139/b94-063
37. Karthik GU, Lakshmidevamma TN, Naika MB, Gasti VD, Masuti D, Gollagi SG, et al. Estimates of genetic variability, association studies and per se performance of tomato genotypes for growth and yield parameters under drought stress conditions. Int J Environ Clim Change. 2024;14(3):709–20. https://doi.org/10.9734/ijecc/2024/v14i34079

38. Parveen A, Rai GK, Mushtaq M, Singh M, Rai PK, Rai SK, et al. Deciphering the morphological, physiological and biochemical mechanism associated with drought stress tolerance in tomato genotypes. Int J Curr Microbiol App Sci. 2019;8(5):227–55. https://doi.org/10.20546/ijcmas.2019.805.028

39. Sivakumar R, Nandhitha GK, Boominathan P. Impact of drought on growth characters and yield of contrasting tomato genotypes. Madras Agric J. 2016;103(1-3):78–82. https://doi.org/10.29321/MAJ.10.001446

40. Tahi H, Wahbi S, El MC, Aganchich A, Serraj R. Changes in antioxidant activities and phenol content in tomato plants subjected to partial root drying and regulated deficit irrigation. Plant Biosyst. 2008;142:550–62. https://doi.org/10.1080/11263500802410900

41. Ilakiya T, Premalakshmi V, Arumugam T, Sivakumar T. Screening of tomato (*Solanum lycopersicum* L.) hybrids with their parents for various growth related parameters under drought stress. J Pharmacogn Phytochem. 2019;8(3):3845–48.

42. Senthilkumar M, Sadashiva AT, Laxmanan V. Impact of water stress on root architecture in tomato (*Solanum lycopersicum* Mill). Int J Curr Microbiol App Sci. 2017;6(7):2095–103. https://doi.org/10.20546/ijcmas.2017.607.247

43. Vijaylaxmi SK, Rathod V, Evoor S, Kantharaju V, Tatagar MH, Laksmidevamma TN. Correlation and path-coefficient analysis in cherry tomato (*Solanum lycopersicum* var. *cerasiforme*). J Pharmacogn Phytochem. 2021;10(2):1136–40.

44. Akter R, Haq ME, Begum B, Zeba N. Performance of tomato (*Solanum lycopersicum* L.) genotypes based on agro-morphogenic traits under drought condition. Asian J Biotechnol Genet Eng. 2019;2(4):1–10.

45. Cui J, Shao G, Lu J, Keabetswe L, Hoogenboom G. Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. Sci Agric. 2019;77(2):221–29. https://doi.org/10.1590/1678-992x-2018-0390

46. Grozeva S, Ganeva D, Pevicharova G. Screening of tomato genotypes for tolerance of reduced irrigation. J Agric Biol Environ Sci. 2019;15:19–21.

47. Lata C, Muthamilarasan M, Prasad M. Drought stress responses and signal transduction in plants. In: Pandey G, editor. Elucidation of abiotic stress signaling in plants. New York: Springer; 2015. p. 195–225. https://doi.org/10.1007/978-1-4939-2540-7_7

48. Patane C, Scordia D, Testa G, Cosentino SL. Physiological screening for drought tolerance in Mediterranean long-storage tomato. Plant Sci. 2016;249:25–34. https://doi.org/10.1016/j.plantsci.2016.05.006

49. Chaves MM, Flexas J, Pinheiro C. Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Ann Bot. 2009;103(4):551–60. https://doi.org/10.1093/aob/mcn125

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