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RESEARCH ARTICLE

Integrated laboratory and greenhouse assessment of tomato genotypes for drought tolerance in Western Himalayas region

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Abstract

The present studies were planned to understand the response of a diverse set of ten tomato genotypes to drought during the seedling stage, which is important for stand establishment and crop growth. Under laboratory condition, the genotypes were evaluated under different osmotic concentration of polyethylene glycol (PEG-6000) at 15 % and 20 % and control condition for 14 days. Under greenhouse condition, test genotypes were evaluated under polyhouse condition with different regulated deficit irrigation (RDI), 100 %, 75 % and 50 % stress of evapotranspiration coefficient (Etc). Moisture stress was induced after 15 days of transplanting by estimating Etc value using pan evaporimeter. In first experiment genotypes EC-620434, Best of All, Marglobe and Arka Vikas were found best under drought stress as there was lesser reduction in germination percentage and in growth parameters such as root and shoot length as compared to other genotypes studied whereas Best of All, Marglobe, Arka Vikas and LA-3846 were identified as the most tolerant to moisture stress as there was lesser reduction in leaf area, root biomass, root and shoot length compared to other genotypes under study in second experiment. Therefore, based on the influence of both the experiments it was found that the genotypes Best of ALL, Marglobe and Arka Vikas should be cultivated in areas prone to drought stress for sustainable tomato production in the mid-hill regions in the Western Himalayas.

Keywords: drought stress; moisture stress; PEG:6000; RDI; Western Himalayas

Introduction

Tomato (*Solanum lycopersicum* L.), a member of family Solanaceae, is one of the most important vegetable crops grown throughout the world. China is the major producer of tomato, followed by India, USA, Turkey and Egypt. In India, tomato is grown in about 0.84 million ha, with annual production of 20.33 million tonnes (1). Tomatoes are consumed as fresh and in processed form. In India, it is one of the most important ingredients for vegetarian and non-vegetarian food preparations. It is a rich source of vitamins and minerals. Tomato has emerged as one of the most important cash crops for the subsistence farmers in the mid-hill regions of Himachal Pradesh in the western Himalayas, covering an area over 14000 ha, with an annual production of 577000 metric tonnes and productivity of 24.26 tonnes ha^{-1} (1). Drought is one of the most important abiotic stresses reducing tomato crop growth and yield, as it resulted in up to 70 % reduction in crop yield in the mid-hill regions in the Western Himalayas. Identification and development of drought stress tolerant cultivars is one important strategy to minimize losses due to drought stress (2).

Several methods have been employed to identify drought tolerant genotypes of tomato (3). PEG compounds have frequently been used to induce osmotic stress *in vitro* for plants to maintain uniform water potential to identify drought tolerant germplasm (4, 5). PEG induced osmotic stress decreases cell water potential (6). Increase in PEG concentration results in a decrease in seed germination and seedling vigour (7). *In vitro* screening using PEG is one of the dependable approaches for the selection of desirable genotypes for cultivation under drought stress. In areas experiencing water shortage and long drought spells, conventional irrigation is a common practice to mitigate water stress. RDI has been employed to minimize adverse effects of drought on crop yield. However, a significant reduction in dry mass yield in tomato using RDI under greenhouse conditions was observed (8). Therefore, the present studies were undertaken to identify tomato genotypes with tolerance to drought using by using different PEG-6000 concentrations and different levels of moisture stress based on Etc.

Materials and Methods

The present studies were carried out at the experimental research farm of Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni Solan, Himachal Pradesh, in the mid-hill region in western Himalayas, India. A set of 10 diverse genotypes were evaluated for drought tolerance under laboratory and field conditions. The test material comprised of two germplasm lines (EC 620434 and EC 620383), 6 improved cultivars (Best of All, Marglobe, Sioux, LA 3846, 97/784 and Punjab Tropic) and two commercial cultivars grown in this region ((Arka Vikas and KS 7). List of tomato genotypes studied in this experiment (Table 1).

Evaluation of tomato germplasm for drought tolerance under *in vitro* conditions

Ten tomato genotypes were screened for drought tolerance by using different concentrations of PEG-6000. The seeds were germinated in Petri dishes and subjected to two concentrations of PEG-6000 (15 % and 20 %), which resulted in water potential equivalent to -0.295 Mpa and -0.491 Mpa, respectively. 100 seeds were placed on a moistened filter paper in each Petridish and were kept in the seed germinator. Distilled water was used for maintaining the untreated control. There were three treatments (control, -0.295 Mpa and -0.491 Mpa) and replicated thrice in a completely randomized factorial design (CRDF). Data were recorded on seed germination percentage, rate of seed germination rate, root length, shoot length, seedling biomass and vigour and vitality indices.

Response of tomato genotypes to drought stress under polyhouse conditions

Tomato seedling nursery was raised in plastic trays using standard media (loamy soil, cocoa-peat and vermiculite in the ratio of 1:1:1). The seedlings were transplanted 25 days after germination in polybags under polyhouse conditions in Randomized Block Design (RBD). The mixture was prepared by using loamy soil, cocoa-peat and vermiculite in the ratio of 1:1:1. The test genotypes were subjected to different levels of moisture stress (100 %, 75 %, 50 % of Etc) and replicated thrice. Drought stress was imposed 15 days after transplanting based on Etc value. Ten seedlings per replication were taken and data were recorded on taproot length, shoot length, number of primary branches, leaf area and root biomass. Etc values were calculated by using the formula (9).

$Etc = K_C \times Et_o$

Where;

K_C is crop coefficient

Et_o= is evapotranspiration

Et_o was measured with the help of US Class A open Pan evaporimeter. The evaporimeter was kept in the centre of the greenhouse of 300 sq m area and the amount of evaporation per unit time was 1.75 mm/day.

Value of crop coefficient in case of tomato under protected conditions for initial growth stage was:

$K_C = 0.6$

Therefore, $Etc = K_C \times Et_o$

$Etc = 0.6 \times 1.75$

$Etc = 1.05$

Statistical analysis

The data generated from these investigations were computed, tabulated and analysed by applying Completely Randomized Design (CRD) factorial. The level of significance was tested for different variables at 5 % (10).

Results and Discussion

Response of tomato germplasm for drought tolerance under *in vitro* conditions

For germination percentage, the genotype Best of All exhibited maximum germination (77.56 %). Minimum seed germination was recorded in 97/784 (52.67 %). However, the interaction effect between the genotypes and moisture stress levels was also significant, maximum germination was observed in Best of All (87.33 %), whereas minimum germination was recorded in KS 7 (70.33 %). At -0.295 Mpa, EC 620434 exhibited maximum seed germination (75.6 %), whereas minimum germination (43.66 %) was observed in genotype 97/784. At -0.491 Mpa stress level, Best of All and Marglobe exhibited maximum seed germination (70 %), whereas minimum germination was observed in KS 7 (39.6 %) (Table 2).

For germination rate, genotype EC-620434 exhibited greater germination rate (7.56), followed by Best of All (7.35), while minimum seed germination rate (5.05) was recorded in 97/784 (Table 2), however, the interaction effects between the genotypes and moisture stress levels shows that maximum germination rate (8.10) was observed in EC-620434, whereas minimum germination rate was observed in KS-7 (6.23) under control conditions. At -0.295 Mpa, maximum germination rate was recorded in EC-620434 (7.65) whereas minimum germination rate was observed in genotype 97/784 (4.10). While

Table 1. List of genotypes

Sr. No.	Genotypes	Sources
1.	EC-620434	IIVR,Varanasi
2.	EC-620383	IIVR,Varanasi
3.	Best of All	IARI, Katrain
4.	Marglobe	IARI, Katrain
5.	Sioux	UHF Nauni
6.	LA-3846	TGRC, UC DAVIS, California
7.	97/784	UHF, Nauni, Solan
8.	Punjab Tropic	PAU, Ludhiana
9.	Arka Vikas	IIHR, Banglore
10.	KS-7	CSAUAT, Research station Kalyanpur

Table 2. Effect of osmotic stress on germination percentage and germination rate of tomato genotypes

Genotypes	Germination percentage			Mean (Genotype)	Germination rate			Mean (Genotype)
	Osmotic stress				Osmotic stress			
	Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa	
EC-620434	83.66 (66.67)	75.66 (60.44)	69.66 (56.57)	76.33 (61.23)	8.10	7.65	6.95	7.56
Best of All	87.33 (69.31)	75.33 (60.47)	70.00 (56.92)	77.56 (62.23)	7.53	7.50	7.03	7.35
Marglobe	75.66 (60.45)	70.00 (56.96)	70.00 (57.05)	71.88 (58.15)	7.30	7.16	6.90	7.12
LA-3846	72.33 (58.24)	66.00 (54.37)	63.33 (52.74)	67.22 (55.12)	6.96	6.76	6.30	6.67
Arka Vikas	73.66 (59.10)	72.66 (58.94)	57.00 (49.01)	67.77 (55.68)	7.10	6.93	5.73	6.58
Sioux	71.66 (57.97)	66.33 (54.56)	63.33 (52.72)	67.10 (55.08)	6.90	6.83	6.36	6.70
KS-7	70.33 (56.16)	56.00 (48.49)	39.66 (39.01)	55.33 (47.88)	6.23	5.66	3.90	5.26
Punjab Tropic	84.00 (66.79)	46.66 (43.02)	44.33 (41.72)	58.33 (50.51)	7.76	4.43	4.13	5.44
97/784	71.33 (57.61)	43.66 (41.33)	43.00 (40.94)	52.66 (46.63)	7.03	4.10	4.03	5.05
EC-620383	70.66 (56.94)	54.00 (47.27)	50.00 (44.94)	58.22 (49.71)	6.43	5.23	4.26	5.31
Mean (T)	76.06 (60.92)	62.63 (52.58)	57.03 (49.16)		6.43	6.22	5.16	
$CD_{0.05}$ (G)		4.36				0.18		
$CD_{0.05}$ (T)		2.38				0.10		
$CD_{0.05}$ (G X T)		7.55				0.32		

at -0.491 Mpa, the genotype Best of All (7.03) showed greater germination rate, whereas minimum germination rate was observed in genotype KS-7 (3.90) (Table 2).

For root length, Best of All exhibited significantly longer root length (8.06 cm) whereas the shortest root length (5.29 cm) was recorded in EC-620383 (Table 3). The interaction effects between the genotypes and moisture stress levels were significant. Maximum root length was recorded in Best of All (9.87 cm), whereas KS-7 (6.11 cm) exhibited minimum root length under control conditions. At -0.295 Mpa, maximum and minimum root lengths were recorded in Best of All (9.32 cm) and EC-620383 (4.493 cm), respectively. At -0.491 Mpa, EC-620434 (6.05 cm) exhibited maximum root length and EC-620383 (3.97 cm) exhibited minimum root length (Table 3).

For seedling biomass, maximum seedling biomass was recorded in Marglobe (46.74 mg) whereas minimum seedling biomass was found in EC-620383 (33.70) (Table 3). The interaction between genotypes and different moisture stress levels shows that maximum and minimum seedling biomass was recorded in genotypes Marglobe (61.367 mg) and KS-7 (41.50 mg) respectively under control condition. At -0.295 Mpa, maximum and minimum seedling biomass was observed in genotypes Marglobe (48.60 mg) and EC-620383 (25.433 mg) respectively. While at -0.491 Mpa, genotypes Punjab Tropic (38.06 mg) and EC-620383 (22.433 mg) exhibited maximum and minimum seedling biomass respectively (Table 3).

For vitality index, maximum vitality index was recorded in genotype EC-620434 (75.19) while minimum vitality index was found in genotype KS-7 (50.51). The effect of the interaction between the different concentration of PEG-6000 and genotypes shows that maximum vitality index was observed in EC-620434 (81.191) whereas minimum vitality index was observed in EC-620383 (59.15) under control. At -0.295 Mpa, maximum and minimum vitality index was recorded in Best of All (75.32) and KS-7 (45.957) respectively. While at -0.491 Mpa, EC-620434 (71.44) and KS-7 (45.11) exhibited maximum and minimum vitality index respectively (Table 3).

For shoot length, genotype Arka Vikas recorded significantly higher shoot length (6.43 cm) whereas the shoot length was shortest (4.40 cm) in EC-620434 (Table 4). The interaction effects for shoot length between the genotypes and osmotic stress levels were significant. Maximum root length was observed in LA-3846 (7.7 cm) under controlled conditions. At -0.295 Mpa, maximum and minimum shoot length was recorded in Arka Vikas (6.43 cm) and EC-620434 (3.66 cm) respectively. While at -0.491 Mpa, maximum and minimum shoot length was recorded in Arka Vikas (6.053 cm)

Table 3. Effect of osmotic stress on seeding biomass, root length and vitality index of ten tomato genotypes

Genotypes	Seedling biomass			Mean (Genotype)	Root length			Mean (Genotype)	Vitality index			Mean (Genotype)
	Osmotic stress				Osmotic stress				Osmotic stress			
	Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa	
EC-620434	44.40	45.00	35.23	41.54	9.17	6.80	6.05	7.34	81.19	72.95	71.44	75.19
Best of All	50.40	34.80	33.46	39.55	9.87	9.32	5.01	8.06	80.18	75.32	68.39	74.63
Marglobe	61.36	48.60	30.26	46.74	8.36	7.06	5.24	6.88	78.36	70.01	70.01	72.79
LA-3846	47.16	37.76	33.46	39.46	7.21	6.33	5.99	6.51	73.77	66.61	65.96	68.78
Arka Vikas	37.533	35.13	32.93	35.20	6.46	6.06	5.78	6.10	69.05	62.82	58.97	63.62
Sioux	53.06	39.90	35.83	42.93	7.36	5.88	5.62	6.29	62.49	58.19	55.58	58.75
KS-7	41.50	39.00	33.00	37.83	6.11	5.69	5.29	5.70	60.46	45.95	45.11	50.51
Punjab Tropic	58.33	39.53	38.06	45.31	8.80	5.72	4.53	6.35	73.83	62.16	57.30	64.43
97/784	60.23	37.76	34.90	44.30	8.89	5.82	5.80	6.84	62.76	62.76	61.11	62.21
EC-620383	53.23	25.43	22.43	33.70	7.42	4.49	3.97	5.29	59.15	55.70	55.63	56.83
Mean (T)	50.72	38.29	32.96		7.96	6.32	5.33		70.12	63.25	60.95	
$CD_{0.05}$ (G)		1.04				0.48				1.96		
$CD_{0.05}$ (T)		0.57				0.26				1.02		
$CD_{0.05}$ (G X T)		1.80				0.84				2.34		

and EC-620434 (3.15), genotypes respectively (Table 4).

For seed vigour index I, the genotype Best of All recorded maximum seed vigour index I (10.69) whereas minimum seed vigour index I was found in EC-620383 (5.26). Genotypes EC-620434 and LA-3846 showed lesser decline in seed vigour index-I with increase in osmotic stress. Hence, they were considered tolerant to drought stress (Table 4). The interaction effect between the genotype and osmotic stress was also significant for seed vigour index I. Maximum and minimum seed vigour index I was recorded in Best of All (15.13) and EC-620383 (6.77) respectively under control. At -0.295 Mpa, maximum seed vigour index I was recorded in Best of All (11.06) whereas minimum seed vigour index was recorded in the genotype EC-620383 (4.87). While at -0.491 Mpa, maximum seed vigour index I was recorded in EC-620434 (8.39) whereas minimum was recorded in Punjab Tropic (3.90) (Table 4).

For seed vigour index II, Genotype EC-620383 recorded significantly higher seed vigour index II (940.77) whereas lowest was found in (615.66) in the genotype Arka Vikas. Genotypes EC-620434 and EC-620383 showed lesser decline in seed vigour index-II with increase in osmotic stress. The interaction effect between the genotype and moisture stress levels was also found significant for seed vigour index II. Maximum seed vigour index II was recorded in Punjab Tropic (980.33) whereas minimum was observed in the genotype Arka Vikas (634.66) under control. At -0.295 Mpa, maximum seed vigour index II was observed in EC-620383 (956.33) whereas minimum was observed in the genotype Arka Vikas (654.00). While at -0.491 Mpa, genotypes EC-620383 (895.00) and Arka Vikas (558.33) exhibited maximum and minimum seed vigour index II respectively (Table 4).

Greenhouse evaluation of *in vitro* screened tomato genotypes under different moisture stress levels

For root length, LA-3846 genotype recorded significantly higher tap root length (18.44 cm) compared to other genotypes while the root length was the lowest (12.12 cm) in the genotype 97/784 whereas the interaction effect between the genotypes and irrigation treatments was found to be significant. Maximum root length was recorded in genotype Marglobe (25.853 cm) and minimum root length was observed in 97/784 (13.46 cm) under 100 % irrigation regime. At 75 % irrigation regime, genotype EC-620383 (17.580 cm) exhibited maximum root length. EC-620434 (12.100 cm) exhibited minimum root length which was at par with genotype 97/784 (12.24 cm) and Punjab Tropic (12.39 cm). However, at 50 % irrigation regimes genotype Arka Vikas exhibited maximum root length (15.570 cm) whereas minimum root length (9.750 cm) was observed in Punjab Tropic (Table 5).

For number of primary branches, data recorded showed significant differences among different irrigation regimes irrespective of genotypes whereas data revealed non-significant differences among genotype as well as interaction between the genotypes and irrigation treatments. Irrespective of genotypes, maximum number of primary branches (1.63) was shown at 100 % irrigation regime whereas minimum number of primary branches (1.36) was observed at 75 % irrigation regime (Table 5).

For maximum leaf area, (96.96 cm^2) was recorded in genotype EC-620434 whereas minimum leaf area (64.79 cm^2) was observed in genotype KS-7 (Table 5). However, interaction between

Table 4. Effect of osmotic stress on shoot length, seed vigour index-I and seed vigour index-II of ten tomato genotypes

Genotypes	Shoot length			Mean (Genotype)	Seed vigour index-I			Mean (Genotype)	Seed vigour index-II			Mean (Genotype)
	Osmotic stress				Osmotic stress				Osmotic stress			
	Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa	
EC-620434	6.81	5.31	5.24	5.79	12.44	8.61	8.39	9.81	964.00	868.66	820.66	884.44
Best of All	7.66	4.46	3.48	5.20	15.13	11.06	5.89	10.69	854.00	771.33	659.00	761.44
Marglobe	7.25	5.68	4.44	5.79	11.86	8.78	6.75	9.13	702.66	654.33	616.00	657.66
LA-3846	7.70	6.14	5.44	6.43	9.91	8.42	7.89	8.74	777.66	755.00	663.33	732.00
Arka Vikas	6.82	6.43	6.05	6.43	9.34	9.27	6.90	8.50	634.66	654.00	558.33	615.66
Sioux	7.02	5.77	5.19	5.99	9.68	7.43	7.37	8.16	768.00	718.33	644.33	710.22
KS-7	6.63	5.38	5.22	5.74	7.92	5.91	4.31	6.05	794.00	721.33	637.66	717.66
Punjab Tropic	6.59	5.82	3.92	5.44	12.96	5.09	3.90	7.32	980.33	783.33	644.66	802.77
97/784	7.54	5.77	5.66	6.32	11.69	5.05	4.95	7.23	858.33	844.00	767.33	823.22
EC-620383	6.39	3.66	3.15	4.40	6.77	4.87	4.14	5.26	971.00	956.33	895.00	940.77
Mean (T)	7.04	5.44	4.78		10.77	7.45	6.05		830.46	772.66	690.63	
$CD_{0.05}$ (G)		0.11				0.60					12.53	
$CD_{0.05}$ (T)		0.06				0.33					6.86	
$CD_{0.05}$ (G X T)		0.19				1.05					21.70	

Table 5. Effect of moisture stress on tap root length (cm), no. of primary branches, leaf area (sq cm) of 10 tomato genotypes

Genotypes	Tap root length (cm)			Mean (Genotype)	No. of primary branches			Mean (Genotype)	Leaf area (sq cm)			Mean (Genotype)
	Moisture stress levels				Moisture stress levels				Moisture stress levels			
	100 % of Etc	75 % of Etc	50 % of Etc		100 % of Etc	75 % of Etc	50 % of Etc		100 % of Etc	75 % of Etc	50 % of Etc	
EC-620434	23.39	12.10	11.78	15.76	1.76	1.46	1.43	1.55	103.28	95.85	91.75	96.96
Best of All	24.90	14.31	12.85	17.35	1.46	1.30	1.30	1.35	95.88	94.48	93.92	94.76
Marglobe	25.85	15.35	13.47	18.22	1.70	1.50	1.40	1.53	95.46	86.87	85.39	89.24
LA-3846	24.86	15.31	15.15	18.44	1.43	1.36	1.30	1.36	81.48	70.65	69.76	73.96
Arka Vikas	20.78	16.57	14.45	17.26	1.76	1.56	1.33	1.55	76.52	74.05	73.80	74.79
Sioux	21.35	17.58	13.60	17.51	1.56	1.46	1.30	1.44	76.36	64.44	62.59	67.80
KS-7	13.46	12.24	10.67	12.12	1.73	1.56	1.40	1.56	75.41	66.71	56.17	66.09
Punjab Tropic	14.83	14.75	12.99	14.19	1.63	1.40	1.33	1.45	67.99	63.88	62.50	64.79
97/784	18.39	17.08	15.57	17.01	1.70	1.56	1.40	1.55	71.31	67.16	59.84	66.10
EC-620383	16.90	12.39	9.75	13.01	1.56	1.50	1.43	1.50	84.97	84.25	78.33	82.52
Mean (T)	20.47	14.77	13.03		1.63	1.47	1.36		82.87	76.83	73.40	
$CD_{0.05}$ (G)			0.65			N/A					0.92	
$CD_{0.05}$ (T)			0.35			0.08					0.50	
$CD_{0.05}$ (G X T)			1.13			N/A					1.59	

genotype and different level of irrigation regimes also showed significant difference. Maximum and minimum leaf area was observed in genotype EC-620434 (103.28 cm^2) and KS-7 (67.99 cm^2) respectively at 100 % irrigation regime. At 75 % irrigation regime, genotype EC-620434 (95.857 cm^2) exhibited maximum leaf area whereas minimum leaf area was shown in genotype KS-7 (63.88 cm^2). At 50 % interval, genotype Best of All and 97/784 exhibited maximum leaf area (93.92 cm^2) and minimum leaf area (56.17 cm^2) respectively (Table 5).

For shoot length, LA-3846 recorded maximum shoot length (40.1 cm) whereas minimum shoot length was observed in genotype KS-7 (23.57 cm). The interaction effect of genotype with different irrigation regimes also revealed significant difference regarding shoot length. Maximum and minimum shoot length was observed in genotype Punjab Tropic (45.5 cm) and KS-7 (26.34 cm) respectively at 100 % irrigation regime. At 75 % irrigation regimes, genotype LA-3846 (38.03 cm) and KS-7 (25.11 cm) exhibited maximum and minimum shoot length respectively. At 50 % irrigation regime, genotype LA-3846 and KS-7 exhibited maximum shoot length (37.69 cm) and minimum shoot length (19.28 cm) respectively (Table 6).

For root biomass, EC-620434 genotype recorded significantly higher root biomass (1.42 g) while the root biomass was lowest (0.61 g) in the genotype KS-7. There was a decrease in root biomass of all the genotypes by increasing irrigation stress i.e. 75 % and 50 % (Table 6). However, the interaction effect between genotypes and different irrigation regimes also exhibited significant difference. Maximum root biomass was recorded in genotype EC-620434 (2.39 g) and minimum root biomass was observed in KS-7 (0.70g) at 100 % irrigation. At 75 % irrigation regimes, the genotype Marglobe (1.26 g) and 97/784 (0.57 g) exhibited maximum and minimum root biomass respectively. At 50 % interval, genotype Marglobe and 97/784 exhibited maximum and minimum root biomass (0.96 g) and (0.44 g) respectively (Table 6).

Drought stress during the early stages of plant development severely impacts germination and seedling establishment, which are crucial for successful crop production. In the present study, PEG-6000 was used to simulate drought conditions and evaluate the drought tolerance of different tomato genotypes. PEG results in a decrease in hydrolysis of seed reserves, resulting in a decrease in seed germination. The effects of drought stress on seed germination have earlier been reported in chilli (11). The reduction in seed germination has earlier been reported in rice (12). Root system plays a major role in plant survival during drought and tolerance to drought is characterised by superior root growth under moisture stress. Similar results were observed in chilli genotypes for drought tolerance (13). The drought tolerance in tomato seedlings using PEG-6000 induced water stress in Uttar Pradesh and found similar results for seedling biomass (14). The vitality index, which integrates germination capacity and seedling growth into a single measure, declined with increasing osmotic stress across all genotypes. The results for seedling level stress tolerance for vitality index were correlated with the findings of early works in Kerala and Telangana region (15). The effect of water stress on seedling vigour and yield attributes in tomato *(Solanum lycopersicum L.)* varieties and found similar result in Uttar Pradesh (14).

Under greenhouse condition using different RDI traits such as root length, shoot length, leaf area and root biomass are critical indicators of plant adaptation strategies under water-limited environments. Root length exhibited a significant increase under mild to moderate moisture stress in several genotypes, suggesting an adaptive mechanism to enhance water acquisition from deeper soil layers. The results are in concurrence with early results reported that, increase in root length led to deeper root system in brinjal genotypes which would help in absorption of more water in their plant body and this condition is essential for proper growth and flowering (16). The results are also in consonance with findings in tomato (4). Relative leaf area was found more in the drought tolerance lines than the susceptible lines because resistant lines had the ability to penetrate the roots even under water deficit conditions and maintain higher water potential in the leaves (17). The results are in consonance with the earlier findings in potato (18) and in brinjal (19). Similar results were found in capsicum (20). A progressive reduction in leaf area was observed with increasing moisture stress; water stress not only results in reduction of photosynthetic rate but also disturbs source-sink relationship resulting in decreased availability of photosynthates to below ground portion. Similar impact of water deficit on root biomass and growth in cucumber (*Cucumis Sativus)* (21) and showed similar effect in tomato (22).

Conclusion

The present study successfully identified tomato genotypes with significant tolerance to drought stress, both under laboratory conditions using PEG-6000 and in greenhouse conditions employing RDI. This study highlights the importance of selecting drought-tolerant genotypes for improving tomato production in areas susceptible to water scarcity. The identified genotypes offer a promising solution for farmers facing the challenges of drought, thereby enhancing food security and agricultural sustainability in

Table 6. Effect of moisture stress on shoot length (cm), root biomass (g) of tomato genotypes

Genotypes	Shoot length (cm)			Mean (Genotype)	Root biomass (g)			Mean (Genotype)
	Moisture stress levels				Moisture stress levels			
	Control	-0.295 Mpa	-0.491 Mpa		Control	-0.295 Mpa	-0.491 Mpa	
EC-620434	42.04	31.76	27.97	33.92	2.39	0.95	0.93	1.42
Best of All	38.96	35.90	32.85	35.90	1.96	0.91	0.86	1.24
Marglobe	40.23	34.33	33.97	36.18	1.98	1.26	0.96	1.40
LA-3846	44.59	38.03	37.69	40.10	1.66	1.04	0.82	1.17
Arka Vikas	36.95	33.54	31.62	34.04	1.09	1.01	0.87	0.99
Sioux	36.57	32.95	29.74	33.08	1.18	1.04	0.70	0.97
KS-7	32.36	30.74	21.30	28.13	0.96	0.57	0.44	0.66
Punjab Tropic	26.34	25.11	19.28	23.57	0.70	0.63	0.49	0.61
97/784	43.83	35.06	32.91	37.27	0.93	0.69	0.64	0.75
EC-620383	45.50	34.01	29.57	36.36	0.99	0.91	0.56	0.82
Mean (T)	38.74	33.14	29.67		1.38	0.90	0.73	
$CD_{0.05}$ (G)		0.85				0.01		
$CD_{0.05}$ (T)		0.46				0.01		
$CD_{0.05}$ (G X T)		1.47				0.02		

affected regions. The combined use of PEG-induced osmotic stress under controlled laboratory conditions and RDI in greenhouse environments offers a reliable and complementary framework for screening tomato germplasm for drought tolerance. Beyond traditional phenotyping, integrating molecular tools such as marker-assisted selection, QTL mapping and transcriptomic or metabolomic profiling can accelerate the identification of genes and pathways underpinning stress resilience. This dual phenotyping molecular approach will enhance the precision and efficiency of selecting parental lines for breeding. The promising genotypes identified through this screening pipeline hold strong potential for incorporation into drought-resilient tomato improvement programs, both as direct candidates for variety development and as donors in hybridization schemes. Future research should validate their performance under multi-location field trials across diverse agro-ecologies, ensuring stable expression of drought tolerance traits and broad adaptation under variable climatic conditions.

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Authors' contributions

Writing the original draft, visualization and conceptualization was done by DS and AV. Writing the review, editing and conceptualization were performed by JKS. All co-authors RN, DT, SS[1], RK, SB and SS[2] reviewed the final version. All authors read and approved the final manuscript. [SS[1]- Shivani Sharma, SS[2]- Shivani Sharma]

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

Ethical issues: None

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