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PEG Induced Screening for Drought Tolerance in Tomato Genotypes

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A B S T R A C T

A total of thirty three genotypes of tomato including three checks were analysed in an experiment to determine their tolerance and susceptible levels against drought stress. Four different concentrations of PEG 6000 *viz.*, 4%, 8%, 12% and 16% were used along with control. The genotypic differences investigated were found significant for all the seedling parameters studied. With increasing concentration of PEG growth parameters of seedlings like germination percentage, germination rate, root length, shoot length, root dry weight and shoot dry weight decreased proportionately. Among the parents EC-620428, Arka Saurabh, EC-620360, EC-620427 and EC-620557 exhibited superior performance and among the crosses evaluated EC-620428 × Arka Saurabh, EC-620360 × Arka Saurabh, EC-620427 × EC-620557 responded superior performance compared to other crosses. These genotypes may be used as positive/tolerant controls in future studies. However, the internal physiological investigation is needed for assessing their variable response.

Introduction

Among the various abiotic stresses elevated temperatures and drought are the main (Pena and Hughes, 2007). Tomato is one of the widely grown vegetables in the world. It is consumed in fresh form as salad and in various processed forms like soup, sauce, ketchup, paste, puree, powder and canned whole fruit etc. and tops the list of processed vegetables. Polyethylene glycol (PEG), a series of polymers that vary from viscous liquids to waxy solids has been used to induce water stress artificially (Larher *et al.*, 1993). PEG induced osmotic stress is found to reduce cell water potential (Govindaraj *et al.*, 2010). An increase in concentration of PEG-6000, resulted a decrease in germination rate, root length, shoot length and seed vigour in certain crop plants (Khodarahmpour, 2011). Tomato has been selected for better growth under PEG simulated water stress (Bressan *et al.*, 2003). *In vitro* selection techniques involving the use of PEG, is one of the reliable methods for screening desirable genotypes and to study further the effects of water scarcity on plant germination indices (Sakthivelu *et al.*, 2008). Tomato genotypes tend to exhibit limited and inadequate genetic variability for drought tolerance. Hence the best way to mitigate the effects of drought stress involves the crossing of cultivated tomato with drought tolerant lines (Pena and Hughes, 2007). The present study aims to

evaluate drought tolerant potential and compare the behaviour of different tomato genotypes under PEG simulated water stress.

Materials and Methods

The study was conducted at Horticulture Laboratory of Central Research Institute for Dry Land Agriculture (CRIDA), Hyderabad during 2016. The method suggested by Panchalingam (1983) and Babu *et al.,* (1985) was followed to screen the genotypes against moisture stress environment under laboratory conditions. Thirty crosses of tomato along with three commercial checks *viz.,* Arka Rakshak, US-440 and NS-516 were screened for moisture stress tolerance by employing germination test in an osmotic solution of Polyethylene Glycol (PEG-6000). Simultaneously, all the accessions were allowed to germinate in distilled water. Three replications of 10 seeds for each accession were counted and distributed over two layers of paper towel (11 × 11 cm) previously moistened with water equivalent to three times the dry weight of the paper and tied both ends with rubber band and kept in a plastic tray with different concentrations (4%, 8%, 12% and 16%) of Polyethylene Glycol (PEG-6000). Germination percentage was recorded for every 7 days. At the end of the 21st day, final germination per cent, germination rate, root length, shoot length, root dry weight and shoot weight was recorded in Polyethylene Glycol (PEG-6000) as against the distilled water was calculated. The experiment was designed as a completely randomized design with two factors. The first factor was the genotypes and the second one is external water stress treatments. The sheets were rolled and placed vertically in plastic beaker, covered with polythene bag and placed at 25±1°C in an illuminated germinator. A seed was considered to be germinated when the emerging radicle elongated to 1 mm. Radicle length, hypocotyl length, seedling fresh weight and dry weight were calculated as described by Uniyal *et al.,* (1998). Observations were recorded on germination percentage, germination rate, root length (cm), shoot length (cm), root dry weight (mg) and shoot dry weight (mg). Analysis of variance was carried out as described by Steel *et al.,* (1997). Statistical significance of means was tested by SPSS package.

Results and Discussion

Significant differences were observed under different PEG-6000 concentrations of 0, 4%, 8%, 12% and 16%. The analysis of variance showed significant differences among the genotypes and treatments (Table 1).

Germination percentage (%)

A decline in seed germination percentage under increasing stress has been observed (Table 2). Significant differences were observed for germination percentage between the genotypes and different PEG-6000 concentrations. Irrespective of the PEG-6000 concentrations, EC-620407 × EC-620557 recorded significantly maximum germination percentage (80.57%) compared to all other genotypes. The germination percentage was lowest (38.91%) in the cross EC-619982 × EC-620557. The interaction effect between the genotype and PEG-6000 concentrations was found non-significant. In 4% concentration of PEG-6000, the cross EC-620428 × Arka Saurabh exhibited maximum (91.66) and EC-619982 × Arka Saurabh exhibited minimum (41.59) germination per percentages. While at 8% concentration of PEG-6000, genotype EC-620428 × Arka Saurabh (91.06%) and EC-619982 × Pusa Ruby (34.59%) exhibited maximum and minimum germination percentage respectively. In case of 12% concentration of PEG-6000, genotypes EC-620360 × Arka

Saurabh (77.70%), EC-620360 × Pusa Ruby (26.20%) had responded as maximum and minimum germination percentage respectively. With 16% concentration of PEG-6000, EC-620407 × EC-620557 (73.21%) responded maximum and minimum in EC-620360 × Pusa Ruby (20.52%).

Maximum seed germination percentage was observed under control condition. It was observed that germination percentage with decreasing water potential of the environment probably was triggered by the low hydraulic conductivity of the environment where, PEG 6000 makes water unavailable to seeds, affecting the imbibition process of the seed which is fundamental for germination. In this study drought stress caused the germination percentage decrease in all of the genotypes. PEG causes the seed reserves materials hydrolysis decrease and finally the germination percentage decrease (Bhatt and Srinivasa 1987, Munns and Weir, 1981, Kulkarni and Desphpande, 2007, Aazami *et al.,* 2010).

The germination rapidity of tolerant genotypes to the drought stress was more than the sensitive genotypes. Results of the current study were in agreement with other experiments in different plants including Ravi *et al.,* (2011) and Alejandra *et al.,* (2010).

Germination rate

Significant differences were observed for germination rate between the genotypes and different PEG-6000 concentrations (Table 3). Irrespective of the PEG-6000 concentrations, EC-620360 × Arka Saurabh recorded significantly maximum germination rate (7.47) compared to all other genotypes.

The germination rate was lowest (3.57) in the genotype EC-619982 × Arka Saurabh. The interaction effect between the genotype and PEG-6000 concentrations was found significant. In 4% concentration of PEG-6000, maximum and minimum germination rate was recorded in EC-620428 × Arka Saurabh (9.14) and EC-619982 × Arka Saurabh (3.53) genotype respectively. While at 8% concentration of PEG-6000, genotype EC-620428 × Arka Saurabh (8.17) and Arka Rakshak (3.28) exhibited maximum and minimum germination rate respectively. In case of 12% concentration of PEG-6000, maximum and minimum germination rate recorded in EC- 620360 × Arka Saurabh (7.48) and EC-620360 × Pusa Ruby (2.27) while with 16% maximum and minimum germination rate recorded in EC-620360 × Arka Saurabh (5.93) and EC-620360 × Pusa Ruby (1.72) are presented in Fig. 9.

Results of the current study were in agreement with other experiments in different plants including Kalefetoglu *et al.,* (2009) in chickpea. The rate of germination seems to be more sensitive to the water stress than final germination percentage caused a significant increase in mean germination time and decrease in germination. Present studies are intensely supported by the finding of Uniyal *et al.,* (1998).

The germination responses show that tolerant genotype have high germination capacity under drought stress (Zhu *et al.,* 2006 and Abdel-Raheem *et al.,* 2007).

Root length (cm)

Root plays a major role in plant survival during drought and also drought tolerant can be characterized by extensive root growth (Table 4). Significant differences were observed for root length between the genotypes and different PEG-6000 concentrations. Irrespective of the PEG-6000 concentrations, EC-620428 × Arka Saurabh recorded significantly maximum root length

(6.74 cm) compared to all other genotypes. The root length was lowest (2.93 cm) in the genotype EC-619982 × EC-620557. The interaction effect between the genotype and PEG-6000 concentrations was found significant.

In 4% concentration of PEG-6000, maximum and minimum root length was recorded in EC-620407 × Arka Abha (8.02 cm) and EC-619982 × EC- EC-620557 (3.38 cm) genotype respectively. While at 8% concentration of PEG-6000, genotype EC-620428 × Arka Saurabh (7.47 cm) and EC-619982 × EC-620557 (3.12 cm) exhibited maximum and minimum root length respectively.

In case of 12% concentration of PEG-6000, genotypes EC-620407 × EC-620557 (6.05 cm) and EC-620428 × Pusa Ruby (2.34 cm) had responded as maximum and minimum root length respectively. In case of 16% concentration of PEG-6000, genotypes EC-620407 × Arka Abha (5.14 cm) and EC-6619982 × Arka Abha (1.43 cm) had responded as maximum and minimum root length respectively.

Root length is an important trait against drought stress in plant varieties, with longer root growth has resistant ability for drought (Leishman and Westoby, 1994). Early and rapid elongation of roots is an important indication of drought tolerance. Ability of continued elongation of root under water stress and longer root length at deeper layer are useful in extracting water in upland conditions (Kim *et al.*, 2001, Narayan, 1991). The plant embryo grows at germination and progresses radicles that become the primary roots and penetrate down into the soil. After radicle emergence, hypocotyl emerges and lifts the growing tip above the ground. Under drought stress condition, the root develops faster than the hypocotyls to acclimatize the drought stress.

Therefore, the growth of radicle and hypocotyls should reflect the adaptability of plant to drought stress (Zhu *et al.*, 2006). Similar results were observed by Kulkarni and Deshpande (2007). Ability of continuous elongation of root under situation of water stress was a remarkable character of some genotypes.

Table.1 Analysis of variance for six characters in tomato

Mean sum of squares							
Source of variation	**df**	**Germination %**	**Germination rate**	**Root length**	**Shoot length**	**Shoot dry weight**	**Root dry weight**
Treatment (A)	4	383.79**	1.01**	1.13**	15.61	967**	6.72**
Genotype (B)	32	2225.64**	76.43**	16.75**	15.66**	942**	47.73**
A×B	156	596.67	6.50	6.02	18.99	1517.05	12.99
Error	424	10.38	0.08	0.06	0.07	3.84	0.08

Table.2 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on germination percentage of tomato genotypes

Crosses/Hybrids	Germination percent (%)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	73.54	69.29	67.01	59.95	42.56	62.47
EC-620407 × Arka Abha	79.76	79.25	60.45	48.94	47.57	63.19
EC-620407 × Punjab Chhuhara	84.37	75.99	70.59	63.63	43.79	67.67
EC-620407 × Pusa Ruby	65.21	63.58	62.49	55.55	54.50	60.27
EC-620407 × EC-520078	85.66	72.38	72.31	60.55	47.49	67.68
EC-620407 × EC-620557	86.39	83.91	82.46	76.89	73.21	80.57
EC-620428 × Arka Saurabh	93.16	91.66	91.06	65.92	52.45	78.85
EC-620428 × Arka Abha	73.77	69.62	54.78	43.09	36.83	55.62
EC-620428 × Punjab Chhuhara	69.33	50.81	34.62	30.32	28.56	42.73
EC-620428 × Pusa Ruby	62.79	56.44	50.64	50.51	49.45	53.96
EC-620428 × EC-520078	70.55	64.01	62.64	50.45	49.63	59.46
EC-620428 × EC-620557	68.56	47.55	46.51	44.04	39.61	49.25
EC-620360 × Arka Saurabh	88.38	86.71	78.37	77.70	62.98	78.83
EC-620360 × Arka Abha	88.77	56.61	54.71	48.10	33.34	56.31
EC-620360 × Punjab Chhuhara	67.78	62.20	46.31	41.59	31.99	49.97
EC-620360 × Pusa Ruby	69.88	64.30	45.50	26.20	20.52	45.28
EC-620360 × EC-520078	52.40	48.24	47.18	41.84	41.35	46.20
EC-620360 × EC-620557	67.47	64.35	54.05	38.75	36.58	52.24
EC-608415 × Arka Saurabh	74.98	72.81	62.65	44.47	31.67	57.31
EC-608415 × Arka Abha	89.26	87.55	86.17	59.80	42.06	72.97
EC-608415 × Punjab Chhuhara	53.90	51.10	41.82	41.28	33.34	44.29
EC-608415 × Pusa Ruby	63.86	42.03	37.23	35.17	27.90	41.24
EC-608415 × EC-520078	64.88	44.48	43.58	41.18	32.39	45.30
EC-608415 × EC-620557	61.96	55.10	53.35	43.15	40.32	50.77
EC-619982 × Arka Saurabh	58.72	41.59	40.76	32.77	28.78	40.53
EC-619982 × Arka Abha	82.87	74.21	64.84	61.64	54.95	67.70
EC-619982 × Punjab Chhuhara	86.18	81.11	49.23	40.44	38.25	59.04
EC-619982 × Pusa Ruby	55.65	52.25	34.59	34.35	33.23	42.01
EC-619982 × EC-520078	63.35	61.76	42.38	39.15	25.48	46.42
EC-619982 × EC-620557	43.58	43.34	39.68	35.42	32.52	38.91
US-440	55.80	53.56	49.01	32.57	22.95	42.78
Arka Rakshak	63.66	58.28	54.58	51.87	37.92	53.26
NS-516	84.53	84.34	76.66	73.76	44.89	72.84
Mean	71.24	63.95	56.30	48.21	39.97	55.93
	S.Em±			**CD (0.01)**		
Treatment (A)	0.32			0.90		
Genotype (B)	0.832			2.31		
A×B	1.86			5.17		

Table.3 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on germination rate of tomato genotypes

Crosses/Hybrids	Germination rate (%)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	7.14	6.22	5.47	5.44	3.48	5.55
EC-620407 × Arka Abha	6.58	6.47	4.63	4.03	3.11	4.96
EC-620407 × Punjab Chhuhara	6.29	5.24	4.52	4.33	2.62	4.60
EC-620407 × Pusa Ruby	6.46	6.13	4.80	4.61	4.57	5.31
EC-620407 × EC-520078	8.25	8.23	5.61	4.45	4.34	6.17
EC-620407 × EC-620557	6.71	5.43	5.07	5.02	4.40	5.33
EC-620428 × Arka Saurabh	9.37	9.14	8.17	5.72	4.77	7.43
EC-620428 × Arka Abha	6.62	6.10	5.05	3.70	3.29	4.95
EC-620428 × Punjab Chhuhara	6.14	4.70	4.33	2.95	2.53	4.13
EC-620428 × Pusa Ruby	5.87	5.28	4.64	4.53	4.43	4.95
EC-620428 × EC-520078	6.24	6.00	5.58	4.41	4.35	5.32
EC-620428 × EC-620557	7.46	6.48	4.59	3.99	3.61	5.22
EC-620360 × Arka Saurabh	8.86	7.57	7.50	7.48	5.93	7.47
EC-620360 × Arka Abha	8.91	5.01	4.81	4.61	3.01	5.27
EC-620360 × Punjab Chhuhara	6.65	5.96	4.51	3.69	5.96	4.73
EC-620360 × Pusa Ruby	6.63	6.51	4.37	2.27	1.72	4.30
EC-620360 × EC-520078	4.86	4.57	4.47	3.92	3.84	4.33
EC-620360 × EC-620557	6.61	6.18	5.23	3.69	3.45	5.03
EC-608415 × Arka Saurabh	7.58	7.23	6.02	4.20	2.94	5.59
EC-608415 × Arka Abha	8.73	8.51	7.16	5.78	3.74	6.78
EC-608415 × Punjab Chhuhara	5.68	4.96	4.89	3.94	3.18	4.53
EC-608415 × Pusa Ruby	6.25	4.16	3.42	3.41	2.56	3.96
EC-608415 × EC-520078	6.31	4.14	4.03	3.74	2.95	4.23
EC-608415 × EC-620557	5.91	5.32	5.15	4.26	3.93	4.91
EC-619982 × Arka Saurabh	5.46	3.53	3.52	2.95	2.39	3.57
EC-619982 × Arka Abha	8.02	7.22	6.36	5.88	5.28	6.55
EC-619982 × Punjab Chhuhara	7.71	7.11	4.42	3.73	1.81	4.96
EC-619982 × Pusa Ruby	4.89	4.81	3.73	3.04	2.83	3.86
EC-619982 × EC-520078	5.81	3.74	3.70	3.14	2.38	3.75
EC-619982 × EC-620557	5.85	3.95	3.78	3.05	2.54	3.84
US-440	5.77	5.12	4.94	3.81	3.57	4.64
Arka Rakshak	5.52	5.29	3.28	2.71	2.18	3.80
NS-516	7.65	7.50	7.29	6.45	5.37	6.85
Mean	6.75	5.87	5.00	4.21	3.54	5.07
	S.Em±			**CD (0.01)**		
Treatment (A)	0.028			0.077		
Genotype (B)	0.071			0.198		
A×B	0.159			0.442		

Table.4 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on root length of tomato genotypes

Crosses/Hybrids	Root length (cm)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	6.40	6.25	5.31	5.13	4.49	5.51
EC-620407 × Arka Abha	8.39	8.02	6.32	5.29	5.14	6.63
EC-620407 × Punjab Chhuhara	6.25	5.13	4.21	3.11	3.09	4.36
EC-620407 × Pusa Ruby	5.40	5.23	5.22	4.40	3.58	4.77
EC-620407 × EC-520078	7.40	7.40	6.41	5.12	5.06	6.28
EC-620407 × EC-620557	8.29	6.44	6.38	6.05	2.88	6.01
EC-620428 × Arka Saurabh	8.26	7.91	7.47	5.68	4.41	6.74
EC-620428 × Arka Abha	5.59	5.43	5.11	4.20	4.06	4.88
EC-620428 × Punjab Chhuhara	8.35	7.34	5.79	5.45	4.23	6.23
EC-620428 × Pusa Ruby	4.52	4.45	3.15	2.34	2.24	3.34
EC-620428 × EC-520078	4.78	4.52	4.51	4.43	4.36	4.52
EC-620428 × EC-620557	6.81	6.75	5.77	5.57	5.05	5.99
EC-620360 × Arka Saurabh	7.63	7.43	7.41	5.73	2.29	6.10
EC-620360 × Arka Abha	8.04	5.11	4.52	3.92	3.61	5.04
EC-620360 × Punjab Chhuhara	7.02	5.86	5.35	4.21	4.15	5.31
EC-620360 × Pusa Ruby	7.46	5.22	3.49	3.42	2.14	4.35
EC-620360 × EC-520078	4.36	4.15	3.57	2.43	2.18	3.34
EC-620360 × EC-620557	6.40	5.21	4.21	4.14	4.07	4.80
EC-608415 × Arka Saurabh	7.17	6.47	5.39	5.28	2.04	5.27
EC-608415 × Arka Abha	7.59	7.41	7.37	5.33	4.84	6.51
EC-608415 × Punjab Chhuhara	4.89	3.93	3.58	3.40	3.13	3.79
EC-608415 × Pusa Ruby	7.16	6.39	4.94	3.74	2.86	5.01
EC-608415 × EC-520078	4.76	3.59	3.58	2.92	2.19	3.41
EC-608415 × EC-620557	3.75	3.71	3.68	3.50	3.21	3.57
EC-619982 × Arka Saurabh	6.00	5.86	5.75	4.87	4.67	5.43
EC-619982 × Arka Abha	6.75	6.62	4.85	4.75	1.43	4.88
EC-619982 × Punjab Chhuhara	7.21	6.75	4.36	3.71	2.85	4.97
EC-619982 × Pusa Ruby	4.68	4.62	3.38	3.14	2.66	3.69
EC-619982 × EC-520078	6.88	6.04	4.13	2.81	1.56	4.28
EC-619982 × EC-620557	3.47	3.38	3.12	2.71	1.98	2.93
US-440	5.43	3.42	3.34	3.29	2.81	3.66
Arka Rakshak	5.85	5.64	4.68	4.24	4.15	4.91
NS-516	6.18	6.02	4.95	4.59	1.27	4.60
Mean	6.33	5.68	4.88	4.20	3.29	4.88
	S.Em±			**CD (0.01)**		
Treatment (A)	0.026			0.071		
Genotype (B)	0.066			0.183		
A×B	0.147			0.408		

Table.5 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on shoot length (cm) of tomato genotypes

Crosses/Hybrids	Shoot length (cm)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	8.42	5.52	5.39	4.42	4.14	5.57
EC-620407 × Arka Abha	7.41	5.26	5.24	4.13	2.01	4.81
EC-620407 × Punjab Chhuhara	9.66	6.95	6.22	2.15	1.87	5.37
EC-620407 × Pusa Ruby	7.55	6.52	5.05	4.49	4.28	5.58
EC-620407 × EC-520078	9.09	7.59	5.44	2.38	2.21	5.34
EC-620407 × EC-620557	8.39	5.17	4.21	3.96	3.26	5.00
EC-620428 × Arka Saurabh	10.36	9.49	5.42	4.35	3.49	6.62
EC-620428 × Arka Abha	7.67	6.77	4.69	4.62	1.47	5.04
EC-620428 × Punjab Chhuhara	6.17	5.47	4.46	3.56	1.59	4.25
EC-620428 × Pusa Ruby	6.46	4.15	4.15	3.63	1.49	3.98
EC-620428 × EC-520078	6.99	6.98	5.87	5.35	1.61	5.36
EC-620428 × EC-620557	8.38	7.82	4.14	3.50	2.11	5.19
EC-620360 × Arka Saurabh	9.91	9.69	5.53	5.28	3.85	6.85
EC-620360 × Arka Abha	10.80	7.46	4.54	3.83	3.05	5.93
EC-620360 × Punjab Chhuhara	6.36	4.35	4.27	3.22	1.03	3.85
EC-620360 × Pusa Ruby	8.60	6.12	5.32	1.16	1.03	4.44
EC-620360 × EC-520078	6.61	5.46	3.82	3.44	3.28	4.52
EC-620360 × EC-620557	8.13	6.54	4.67	1.38	1.20	4.38
EC-608415 × Arka Saurabh	7.53	4.42	3.03	2.90	2.29	4.03
EC-608415 × Arka Abha	9.14	8.35	8.18	4.27	3.32	6.65
EC-608415 × Punjab Chhuhara	6.82	5.64	3.82	3.67	2.55	4.50
EC-608415 × Pusa Ruby	8.33	3.53	2.60	0.70	0.61	3.15
EC-608415 × EC-520078	5.42	4.82	3.54	2.68	0.58	3.41
EC-608415 × EC-620557	6.17	4.87	4.23	3.07	0.72	3.81
EC-619982 × Arka Saurabh	7.50	6.71	6.13	1.70	1.04	4.62
EC-619982 × Arka Abha	8.21	3.78	3.75	2.50	2.47	4.14
EC-619982 × Punjab Chhuhara	8.83	8.05	3.37	3.31	2.45	5.20
EC-619982 × Pusa Ruby	6.68	5.49	3.48	2.53	0.45	3.73
EC-619982 × EC-520078	7.74	5.14	4.50	3.63	o.42	4.28
EC-619982 × EC-620557	4.72	3.11	2.85	2.33	0.27	2.66
US-440	7.34	5.66	5.46	4.09	0.43	4.59
Arka Rakshak	6.71	6.45	2.40	1.58	0.74	3.57
NS-516	9.01	8.38	8.28	3.35	2.23	6.25
Mean	7.79	6.11	4.66	3.24	1.97	4.77
	S.Em±			**CD (0.01)**		
Treatment (A)	0.027			0.074		
Genotype (B)	0.068			0.191		
A×B	0.153			0.426		

Table.6 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on root dry weight (mg) of tomato genotypes

Crosses/Hybrids	Root dry weight (mg)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	10.66	7.62	6.24	3.55	3.49	6.31
EC-620407 × Arka Abha	9.93	8.18	4.47	3.83	3.04	5.89
EC-620407 × Punjab Chhuhara	5.80	5.44	5.34	3.29	3.26	4.63
EC-620407 × Pusa Ruby	5.10	4.59	4.49	3.61	3.30	4.22
EC-620407 × EC-520078	6.26	6.06	5.42	3.51	3.08	4.87
EC-620407 × EC-620557	9.28	6.32	5.56	5.53	4.54	6.25
EC-620428 × Arka Saurabh	11.99	11.40	9.31	5.50	2.55	8.15
EC-620428 × Arka Abha	8.96	8.36	6.86	2.91	2.26	5.87
EC-620428 × Punjab Chhuhara	5.82	5.41	4.59	3.55	1.95	4.26
EC-620428 × Pusa Ruby	4.41	3.19	2.68	1.66	1.81	2.75
EC-620428 × EC-520078	3.85	3.50	3.28	3.00	2.23	3.17
EC-620428 × EC-620557	5.22	4.30	4.28	4.18	3.59	4.31
EC-620360 × Arka Saurabh	10.65	9.62	7.64	7.52	6.11	8.31
EC-620360 × Arka Abha	10.80	8.85	5.52	2.80	1.87	5.97
EC-620360 × Punjab Chhuhara	5.46	5.42	5.28	1.94	1.18	3.85
EC-620360 × Pusa Ruby	5.05	4.63	3.81	3.22	1.46	3.63
EC-620360 × EC-520078	2.94	2.87	2.37	2.36	1.69	2.44
EC-620360 × EC-620557	4.85	2.88	2.60	2.25	1.64	2.84
EC-608415 × Arka Saurabh	5.94	4.33	4.18	3.75	2.90	4.22
EC-608415 × Arka Abha	10.22	9.83	9.55	5.37	2.94	7.58
EC-608415 × Punjab Chhuhara	6.01	7.13	4.24	2.06	1.09	4.10
EC-608415 × Pusa Ruby	4.17	4.16	4.09	3.13	1.11	3.33
EC-608415 × EC-520078	4.10	2.25	2.13	2.10	2.06	2.53
EC-608415 × EC-620557	3.10	3.06	2.44	2.16	1.14	2.38
EC-619982 × Arka Saurabh	5.16	4.22	3.16	3.16	2.99	3.74
EC-619982 × Arka Abha	9.50	4.19	4.14	3.18	3.07	4.82
EC-619982 × Punjab Chhuhara	9.56	8.32	6.28	2.91	1.92	5.80
EC-619982 × Pusa Ruby	5.23	3.87	3.86	0.96	0.94	2.97
EC-619982 × EC-520078	3.88	3.83	3.75	2.78	0.99	3.04
EC-619982 × EC-620557	2.10	1.97	1.93	1.91	1.84	1.95
US-440	3.94	2.81	2.62	1.84	0.94	2.43
Arka Rakshak	4.90	3.94	2.94	2.82	2.80	3.48
NS-516	8.87	8.87	8.85	3.87	3.87	6.87
Mean	6.47	5.49	4.75	3.21	2.41	4.47
	S.Em±			CD (0.01)		
Treatment (A)	0.08			0.03		
Genotype (B)	0.21			0.07		
A×B	0.166			0.462		

Table.7 Effect of different concentration of PEG-6000 (control, 4%, 8%, 12% and 16% on shoot dry weight (mg) of tomato genotypes

Crosses/Hybrids	Shoot dry weight (mg)					
	Treatment					
	Control	4%	8%	12%	16%	Mean
EC-620407 × Arka Saurabh	79.78	70.75	49.56	29.74	28.14	51.59
EC-620407 × Arka Abha	76.77	58.25	45.04	33.80	24.68	47.71
EC-620407 × Punjab Chhuhara	85.25	77.99	58.16	33.07	24.68	55.83
EC-620407 × Pusa Ruby	91.71	62.50	54.50	42.45	41.25	58.48
EC-620407 × EC-520078	83.07	51.81	46.56	46.56	33.93	52.37
EC-620407 × EC-620557	74.08	54.73	46.75	40.05	31.51	49.42
EC-620428 × Arka Saurabh	88.07	87.78	85.78	43.52	33.04	67.64
EC-620428 × Arka Abha	82.07	71.04	65.94	26.99	21.25	53.46
EC-620428 × Punjab Chhuhara	74.62	57.28	53.94	35.49	30.79	50.42
EC-620428 × Pusa Ruby	82.42	43.57	41.12	30.66	23.41	44.23
EC-620428 × EC-520078	67.55	50.73	47.48	33.81	30.44	46.00
EC-620428 × EC-620557	80.31	63.96	48.88	43.44	28.56	53.01
EC-620360 × Arka Saurabh	86.47	85.78	50.36	50.35	35.95	61.78
EC-620360 × Arka Abha	86.46	62.26	32.55	24.25	19.46	44.99
EC-620360 × Punjab Chhuhara	72.76	70.23	55.50	28.94	22.83	50.05
EC-620360 × Pusa Ruby	70.52	68.54	51.92	34.63	22.19	49.56
EC-620360 × EC-520078	82.38	47.37	42.33	34.99	24.52	46.32
EC-620360 × EC-620557	43.18	43.00	40.47	31.59	28.25	37.30
EC-608415 × Arka Saurabh	70.25	68.14	44.24	34.49	29.42	49.31
EC-608415 × Arka Abha	86.05	86.00	84.12	49.54	28.59	66.86
EC-608415 × Punjab Chhuhara	70.42	66.06	61.15	18.25	16.59	46.49
EC-608415 × Pusa Ruby	52.74	47.91	29.55	27.17	19.86	35.44
EC-608415 × EC-520078	69.13	66.55	32.59	22.63	22.38	42.66
EC-608415 × EC-620557	82.30	41.66	38.32	36.18	27.17	45.13
EC-619982 × Arka Saurabh	66.80	65.68	37.31	35.41	26.41	46.32
EC-619982 × Arka Abha	83.52	48.75	42.35	31.64	26.78	46.61
EC-619982 × Punjab Chhuhara	84.82	84.36	26.65	19.20	15.17	46.04
EC-619982 × Pusa Ruby	64.35	57.93	56.47	25.36	15.38	43.90
EC-619982 × EC-520078	50.13	46.36	26.53	25.28	16.39	32.94
EC-619982 × EC-620557	66.52	60.61	31.07	19.70	18.39	39.26
US-440	80.38	40.04	31.69	31.58	24.45	41.63
Arka Rakshak	62.06	60.75	33.58	33.04	25.59	43.00
NS-516	83.17	81.42	80.38	30.45	23.02	59.69
Mean	75.15	62.11	47.66	32.85	25.46	48.75
	S.Em±			CD (0.01)		
Treatment (A)	0.197			0.549		
Genotype (B)	0.506			1.41		
A×B	1.133			3.152		

Shoot Length (cm)

The results revealed that there is a significant difference in shoot length between the genotypes and different PEG-6000 concentrations (Table 5). Irrespective of the PEG-6000 concentrations, EC-620360 × Arka Saurabh recorded significantly maximum shoot length (6.85 cm) compared to all other genotypes. The shoot length was lowest (2.66 cm) in the genotype EC-619982 × EC-620557. The interaction effect between the genotype and PEG-6000 concentrations was found significant. In 4% concentration of PEG-6000, maximum and minimum shoot length was recorded in EC-620360 × Arka Saurabh (9.69 cm) and EC-619982 × EC-620557 (3.11 cm) genotype respectively. While at 8% concentration of PEG-6000, genotype EC-608415 × Arka Abha (8.18 cm) and Arka Rakshak (2.40) exhibited maximum and minimum shoot length respectively. In case of 12% concentration of PEG-6000, genotypes EC-620360 × Arka Saurabh (5.28) and EC-608415 × Pusa Ruby (0.70 cm) had responded as maximum and minimum shoot length respectively. In case of 16% concentration of PEG-6000, genotypes EC-620407 × Pusa Ruby (4.28) and EC-619982 × EC-620557 (0.27 cm) had responded as maximum and minimum shoot length respectively.

Genotypes with indeterminate growth habit showed more reduction in shoot length as compared to determinate type. It indicates that determinate tomato can be well suited to drought areas than indeterminate growth habit. Turner (1979) has recommended indeterminate growth habit for drought tolerance. But the results of present experiment advocate determinate growth habit for drought resistance. Present experimental results were similar to earlier studies of Govindaraj (2010) and Kulkarni and Desphpande (2007). It is generally accepted that the roots suffer first from exposure to stresses, followed by their associated plant parts (Misra and Dwivedi, 2004 and Abida *et al.,* 2013).

Root dry weight (mg)

Highest root weight was recorded by EC-620360 × Arka Saurabh (8.31) (Table 6). Regardless of the PEG-6000 concentrations, the root dry weight was lowest (2.43) in the genotype US-440. The interaction effect between the genotype and PEG-6000 concentrations was found significant. In 4% concentration of PEG-6000, maximum and minimum root dry weight was recorded in EC-620428 × Arka Saurabh (11.40 mg) and EC-619982 x EC-620557 (1.97 mg) genotype respectively. While at 8% concentration of PEG-6000, genotype EC-620428 × Arka Saurabh (9.31 mg) and EC-619982 x EC-620557 (1.93 mg) exhibited maximum and minimum root dry weight respectively. In case of 12% concentration of PEG-6000, genotypes EC-620360 × Arka Saurabh (7.52 mg) and EC-619982 × Pusa Ruby (0.96 mg) had responded as maximum and minimum root dry weight respectively. With 16% concentration of PEG-6000, genotypes EC-620360 × Arka Saurabh (6.11 mg) and EC-619982 × Pusa Ruby (0.94 cm) had responded as maximum and minimum root dry weight respectively

Growth parameters like dry weight is known to have a profound effect on water limited conditions. In the present study a reduction in root dry weight was recorded in stressed conditions in all the genotypes. Present investigation is in confirmation with Ali *et al.,* 1999, Bhatt and Srinivas (1987), Umesh Chandra and Gupta (1994), Deshpande and Kulakarni (2005), Ragab *et al.,* (2007), Wani *et al.,* (2010) and Tyagi *et al.,* (1995). Root dry weight depends on the germination percent and root length, low water uptake and restricted metabolic activities were given to decrease in the root dry weight. Most of the tolerant genotypes accumulated more dry matter under control that too increased under stress however moderately tolerant or susceptible genotypes recorded comparatively less increase or even decrease in dry weight of roots.

Shoot dry weight (mg)

Irrespective of the PEG-6000 concentrations, EC-620428 × Arka Saurabh recorded significantly maximum shoot dry weight (67.64 mg) compared to all other genotypes (Table 7). Significant differences were observed for shoot dry weight between the genotypes and different PEG-6000 concentrations.

The shoot dry weight was lowest (32.94 mg) in the genotype EC-619982 × EC-520078. The interaction effect between the genotype and PEG-6000 concentrations was found significant. In 4% concentration of PEG-6000, maximum and minimum shoot dry weight was recorded in EC-620428 × Arka Saurabh (87.78 mg) and US-440 (40.04 mg) genotype respectively. While at 8% concentration of PEG-6000, genotype in EC-620428 × Arka Saurabh (85.78 mg) and EC-619982 × Punjab Chhuhara (26.65 mg) exhibited maximum and minimum shoot dry weight respectively. In case of 12 % concentration of PEG-6000, genotypes EC-620360 × Arka Saurabh (50.35 mg) and EC-608415 × Punjab Chhuhara (18.25 mg) had responded with maximum and minimum shoot dry weight respectively. In case of 16 % concentration of PEG-6000, genotypes EC-620407 × Pusa Ruby (41.25 mg) and EC-619982 × EC-520078 (16.39 mg) had responded with maximum and minimum shoot dry weight respectively. These results are in accordance with Kulkarni and Deshpande (2006).

Among all crosses, EC-620428 × Arka Saurabh, EC-620360 × Arka Saurabh, EC-620427 × EC-620557 responded superior performance compared to others. Difference in sensitivity and response of plants to PEG at cultivar level largely depends upon genetic constitution of the plants (Garsia-Reina *et al.*, 1988). According to Imanparast and Hassanpanah (2009) genotypes that had good root length had excess germination percentage too and seeds had good root growth. These results for seedling level stress tolerance were correlated with the findings of Fischer and Maurer, (1978). Hence, genotypes with higher germination percentage, root length and dry weights should be selected while screening for drought tolerance. These genotypes may be used as positive/tolerant controls in future studies. However, the internal physiological investigation is needed for assessing their variable response.

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