International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 15-09-2021, Accepted: 30-09-2021, Published: 16-10-2021
Volume 3, Issue 4, 2021, Page No. 22-33

Physiological and root growth response of eggplant genotypes upon drought stress and assessment of genetic parameters at different developmental stage

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Abstract
In order to comprehend the effect and presence of genetic variability for drought physiological and root growth response upon drought stress in eggplant at different growth stage of eggplant. Current pot culture experiment was conducted with 50 eggplant genotypes in accordance with a factorial CRD with 3 replicates per genotypes. Stress treatment was applied at two levels: control (normal moisture) and moisture stress condition during flower initiation stage and fruit initiation stage. The obtained results showed highly significant differences ($P \leq 0.01$) among the genotypes in different levels of drought treatment during both the developmental stages of eggplant and even at their interaction levels. Except root- shoot ratio had shown no significant difference at interaction level (moisture stress levels x stages of the plant). The genetic variability analysis revealed the traits like, MSI, RWC (%), epicuticular wax (mg/dm^2), root length (cm) and root to shoot ratio had shown high phenotypic and genotypic coefficient of variation as well high broad sense heritability coupled with high genetic advance over mean in different moisture condition as well as in different stages of eggplant. The comparative overall mean performance revealed that the genotypes like, Very Green Long, Pusa Upkar, Swarna Pratibha, Pusa Ankur, *Solanum indicum*, IIHR-322, R-2580, M4, *Solanum torvum* and IIHR-7 screened as drought tolerant genotypes which showed relatively better performance at different physiological and root traits. The obtained data could be used in self-improvement or eggplant breeding programs for better physiological drought tolerance traits.

Keywords: membrane stability index, relative water content, epicuticular wax, root length, root to shoot ratio, number of lateral roots

Introduction
Eggplant (*Solanum melongena* L.) is an important member of *Solanaceous* family grown in tropical and subtropical regions of the world, including India. It is a warm season herbaceous perennial but grown as an annual crop for commercial purpose. Eggplant is rich in carbohydrates, fats, protein, dietary fiber, minerals, vitamins and antioxidant (Somawathi *et. al.*, 2014) [55]. Numerous parts of the plant are used in decoction for remedial ailments such as diabetes, leprosy, gonorrhea, cholera, bronchitis, dysuria, dysentery, asthenia and hemorrhoids (Gill, 1992) [19]. Further, it is reported to have hypolipidemic action, spasmogenic activity, CNS depressant property, Calcium Channel Blocking action and hypotension activity (Das and Barua, 2013) [9]. It is potentially used as raw material in pickle making and dehydration industries (Singh *et al.*, 1963) [53]. Drought is an insufficiency of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of the crop to restrict expression of its full genetic yield potential (Singh *et al.*,2014) [55]. Almost 20 percent of India's total land area is drought prone and chronic drought prone area is one in which the probability of a drought year is higher than 40 percent. It is complex phenomenon in crop plants and its expressivity is mainly depended on morphological (earliness, root elongation, reduced leaf area, leaf rolling, efficient rooting system and stability of yield) and biochemical (accumulation of proline, betaine, epicuticular wax) parameters (Prabhavathi *et al.*, 2002) [38]. It has reported that though eggplant is hardy crop the reduction in fruit yield in eggplant is huge due to abiotic stress (Dipty, 2012; Chen *et al.*, 2002; Gobu *et al.*,2017; Faizan *et al.*, 2021) [11, 8, 21]. India is major diversity hub for eggplant representing genetic variability for morphological and quality enhancement. The exploitation of presence of variability may produce resistance against several pests (mainly fruit and shoot borer) and diseases (*Fusarium*, Bacterial and *Verticillium* wilt), nematodes (*Meloidogyne* sp.) as well as abiotic stresses (drought, salinity and frost) (Sihachakr *et al.*,1994; Kashyap *et al.*,2003; Faiz, 2019; Topal *et al.*,2019) [51, 25, 16, 57]. Screening of genotypes for drought stress based on physiological and root traits is one of the important and best criteria to enhance magnitude of screening. Besides, the optimization of eggplant breeding programs depends on information of the nature and degree of variations in the available material, magnitude of correlation of traits with yield, extent to which these characters are heritable as well as extent of environmental influence on them (Aruah *et al.*, 2012) [2]. Efficiency of selection directly depends on the magnitude of heritability and genetic advance in relation to the mean performance of the trait (Kumar *et al.*, 2013) [28].
With this background, this investigation was performed to understand the response and presence of genetic variability for

moisture stress on eggplant genotypes at flower initiation stage and fruit initiation stage on the basis of physiological and root traits.

Material and Methods

Fifty eggplant genotypes were used in the investigation, Seeds were soaked in 20 ppm of GA_3 overnight, shade dried and treated with Bavastin @ 3 g per kg of seeds and then sown in pro-trays. Seedlings were transplanted after 30 days of sowing (DAS) in such a manner that each pot should consist of two seedlings in control as well as moisture stressed pots in three replications each. Soil moisture was monitored by using tensiometer. These tensiometers were installed 15 cm apart from the base of plant and pots were irrigated when soil moisture reaches to 50 centibars. As per schedule, all the pots were irrigated until 30 days after transplanting (DAT). Then, the moisture stress was imposed in the treatment pots for 15 days (on the 7th day of water stress, soil moisture tension in tensiometer reached the maximum level of 85 centibars), at two critical stages *viz.*, flower initiation stage and fruit initiation stage, while normal watering was done in control pots. The observations were recorded in normal moisture as well as moisture stressed pots on different parameters.

Physiological observation

1. Leaf canopy temperature (°C): Canopy temperature of plants was measured by using infrared thermometer (EQUINOX, EQDT530A) by projecting the laser beam on canopy five leaves of plants and the average was computed.
2. SPAD Chlorophyll meter reading: Chlorophyll content of plant leaf was measured by using SPAD chlorophyll meter (KONICA MINOLTA, SPAD 502 PLUS, Version: 1.20.0000) by leaf was clamped avoiding the midrib region and inserted into the sensor mouth of SPAD meter. Average readings were taken five leaves of plants.
3. Membrane Stability Index: Membrane stability index (MSI) for different genotypes was calculated by recording electrical conductivities (EC) (Sairam, 1994). The 1g leaf samples were put into test tubes containing 100 ml of distilled water continuously stirred and EC meter readings were taken (ECa). The sampled test tubes were kept in hot water bath (50 °C) for 30 min. and cooled and again EC meter readings were taken (ECb). In final step the sampled test tubes were kept in hot water bath (100 °C) for 30 min. and cooled and final EC meter readings were taken (ECc). MSI can be calculated by using the following formula (Blum and Ebercon, 1981).
   MSI= (ECb – ECa/ ECc) x 100
4. Relative water content (%) (RWC): Standard number of leaf disc from each genotype excised and weighed (FW). The fresh leaf discs were submerged in test tube containing distilled water for overnight and again turgid weight was recorded after wiping with tissue (TW). The turgid leaf discs were dried 70 °C for 48 hours and dry weight of discs was measured (DW).
5. RWC was calculated using the following formula (Dhopte and Manuel, 2002).
   RWC= (FW-DW/TW-DW) ×100
6. Epicuticular wax (mg/dm^2) (EW): Leaf surface or epicuticular wax estimation is generally done by colorimetric assay (Ebercon *et al.,* 1976). Standard number of leaf disc from each genotype excised and dipped in test tube containing 15ml of chloroform for 10 sec. and kept in a boiling water bath until no chloroform smell resides. A 5 ml of wax reagent (20 gm of potassium dichromate with 40 ml of deionized water, the resulting slurry was then mixed with 1 litre of conc. H_2SO_4) was added to each tube and kept at 60 °C in water bath for 30 min. After cooling, 12 ml of deionized water was added to each tube and the solution was filtered through a filter paper. The absorbance was measured at 590 nm with spectrophotometer. The wax content was calculated using standard carnauba plant wax (0.5 to 5.0 mg).

Root observation

1. Root length (cm): Root length of the plants in moisture stressed and control (non-stress) condition was measured in terms of centimetres using a scale from collar to tip of the root in each plant from all replications.
2. Number of lateral roots per plant: The number of primary roots per plant was counted from plants under moisture stress and control condition in all the genotypes.
3. Shoot length (cm): The height of shoot was recorded from the base of the stem to the tip of the plant.
4. Root to shoot ratio: Root to shoot ratio is calculated by using the following formula.
   Root to shoot ratio= Length of root (cm)/Length of shoot (cm)

Results and Discussion

Analysis of variance for physiological and root traits

The combined analysis of variance was done to test the significance of differences among eggplant genotypes for physiological and root traits under different levels of moisture stresses at different stages of the plant as well as their interaction Effects of genotypes with moisture stress levels and stages of plant (genotypes × moisture stress levels × stages of plant). It was observed that, there were significant genotypic differences for all the physiological and root parameters under study even at one percent level of probability.

Highly significant variation was observed due to different moisture stress levels (moisture stress and normal moisture) as well as stages of plant (flower initiation and fruit initiation) for all the characters.

Contrarily, root to shoot ration had shown no significant difference for interaction effects of moisture stress levels × developmental stages of plant. This is because of the effect of drought stress on plant during flower initiation stage and fruit initiation stage is similar. Further, the interaction effects due to genotypes x moisture stress levels × stages of the plant were also found to be highly significant for all the traits ($p < 0.01$). The mean sum of squares of all the characters of the combined analysis is presented in the Table 1. The mean reduction of moisture stress condition over control condition for different physiological and root characters was represented in Table 4 and 5 which were recorded during flower and fruit initiation stage respectively.

Table 1: Analysis of variance for physiological and root traits

Source of Variation	D.F.	Leaf canopy temperature (℃)	SPAD Chlorophyll meter reading	Membrane stability index	Relative water content (%)	Epicuticular wax (mg/dm^2)	Root length (cm)	Shoot length	Number of lateral roots	Root to shoot ratio
A	1	6679.27**	7254.34**	19288.77**	17565.19**	0.222**	151.42**	302.75**	15645.8**	0.313**
B	1	616.04**	7127.77**	11299.88**	191369.9**	4.758**	207.91**	22632.78**	174.52**	7.44**
A x B	1	214.67**	61.318**	582.27**	824.572**	1.071**	47.83**	230.35**	39.47**	0.00^{NS}
C	49	11.62**	613.829**	516.35**	2009.192**	0.587**	458.82**	18930.6**	36.21**	0.314**
A x C	49	7.026**	156.322**	356.8**	1387.556**	0.508**	59.30**	9778.5**	21.94**	0.067**
B x C	49	3.726**	137.761**	271.52**	693.124**	0.09**	235.07**	10888.70**	17.41**	0.138**
A x B x C	49	3.565**	133.42**	221.17**	1157.27**	0.103**	68.81**	5402.54**	13.01**	0.075**
Error C	400	1.275	5.093	1.052	7.68	0.003	1.906	1239.13	0.856	0.002
Total	599	15.511	112.698	164.479	784.544	0.117	69.195	69405.31	34.296	0.063
General mean		30.418	58.662	25.399	65.431	1.348	32.809	45.33	19.609	0.758
C.V. %		3.712	3.847	4.039	4.235	3.918	4.208	3.88	4.72	5.727
S.Em. ±										
A		0.065	0.130	0.059	0.16	0.003	0.079	0.102	0.053	0.0025
B		0.065	0.130	0.059	0.16	0.003	0.079	0.102	0.053	0.0025
A x B		0.092	0.184	0.083	0.226	0.004	0.112	0.144	0.075	0.0035
C		0.326	0.651	0.296	0.8	0.015	0.398	0.508	0.267	0.0125
A x C		0.461	0.921	0.418	1.131	0.021	0.563	0.719	0.377	0.0177
B x C		0.461	0.921	0.418	1.131	0.021	0.563	0.719	0.377	0.0177
A x B x C		0.651	1.303	0.592	1.6	0.030	0.79	1.016	0.534	0.0251
C.D. @5%										
A		0.181	0.362	0.165	0.445	0.009	0.222	0.284	0.149	0.007
B		0.181	0.362	0.165	0.445	0.009	0.222	0.284	0.149	0.007
A x B		0.256	0.512	0.233	0.629	0.012	0.313	0.400	0.21	0.01
C		0.906	1.811	0.823	2.224	0.042	1.108	1.412	0.743	0.035
A x C		1.282	2.562	1.164	3.145	0.06	1.567	1.999	1.05	0.049
B x C		1.282	2.562	1.164	3.145	0.06	1.567	1.999	1.05	0.049
A x B x C		1.813	3.623	1.647	4.448	0.085	2.216	2.825	1.486	0.07
C.D.@1%										
A		0.2386	0.4769	0.2166	0.5856	0.0109	0.2917	0.373	0.1954	0.0091
B		0.2386	0.4769	0.2166	0.5856	0.0109	0.2917	0.373	0.1954	0.0091
A x B		0.3374	0.6745	0.3067	0.8283	0.0157	0.4125	0.527	0.2767	0.0128
C		1.1932	2.3846	1.0837	2.9281	0.0556	1.4586	1.859	0.9780	0.0457
A x C		1.6873	3.3725	1.5329	4.1408	0.0790	2.0629	2.632	1.3828	0.0647
B x C		1.6873	3.3725	1.5329	4.1408	0.0790	2.0629	2.632	1.3828	0.0647
A x B x C		2.3861	4.7692	2.167	5.8563	0.1116	2.9172	3.719	1.9556	0.0918

D.F. = Degrees of Freedom, Factor A= Plant Stages (Flower initiation and Fruit initiation), Factor B= Drought Level (Moisture stress and normal moisture), Factor C= Number of genotypes.
** = Significance @ 1 %, * = Significance @ 5%, NS = Non-Significant

Response physiological traits upon drought stress

Leaf canopy temperature at flower initiation stage, under normal moisture condition was 32.14 ℃ and it ranged from 28.45 to 36.55 ℃. However, under moisture stress, the mean was 35.37 ℃ and it ranged from 31.12 to 40.32 ℃. At fruit initiation stage, the leaf canopy temperature under moisture stress was in the range of 25.83 to 29.93 ℃ with a mean of 27.50 ℃. Though, under normal moisture condition, the mean was 26.67 ℃ and it ranges from 24.50 to 29.60 ℃ (Table 2). The *per se* performance of eggplant genotypes indicated that, at flower initiation stage, the least leaf canopy temperature over control was observed in the genotype, L-2230 (-0.43 ℃) followed by R-2594 (-0.38 ℃) (Table 4). During fruit initiation stage the *per se* performance of eggplant genotypes indicated that, the least leaf canopy temperature over control was observed in the genotype, Swarna Pratibha (-0.67 ℃) followed by IC354140 (-0.40 ℃) (Table 4). The relatively less leaf canopy temperature of genotypes under moisture stress over control would be an indication of tolerance to drought condition because of tissue holding maximum amount of moisture which reduces the temperature pressure over plant (Siddique *et al.*, 2000) [50]. Halder and Burrage (2003) [23] showed that leaf temperature significantly increases in moisture stress condition and results in decreased transpiration rate. The plants that showed a lower leaf temperature were exhibiting higher photosynthetic rate.

During flower initiation stage, the SPAD chlorophyll reading in moisture stress condition ranged from 32.53 to 86.27 with a mean of 58.95. Nevertheless, under normal moisture condition, this trait recorded a mean of 51.42 and it was ranging from 34.10 to 65.20. At fruit initiation stage, under normal moisture condition, the SCMR was in the range of 40.60 to 80.90 with a mean of 59.01. However, in the case of moisture stress, SCMR was ranging from 40.40 to 87.67 with a mean of 65.27 (Table 2). The *per se* performance of eggplant genotypes during flower initiation stage indicated that, the maximum SCMR over control was observed in the genotype, Swarna Mani (33.47) followed by Rampur Local (26.56) (Table 4). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum SCMR over control was observed in the genotype, L-2232 (27.27) followed by Arka Kranti (25.57) (Table 4). Rong-Hua *et al.* (2006) [42] and Rahimi *et al.* (2011) [40] reported that upon drought or moisture stress the intensity if SPAD chlorophyll reading increases due to decreased water content in tissue. The drought tolerant genotype is which shows high SPAD chlorophyll reading upon drought stress (Kirnak *et al.*, 2001; El-Tayeb, 2006) [14]. During flower initiation stage, the mean value of membrane stability index under moisture stress condition was 36.39 with a range of 17.77 to 63.14. However, mean MSI under normal moisture condition was ranging from 9.33 to 63.37 with a mean of 25.74. While, during fruit initiation stage, the MSI in normal moisture condition was at the range of 9.33 to 35.55 with a mean of 16.37. But, under moisture stress condition, the mean value of MSI was 23.08 with a range of 7.31 to 44.29 (Table 2). The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum membrane stability index over control was observed in the genotype, Shobha (43.37) followed by Long Green (41.24) (Table 4). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum MSI over control was observed in the genotype Malapur Local (25.26) followed by the wild species, *Solanum mammosum* (20.26) (Table 4). Premachandra *et al.* (1992) [39], McDonald and Archbold (1998) [30] have shown that, reduced water application affected the electrolyte leakage. The ion leakage in the membrane was due to damage to cell membranes which become more permeable (Senaratna and McKersie, 1983). The maximum cell membrane integrity will provide the relatively higher MSI value which indicates drought tolerant ability genotype (Usha and Bhumika, 2012; Gobu *et al.*, 2017; Bangar *et al.*, 2019) [58, 21, 3]. During the flower initiation stage, the change in overall mean value under moisture stress condition compared to normal moisture was 10.65 which accounted to 92.07 percent. During fruit initiation stage, the change in overall mean value under moisture stress condition compared to normal moisture was 6.71 and it accounted to 50.86 percent. The relatively lower value of MSI during fruit initiation stage is probably due the over production of reactive oxygen species (ROS), because of which there will be commotion of the cell membrane due to alteration in its phospholipid and fatty acid compositions (Sibel and Birol, 2007; Ratnasekera and Subhashi, 2015) [49, 41] in moisture stress condition (Table 6 & Figure 3). During flower initiation, the relative water content in moisture stress condition ranged from 16.11 to 167.15 percent with a mean of 51.81 percent. Nonetheless, mean RWC under normal moisture was 89.87 percent with a range of 65.67 to 165.98 percent. The mean RWC under normal moisture condition at fruit initiation stage was 76.71 percent with a range of 63.10 to 97.53 percent. However, under moisture stress, this trait recorded a mean value of 43.33 percent and it was ranging from 19.26 to 97.84 percent (Table 2). The stress tolerant genotype is one which can retain more water in the leaves even under stress condition which is measured by estimating the relative water content. The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum RWC over control was observed in the genotype, M21 (81.30 percent) followed by IIHR-322 (38.86 percent) (Table 4). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum RWC over control was observed in the genotype, R-2581 (23.50 percent) followed by Early Round Market (14.98 percent) (Table 4). Similarly, Rahimi *et al.* (2011) [40] reported significantly decreased relative water content. Drought tolerant genotypes preserve the turgor pressure of cell against water loss from plant tissue mainly through process of osmoregulation. Which causes the plant to continue water absorption and retain metabolic activities (Gunasekera and Berkowiz, 1992; McDonald and Archbold, 1998) [30].

At flower initiation stage, the mean value of epicuticular wax under moisture stress was 1.41 mg/dm^2 with a range of 1.00 - 2.57 mg/dm^2. However, under normal moisture condition, mean epicuticular wax was in the range of 0.71 - 1.92 mg/dm^2 with a mean of 1.32 mg/dm^2. During fruit initiation stage, the epicuticular wax under normal moisture condition was in the range of 0.41 -2.25 mg/dm^2 with a mean of 1.20 mg/dm^2. Nevertheless, under moisture stress, the mean value of epicuticular wax was 1.46 mg/dm^2 with a range of 0.82 - 2.53 mg/dm^2 (Table 2).

The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum epicuticular wax over control was observed in the genotype, IIHR-322 (0.65 mg/dm^2) followed by a wild species, *Solanum mammosum* (0.64 mg/dm^2) (Table 4). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum epicuticular wax over control was observed in the genotypes, Punjab Sadabahar, Malapur Local and M-21 (0.95 mg/dm^2) followed by M4 (0.89 mg/dm^2) (Table 4). Samdur *et al.* (2003) [46] and Burow *et al.* (2008) [6] stated that epicuticular wax load is known to enhance the efficiency of water use by suppressing the transpiration under dehydration in peanut and sorghum, respectively. Mamrutha *et al.* (2010) reported that high wax amount is correlated with drought resistance in crop plants and surface wax is one of the important characters of drought tolerance.

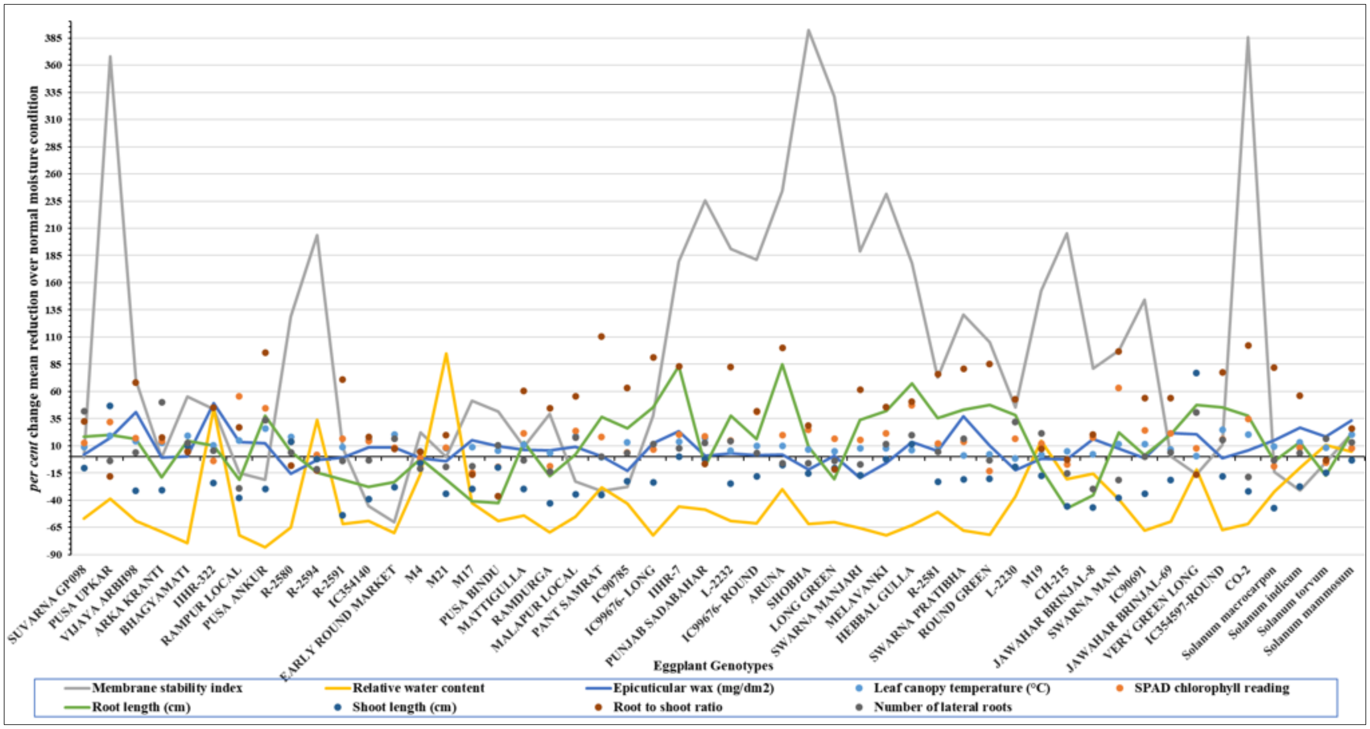

Fig 1: Per-cent change mean reduction over normal moisture condition for eggplant genotypes recorded during flower initiation stage

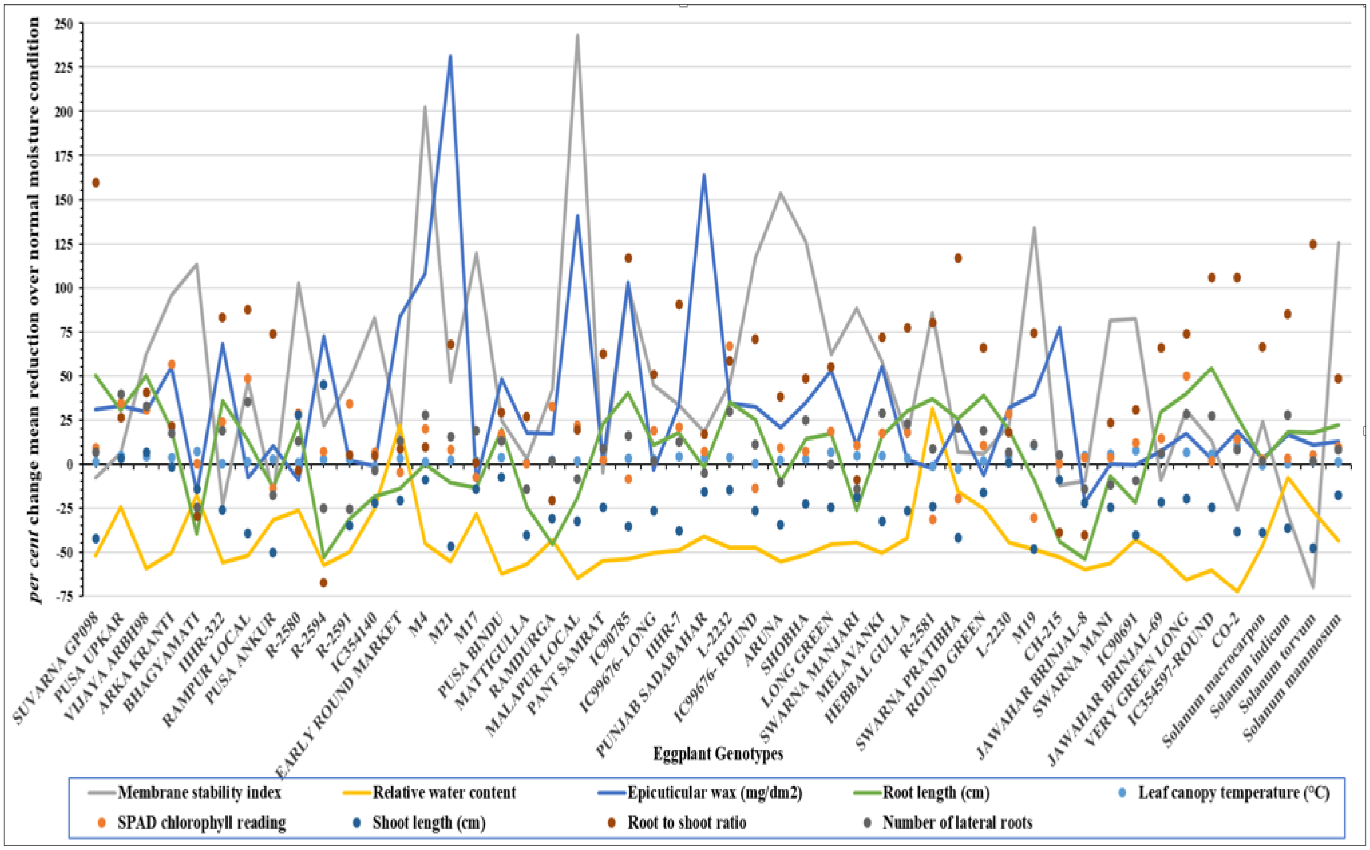

Fig 2: Per-cent change mean reduction over normal moisture condition for eggplant genotypes recorded during fruit initiation stage

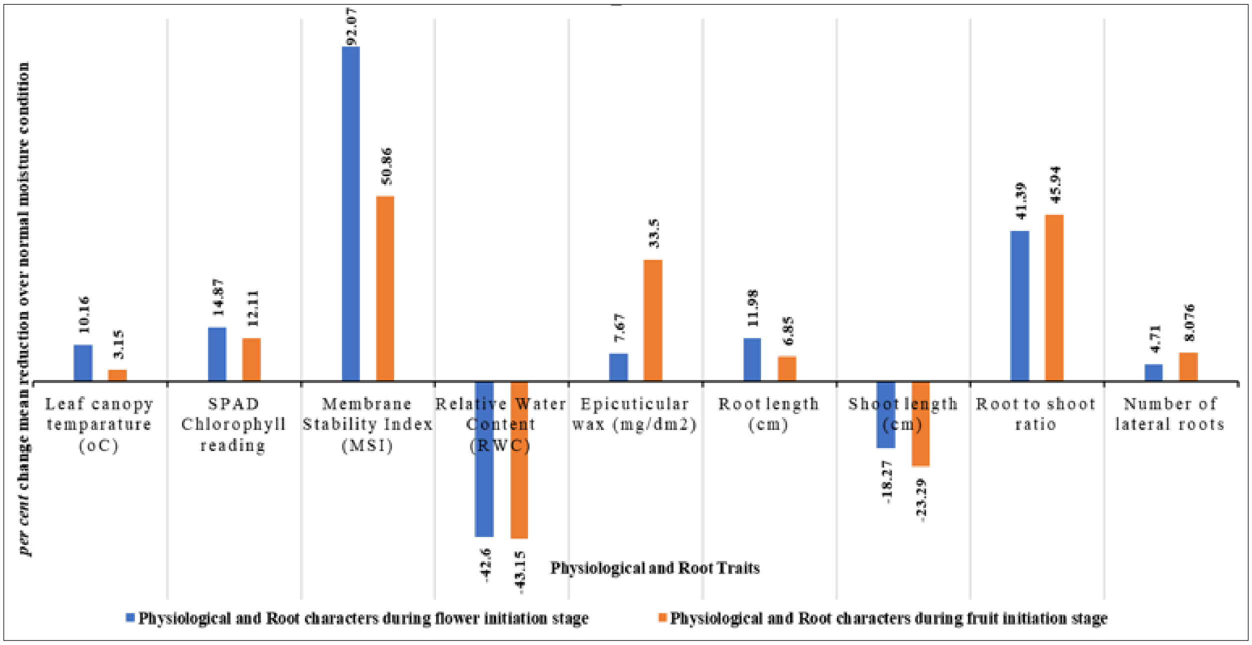

Fig 3: Overall change in *per cent* mean under moisture stress condition compared to normal moisture for different traits under flower and fruit initiation stage of eggplant genotypes.

Response root morphological traits upon drought stress

At flower initiation stage, the root length in moisture stress condition was in the range of 14.50 - 52.29 cm with a mean of 34.18 cm. However, under normal moisture condition, the root length ranged from 17.00 - 64.00 cm with a mean of 32.44 cm. During fruit initiation stage, under normal moisture, the root length ranged from 16.00 - 58.00 cm with a mean of 32.00 cm. Nevertheless, the root length in moisture stress condition was in the range of 17.89- 49.47 cm with a mean of 32.61 cm (Table 3). The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum root length over control was observed in the genotype, IIHR-7 (17.45 cm) followed by Aruna (17.00 cm) (Table 5). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum root length over control was observed in the genotype IC354597-Round (17.47 cm) followed by Very Green Long and Suvarna GP098 (11.50 cm) (Table 5). Bikash and Michihiro (2009) [4] and Franco *et al.* (2011) [18] reported that in moisture stressed condition; root length would be more compared to normal moisture condition. Estimate root length upon drought stress important feature in order to identify drought tolerant genotype (Wasaya *et al.*,2018) [59]. During flower initiation stage, the change in overall mean value under moisture stress condition compared to normal moisture was 1.74 cm which accounted to 11.98 percent over normal moisture. While, during fruit initiation stage, the change in mean value under moisture stress condition compared to normal moisture was 0.61 cm and it accounted to 6.85 percent (Table 6). The variation in root length and overall mean reduction value compared to normal moisture condition at flower initiation stage and fruit initiation stages maybe due to imposition of prolonged drought spell of about 15 days and use of repeated destructive method. During flower initiation stage, in moisture stress condition, the mean shoot length was in the range of 20.50 to 51.00 cm with a mean of 39.10 cm. However, the mean shoot length under normal moisture was 50.14 cm and it ranges from 24.00 to 77.00 cm. While in case of fruit initiation stage, the mean shoot length in moisture stress condition was 39.28 cm with a range of 25.33 to 51.86 cm. But, in normal moisture condition, the mean shoot length was 52.80 cm with a range of 29.00 to 77.00 cm (Table 3). The *per se* performance of eggplant genotypes indicated that, maximum shoot length during flower initiation stage over control was recorded in the genotype, Very Green Long (18.50 cm) followed by Pusa Upkar (15.00 cm) (Table 5). While, during fruit initiation stage the *per se* performance of eggplant genotypes indicated that, the maximum shoot length over control was recorded in genotype R-2594 (14.33 cm) followed by R-2580 (8.67 cm) (Table 5). Similarly, the results were consent with findings of Kirnak *et al.* (2001) [27], Ebrahim *et al.* (2012) and Mili *et al.* (2014) [32]. The reduction of shoot length in stressed condition was due to prolonged (15 days) drought imposture to plants which leads to wilting of apical shoots and enhance lateral branches for growth and development. In moisture stress condition, during flower initiation stage, the average number of lateral roots was 14.78 with a range of 11.00 - 21.50. However, under normal moisture was 14.22 and it was in the range of 11.00 to 19.00. During fruit initiation stage, the number of lateral roots in normal moisture condition was in the range of 19.00 - 31.00 with a mean of 23.92. Nevertheless, under moisture stress, the mean value of number of lateral roots was 25.51 with a range of 15.00 - 31.97 (Table 3). The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum number of lateral roots over control was observed in the genotype Arka Kranti (5.50) followed by Suvarna GP098 (5.00) (Table 5). At fruit initiation stage, the *per se* performance of eggplant genotypes indicated that, the maximum number of lateral roots over control was observed in the genotype Pusa Upkar (7.94) followed by Rampur Local (7.39) (Table 5). These results were in accordance with that of Rouhani *et al.* (1986). Franco *et al.* (2011) and Wasaya *et al.* (2018) [59] reported that, lateral roots were essential to maintain cellular hydration by avoiding the moisture-deficit condition. The increase in number of later roots would be a property of drought tolerant genotypes (Sangakkara *et al.*, 2010; Steele *et al.*, 2013) [47, 56]. During flower initiation stage, the root to shoot ratio in moisture stress condition ranged from 0.48 to 1.63 with a mean of 0.89. While in normal moisture condition, the root to shoot ratio was in the range of 0.40 to 1.69 with a mean of 0.67. At fruit initiation stage, under normal moisture, the root to shoot ratio was in the range of 0.36 to 1.21 with a mean of 0.62. However, the root to shoot ratio under moisture stress was ranging from 0.37 to 1.62 with a mean of 0.85 (Table 3). The *per se* performance of eggplant genotypes at flower initiation stage indicated that, the maximum value for root to shoot ratio over control was observed in the genotype, IIHR-7 (0.58) followed by Swarna Mani and *Solanum macrocarpon* (0.57) (Table 5). The *per se* performance of eggplant genotypes at fruit initiation stage indicated that, the maximum root to shoot ratio over control was observed in case of *Solanum torvum* (0.91) followed by Suvarna GP098 (0.71) (Table 5). Kirnak *et al.* (2001) [27] reported that root to shoot ratio was 2.1 times higher in waters stressed plants, showing that water stress in eggplants alters the pattern of dry matter distribution favouring the roots. A similar finding was reported by Gobu *et al.* (2017) [21]. Root to shoot ratio has an important role in drought tolerance, increase in root to shoot ratio value would be an indication of drought tolerance (Pace *et al.*, 1999) [37]. Percent change mean reduction over normal moisture condition for 50 eggplant genotypes in different observation recorded during flower and fruit initiation stage represented in Figure 1 and 2.

Table 2: Estimates of genetic parameters for physiological traits at flower initiation stage in eggplant genotypes

Characters	MEAN		RANGE		PCV (%)		GCV (%)		h^2 (%)		GAM (%)	
	Moisture stress	Normal moisture	Moisture stress	Normal moisture	Moisture stress	Normal moisture	Moisture stress	Normal moisture	Moisture Stress	Normal moisture	Moisture stress	Normal moisture
Flower initiation stage												
LCT (℃)	35.37	32.14	31.12 - 40.32	28.45 - 36.55	6.76	5.67	5.61	4.36	68.66	58.92	9.57	6.89
SPAD	58.95	51.42	32.53 - 86.27	34.10 - 65.20	19.00	14.63	18.54	14.16	95.27	93.69	37.28	28.23
MSI	36.39	25.74	17.77 - 63.14	9.33 - 63.37	31.25	57.81	31.01	57.66	98.48	99.45	63.40	118.45
RWC (%)	51.81	89.87	16.11 - 167.15	65.67 - 165.9	64.23	21.82	64.08	21.50	99.53	97.11	131.69	43.65
EW (mg/dm^2)	1.41	1.32	1.00 - 2.57	0.71 - 1.92	20.87	18.80	20.57	18.25	97.10	94.23	41.75	36.49
Fruit initiation stage												
LCT (℃)	27.50	26.67	25.83 - 29.93	24.50 - 29.6	4.50	4.54	2.65	2.72	34.76	35.84	3.22	3.35
SPAD	65.27	59.01	40.40 - 87.67	40.60 - 80.9	15.58	14.70	15.11	14.24	93.98	93.82	30.17	28.41
MSI	23.08	16.37	7.31 - 44.29	9.33 - 35.5	36.35	37.07	36.19	36.86	99.12	98.87	74.22	75.51
RWC (%)	43.33	76.71	19.26 - 97.84	63.10 - 97.53	33.40	10.76	33.18	9.79	98.71	82.78	67.91	18.35
EW (mg/dm^2)	1.46	1.20	0.82 - 2.53	0.41 -2.25	22.89	35.10	22.59	34.90	97.34	98.82	45.91	71.46

PCV= Phenotypic co-efficient of variation, GCV= Genotypic co-efficient of variation, h^2= Broad sense heritability, GAM= Genetic Advance as percent over mean, LCT= Leaf canopy temparature, MSI-Membrane stability index, RWC= Relative water content (%), EW= Epicuticular wax.

Table 3: Estimates of genetic parameters for root characters at flower and fruit initiation stage in eggplant genotypes

Characters	MEAN		RANGE		PCV (%)		GCV (%)		h^2 (%)		GAM (%)	
	Moisture Stress	Normal moisture	Moisture Stress	Normal moisture	Moisture stress	Normal moisture	Moisture stress	Normal moisture	Moisture stress	Normal moisture	Moisture stress	Normal moisture
Flower initiation stage												
Root length (cm)	34.18	32.44	14.50 -52.29	17.00 - 64.0	21.12	31.10	20.63	30.87	95.40	98.51	41.51	63.12
Shoot length (cm)	39.10	50.14	20.50 -51.00	24.00 - 77.0	16.97	23.26	16.48	22.96	94.32	97.44	32.98	46.69
Number of lateral roots	14.78	14.22	11.00 -21.50	11.00 - 19.0	14.45	14.47	13.55	14.00	87.90	93.55	26.17	27.89
Root to shoot ratio	0.89	0.67	0.48 - 1.63	0.40 - 1.7	26.48	35.03	25.60	34.82	93.52	98.80	51.00	71.29
Fruit initiation stage												
Root length (cm)	32.61	32.00	17.89- 49.47	16.00 - 58.0	22.42	26.46	21.94	26.20	95.70	98.01	44.21	53.43
Shoot length (cm)	39.28	52.80	25.33 -51.86	29.00 - 77.0	15.88	18.50	15.34	18.13	93.30	96.01	30.53	36.59
Number of lateral roots	25.51	23.92	15.00 -31.97	19.00 - 31.0	13.05	14.44	11.92	13.97	83.39	93.60	22.42	27.84
Root to shoot ratio	0.85	0.62	0.37 - 1.62	0.36 - 1.21	27.40	31.68	26.79	31.34	95.61	97.84	53.96	63.86

PCV= Phenotypic co-efficient of Variation, GCV= Genotypic co-efficient of variation, h^2= Broad sense heritability, GAM= Genetic Advance as percent over mean.

Table 4: *Per se* performance of eggplant genotypes under moisture stress condition over normal moisture condition for physiological traits at flower initiation stage and fruit initiation stage.

Genotype	Leaf canopy temperature (℃)		SPAD chlorophyll reading		Membrane stability index		Relative water content		Epicuticular wax (mg/dm^2)	
	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage
Suvarna GP098	2.97	0.33	7.80	6.20	-0.54	-2.69	-42.16	-33.10	0.03	0.38
Pusa Upkar	5.80	1.30	14.13	18.63	40.97	2.04	-36.86	-18.43	0.23	0.34
Vijaya ARBH98	4.57	1.20	9.40	18.13	17.65	5.87	-48.39	-41.62	0.29	0.34
Arka Kranti	4.03	1.10	6.80	25.57	-0.44	13.86	-68.57	-33.84	-0.01	0.72
Bhagyamati	6.12	2.00	3.07	0.20	19.97	17.34	-65.90	-11.09	0.00	-0.28

IIHR-322	3.32	0.03	-2.10	13.77	15.76	-2.76	38.86	-47.75	0.65	0.63
Rampur Local	4.50	0.30	26.56	23.67	-4.94	4.66	-53.69	-36.15	0.15	-0.15
Pusa Ankur	7.95	0.70	22.40	-10.90	-8.24	-2.76	-80.67	-24.59	0.14	0.18
R-2580	5.72	0.20	7.87	17.47	27.74	11.02	-45.03	-19.76	-0.18	-0.19
R-2594	-0.38	0.67	0.67	3.17	19.15	3.54	32.93	-48.37	-0.03	0.53
R-2591	2.88	0.70	10.03	21.37	2.45	5.88	-50.89	-32.39	-0.01	0.02
IC354140	5.13	-0.40	8.30	4.33	-16.17	17.35	-50.80	-20.57	0.12	-0.01
Early Round Market	6.82	0.90	4.29	-2.73	-31.34	3.87	-60.08	14.98	0.13	0.43
M4	1.69	0.30	-0.77	12.07	9.02	18.87	-13.90	-35.35	-0.01	0.89
M21	2.67	0.57	4.53	5.50	-0.23	7.74	81.30	-49.22	-0.04	0.95
M17	2.96	0.50	-7.73	-4.27	9.69	14.49	-69.62	-23.36	0.20	-0.13
Pusa Bindu	1.70	1.00	-5.43	11.57	7.01	4.41	-53.01	-43.51	0.13	0.54
Mattigulla	3.73	0.20	11.37	0.20	3.37	0.55	-45.91	-42.83	0.10	0.19
Ramdurga	1.10	0.57	-5.07	21.47	10.57	4.72	-59.89	-31.48	0.08	0.24
Malapur Local	5.77	0.47	12.37	12.77	-10.65	25.26	-46.29	-43.81	0.12	0.95
Pant Samrat	-0.20	0.50	8.16	1.50	-14.23	-0.80	-28.37	-43.21	0.00	0.02
IC90785	4.15	0.80	2.40	-7.03	-12.05	13.22	-36.50	-42.71	-0.18	0.70
Ic99676-Long	3.83	0.70	3.77	12.53	12.83	6.01	-79.23	-35.14	0.17	-0.05
IIHR-7	4.65	1.13	10.77	12.50	29.92	7.19	-33.45	-35.39	0.22	0.39
Punjab Sadabahar	5.13	0.93	9.12	4.13	32.43	3.56	-31.89	-28.68	0.01	0.95
L-2232	1.73	0.97	7.00	27.27	24.56	8.82	-51.03	-35.69	0.04	0.22
IC99676-Round	3.07	0.13	19.23	-8.70	18.70	14.34	-51.52	-33.71	0.02	0.34
Aruna	3.05	0.63	10.20	4.63	25.81	16.11	-25.07	-43.00	0.03	0.21
Shobha	2.03	0.70	12.76	4.33	43.37	18.53	-52.60	-36.41	-0.20	0.37
Long Green	1.65	1.63	8.77	9.80	41.24	11.76	-49.02	-34.02	0.01	0.34
Swarna Manjari	2.43	1.17	8.33	6.03	20.61	14.35	-57.24	-36.25	-0.24	0.13
Melavanki	2.40	1.30	10.53	9.17	26.52	6.66	-63.16	-38.18	-0.10	0.59
Hebbal Gulla	1.87	0.87	19.53	8.63	19.44	2.81	-57.03	-34.96	0.21	0.03
R-2581	3.20	-0.33	6.27	-18.80	7.49	10.20	-43.24	23.50	0.06	-0.04
Swarna Pratibha	0.40	-0.67	6.77	-13.17	16.15	1.27	-58.95	-12.57	0.41	0.26
Round Green	0.67	0.50	-7.27	5.33	12.34	0.80	-58.96	-19.51	0.15	-0.11
L-2230	-0.43	1.23	5.63	13.83	5.58	4.21	-60.74	-35.86	-0.18	0.33
M19	0.58	2.60	6.53	-21.13	19.21	17.14	10.86	-42.43	-0.03	0.25
CH-215	1.60	1.30	-2.57	0.13	23.74	-2.53	-23.33	-45.56	-0.04	0.42
Jawahar Brinjal-8	0.70	1.27	7.43	1.92	9.76	-1.20	-13.06	-57.15	0.18	-0.23
Swarna Mani	3.80	1.50	33.47	2.30	12.08	12.06	-27.81	-47.75	0.11	0.00
IC90691	3.82	2.07	13.93	8.33	23.44	12.23	-57.03	-33.86	-0.01	-0.01
Jawahar Brinjal-69	2.37	1.50	12.17	8.50	0.15	-1.06	-52.97	-35.32	0.22	0.12
Very Green Long	0.20	1.70	3.13	20.95	-7.95	10.32	-9.84	-64.11	0.22	0.25
IC354597-Round	7.55	1.43	9.43	1.02	4.26	1.71	-62.10	-46.26	-0.01	0.04
CO-2	6.11	2.80	21.03	8.08	35.97	-3.55	-50.47	-50.82	0.08	0.27
Solanum macrocarpon	3.24	-0.17	-5.35	1.70	-4.15	2.76	-45.11	-36.55	0.21	0.04
Solanum indicum	3.78	0.10	5.23	2.33	-9.79	-7.87	-8.12	-5.44	0.34	0.29
Solanum torvum	2.39	0.30	-1.88	2.90	-1.53	-16.91	8.55	-20.59	0.23	0.17
Solanum mammosum	6.33	0.30	3.63	5.04	5.82	20.06	3.89	-38.83	0.64	0.28
Mean Total	3.22	0.83	7.53	6.25	10.65	6.71	-38.06	-33.37	0.09	0.26

Table 5: *Per se* performance of eggplant genotypes under moisture stress condition over normal moisture condition for root traits at flower initiation stage and fruit initiation stage.

Genotype	Root length (cm)		Number of lateral roots		Shoot length (cm)		Root to shoot ratio	
	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage	Mean reduction at Flower Initiation stage	Mean reduction at Fruit Initiation stage
Suvarna GP098	5.00	11.50	5.00	1.50	-5.00	-21.95	0.19	0.71
Pusa Upkar	5.00	5.50	-0.50	7.94	15.00	1.00	-0.14	0.16
Vijaya ARBH98	4.00	8.00	0.50	6.50	-16.78	2.67	0.32	0.16
Arka Kranti	-6.00	4.00	5.50	3.50	-17.00	-0.67	0.10	0.11
Bhagyamati	4.00	-13.50	1.50	-6.38	3.50	-5.67	0.03	-0.26
IIHR-322	2.25	7.50	1.00	3.75	-12.00	-15.06	0.20	0.30
Rampur Local	-8.50	3.50	-5.50	7.39	-26.50	-23.67	0.15	0.38
Pusa Ankur	9.00	-4.50	4.00	-4.40	-14.61	-25.67	0.47	0.48
R-2580	1.50	7.00	0.50	3.00	5.00	8.67	-0.07	-0.03
R-2594	-2.50	-20.11	-1.50	-5.00	-0.75	14.33	-0.07	-0.80
R-2591	-8.50	-14.50	-0.50	-7.50	-41.50	-21.00	0.37	0.04
IC354140	-17.88	-10.50	-0.50	-1.00	-26.50	-12.33	0.17	0.05
Early Round Market	-9.00	-4.50	2.00	2.50	-20.00	-13.00	0.04	0.05
M4	-0.50	0.00	-1.50	5.50	-3.28	-4.33	0.02	0.05
M21	-7.52	-3.50	-1.50	3.08	-21.00	-36.00	0.11	0.29
M17	-16.00	-4.83	-1.50	4.50	-16.00	-6.00	-0.12	0.00
Pusa Bindu	-22.50	5.50	1.50	3.00	-4.00	-3.00	-0.48	0.21
Mattigulla	4.00	-9.50	-0.50	-4.50	-15.00	-25.33	0.36	0.16
Ramdurga	-9.66	-26.50	-2.50	0.50	-29.68	-15.00	0.36	-0.25
Malapur Local	0.50	-5.25	2.50	-2.00	-19.00	-21.33	0.28	0.08
Pant Samrat	8.75	5.39	0.00	2.00	-19.00	-12.33	0.49	0.30
IC90785	6.00	10.50	0.50	3.50	-12.00	-18.33	0.27	0.58
IC99676- LONG	10.50	3.50	1.50	0.50	-9.50	-15.33	0.52	0.28
IIHR-7	17.45	5.00	1.00	2.94	0.00	-21.33	0.58	0.45
Punjab Sadabahar	-2.50	-0.50	1.50	-1.50	-0.87	-9.00	-0.05	0.09
L-2232	12.00	10.50	2.00	6.50	-14.50	-7.33	0.45	0.36
IC99676- ROUND	4.50	6.50	0.50	2.50	-10.50	-13.67	0.20	0.36
Aruna	17.00	-2.75	-1.00	-3.00	-3.00	-18.67	0.50	0.20
Shobha	3.50	5.00	-1.00	5.50	-7.00	-12.33	0.24	0.31
Long Green	-10.40	6.00	-0.50	0.00	-5.50	-15.00	-0.11	0.32
Swarna Manjari	8.50	-10.50	-1.00	-4.50	-9.22	-11.67	0.29	-0.06
Melavanki	12.26	4.50	1.50	6.00	-1.00	-19.00	0.29	0.36
Hebbal Gulla	13.50	7.50	3.00	4.57	5.00	-15.67	0.23	0.33
R-2581	11.00	11.00	0.50	2.00	-11.50	-14.67	0.47	0.39
Swarna Pratibha	12.50	8.50	2.50	4.50	-11.50	-27.33	0.43	0.59
Round Green	11.00	10.45	-0.50	4.50	-11.50	-9.00	0.34	0.32
L-2230	10.00	5.50	3.50	1.50	-4.00	0.33	0.33	0.12
M19	-4.00	-2.84	3.00	2.50	-10.50	-28.36	0.04	0.38
CH-215	-18.00	-15.50	-2.00	1.00	-22.00	-5.14	-0.02	-0.24
Jawahar Brinjal-8	-19.50	-28.56	-5.00	-3.15	-26.00	-11.00	0.20	-0.44
Swarna Mani	7.50	-2.75	-3.00	-3.50	-22.00	-12.00	0.57	0.19
IC90691	0.50	-7.50	0.00	-3.00	-19.50	-19.33	0.35	0.22
Jawahar Brinjal-69	6.00	8.50	0.50	1.59	-11.05	-10.33	0.31	0.41
Very Green Long	11.00	11.50	4.50	6.50	18.50	-9.67	-0.16	0.44
IC354597-ROUND	16.29	17.47	2.00	6.00	-9.50	-12.67	0.54	0.66
CO-2	10.50	8.00	-3.00	2.00	-17.00	-23.00	0.54	0.53
Solanum macrocarpon	-1.50	0.75	-0.50	0.42	-26.00	-21.33	0.57	0.45
Solanum indicum	4.50	6.29	0.50	6.97	-11.50	-25.00	0.45	0.43
Solanum torvum	-7.00	6.50	2.00	0.50	-3.50	-24.33	-0.05	0.91
Solanum mammosum	8.50	7.28	2.50	2.31	-1.50	-10.33	0.21	0.28
Mean Total	1.74	0.61	0.47	1.59	-11.05	-13.52	0.23	0.23

Table 6: Comparative overall mean performance of eggplant genotypes for various traits

Characters	Normal moisture condition	Moisture stress condition	Changes in mean value under moisture stress condition compared to normal moisture	Change in percent mean under moisture stress condition compared to normal moisture
Physiological characters during flower initiation stage				
Leaf canopy temparature (°C	32.14	35.37	+3.22	+10.16
SPAD Chlorophyll reading	51.42	58.95	+7.53	+14.87
Membrane Stability Index (MSI)	25.74	36.39	+10.65	+92.07
Relative Water Content (RWC)	89.87	51.81	-38.06	-42.60
Epicuticular wax (mg/dm^2)	1.32	1.41	+0.09	+7.67
Physiological characters during fruit initiation stage				
Leaf canopy temparature (°C)	26.67	27.50	+0.83	+3.15
SPAD Chlorophyll reading	59.01	65.26	+6.25	+12.11
MSI	16.37	23.08	+6.71	+50.86
RWC	76.71	43.33	-33.37	-43.15
Epicuticular wax (mg/dm^2)	1.20	1.46	+0.26	+33.50
Root characters during flower initiation stage				
Root length (cm)	32.44	34.18	+1.74	+11.98
Shoot length (cm)	50.14	39.10	-11.045	-18.27
Root to shoot ratio	0.67	0.90	+0.23	+41.39
Number of lateral roots	14.22	14.69	+0.47	+4.71
Root characters during fruit initiation stage				
Root length (cm)	32	32.61	+0.61	+6.85
Shoot length (cm)	52.8	39.28	-13.52	-23.29
Root to shoot ratio	0.63	0.85	+0.23	+45.94
Number of lateral roots	23.92	25.51	+1.59	+8.076

Estimate of genetic variability for physiological and root traits

The high PCV and GCV reported by MSI, RWC, epicuticular wax, root length and root to shoot ratio was observed for moisture stressed condition as well as in normal moisture condition during both the developmental stage of eggplant. Except, RWC during fruit initiation stage in normal moisture condition was found low (Table 2 and Table 3). The moderate PCV and GCV found in parameters like SPAD and number of lateral roots. The maximum GCV value over PCV value for particular character represents the presence of variation is mainly due to genetic constitution of plant with less environmental factor influence. The maximum percentage of GCV and PCV value contribute maximum towards greater diversity. The obtained results revealed that the use of above-mentioned trait would have ample scope for selection of genotype for drought tolerance. The obtained results are in accordance with findings of Nautiyal *et al.* (2008) [34], Nayak and Nagre (2013) [35], Usha and Bhumika (2012) [58], Khadem *et al.* (2010), Solanki and Sarangi (2015) [54], Bangar *et al.* (2019) [3], Rouhani *et al.* (1986). Franco *et al.* (2011) [18] and Wasaya *et al.* (2018) [59]. The leaf canopy temperature had reported low GCV and PCV value because of high environmental factor influence (Melandri *et al.*, 2019) [31]. Though Mukherjee *et al.* (2010) [33] and Ndiso *et al.* (2016) [36] reported that genetic variability for leaf canopy temperature existence and it was negatively related with yield.

The high broad sense heritability coupled with high genetic advance over mean was found in SPAD, MSI, RWC, epicuticular wax, root length, shoot length, number of lateral roots per plant and root to shoot ration was observed for moisture stressed condition as well as in normal moisture condition during flower initiation and fruit initiation developmental stage of eggplant. Except, RWC was found moderate during fruit initiation stage in normal moisture condition (Table 2 and Table 3). All traits are having maximum broad sense heritability in moisture stressed condition and normal moisture condition during both the developmental stage. Except leaf canopy temperature during fruit initiation stage in both moisture level found low. The traits having maximum heritability would help in selection of elite genotypes from diverse eggplant population for drought tolerance. In order to improve effectiveness of selection heritability tied with genetic advance over mean which explains the traits having high broad sense heritability coupled with high genetic advance over mean might be governed by additive gene action and have a great scope for direct selection of drought tolerant eggplant genotype (Gobu *et al.*,2017) [21]. Similarly, the consent results findings were reported by Chakravarti *et al.* (2010) [33], Gobu *et al.* (2017) [21], Bangar *et al.* (2019) [3], Khadem *et al.* (2010) [26], Solanki and Sarangi (2015), Rouhani *et al.* (1986) [53]. Franco *et al.* (2011) [18] and Wasaya *et al.* (2018) [59], Sangakkara *et al.* (2010) [47], Steele *et al.* (2013) [56], Pace *et al.* (1999) [37], Ahmad *et al.* (2009) [1], Saensee *et al.* (2012) [44] and Mili *et al.* (2014) [32].

Conclusion

Based on comparative mean performance of physiological and root traits the best perfoming ten drought tolerant genotypes were screened in accounted to all trait. Out of 50 eggplant genotypes the genotypes used like Very Green Long, Pusa Upkar, Swarna Pratibha, Pusa Ankur, *Solanum indicum*, IIHR-322, R-2580, M4, *Solanum torvum* and IIHR-7 are having desirable feature for particular trait. Further, the factorial analysis results revealed that the flower initiation stage is more sensitive to moisture stress compare fruit initiation stage and most suitable stage for screening for drought stress. The trait like SPAD, MSI, RWC, epicuticular wax, root length, shoot length, number of lateral roots per plant and root to shoot ration have maximum heritability tied with high genetic advance over mean. The direct selection for drought tolerant genotypes over these traits would be helpful.

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