

# Impact of drought on flowering, yield and quality parameters in diverse genotypes of tomato (*Solanum lycopersicum* L.)

R. Sivakumar (\*), S. Srividhya

Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India.

**Key words:** ascorbic acid, drought, flower abscission, lycopene, soluble protein, SPS, yield.

**Abstract:** The effect of drought stress on flowering, yield and quality of tomato (*Solanum lycopersicum*) genotypes was investigated under field conditions in rainout shelter. The drought condition was imposed on the first day after transplanting based on field capacity of soil. Experimentation was undertaken with ten genotypes adopting Factorial Randomized Block Design with three replications and two treatments viz., 1.0 IW/CPE and 0.5 IW/CPE field capacity. As the stress increased from 100% field capacity to 50% field capacity, reductions in chlorophyll index, soluble protein content, days to flower initiation, sucrose phosphate synthase (SPS) activity, fruit volume, fruit diameter, yield and increased flower abscission percentage were noted. Significant increases in TSS and lycopene were observed under drought. The genotypes LE 118, LE 57 and LE 114 showed significantly less reduction in soluble protein content; SPS activity and fruit yield during drought were considered as drought tolerant. Genotypes LE 1 and LE 125, which gave the lowest soluble protein content, SPS activity and ultimately poor yield, were considered as drought susceptible.

## 1. Introduction

Drought stress can affect plant growth, development and yield. It has been estimated that up to 45% of world agricultural lands are subjected to drought (Bot *et al.*, 2000). Water deficit leads to the perturbation of most of the physiological and biochemical processes and consequently reduces plant growth and yield (Boutraa, 2010). Abscission of reproductive organs like flower buds and flowers is a major yield-limiting factor in vegetable crops (Wien *et al.*, 1989). The abscission of floral organs during stresses has been associated with changes in physiological processes (Aloni *et al.*, 1996).

It has been reported that, in tomato, the abscission of flowers and flower buds and the reduction in photosynthesis were higher in susceptible cultivars compared to tolerant cultivars (Bhatt *et al.*, 2009). In soybean, flower retention and fruit set are highly sensitive to environmental stresses (Kokubun *et al.*, 2001). Etsushi *et al.* (2009) reported that Soil Plant Analytical Development (SPAD) method readings sig-

nificantly correlated with chlorophyll content, rubisco content, photosynthetic rate, and Fv/Fm ratio. A major portion of soluble protein (50%) in leaves is occupied by rubisco, a prime enzyme for carbon fixation in photosynthesis (Noggle and Fritz, 1986). Daniel and Triboi (2002) showed that heat stress decreased the duration of soluble protein accumulation in terms of days after anthesis but not in terms of thermal time.

Drought decreased leaf N, whereas heat stress did not influence it and, however, the total soluble protein content was decreased during drought, heat, and a combination of drought and heat. Heat and drought stress induced suppression of photosynthesis by mainly decreasing the proportion of soluble protein to total leaf N, adversely affecting the rubisco protein and activity (Xu and Zhou, 2006). Bhatt *et al.* (2009) reported there was a considerable decrease in SPS activity in flowers under water deficit condition; a relatively higher decrease was observed in the susceptible genotypes. SPS activity was shown to decrease during leaf desiccation (Foyer *et al.*, 1998), or to remain constant (Zrenner and Stitt, 1991). However, Yang *et al.* (2002) and Niedzwiedz-Siegen *et al.* (2004) observed an increase in SPS activity in rice and wheat leaves, respectively, under

(\* Corresponding author: [sivatnau5@gmail.com](mailto:sivatnau5@gmail.com))

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mild drought.

Tomato (*Solanum lycopersicum*) is one of the most popular and widely grown vegetables in the world. Considering the potentiality of this crop, there is plenty of scope for its improvement, especially under the drought situation. Water is a scarce resource for irrigation. Although the concept of drought tolerance has been viewed differently by molecular biologists, biochemists, physiologists and agronomists, the major concern is to enhance the biomass and yield under limited water input, which is a characteristic feature of rainfed agriculture.

There are several physiological and biochemical traits contributing to the drought tolerance of horticultural crops. However, a large number of tomato genotypes have not been screened for drought tolerance or exploited for their cultivation under drought. To breed drought tolerant genotypes, it is necessary to identify physiological traits of plants which contribute to drought tolerance. Chlorophyll pigments and soluble protein content in leaves which have a greater correlation to crop yield show reduced levels under drought. The reproductive stage of the crop is highly sensitive to any abiotic stress. Hence, reduction in crop yield under drought is mainly attributed to the effect on flowering characters and a decrease in SPS enzyme activity. Therefore, the present investigation was carried out to study the physiological traits such as SPAD value, soluble protein content, SPS activity, flowering characters, and yield to facilitate the screening and selection of tomato genotypes for drought tolerance.

## 2. Materials and Methods

### *Plant materials and cultivation*

The study was undertaken to determine the effect of drought on flowering and yield of tomato genotypes in the field experiment at Rainout Shelter of Crop Physiology Department, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during 2012-13. The experiment was conducted with 10 tomato genotypes (LE 1, LE 27, LE 57, LE 114, LE 118, LE 125, CO 3, PKM 1, TNAU THCO 3 and COTH 2) and two treatments (1.0 and 0.5 IW/CPE (Irrigation Water/Cumulative Pan Evaporation) with three replications following a Factorial Randomized Block Design. Seeds of selected genotypes were sown in trays filled with vermicompost for nursery use. Twenty-five day old seedlings were transplanted in the rainout shelter;

plot size 1.35 x 1.5 m. Drought was imposed on the first day after transplanting to all genotypes in both IW/CPE ratio treatments. Furrow irrigation was applied when the cumulative pan evaporation reading reached 50 mm (1.0 IW/CPE ratio) and 75 mm (0.50 IW/CPE ratio). Crop was supplied with FYM (25 t/ha rate), NPK fertilizers (75:100:50 kg/ha), borax 10 kg and zinc sulphate 50 kg/ha as basal dose and 75 kg N/ha on the 30th day after planting during earthing up. Other cultivation operations including weed control (Applied Pendimethalin 1.0 kg a.i./ha as pre-emergent herbicide followed by one hand-weeding at 30 days after planting) and plant protection measures were carried out as per the recommended package of practices of Tamil Nadu Agricultural University, Coimbatore.

### *Physiological parameters*

SPAD readings were recorded using Chlorophyll Meter (SPAD 502) designed by the Soil Plant Analytical Development (SPAD) section, Minolta, Japan. Data were recorded as described by Peng *et al.* (1996). Soluble protein content of the leaf was estimated as per the method of Lowry *et al.* (1951) and expressed as mg g<sup>-1</sup> FW. Sucrose phosphate synthase (SPS) activity was determined as described by Pavlinova *et al.* (2002). Sucrose was measured using anthrone reagent as modified by Ashwell (1957). Absorbance was measured at 630 nm and the activity was expressed in mg sucrose mg<sup>-1</sup> protein h<sup>-1</sup>.

### *Flowering parameters*

Days to flowering (the number of days from seedling emergence to opening of the first flower) were recorded for each plant in the three replications and the average was taken. Abscission study was conducted on single flower basis. Flower number of tagged plants and dropped flowers per plant were counted every three days. These records were used to calculate the flower abscission and expressed in terms of percentage.

### *Yield parameters*

Average fruit weight was calculated by adding the weight of five fruits from each plant at second harvest and dividing it by the total number of fruits and expressed in g fruit<sup>-1</sup>. The fruit volume was estimated by water displacement method. Individual fruits were immersed in 1 L of water; amount of water displaced was measured and volume was worked out per fruit and expressed as cc. Polar diameter was measured from stalk end to blossom end of fruit by using Vernier Calipers and the average of five fruits

was worked out and expressed in cm. The fruit weight per plant was recorded in control and stressed plants for each picking and fruit yield (kg per plant) was calculated as fresh weight of fruits in all the pickings.

#### Quality parameters

Juice extracted from cut fruit was used to determine TSS with the help of a Hand Refractometer (0 to 32°Brix) at room temperature and the value was noted in °Brix. Ripened fruit samples were analyzed for ascorbic acid content, using 2,6-Dichlorophenol indophenol dye titrimetrically as per Sadasivam and Manickam (1996). Lycopene content of fruit was extracted using petroleum ether and OD of the extract was measured at 503 nm in UV-VIS-spectrophotometer using petroleum ether as a blank (Ranganna, 1986). Lycopene content of the sample was calculated using the following formula and expressed in mg 100 g<sup>-1</sup>.

$$\text{Lycopene} = \frac{3.1206 \times \text{OD of sample} \times \text{volume made up} \times \text{dilution}}{\text{Weight of sample} \times 1000} \times 100$$

#### Statistical analysis

Data from the various parameters were analyzed statistically as per the procedure of Gomez and Gomez (1984).

### 3. Results

#### Decreased SPAD value under drought

Control (1.0 IW/CPE) plants showed a higher mean chlorophyll index value (47.57) than treated (0.5 IW/CPE) plants (44.04). Among the genotypes, CO 3 and PKM 1 recorded significantly higher chlorophyll index values of 50.1 and 46.1, and 49.5 and 46.7 at 1.0 IW/CPE and 0.5 IW/CPE conditions, respectively. During drought, the genotypes LE 114 (45.8), LE 57 (45.7), COTH 2 (45.5) and LE 118 (45.0) were found to be on par with each other.

#### Decreased soluble protein due to drought

Control (1.0 IW/CPE ratio) plants showed a higher mean soluble protein content (13.26) than the drought (0.5 IW/CPE ratio) imposed plants (8.98). Among the genotypes, COTH 2 (15.63) and THCO 3 (15.18) registered the highest soluble protein content under 1.0 IW/CPE ratio level and LE 57 (11.99) and LE

118 (11.74) under drought conditions (0.5 IW/CPE). The lowest soluble protein content was found for LE 125 (8.16) and LE 1 (8.68) (Table 1).

Table 1 - Effect of drought on chlorophyll index SPAD value and soluble protein content of tomato genotypes at 60 DAT

Genotypes	SPAD value			Soluble protein (mg g <sup>-1</sup> )		
	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean
LE 1	42.00	<u>38.40</u>	40.20	10.85	<u>6.51</u>	8.68
LE 27	48.20	44.40	46.30	13.98	10.72	12.35
LE 57	47.60	45.70	46.70	15.03	<b>11.99</b>	13.51
LE 114	48.20	45.80	47.00	13.43	10.19	11.81
LE 118	48.40	45.00	46.70	14.58	<b>11.74</b>	13.16
LE 125	45.00	<u>39.50</u>	42.30	11.07	<u>5.24</u>	8.16
CO 3	50.10	46.10	48.10	11.55	8.69	10.12
PKM 1	49.50	<b>46.70</b>	48.10	11.33	7.69	9.51
THCO 3	48.40	43.30	45.90	15.18	8.46	11.82
COTH 2	48.30	45.50	46.90	15.63	8.58	12.11
<b>Mean</b>	<b>47.57</b>	<u><b>44.04</b></u>	45.82	<b>13.26</b>	<u><b>8.98</b></u>	11.12
	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>
<b>SEd</b>	1.15	0.38	1.62	0.137	0.061	0.194
<b>CD (0.05)</b>	2.28	0.76	NS	0.278	0.124	0.393

#### Altered flowering characters from drought

Our data on number of days to flower initiation revealed that genotypes, treatments and interactions attained statistical significance (Table 2). In the case of treatments, the plants under drought initiated flowers earlier (26) than control plants (30). At 0.5

Table 2 - Effect of drought on flowering characters of tomato genotypes during flowering stage

Genotypes	Days to flower initiation (DAT)			Flower abscission (%)		
	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean
LE 1	29	25	27	10.90	<b>20.10</b>	15.50
LE 27	30	27	29	13.20	15.80	14.50
LE 57	30	25	28	12.60	<u>15.10</u>	13.80
LE 114	29	26	28	11.90	15.40	13.70
LE 118	32	<b>28</b>	30	10.90	13.90	12.40
LE 125	31	25	28	11.90	17.10	14.50
CO 3	26	<u>23</u>	25	10.20	15.90	13.10
PKM 1	28	24	26	9.90	16.40	13.20
THCO 3	32	<b>28</b>	30	10.90	17.40	14.20
COTH 2	31	27	29	11.20	<b>18.10</b>	14.70
<b>Mean</b>	<b>30</b>	<u><b>26</b></u>	28	<u><b>11.40</b></u>	<b>16.50</b>	13.90
	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>
<b>SEd</b>	0:18	0:08	0:26	0.08	0.03	0.11
<b>CD (0.05)</b>	0:37	0:17	0:52	0.16	0.07	0.22

IW/CPE ratio level, LE 118, THCO 3 (28), LE 27 and COTH 2 (27) registered a delay in flowering compared to other genotypes. The variety CO 3 showed its supremacy for earlier flowering, both under control (26) and drought (23) conditions, compared to the other genotypes; PKM 1 (28 and 24) ranked next.

The differences due to genotypes, treatments and interactions attained significance for flower abscission (Table 2). Among the treatments, the plants imposed with 1.0 IW/CPE ratio recorded lesser mean percentage of flower abscission (11.4) than 0.5 IW/CPE ratio plants (16.5). Among the genotypes, LE 1 recorded greater mean percentage of flower abscission (15.5) than the other genotypes considered. Interestingly, among the control plants, LE 27 and LE 57 recorded higher flower abscission (13.2, 12.6) while, under drought, LE 1 and COTH 2 recorded higher flower abscission of 20.1 and 18.1, respectively. At 0.5 IW/CPE ratio level, LE 118 showed its supremacy with lower abscission of 13.9 followed by LE 57 (15.1), LE 114 (15.4) and LE 27 (15.8).

SPS is the plant enzyme thought to play a major role in sucrose biosynthesis. It is considered to play a major role in the re-synthesis of sucrose (Wardlaw and Willenbrink, 1994) and sustain the assimilatory carbon flux from source to developing sink (Isopp *et al.*, 2000). Among the genotypes, LE 57 recorded significantly higher enzyme activity of 2.75 under control followed by the genotypes LE 27 (2.61), LE 118 (2.53) and LE 114 (2.46). At 0.5 IW/CPE ratio level,

the highest activity of 1.97 was registered by LE 118 followed by LE 57 (1.90) while the lowest was recorded by LE 1 (0.57) and LE 125 (0.69) (Fig. 1).

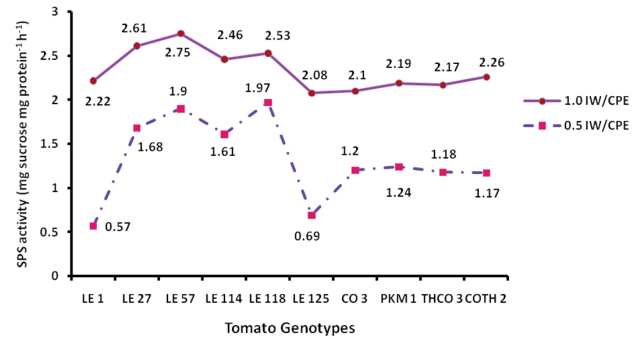


Fig. 1 - Effect of drought on SPS activity of tomato genotypes at 60 DAT.

The data on yield components such as average fruit weight, fruit volume, fruit diameter, fruit number and fruit yield attained statistical significance except fruit diameter. Comparing the treatments, control (1.0 IW/CPE ratio) plants recorded higher fruit weight (20.25) than under drought condition (13.75) (Table 3). Relating the genotypes, COTH 2 recorded higher fruit weight of 45.40 which was on par with THCO 3 (44.45) at 1.0 IW/CPE ratio level while the lowest was registered by LE 125 (9.06) followed by LE 57 (9.48). At 0.5 IW/CPE ratio level, relatively higher fruit weight was recorded by COTH 2 (29.87) followed by THCO 3 (28.78), CO 3 (19.93),

Table 3 - Effect of water deficit on the yield parameters of tomato genotypes

Genotypes	Average fruit weight (g)			Fruit volume (cc)			Fruit diameter (cm)		
	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean
LE 1	11.18	<u>5.72</u>	8.45	12.020	<u>6.48</u>	9.25	3.41	<u>2.43</u>	2.920
LE 27	10.68	7.23	8.96	11.52	7.95	9.74	3.34	3.05	3.20
LE 57	9.48	7.89	8.69	10.09	8.62	9.36	3.11	<u>3.48</u>	3.30
LE 114	9.55	7.49	8.52	10.31	8.25	9.28	3.53	3.25	3.39
LE 118	10.01	<b>7.95</b>	8.98	10.92	8.61	9.77	4.12	3.76	3.94
LE 125	9.06	<u>3.89</u>	6.48	9.65	<u>4.64</u>	7.15	3.30	<u>2.72</u>	3.01
CO 3	26.38	19.93	23.16	28.39	22.69	25.54	5.40	4.84	5.12
PKM 1	26.31	18.75	22.53	28.34	22.49	25.42	5.51	4.71	5.11
THCO 3	44.45	<b>28.78</b>	36.62	48.02	<b>29.64</b>	98.33	6.57	5.59	6.08
COTH 2	45.40	<b>29.87</b>	37.64	48.95	<b>30.69</b>	39.82	6.31	<b>5.73</b>	6.02
<b>Mean</b>	<b>20.25</b>	<u>13.75</u>	17.00	<b>21.82</b>	<u>15.01</u>	18.41	<b>4.46</b>	<u>3.96</u>	4.21
	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>
<b>SEd</b>	0.582	0.260	0.823	0.594	0.266	0.841	0.053	0.024	0.075
<b>CD (0.05)</b>	1.178	0.527	1.667	1.203	0.538	1.702	0.108	0.048	0.152

PKM 1 (18.75), LE 118 (7.95) and LE 57 (7.89).

The data on fruit volume recorded similar trend of fruit weight. Regarding the treatments, the plants imposed with 1.0 IW/CPE ratio recorded the fruit volume of 21.82 than 0.5 IW/CPE ratio (15.01) (Table 3). Under control, higher volume of fruit was recorded in the genotype COTH 2 (48.95) which was on par with THCO 3 (48.02). Under 0.5 IW/CPE ratio level, the lowest fruit volume was recorded by LE 125 (4.64) followed by LE 1 (6.48). Other than hybrids and varieties, LE 57 showed higher fruit volume of 8.62 followed by LE 118 (8.61), LE 114 (8.25) and LE 27 (7.95) at 0.5 IW/CPE ratio level.

With regard to fruit diameter, THCO 3 (6.08) and COTH 2 (6.02) recorded higher average diameter of fruits which was on par with each other. For treatments, plants imposed with 1.0 IW/CPE ratio recorded higher fruit diameter (4.46) than 0.5 IW/CPE ratio (3.96) (Table 3). Among the genotypes, COTH 2 registered higher fruit diameter of 5.73 followed by THCO 3 (5.59), CO 3 (4.84) and PKM 1 (4.71) at 0.5 IW/CPE ratio level. Other than hybrids and varieties, LE 118 showed higher fruit diameter of 3.76 followed by LE 57 (3.48), LE 114 (3.25) and LE 27 (3.05) at 0.5 IW/CPE ratio condition while the lowest was recorded by LE 1 (2.43) and LE 125 (2.72).

Comparing the irrigation treatments, plants that received 1.0 IW/CPE ratio recorded higher fruit yield than 0.5 IW/CPE ratio (Fig. 2). Among the genotypes, LE 57 recorded significantly superior fruit yield of 16.64 followed by COTH 2 (15.89), LE 118 (15.02),

THCO 3 (14.67) and LE 27 (14.42) with 1.0 IW/CPE ratio level. But, at 0.5 IW/CPE ratio condition, LE 57 documented higher fruit yield of 11.12 followed by LE 118 (10.14), LE 114 (8.54) and LE 27 (8.13) while the lowest yield of 2.22 was recorded by LE 125 followed by LE 1 (2.57).

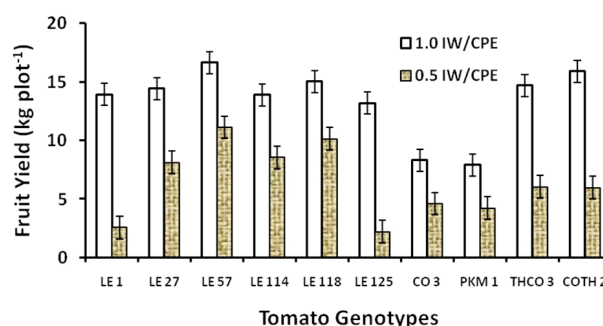


Fig. 2 - Effect of drought on the yield of tomato genotypes.

#### Quality parameters were altered under drought

The data on TSS content of the fruits revealed that the genotypes, treatments and interactions attained statistical significance (Table 4). Among the treatments, plants imposed with 0.5 IW/CPE ratio recorded higher brix value (3.01) than 1.0 IW/CPE ratio (2.89). Among the genotypes, THCO 3 recorded higher average brix value of 4.00 than the rest of the genotypes. At 0.5 IW/CPE ratio condition, the highest TSS value was recorded by THCO 3 (4.1) followed by COTH 2 (3.9), PKM 1 (3.6) and CO 3 (3.4) while the lowest was registered by LE 125 (2.2).

Plants imposed with 0.5 IW/CPE ratio recorded

Table 4 - Effect of water deficit on fruit quality of tomato genotypes

Genotypes	TSS (° Brix)			Lycopene (mg 100 g <sup>-1</sup> )			Vitamin C (mg 100 g <sup>-1</sup> )		
	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean	1.0 IW/CPE	0.5 IW/CPE	Mean
LE 1	2.50	2.70	2.60	2.21	2.39	2.30	14.45	14.42	14.44
LE 27	2.50	2.60	2.55	2.52	2.73	2.63	14.76	14.96	14.86
LE 57	2.40	2.60	2.50	2.46	2.68	2.57	14.95	15.30	15.13
LE 114	2.40	2.50	2.45	2.82	2.88	2.85	13.97	14.05	14.01
LE 118	2.40	2.50	2.45	2.85	2.95	2.90	14.36	14.36	14.36
LE 125	2.20	2.20	2.20	2.13	2.67	2.40	13.46	13.43	13.45
CO 3	3.30	3.40	3.35	4.54	4.84	4.69	24.05	24.17	24.11
PKM 1	3.50	3.60	3.55	3.78	4.05	3.92	23.06	23.21	23.14
THCO 3	3.90	4.10	4.00	3.35	3.53	3.44	15.42	15.64	15.53
COTH 2	3.80	3.90	3.85	3.54	3.55	3.55	16.19	16.30	16.25
<b>Mean</b>	<b>2.89</b>	<b>3.01</b>	2.95	<u>3.02</u>	<b>3.23</b>	3.12	<u>16.47</u>	<b>16.58</b>	16.53
	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>	<b>G</b>	<b>T</b>	<b>G x T</b>
<b>SEd</b>	0.03	0.01	0.04	0.048	0.022	0.068	0.147	0.066	0.208
<b>CD (0.05)</b>	0.05	0.02	0.07	0.097	0.044	0.138	0.297	NS	NS

higher lycopene content (3.23) than 1.0 IW/CPE ratio (3.02). With respect to the genotypes, CO 3 recorded significantly higher average lycopene content (4.69). At 0.5 IW/CPE ratio level, lowest lycopene content was recorded by LE 1 (2.39) and LE 125 (2.67). The data on vitamin C content indicated that a narrow increment under drought compared to control (Table 4). 0.5 IW/CPE ratio recorded higher ascorbic acid (16.58) than 1.0 IW/CPE ratio (16.47). Among the genotypes, CO 3 recorded higher average vitamin content of 24.11 followed by PKM 1 (23.14). At 0.5 IW/CPE ratio level, the higher value was registered by CO 3 (24.17) followed by PKM 1 (23.21), COTH 2 (16.30) and THCO 3 (15.64) while the lowest values were recorded by the genotypes LE 125 (13.43) and LE 114 (14.05). Interestingly, only genotypes attained significant difference not the treatments or interactions in the case of ascorbic acid.

#### 4. Discussion and Conclusions

In the present study, SPAD value, an index for total chlorophyll content in plants, showed a reduction under drought stress. Hawkins *et al.* (2009) reported that SPAD values can be used to evaluate the response of plant species to drought and heat stresses in the field. The adverse effect of drought on greenness of the leaf in the current investigation could be observed in the susceptible genotypes LE 125 and TNAU THCO 3 which depicted the highest reduction of SPAD values at the time of reproductive development stage. On the contrary, the tolerant genotype LE 57 showed only a very low reduction in SPAD value. Hence, the intensity of greenness in terms of SPAD values of the plant influenced the photosynthetic rate and thereby plant efficiency for increased biomass production. Ma *et al.* (1995) also reported a highly significant correlation of SPAD readings with photosynthetic rate in soybean.

The ability of the genotypes LE 57 and LE 114 to maintain high SPAD values under field conditions in response to water deficit has been revealed. Therefore, these genotypes were able to endure drought injury better than the sensitive lines.

The soluble protein content of the leaf, a measurement of RuBP carboxylase activity, was considered an index for photosynthetic efficiency. Rubisco enzyme makes up nearly 80% of the soluble proteins in leaves of many plants (Joseph *et al.*, 1981). Diethelm and Shibles (1989) opined that, the Rubisco content per unit leaf area was positively cor-

related with that of soluble protein content of the leaf.

Several studies have reported that drought stress in tomato (Bartholomew *et al.*, 1991), *Arabidopsis* (Williams *et al.*, 1994), and rice (Vu *et al.*, 1999) leads to a rapid decrease in the abundance of Rubisco small subunit (rbcS) transcripts, which may indicate the decreased synthesis of soluble protein.

The present study also confirms the above findings with a 32.3% reduction of soluble protein content under drought compared to control. Drought stress induces degradation of soluble proteins and this effect could be revealed through a reduction in leaf soluble protein content of various genotypes. In the present study, the reduction was, however, low in LE 118 and high in COTH 2 and THCO 3 under drought stress. Maintenance by the genotypes of soluble protein content could be attributed to higher Rubisco activity, leading to more carbon fixation and ultimately to higher photosynthetic efficiency under drought, which is one of the important traits for drought tolerance.

Reproduction is the crucial stage to be affected by any abiotic stress in any crop. An increase in the frequency of water stress days during flower development affects plant reproduction with immediate and long-term effects (Srivastava *et al.*, 2012). Drought stress, in general, induces early flowering and in the present study as well flower initiation occurred three days earlier than the control. This early flowering under drought might be due to rapid phenological development in order to complete the life cycle under an unfavorable environmental condition.

Differences due to genotypes, treatments and interactions attained significance for flower abscission (Table 2). Among the treatments, the plants imposed with 1.0 IW/CPE ratio recorded a lower mean percentage of flower abscission than plants under 0.5 IW/CPE. Among the genotypes, LE 1 recorded the highest percentage of flower abscission. Interestingly, under control conditions, genotypes LE 27 and LE 57 gave high flower abscission, while LE 1 and COTH 2 recorded higher flower abscission under drought. An earlier finding by Bhatt *et al.* (2009) in tomato strongly supports the results of the present study.

A lower rate of flower abscission in the tolerant genotypes might be due to the maintenance of photosynthesis and efficient translocation of photosynthates to the reproductive parts under drought. The reduction in photosynthesis during stress may decrease the availability of assimilates to the devel-

oping floral organs and leads to the abscission of flowers and flower buds in susceptible cultivars. However, some workers are of the opinion that the abortion of reproductive organs is not solely due to a poor assimilate supply but also due to other factors such as assimilate utilization (Ruiz and Guardiola, 1994; Aloni *et al.*, 1996).

In the present study, there was a reduction in SPS activity under drought conditions compared to control. The highest percent reduction (74.3) was observed in the genotype LE 1, however the lowest reduction was noted for LE 118. As observed also by Huber and Huber (1996), there was a significant elevation in SPS activity in response to water stress. In contrast to this finding, the present study revealed a decreased activity of SPS under drought conditions. Bhatt *et al.* (2009) observed a considerable reduction in SPS activity in susceptible cultivars during stress. The present study corroborates these findings. The reduced photosynthesis during water stress may also lead to a reduction in the capacity for both starch and sucrose synthesis and cause a decline in the SPS activity (Vassey and Sharkey, 1989).

Our results reveal that drought stress caused the reduction in fruit weight up to 30% under field conditions. Among the genotypes, LE 57, LE 118, and LE 114 had a lower reduction in fruit weight. All the genotypes exhibited a similar trend in fruit volume and fruit diameter in response to drought stress, which also caused remarkable changes in fruit number and an overall reduction up to 31% was observed compared to control. The reduction in fruit weight, in response to drought stress, had a direct influence on fruit yield of the various genotypes of tomato. Drought stress resulted in an overall yield loss of tomato fruits up to 55%. The greatest yield loss (70 to 80%) was exhibited by LE 1 and LE 125. The varieties and hybrids showed a reduction of fruit yield from 40.5 to 50.4% compared to control. Significantly less reduction (35 to 40%) was exhibited by LE 118, LE 57, LE 114, and LE 27 showing their somewhat tolerant nature toward drought stress (Fig. 2). Therefore, it can be clearly stated that water deficit, as a result of soil drying, caused a major adverse effect on yield and yield components even in tolerant genotypes. The present study confirms previous findings by Farooq *et al.* (2009) and Manjunatha *et al.* (2004). Doorenbos and Kassam (1979) indicated that the highest demand for water supply in tomato plants occurs at the flowering phase. Water deficit during this stage would have reduced the number of flowers produced and, as suggested by Mahendran

and Bandara (2000), limitation of water at flowering stage not only reduces flower formation but also increases flower shedding.

Purseglove *et al.* (1981) stated that, although the cultivar has a dominant influence over quality determinant properties, the environment in which it grows also has a significant role in the quality characters. Fruit quality, mainly total soluble solids, vitamin C, and acid contents have been reported to change under moisture stress (Kozłowski, 1972). However, in the present study, a slight enhancement in ascorbic acid content was noticed in all the genotypes in response to drought stress. Furthermore, TSS, Lycopene and citric acid content of the fruit also increased slightly. Our work corroborates earlier findings by Ali *et al.* (1980) in tomato. Also Nahar *et al.* (2011) explained that the fruit quality improvement under water deficit conditions in tomato might be due to the synthesis of ascorbic, citric, and malic acid. In the present study, LE 118, LE 57, and LE 27 showed their primacy with the highest ascorbic acid content, as well as higher TSS and lycopene content. This finding is strongly supported by Tambussi *et al.* (2000), who also reported that the increase in ascorbic acid might be an effective strategy to protect membranes from oxidative damage in water stressed condition.

From perusal of the results obtained for SPAD value, soluble protein, SPS activity, fruit characters, lycopene, ascorbic acid, TSS and yield, it can be inferred that genotypes LE 114, LE 57, LE 118, and LE 27 performed better under drought conditions and can be categorized as drought tolerant genotypes compared to genotypes LE 1 and LE 125, drought susceptible ones. However, further studies are required to confirm the results by molecular evidence. The tolerant genotypes could be utilized for further breeding programmes to evolve new tomato genotypes for better drought tolerance with higher yield.

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