Original Research A	Article
Impact of Drought on Chlorophyll, Soluble protein, Abscisic acid, Yield and Q	uality

Characters of Contrasting Genotypes of Tomato (Solanum lycopersicum)

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#### 5 Abstracts

Impact of drought stress on chlorophyll, chlorophyll fluorescence (Fv/Fm), chlorophyll 6 stability index (CSI), soluble protein, abscisic acid (ABA), yield and quality of tomato (Solanum 7 lycopersicum) genotypes was investigated for the assessment of drought tolerance under field 8 conditions in rainout shelter. The drought condition was created first day from transplanting 9 based on Irrigation water (IW) / Cumulative Pan Evaporation (CPE) of soil. Experiment was laid 10 out with 10 genotypes by adopting FRBD with three replications and two treatments viz., 11 12 1 IW/CPE and 0.5 IW/CPE. The result revealed that the reductions in chlorophyll content, Fv/Fm, chlorophyll stability index (CSI), soluble protein and yield were noticed at drought 13 condition (0.5 IW/CPE). The genotypes LE 114, LE 57, and LE 118 which showed significantly 14 less reduction in the above parameters during drought were considered as drought tolerant. 15 However, the ABA content and quality characters like total soluble solids (TSS), lycopene 16 content were increased under drought condition. Genotypes LE 1 and LE 125 which recorded the 17 lowest chlorophyll content, Fv/Fm, CSI, soluble protein and higher ABA content ultimately poor 18 yield were considered as drought susceptible. 19

20 Key words:

21 Drought; Tomato; Chlorophyll; Chlorophyll Fluorescence; Soluble protein; CSI; ABA; TSS

22 **1. Introduction** 

Drought is the major inevitable and recurring feature of semi-arid tropics and despite our improved ability to predict their onset, duration and impact, crop scientists are still concerned about it as it remains the single most important factor affecting the yield potentials of crop species. It is one of the serious environmental factor affecting plant growth, yield and quality. It induces various physiological and biochemical adaptations in plants. Drought is one of the most important factors for yield reduction in the majority of the cultivated areas, affected 40 to 60% of the world's agriculture lands [1].

Water deficit leads to the perturbation of most of the physiological and biochemical 30 processes and consequently reduces plant growth and yield [2]. Gladden et al. [3] showed that 31 water deficit earlier in the growth of tomato caused a significant reduction in leaf chlorophyll 32 content. Abdellah et al. [4] recorded the highest reduction in the chlorophyll content in 33 susceptible wheat cultivar under water stress of 30% FC. Water stress reduced the total 34 35 chlorophyll content significantly in different genotypes of moth bean and reduction was more pronounced in late flowering genotypes [5]. Sanadhya et al. [6] reported that the water stress 36 reduced the chlorophyll content and hill activity with increased levels of stress in mung bean. 37

There was a reduction of only 1.3% and 2.2% in Fv/Fm under moderate and severe stress compared to control in *Withania somnifera* [7]. Chlorophyll fluorescence emission well on the level of water stress and, thus, can be used to identify elevated drought tolerance in tomato for selection of resistant genotypes [8]. Decreased chlorophyll content and chlorophyll stability index under both moisture stress and temperature stress was found by Sairam *et al.* [9] in wheat.

Daniel and Triboi [10] showed that heat stress decreased the duration of soluble protein accumulation in terms of days after anthesis but not in terms of thermal time. Few studies have investigated the combined influence of drought and heat stress on nitrogen metabolism. Abdellah *et al.* [4] reported that the increased ABA content was observed in wheat cultivar by water stress (30% FC) over control. Under intense water stress, the concentrations of ABA in plants increases, which trigger a number of processes starting from decrease in turgor pressure, decline in cellular expansion and stomatal closure to reduce water loss in leaves [11].

Meenakumari et al. [12] studied the physiological parameter governing drought tolerance 51 in maize and recorded more than 80 per cent reduction in yield in highly susceptible lines while 52 in relatively tolerant genotypes reduction was up to 50 per cent. Manojkumar et al. [13] reported 53 that water stressed tomato plants showed significant difference in the TSS level at different 54 irrigation levels. As the irrigation frequency increased TSS level decreased. Maximum per cent 55 TSS was observed under IW/CPE ratio of 0.60 (6.10%) and minimum was recorded at the 56 IW/CPE ratio of 1.20 (4.80%). The fruit quality improvement was observed under water deficit 57 condition in tomato as a result of the synthesis of ascorbic acid, citric acid and malic acid [14]. 58

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. Some of the adoptive mechanisms of plants to drought stress, which do not decreases plant yield to a greater extent, assume greater importance. There are several physiological and biochemical traits contributing to the drought tolerance of horticultural crops. However, large number of tomato genotypes have not been screened for drought tolerance or exploited for their cultivation under drought situation and

66 field condition.

To breed drought tolerant genotypes, it is necessary to identify physiological traits of plants, which contributes to drought tolerance. Therefore, the present investigation was carried out to study the chlorophyll characters, soluble protein and ABA to facilitate the screening and selection of tomato genotypes for drought tolerance.

71

#### 2. Materials and Methods

72 The study was undertaken to find out effect of drought on chlorophyll characters, 73 soluble protein, ABA, yield and quality in tomato in the field experiment at Rainout Shelter 74 of Crop Physiology Department, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. 75 The experiment was conducted with 10 tomato genotypes viz., LE 1, LE 27, LE 57, LE 114, 76 LE 118, LE 125, CO 3, PKM 1, TH CO 2 and TNAU TH CO 3 and two treatments viz., 1.0 77 IW/CPE and 0.5 IW/CPE with three replications. Seeds of selected genotypes were sown in 78 trays filled with vermicompost for nursery. Twenty five days old seedlings were 79 transplanted and drought was imposed at first day after transplanting onwards based on IW/CPE, 0.5 IW/CPE for drought stress and 1.0 IW/CPE for control were maintained by 80 irrigation the field at regular interval based cumulative pan evaporation. Crop was supplied 81 82 with fertilizers and other cultivation operations including plant protection measures as per recommended package of practices of Tamil Nadu Agricultural University, Coimbatore. All the 83 observations were recorded on third leaf from top at 60 DAT. The experiment was laid out in 84 factorial randomized block design with three replications. 85

86 **2.1. Chlorophyll characters** 

87 Total chlorophyll content was estimated following the method suggested by Arnon [15]
88 and expressed as mg g<sup>-1</sup>. Chlorophyll fluorescence measurements were recorded using Plant
89 Efficiency Analyzer (Hansatech, UK) following the method advocated by Lu and Zhang [16].

90 Measurements were made on intact leaves, which were dark adapted for 30 min prior to 91 measurement. The minimal fluorescence level ( $F_0$ ) with all PS II reaction centers open was 92 assessed by measuring the modulated light, which was sufficiently low (< 0.1 µmol m<sup>-2</sup> s<sup>-1</sup>) not to 93 induce any significant variable fluorescence. The maximal fluorescence level (Fm) with all PS II 94 reaction centers closed were determined by a 0.8 s saturating pulse at 8000 µmol m<sup>-2</sup> s<sup>-1</sup> in dark 95 adapted leaves [17]. Using light and dark fluorescence parameters, the maximal efficiency of PS II 96 photochemistry in the dark adapted state, Fv/Fm = (Fm-Fo) / Fm [18] was calculated.

97 Estimation of CSI was carried out based on the protocol of Koleyoras [19] and expressed
98 in terms of per cent by using following formula.

 99
 Total chlorophyll content (Treated)

100 Chlorophyll stability index (CSI) = ------ x 100

101Total chlorophyll content (Control)

#### 102 **2.2. Estimation of protein and ABA content**

Soluble protein content of leaf was estimated as per the method of Lowry *et al.* [20] and expressed as mg g<sup>-1</sup> fresh weight. Quantification of **abscisic acid** was done by using the instrument HPLC cyber lab with the column of RP 18 (4.6 mm ID x 250 mm) and mobile phase of acetonitrile (60) and water (40) by adopting the protocol of Krochko *et al.* [21]. Leaf samples were extracted using 80 per cent chilled methanol following series of steps and finally partially purified methanolic extracts were filtered through 0.52  $\mu$ m Millipore filters and injected into 20  $\mu$ L injector loop fitted over the Cyber lab RP protected by guard column.

110 A volume of 20  $\mu$ L of sample was injected into HPLC. The elution was carried out by 111 a binary gradient of 60 per cent HPLC grade acetonitrile for 20 minute at the flow rate of 1 112 mL min<sup>-1</sup>.

113 The column elutes were passed through an UV detector set at 254 nm and the ABA 114 were estimated measuring the peak area and comparing with standard curve of hormones. 115 The peak areas were measured and ABA concentration quantified using the standard curve 116 obtained from ABA.

117 The total weight of fruits harvested from each plant of all picking was added and average 118 yield per plant was worked out and expressed in gram per plant. Later the **yield per hectare** was 119 calculated and expressed as tonnes per hectare.

#### 120 **2.3. Quality characters**

Drop of juice extracted from cut fruit was used to determine **TSS** with the help of Hand Refractometer (0 to 32°Brix) at room temperature and the value was noted in °Brix. Lycopene content of fruit was extracted by using petroleum ether and OD of the extract was measured at 503 nm in UV-VIS-spectrophotometer using petroleum ether as a blank [22].

125 **Lycopene** content of the sample was calculated by using the following formula and 126 expressed in mg  $100 \text{ g}^{-1}$ .

3.1206 x OD of sample x volume made up x dilution
 Lycopene = ------ x 100
 Weight of sample x 1000
 The data on various parameters were analyzed statistically as per the procedure suggested
 by Gomez and Gomez [23]. Wherever the treatment differences are found significant, critical

differences were worked out at five per cent probability level and the values were furnished anddiscussed.

134

#### 135 **3. Results and Discussion**

#### 136 **3.1. Impact of drought on chlorophyll characters**

The intensity of the greenness in terms of chlorophyll content of the plant had 137 influenced the photosynthetic rate and thereby the efficiency of the plant for increased biomass 138 139 production. Ma et al. [24] reported a highly significant correlation of chlorophyll in terms of SPAD 140 with photosynthetic rate in soybean and Kapotis et al. [25] in weed species (Amaranthus viltus L.). Chlorophyll content in terms of SPAD values can be used for evaluation for the response of plant 141 142 species to the drought and heat stresses in the field [26]. In the present study, the adverse effect of drought on greenness of the leaf could be observed through about 23.48 per cent reduction in 143 144 mean total chlorophyll content. The reduction of chlorophyll content under drought might be due 145 to the fact that drought stress blemishes the chlorophyll content through causing internal modification in the thylakoid membrane. Similar to this finding, Ghaffari et al. [27] stated that 146 the tolerant sunflower line had higher chlorophyll than the susceptible line under drought. 147 148 Among the genotypes, highest reduction of total chlorophyll content was recorded in the genotype LE 1 (34.76%) followed by LE 125 (33.10%) and CO TH 2 (31.65%) under drought 149 (Table 1.). The present study also indicated the ability of the genotypes LE 57 (18.79%), LE114 150 (19.65%) and LE 118 (21.37) in maintaining total chlorophyll content under drought (0.5 IW/CPE) by 151 showing less reduction. Therefore, these genotypes were able to endure drought injury better than the 152

sensitive lines. These findings are in agreement with the earlier findings of Petcu *et al.* [28] insunflower.

A considerable reduction in **chlorophyll fluorescence** (**Fv/Fm**) was observed under drought condition. The possible reason for this effect is that the drought stressed plants have lower capacity for the use of transported electrons and their electron transport chain is more reduced at any light condition [29].

For the treatments, lesser mean fluorescence value (0.63) was registered by 0.5 IW/CPE 159 with the reduction of 25.88 per cent than 1.0 IW/CPE (0.85). Relating to the genotypes, LE 57 160 was significantly superior chlorophyll fluorescence value (0.74) followed by LE 118 and LE 27 161 while the lowest was recorded by LE 125 (0.47). The genotype, LE 57 proved its supremacy 162 with less reduction (20.69%) of Fv/Fm followed by LE 118 (20.69%) (Table 1). The high Fv/Fm 163 ratio indicates that genotype has more efficient in protecting their photosynthetic apparatus under 164 drought. This result is in agreement with Mishraa et al. [8] in tomato. Lower values of Fv/Fm 165 166 ratio under drought, indicated an injury to electron transfer system in photo system II, causing an imbalance between generation and utilization of electrons, resulting changes of quantum yield 167 168 efficiency [30].

# Table 1. Effect of water deficit on total chlorophyll content and Fv/Fm of tomato genotypes at 60 days after transplanting

Conotypes	Total chlorophy	ll content (mg g <sup>-1</sup> )	Chlorophyll fluorescence (Fv / Fm)		
Genotypes	<b>1.0 IW/CPE</b>	0.5 IW/CPE	1.0 IW/CPE	0.5 IW/CPE	
LE 1	2.555	1.667	0.83	0.57	
LE 27	2.932	2.284	0.87	0.67	
LE 57	2.895	2.351	0.93	0.74	
LE 114	2.932	2.356	0.81	0.56	
LE 118	2.944	2.315	0.87	0.69	

LE 125	2.007	1.878	0.75	0.47
CO 3	3.291	2.371	0.84	0.62
PKM 1	3.011	2.402	0.82	0.61
THCO 3	3.005	2.227	0.89	0.69
COTH 2	3.425	2.341	0.90	0.67
Mean	2.900	2.219	0.85	0.63
	G	Т	G	Т
SEd	0.0241	0.0108	0.007	0.003
CD (0.05)	0.0487	0.0218	0.015	0.007

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173 Chlorophyll Stability Index (CSI) is an indicator of the stress tolerance capacity of the 174 plants and is a measure of integrity of membrane [31]. A higher CSI helps the plants to withstand 175 stress through better availability of chlorophyll, leading to increased photosynthetic rate, more 176 dry matter production and higher productivity. Kilen and Andrew [32] observed a high 177 correlation between CSI and drought tolerance in corn.

Drought condition aggravates chlorophyll degradation in later part of growth due to loss of membrane compartmentation. Membrane stability index decreased significantly under water stress condition over control in wheat varieties [33].

In the present study also corroborates the earlier findings with 18.49% reduction of CSI in drought (0.5 IW/CPE) compared to 1.0 IW/CPE. The primary effect of drought at the cellular level is to affect the integrity of membrane which in turn leads to disruption of cellular compartment ultimately destruction chlorophyll contents. The earlier findings of Fariduddin *et al.* [34] confirm the present study.

The lowest reduction of CSI was observed in the genotypes LE 114 (14.68%) followed
by LE 118 (15.46%) while the highest reduction was showed by LE 125 (24.73%) and CO TH 2

(24.29%) under drought condition (**Table 2.**). The ability of the genotype maintained the higher CSI under drought is a desirable character for tolerance. Maintenance of CSI at drought condition by the genotype might be due to high membrane stability. Beena *et al.* [35] reported that high membrane stability index and chlorophyll stability index were recorded in tolerant inbred lines of rice than in susceptible lines under water stress condition.

#### 193 **3.2. Impact of drought on soluble protein**

The soluble protein content of the leaf, being a measure of RuBP carboxylase activity was considered as an index for photosynthetic efficiency. Rubisco enzyme forms nearly 80 per cent of the soluble proteins in leaves of many plants [36]. Diethelm and Shibles [37] opined that the rubisco content per unit leaf area was positively correlated with that of soluble protein content of the leaf. The amount of rubisco in leaves is controlled by the rate of synthesis and degradation. Even under drought stress the rubisco holo enzyme is relatively stable with a half life of several days [38].

However, drought stress in tomato[39], Arabidopsis[40] and rice [41] leads to a rapid decrease in the abundance of rubisco small subunit (*rbc*S) transcripts, which may indicate decreased synthesis. In the present study also confirms the earlier findings with 32.28 per cent reduction of soluble protein content under drought. The reduction of soluble protein content might be due to the degradation of available soluble protein in plant and reduction of synthesis of new protein.

Among the genotypes, CO TH 2 (15.63) and TH CO 3 (15.18) registered highest soluble protein content at under 1.0 IW/CPE ratio level. During drought (0.5 IW/CPE), LE 57 recorded significantly superior soluble protein content (11.99), however the genotype LE 118 proved its

endurance to water deficit with less reduction (19.48%) and LE 125 showed highest reduction of
52.66 per cent.

Biochemical limitations of photosynthetic carbon fixation by the inhibition of rubisco activity play an important role mostly under conditions of prolonged or more severe drought [42, 43]. Maintenance of soluble protein content by the genotypes could be attributed to higher rubisco activity leads to more carbon fixation and ultimately to higher photosynthetic efficiency under drought is one of the important traits for drought tolerance.

Table 2. Effect of water deficit on CSI and soluble protein content of tomato genotypes at
60 days after transplanting

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- 220

Constynes	Chlorophyll stability index (%)		Soluble protein content (mg g <sup>-1</sup> )		
Genotypes	<b>1.0 IW/CPE</b>	0.5 IW/CPE	1.0 IW/CPE	0.5 IW/CPE	
LE 1	79.0	65.5	10.85	6.51	
LE 27	83.3	70.2	13.98	10.72	
LE 57	84.6	69.5	15.03	11.99	
LE 114	83.8	71.5	13.43	10.19	
LE 118	85.4	72.2	14.58	11.74	
LE 125	79.9	63.9	11.07	5.24	
CO 3	83.0	66.4	11.55	8.69	
PKM 1	82.4	66.9	11.33	7.69	
THCO 3	79.5	63.0	15.18	8.46	
COTH 2	80.7	61.1	15.63	8.58	
Mean	82.2	67.0	13.26	8.98	
	G	Т	G	Т	
SEd	0.52	0.23	0.137	0.061	
CD (0.05)	1.06	0.47	0.278	0.124	

221 3.3. Impact of drought on ABA content

It was found a significant per cent increment of **ABA content** in leaf under drought condition (39.45%) over control. The increment of ABA content under drought condition was reported by several workers [4, 11, 44]. Accumulation of ABA under drought condition is a favourable mechanism for drought tolerance through reducing transpiration rate by closing of stomata. However, complete closure of stomata leads to increment of leaf temperature which produces reactive oxygen species ultimately death of the plant.

Among the genotypes, the elevation in ABA was less in LE 114 (24%) under drought, 228 229 whereas nearly double fold increment of ABA content was observed in LE 125 and LE 1 (Fig. 1). ABA synthesized in response to drought stress, is known to induce stomatal closure which 230 231 leads to reduced transpirational water loss [45]. In the present study, LE 1 and LE 125 showed higher ABA content which ultimately recorded less transpiration rate by closing of stomata. 232 However, the genotype LE 114 showed a moderate increment of leaf ABA content leads to 233 234 partial closure of stomata with maintains the photosynthetic rate and leaf temperature. Hence, both the physiological characters are important for drought tolerance. The present study in 235 agreement with earlier findings of Wang and Huang [46], who reported that highly significant 236 negative correlation between ABA content and leaf water potential, stomatal conductance, 237 transpiration rate and net photosynthetic rate. 238

# Fig 1. Effect of water deficit on ABA content (nmol g<sup>-1</sup>) of tomato genotypes at 60 days after transplanting



244 **3.4. Impact of drought on yield characters** 

Comparing two treatments, plants received 1.0 IW/CPE ratio recorded higher average fruit yield of 62.32 than drought imposed plants (29.92) (**Table 3**). At 0.5 IW/CPE ratio level, LE 57 showed its supremacy of higher fruit yield of 54.94 which was on par with LE 118 (50.06), LE 114 (42.17) and LE 27 (40.17) while the lowest was recorded by LE 125 (10.95) and LE 1 (12.71). Drought stress resulted in the overall yield loss of tomato fruits up to 52 per cent under field condition. The highest yield loss of 83.18 and 81.51 per cent were shown by LE 125 and LE 1 respectively.

A significantly lesser reduction of 32.49 per cent was exhibited by LE 118 followed by LE 57 (33.13%) and LE 114 (38.55) showing their tolerance nature to drought stress. Therefore, it could be clearly revealed that water deficit as the result of drying soil caused a major adverse effect on yield and yield components even in tolerant genotypes. The reduction in fruit yield and

related parameters under drought probably due to reduction of water content in plant which disrupting leaf gas exchange properties which limited the source size and activity (photosynthesis) and partitioning of photo assimilates to fruits. The present study confirms the early findings of Farooq *et al.* [47] and Manjunatha *et al.* [48]. Izzeldin *et al.* [49] also explained that the impact of drought before the time of flowering affects the reproductive system with the increasing sterility of flowers, so that flowering and fruiting will fail if the water shortage is prolonged.

#### 263 **3.5. Impact of drought on quality characters**

Plants imposed with 0.5 IW/CPE ratio recorded higher Total Soluble Solids (TSS: <sup>o</sup>Brix) 264 brix value (3.01) than 1.0 IW/CPE ratio (2.89). Among the genotypes, TH CO 3 recorded higher 265 average brix value of 4.00 than the rest of the genotypes. At 0.5 IW/CPE ratio condition, the 266 highest TSS value was recorded by TH CO 3 (4.1) followed by CO TH 2 (3.9), PKM 1 (3.6) and 267 CO 3 (3.4) while the lowest was registered by LE 125 (2.2). Regarding treatments, plants 268 269 imposed with 0.5 IW/CPE ratio recorded 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 270 content (4.69). Hence, the present study indicated that the quality parameters like TSS and 271 272 lycopene increased slightly under drought compared to control.

Present study corroborates with early findings of Ali *et al.* [50] in tomato. Nahar *et al.* [51] also explained that the fruit quality improvement under water deficit condition in tomato might be due to the synthesis of ascorbic acid, citric acid and malic acid. In the present study, LE 118, LE 57 and LE 27 showed their primacy with highest increment of TSS and lycopene content. This finding was strongly supported by Tambussi *et al.* [52] and it was also explained

that the increase in lycopene and TSS might be an effective strategy to protect membranes fromoxidative damage in water stressed condition.

#### 280 **4. Conclusion**

Water stress causes detrimental effects on plant activities, which are likely to alter the yielding potential of the crops. Hence, to identify the physiological parameters, which get altered under drought conditions is pre-requisite to evaluate drought tolerant varieties. It is concluded that the tomato genotypes LE 118, LE 57 and LE 114 were identified as the most tolerant lines to drought stress imposed provided with Rainout shelter. As the genotypes LE 125 and LE 1 recorded significantly lesser yield under the same condition, these two genotypes were considered as susceptible to water deficit.

Table 3. Effect of water deficit on yield and quality of tomato genotypes

Construng	Estimated fruit yield (tonnes ha <sup>-1</sup> )		TSS (° Brix)		Lycopene (mg 100 g <sup>-1</sup> )	
Genotypes	1.0 IW/CPE	0.5 IW/CPE	1.0 IW/CPE	0.5 IW/CPE	1.0 IW/CPE	0.5 IW/CPE
LE 1	68.74	12.71	2.5	2.7	2.21	2.39
LE 27	71.20	40.17	2.5	2.6	2.52	2.73
LE 57	82.16	54.94	2.4	2.6	2.46	2.68
LE 114	68.62	42.17	2.4	2.5	2.82	2.88
LE 118	74.15	50.06	2.4	2.5	2.85	2.95
LE 125	65.10	10.95	2.2	2.2	2.13	2.67
CO 3	41.04	22.74	3.3	3.4	4.54	4.84
PKM 1	38.98	20.94	3.5	3.6	3.78	4.05
THCO 3	54.33	22.38	3.9	4.1	3.35	3.53
COTH 2	58.85	22.13	3.8	3.9	3.54	3.55
Mean	62.32	29.92	2.89	3.01	3.02	3.23

		G	Т	G	Т	G	Т
SEd		0.960	0.429	0.03	0.01	0.048	0.022
CD (0	.05)	1.943	0.869	0.05	0.02	0.097	0.044
Refer	ences						
1.	Mollas	sadeghi V, Valiz	zadeh M, Shah	nryari R, Ir	nani AA. E	valuation of	end drought
	tolerar	nce of 12 wheat	genotypes by	stress ind	ices. Middle	e-East J. Sci	. Res. 2011;
	7(2): 2	241-247.					
2.	Boutra	a T, Akhkha A,	Shoaibi AA, A	lhejeli AM	. Effect of w	ater stress o	n growth and
	water	use efficiency (W	UE) of some	wheat culti	vars (Triticu	<i>m durum</i> ) gr	own in Saudi
	Arabia	. Journal of Taiba	h University fo	or Science. 2	2010; 3: 39–4	18	
3.	Gladde	en L, Wang A, H	sieh YC, Tsou	I. Using de	eficit irrigatio	on approach f	for evaluating
	the eff	ects of water rest	riction on field	grown toma	ato ( <i>Lycoper</i> .	sicon esculen	tum). African
	Journa	l of Agricultural	Research. 2012	; 7(14): 208	3- 2095.		
4.	Abdell	ah A, Boutraa T	', Alhejely A. '	The rates o	of photosynth	nesis, chloroj	phyll content,
	dark re	espiration, proline	and abscicic a	cid (ABA)	in wheat (Tra	iticum durum	a) under water
	deficit	conditions. Int. J	. Agric. Biol. 20	011; 13(2):	215-221.		
5.	Garg I	3K. Burman U. k	Xathuia S. Effec	t of water	stress on mo	th bean (Vigr	na aconitifolia
	(Jacq)	Marechal) genoty	bes. Indian J. Pla	ant Physiol.	2004: 9: 29-3	5.	
C			V V landar DI		, T. Classica - C		
0.	Sanadi	nya D, Kainuria E	, Kakraiya BL,	Mank CP.		plant growth	regulators on
	photos	ynthesis in mung	g bean subjecte	ed to water	stress. India	an J. Plant P	'hysiol. 2012;
	17(3&	4): 241-245.					

310	7.	Shah S, Saravanan R, Gajbhiye NA. Leaf gas exchange, chlorophyll fluorescence, growth
311		and root yield of Ashwagandha (Withania somnifera Dunal.) under soil moisture stress.
312		Indian J. Plant Physiol. 2010; 15(2): 117-124.
313	8.	Mishraa KB, Iannaconeb R, Petrozzab A, Mishraa A, Armentanob N, Vecchiab GL,
314		Trtilek M, Cellini F, Nedbala L. Engineered drought tolerance in tomato plants is
315		reflected in chlorophyll fluorescence emission. Plant Sci. 2012; 182: 79-86.
316	9.	Sairam RK, Desmukh PS, Shukla DS. Tolerance of drought and temperature stress in
317		relation to increased antioxidant enzyme activity in wheat. J. Agron. Crop Sci. 1997;
318		178: 171-177.
319	10	Daniel C, Triboi E. Changes in wheat protein aggregation during grain development:
320		Effects of temperature and water stress. Eur. J. Agron. 2002; 16: 1-12.
321	11	. Thompson S, Wilkinson S, Bacon MA, Davies WJ. Multiple signals and mechanisms that
322		regulate leaf growth and stomatal behaviour during water deficit. Physiol. Plant. 1997;
323		100: 303-313.
324	12	. Meenakumari SD, Vimala Y, Pawan A. Physiological parameters governing drought
325		tolerance in maize. Indian J. Plant Physiol. 2004; 9: 203-207.
326	13	Manojkumar G, Singh P, Batra BR. A note on response of tomato to irrigation and
327		fertility levels. Haryana J. Hort. Sci. 1998; 27(3): 215-217.
328	14	Nahar K, Gretzmacher R. Response of shoot and root development of seven tomato
329		cultivars in hydrophonic system under water stress. Academic J. Plant Sci. 2011; 4(2):
330		57-63.

331	15. Arnon DI. Copper enzymes in isolated chloroplasts, polyphenoxidase in beta vulgaris.
332	Plant Physiology. 1949; 24: 1-15.
333	16. Lu C, Zhang J. Effects of water stress on photo system II photochemistry and its thermo
334	stability in wheat plants. J. Exp. Bot. 1999; 50: 1199-1206.
335	17. Lu CM, Lu QT, Zhang JH, Kuang TY. Characterization of photosynthetic pigment
336	composition, photosystem II photochemistry and thermal energy dissipation during leaf
337	senescence of wheat plants grown in the field. J. Exp. Bot. 2001; 52:1805-1810.
338	18. Van Kooten O, Snell JHF. The use of chlorophyll fluorescence nomenclature in plant
339	stress physiology. Photosyn. Res. 1990; 25: 147-150.
340	19. Koleyoras AS. A new method of determining drought resistance. Plant Physiol. 1958; 33:
341	232-233.
342	20. Lowry OH, Brought NTR, Farr LA, Randall RJ. Protein measurement with folin phenol
343	reagent. J. Biol. Chem. 1951; 193: 265-275.
344	21. Krochko JE, Abrams GD, Loewan MK, Abrams SR, Cultler AJ. ABA-8-hydroxylase
345	is a cytochrome P450 monoxygenase. Plant Physiol. 1998; 118: 849-860.
346	22. Ranganna S. Handbook of analysis and quality control for fruit and vegetable products.
347	1986. 2 <sup>nd</sup> Ed. Tata Mc Graw Hill Publication Co. Ltd, New Delhi, India.
348	23. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 1984. 2 <sup>nd</sup> Ed.
349	John Wiley and sons, NewYork, USA, pp. 680.
350	24. Ma BL, Morrison MJ, Voldeng HD. Leaf greenness and photosynthetic rates in soybean.
351	Crop Sci. 1995; 35: 1411-1414.

25. Kapotis G, Zervoudakis G, Veltsislas T, Salahas G. Comparison of chlorophyll meter
readings with leaf chlorophyll concentration in Amaranthus viltus: Correlation with
physiological processes. Russ. J. Plant. Physiol. 2003; 50: 395-397.
26. Hawkins TS, Gardiner ES, Comer GS. Modeling the relationship between extractable
chlorophyll and SPAD-502 readings for endangered plant species research. J. Nature
Conservation. 2009; 17: 123-127.
27. Ghaffari M, Toorchi M, Valizadeh M, Shakiba MR. Morpho-physiological screening of
sunflower inbred lines under drought stress condition. Turk. J. Field Crops. 2012; 17(2):
185-190.
28. Petcu E, Arsintescu A, Stanciu D. The effect of hydric stress on some characteristics of
sunflower plants. Romanian Agric. Res. 2001; 16: 15-22.
29. Dias MC, Bruggemann W. Limitations of photosynthesis in Phaseolus vulgaris under
drought stress: gas exchange, chlorophyll fluorescence and Calvin cycle enzymes.
Photosynthetica. 2010; 48(1): 96-102.
30. Reddy AR, Chaitanya KV, Vivekanandan M. Drought-induced responses of
photosynthesis and antioxidant metabolism in higher plants. J. Plant Physiol. 2004; 161:
1189-1202.
31. Murthy KS, Majumder SK. Modifications of the technique for determination of
chlorophyll stability index in relation to studies of drought resistance in rice. Curr. Sci.
1962; 31: 470-471.

372	32. Kilen TC, Andrew RH. Measurement of drought resistance in corn. Agron. J. 1969;
373	61(5): 669-672
374	33. Gupta NK, Gupta S, Kumar A. Exogenous cytokinin application increases cell membrane
375	and chlorophyll stability in wheat (Triticum aestivum L.). J. Cereal Res. Comm. 2000;
376	28(3): 287-291.
377	34. Fariduddin Q, Khanam S, Hasan SA, Ali B, Hayat S, Ahmad A. Effect of 28-homobrassinolide
378	on the drought stress-in-duced changes in photosynthesis and antioxidant system of Brassica
379	<i>juncea</i> L. Acta Physiol. Plant. 2009; 33: 889-897.
380	35. Beena R, Thandapani V, Chandrababu R. Physio-morphological and biochemical
381	characterization of selected recombinant inbred lines of rice for drought resistance.
382	Indian J. Plant Physiol. 2012; 17(2): 189-193.
383	36. Joseph MC, Randall DD, Nelson CJ. Photosynthesis anmd RUBP-case of polyploidy tall
384	fescue. Plant Physiol. 1981; 68: 894-898.
385	37. Diethelm R, Shibles R.Relationship of enhancedsink de-mand with
386	photosynthesisandamount and activityofribulose1, 5-bisphosphatecarboxylasein soybean
387	leaves. J.Plant Physiol. 1989; 134: 70-74
388	38. Webber AN, Nie GY, Long SP. Acclimation of photosynthetic proteins to rising
389	atmospheric CO <sub>2</sub> . Photosyn. Res. 1994; 39: 413-425.
390	39. Bartholomew DM, Bartley GE, Scolnik PA. Abscisic-acid control of
391	rbcSandcabtranscriptionintomatoleaves. PlantPhysiol. 1991;96:291-296.

392	40. WilliamsSJ,Bulman	MP,Neill	SJ.	Wilt-inducedABAbiosynthesis,gene-
393	expressionanddown-reg	ulationofrbcSm	essenger	RNAlevelsinArabidopsisthaliana.
394	Physiol. Plant. 1994; 91	:177-182.		
395	41. Vu JCV, Gesch RW,	Allen LH, Boo	te KJ, Boy	wes G. CO <sub>2</sub> enrichment delaysarapid,
396	drought - induced decre	ase in Rubisco s	small subun	it transcript abundance. J. Plant
397	Physiol. 1999; 155: 139	-142.		
398	42. Lawlor DW, Cornic G	. Photosynthetic	c carbon as	ssimilation and associated metabolism
399	in relation to water defi	cits in higher p	lants. Plant	Cell Environ. 2002; 25: 275-294.
400	43. Medrano H, Escalona J	M, Bota J, Guli	as J, Flexas	s J. Regulation of photosynthesis of C <sub>3</sub>
401	plants in response to pro	ogressive drough	nt: Stomata	l conductance as a reference parameter.
402	Ann. Bot. 2002; 89: 895	5-905.		
403	44. Unyayar S, Keles Y,	Unal E. Proline	e and ABA	A levels in two sunflower genotypes
404	subjected to water stres	ss. Bulg. J. Plan	nt Physiol.	2004; 30: 34-47.
405	45. Schroeder JI, Allen GJ,	Hugouvieux V, I	Kwak JM, V	Waner D. Guard cell signal transduction.
406	Annu. Rev. Plant Physiol	. Plant Mol. Biol	. 2001; 52: 6	527-658.
407	46. Wang Z, Huang B. Ph	siological rec	overy of K	entucky bluegrass from simultaneous
408	drought and heat stress.	Crop Sci. 2004	; 44: 1729-1	1736.
409	47. Farooq M, Wahid A, K	Kobayashi N, Fu	ijita D, Bas	sra SMA. Plant drought stress: effects,
410	mechanisms and manage	ement. Agron. Su	stain. Dev.	2009; 29: 185-212.

411	48. Manjunatha MV, Rajkumar GR, Hebbara M, Ravishankar G. Effect of drip and surface
412	irrigation on yield and water-production efficiency of brinjal (Solanum melongena) in saline
413	vertisols. Indian J. Agric. Sci. 2004; 74(11): 583-587.
414	49. Izzeldin H, Lippert LF, Takatori FH. An influence of water stress at different growth
415	stages on yield and quality of lettuce seed. J. Amer. Soc. Hort. Sci. 1980; 105(1): 68-71.
416	50. Ali AK, Delbert WH, William OP. Evaluating leaf water potential, stomatal resistance
417	and canopy surface temperature of tomatoes as indices for irrigation timing. Acta Hort.
418	1980; 100: 181-192.
419	51. Nahar K, Ullah SM, Islam N. Osmotic adjustment and quality response of five tomato cultivars
420	(Lycopersicon esculentum Mill) following water deficit stress under subtropical climate. Asian
421	J. Plant Sci. 2011; 10: 153-157.
422	52. Tambussi EA, Bartoli CG, Beltrano J, Guiamet JJ, Araus JL. Oxidative damage to
423	thylakoid proteins in water-stressed leaves of wheat (Triticum aestivum). Physiol. Plant.

424 2000; 108: 398-404.