

*Full Length Research Paper*

# Effects of water deficit stress on seed yield and antioxidants content in soybean (*Glycine max* L.) cultivars

Hassan Masoumi<sup>1\*</sup>, Farrokh Darvish<sup>1</sup>, Jahanfar Daneshian<sup>2</sup>, Ghorban Normohammadi<sup>1</sup> and Davood Habibi<sup>3</sup>

<sup>1</sup>Department of Agronomy and Plant Breeding, Science and Research Branch, Islamic Azad University, Iran.

<sup>2</sup>Department of Oilseed crops, Seed and Plant Improvement Institute, Iran.

<sup>3</sup>Faculty of Agriculture and Natural Sciences, Karaj Branch, Islamic Azad University, Karaj, Iran.

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The metabolic reasons associated with differential sensitivity of soybean cultivars to water deficit stress are not well understood. Therefore, field experiments were conducted in 2008 and 2009 to determine some agronomic traits and activity of antioxidants under different levels of irrigation. The experimental design was randomized complete block in a split plot arrangement with four replications at both years. Irrigation treatments were (S<sub>1</sub>, 50; S<sub>2</sub>, 100 and S<sub>3</sub>, 150 mm evaporation from the Class "A pan" evaporation) and cultivars were (L<sub>17</sub>, Clean, TMS, Williams\*Chippewa and M<sub>9</sub>). Results showed that, water deficit stress increased antioxidants content [superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX)] significantly, but content of them were more at mild than high water deficit stress (S<sub>2</sub>>S<sub>3</sub> >S<sub>1</sub>). Furthermore, water deficit stress, decreased total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index in all of cultivars. Among cultivars, L<sub>17</sub> and Williams\*Chippewa produced the highest seed yield at the optimum condition of irrigation and both water deficit stress levels, respectively. Assessment of correlation results indicated that, there was a positive and significant correlation among SOD and seed yield in both water deficit stress levels, too.

**Key words:** Soybean, water deficit, antioxidant enzymes.

## INTRODUCTION

Soybean is one of the most important oil seed crops in Iran that is usually confronted with water deficit stress and reduction of yield. The reasons are concerned to summer cultivation of soybean (substituting crop) and presence of competitor crops which have partially the same growth season. Drought stress significantly limits plant growth and crop productivity. However in certain tolerant/adaptable crop plants morphological and metabolic changes occur in response to drought, which contribute towards adaptation to such unavoidable

environmental constraints (Ben Amor et al., 2007). Exposure of plants to most adverse conditions causes oxidative stress, which affects plant growth due to the production of Reactive Oxygen Species (ROS) such as superoxide radicals ( $\text{O}_2^-$ ), singlet oxygen ( $^1\text{O}_2$ ), hydroxyl radicals ( $\text{OH}^\bullet$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) (Mittler et al., 2004).

These ROS are all very reactive and cause severe damage to membranes, DNA and proteins (Tuanhui et al., 2010). The reaction of plants to water stress differs significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of development (Demiral and Turkan, 2005). Mechanisms of active oxygen species detoxification exist in all the plants and include activation

\*Corresponding author. E-mail: Masoumi\_hassan118@yahoo.com. Tel: +989126078513. Fax: +982188842112.

**Table 1.** Monthly temperature and precipitation during the growing season in 2007 to 2008 and 2008 to 2009.

Month	Average temperature (°C)						Precipitation (mm)	
	Minimum		Maximum		Mean		2007 to 2008	2008 to 2009
	2007 to 2008	2008 to 2009	2007 to 2008	2008 to 2009	2007 to 2008	2008 to 2009		
May	12.1	12.0	26.0	25.8	19.1	18.9	19.9	19.8
June	16.9	16.8	32.6	32.5	24.7	24.7	0.3	0.1
July	19.1	19.2	35.1	35.2	27.1	27.2	4.6	5.2
August	19.6	19.6	35.1	35.0	27.4	27.3	1.8	1.5
September	15.9	15.8	31.2	31.3	23.5	23.5	0.4	0.2
October	11.8	12.0	24.9	25.1	18.4	18.6	11.6	10.6

\* Data recorded at the Karaj meteorological Station.

of enzymatic [superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX)] (Johnson et al., 2003) as well as non-enzymatic (flavones, anthocyanins, carotenoids and ascorbic acid) antioxidants (Nayyar and Gupta, 2006). SOD is a class of enzymes that catalyze the dismutation of superoxide into oxygen and hydrogen peroxide. As such, it is an important antioxidant defense in nearly all cells exposed to oxygen (Corpas et al., 2006) and plays a key role in the reduction of oxidative damages.

Catalase is a common enzyme found in nearly all living organisms that are exposed to oxygen, where it functions to catalyze the decomposition of hydrogen peroxide to water and oxygen (Vertuani et al., 2004). Catalase has one of the highest turnover number of all enzymes; one molecule of catalase can convert millions of molecules of hydrogen peroxide to water and oxygen per second (Chelikani et al., 2004). Also, GPX is the general name of an enzyme family with peroxidase activity whose main biological role is reduce lipid hydroperoxides to their corresponding alcohols and to reduce free hydrogen peroxide to water (Ran et al., 2007). The degree to which the activities of antioxidant enzymes and the amount of antioxidants are elevated under drought stress is extremely variable among several plants species (Zhang and Kirkham, 1995) and even between two cultivars of the same species (Bartoli et al., 1999). However, under conditions of environmental stress, production of ROS can increase and endogenous protective activity may then become inadequate. Various associations between water deficit stress and endogenous levels of water-soluble antioxidants have been described (Zelman and Das, 1991; Borrmann et al., 2009; Manavalan et al., 2009).

Environmental stresses including drought and temperature affect nearly every aspect of the physiology and biochemistry of plants and significantly diminish yield (Vranov et al., 2002). Drought stress induces cellular accumulation of ROS which can damage membrane lipids, proteins and nucleic acids (Munns, 2002; Lovelli et

al., 2007). Several studies have pointed out that drought-tolerant species increased their antioxidant enzyme activities and antioxidant contents in response to drought treatment, whereas drought-sensitive species failed to do so (Foyer et al., 1994; Selote and Khanna-Chopra, 2004). In addition, plants are subjected to the interaction of two or more environmental stress factors under natural conditions and many studies have been carried out to study the effects of these stress factors on plant metabolism separately. Therefore, the aim of the study was to investigate the effect of water deficit stress levels on number of pods per plant, thousand seed weight, seed yield, total chlorophyll content and activities of three antioxidant enzymes (CAT, SOD, GPX) for five cultivars of soybean.

## MATERIALS AND METHODS

### Experimental set-up

The experiment was carried out at educational farm of Karaj Islamic Azad University (35° 48' 29" N, 51° 10' 29" E, and 1321 masl)<sup>1</sup>, Iran during the 2007 to 2008 and 2008 to 2009 growing seasons. This location is a semiarid area (according to the Koopen climate classification) characterized by warm and dry summers, long term (30 years) mean annual rainfall and temperature of 246 mm and 23.36°C, respectively. The meteorological data recorded during the trial period in each growing season are given in Table 1. Two weeks before sowing, soil samples were taken in order to determine the physical and chemical properties. Two composite soil samples were collected at depths of 0 to 30 and 30 to 60 cm. Samples were air dried, crushed and tested for pH, Electrical Conductivity (EC), organic carbon, total N, available P and available K. Details of soil properties are shown in Table 2.

The experimental design was a split plot in a randomized complete block with four replications. Each replication was divided into three main plots, which differed in severity of imposed water shortage. The water deficit treatments were applied by changes in irrigation intervals. Irrigations were carried out when an amount of evaporated water from class "A pan" evaporation reached 50 (S<sub>1</sub>; optimum conditions of irrigation), 100 (S<sub>2</sub>; mild water deficit) and

1 - masl : meter above sea level

**Table 2.** Physico-chemical properties of the soil in the experimental field.

Soil properties	Values (cm)			
	2007 to 2008		2008 to 2009	
	0 to 30	30 to 60	0 to 30	30 to 60
EC (dSm <sup>-1</sup> )	1.4	2.25	1.31	2.1
pH	7.8	7.6	7.6	7.3
Organic carbon (%)	0.72	0.49	0.67	0.51
Total N (%)	0.07	0.05	0.05	0.03
Available P (mg kg <sup>-1</sup> )	6.1	5.7	7.6	7.2
Available K (mg kg <sup>-1</sup> )	182	186	195	188

150 (S<sub>3</sub>; high water deficit) mm, respectively. Irrigation levels were randomized to the main plots. Amount of irrigation was identical for all water deficit treatments from the beginning of planting time till complete establishment of plants (appearance of fourth and fifth nodes; R<sub>5</sub>). Total irrigation water applied in optimum conditions of irrigation (S<sub>1</sub>), mild and high water deficit stress levels (S<sub>2</sub>, S<sub>3</sub>) were 465, 234.5 and 146.56 m<sup>3</sup>, respectively. After this stage, the plots were irrigated according to their prescribed treatment. Soybean Cultivars included L<sub>17</sub> (V<sub>1</sub>), Clean (V<sub>2</sub>), T.M.S (V<sub>3</sub>), Williams\* Chippewa (V<sub>4</sub>) and M<sub>9</sub> (V<sub>5</sub>), that were arranged in sub plots.

Before planting, the soil surface was ploughed in autumn and then disked twice in the spring (at the beginning of April and middle of May). Triple super phosphate fertilizer was applied before sowing at a rate of 150 kg ha<sup>-1</sup>. The N fertilizer (15 kg ha<sup>-1</sup>) in the form of urea, was applied before planting (one third of the application) and side-dressed (two-third of application) before starting the first stress treatment. Plots were 7 m long and consisted of six rows, 0.6 m apart. Between all main plots, a 3 m wide strip was left bare to eliminate all influences of lateral water movement. Soil surface of cultivated area was thoroughly irrigated 6 days before planting. The soybean seeds were inoculated with *Rhizobium japonicum* bacteria before planting and were hand-planted on 24th May, 2008 and 26th May, 2009 at the rate of 20 seeds/m of row and then were thinned to achieve a density of approximately 333,333 ha<sup>-1</sup>. During the whole growth season, weeds and insects were effectively controlled.

#### Measurement of number of pods per plants, thousand seed weight seed yield and harvest index (HI).

Six representative plants per plot were sampled to calculate the number of pods per plant and Harvest Index (HI). Number of pods were added for all six plants separately, and then averaged. HI was computed as the division of seed yield per biological yield. Biological yield was by sampling six plants in each plot. Samples were dried in an oven at 60°C for 72 h and then weighted. One thousand seed weight was determined by measuring the weight of 500 seeds from each plot and multiplying by 2 in order to express as 1000 seeds. After the soybean cultivars reached physiological maturity seed yield was determined by harvesting two central rows in first week of October in both years.

#### Measurement of antioxidant enzymatic

##### activities Sampling

To quantify antioxidant enzymatic activity, fifteen leaves were taken from each plot randomly and were placed in liquid N<sub>2</sub> and then stored at -80°C pending biochemical analysis.

#### Samples preparation for enzyme assays and protein measurement

Leaves from each sample were washed with distilled water and homogenized in 0.16 M Tris buffer (pH = 7.5) at 4°C. Then, 0.5 ml of total homogenized solution was used for protein determination by the Lowry et al. (1951) method. Based on the amount of protein per volume of homogenized solution, the following enzymes were assayed in the volume containing a known protein concentration in order to calculate the specific activities of the enzymes.

#### Assays of antioxidant enzymes

**Superoxide dismutase (SOD) activity:** The activity was measured based on Misra and Fridovich (1972) in which the activity was measured on the basis of its ability to inhibit free radical chain oxidation in which O<sup>-2</sup> was a chain propagating radical and the auto oxidation of epinephrine (0.25 mM) using SOD as a standard for calibration of activity.

**Catalase (CAT) activity:** Catalase activity was measured at 25°C as previously described by Paglia and Valentine (1987) that used hydrogen peroxide as substrate and one unit of catalase was defined as the rate constant of the first order reaction (k).

**Glutathion peroxidase (GPX) activity:** The activity was measured by the Paglia and Valentine (1987) method in which 0.56 M (pH=7) phosphate buffer, 0.5 M EDTA, 1mM NaN<sub>3</sub>, 0.2mM NADPH were added to the extracted solution. Glutathion peroxidase (GPX) catalyses the oxidation of glutathion (GSH) by cumene hydroperoxide in the presence of glutathion reductase and NADPH, the oxidized glutathion is immediately converted to the reduced form with the concomitant oxidation of NADPH to NADP. The decrease in absorbance at 340 nm was measured with a spectrophotometer.

#### Measurement of total chlorophyll

Fresh leaves (1 g) were extracted with 80% acetone and centrifuged at 5000 × g for 10 min. The absorbance of the supernatant was read at 645 and 663 nm and calculated for total chlorophyll (Arnon, 1949).

#### Statistical analysis

All data were analyzed with an analysis of variance (ANOVA) using the GLM procedure in SAS (SAS Institute, 2002). The assumptions of variance analysis was tested by ensuring that the residuals were

**Table 3.** The mean squares of ANOVA for effect of irrigation levels on some antioxidants content in soybean cultivars.

Features	Df	Superoxide dismutase (SOD)	Catalase (CAT)	Glutathione peroxidase (GPX)
Year	1	Ns	ns	Ns
Irrigation levels	2	**	**	**
Year* Irrigation levels	2	Ns	ns	Ns
Cultivars	4	**	**	**
Cultivars * Irrigation levels	8	**	**	**
Year * Cultivars	4	Ns	ns	Ns
Year * Cultivars * Irrigation levels	8	Ns	ns	**

\*, and \*\*: Significant, at the 5% and 1% levels of probability, respectively.

random and homogenous, with a normal distribution about a mean of zero. The LSMEANS command was used to compare means at a  $p < 0.05$  probability. Correlation analysis using PROC CORP in SAS were conducted to determine the relationship between measurement parameters and seed yield.

## RESULTS

The mean monthly temperature and precipitation often had the same trend in both years during the growth season (Table 1). The negligible variation between the two years could explain the non significant interaction of the years and treatments in most traits.

### Measurement of antioxidant enzymes activities

#### *Superoxide dismutase (SOD)*

SOD content was affected by water deficit and cultivars as well as the interaction of water deficit \*cultivars (Table 3). Mean comparison indicated that the SOD content in water deficit conditions ( $S_2, S_3$ ) were higher than the optimum condition of irrigation ( $S_1$ ). Of course, the SOD content had a decline order of  $S_2 > S_3 > S_1$  (Table 4). Among cultivars and at the optimum conditions of irrigation, the highest and lowest SOD content was observed in  $L_{17}$  and T.M.S, respectively. In both mild and high water deficit stress levels, the highest and lowest SOD content were obtained from Williams\*Chippewa and T.M.S. A positive and significant correlation was among SOD content with seed yield, CAT and GPX content in mild and high water deficit stress. Also, there was a positive correlation among SOD content and total chlorophyll in high water deficit stress (Tables 8, 9).

#### *Catalase (CAT)*

Analysis of variance for CAT content showed that, there

were significant differences ( $p < 0.01$ ) among irrigation levels, cultivars and also interaction of irrigation levels  $\times$  cultivars (Table 3). The CAT content increased in mild and high water deficit stress ( $S_2, S_3$ ) compared to normal condition of irrigation. But CAT content was more in mild than high water deficit stress levels. At the optimum condition of irrigation, the highest and lowest CAT content were observed in cultivars of  $L_{17}$  and T.M.S. Furthermore, the differences in CAT content among Williams\*Chippewa and  $M_9$  were not significant. At the mild and high water deficit stress levels ( $S_2, S_3$ ), there were significant differences among Cultivars. In both conditions, the highest and lowest CAT content were obtained from Williams\*Chippewa and T.M.S (Table 4). Meanwhile, there was observed a positive and significant correlation between CAT content and seed yield at optimum condition of irrigation and high water deficit stress (Tables 7, 8).

#### *Glutathione peroxidase (GPX)*

Mean comparison of interactions effects between irrigation levels\*cultivars indicated that GPX content increased with intensification in water deficit (Table 3). But similar to CAT and SOD, GPX content was more in mild water deficit stress than high water deficit stress and optimum condition of irrigation ( $S_2 > S_3 > S_1$ ). Assessment of interaction between irrigation levels\*cultivars showed that at the optimum condition of irrigation, cultivars of  $L_{17}$  and T.M.S had the highest and lowest GPX content, respectively. Whereas, at both mild and high water deficit stress levels, cultivars of Williams\*Chippewa and T.M.S indicated the highest and lowest GPX content (Table 4). In this experiment, there was a positive and significant correlation between GPX content and seed yield at the optimum condition of irrigation and high water deficit stress and the same correlation was observed among GPX content and total chlorophyll content in all of the irrigation levels (Tables 7, 8 and 9).

**Table 4.** Effects of irrigation levels on some antioxidants content in soybean cultivars.

Levels of irrigation	Cultivar	Superoxide dismutase (u mg <sup>-1</sup> protein)	Catalase (u mg <sup>-1</sup> protein)	Glutathione peroxidase (u mg <sup>-1</sup> protein)
S <sub>1</sub>		1591.86 <sup>c</sup>	104.56 <sup>c</sup>	18.14 <sup>c</sup>
S <sub>2</sub>		2442.48 <sup>a</sup>	130.30 <sup>a</sup>	34.75 <sup>a</sup>
S <sub>3</sub>		2152.15 <sup>b</sup>	121.69 <sup>b</sup>	28.14 <sup>b</sup>
	L <sub>17</sub>	2216.43 <sup>b</sup>	125.71 <sup>a</sup>	29.00 <sup>b</sup>
	Clean	2089.41 <sup>d</sup>	121.50 <sup>b</sup>	25.64 <sup>d</sup>
	T.M.S	1556.41 <sup>e</sup>	99.81 <sup>c</sup>	20.45 <sup>e</sup>
	Williams*Chippewa	2304.09 <sup>a</sup>	127.71 <sup>a</sup>	32.95 <sup>a</sup>
	M <sub>9</sub>	2144.5 <sup>c</sup>	119.53 <sup>b</sup>	26.92 <sup>c</sup>
S <sub>1</sub>	L <sub>17</sub>	1856.15 <sup>a</sup>	119.15 <sup>a</sup>	22.68 <sup>a</sup>
S <sub>1</sub>	Clean	1772.70 <sup>b</sup>	114.09 <sup>ab</sup>	19.87 <sup>b</sup>
S <sub>1</sub>	T.M.S	1307.56 <sup>d</sup>	83.86 <sup>d</sup>	14.42 <sup>e</sup>
S <sub>1</sub>	Williams*Chippewa	1524.68 <sup>c</sup>	106.96 <sup>b</sup>	17.59 <sup>c</sup>
S <sub>1</sub>	M <sub>9</sub>	1498.20 <sup>c</sup>	98.72 <sup>c</sup>	16.14 <sup>d</sup>
S <sub>2</sub>	L <sub>17</sub>	2711.18 <sup>b</sup>	134.29 <sup>b</sup>	40.14 <sup>b</sup>
S <sub>2</sub>	Clean	2303.22 <sup>d</sup>	127.77 <sup>c</sup>	30.56 <sup>d</sup>
S <sub>2</sub>	T.M.S	1858.18 <sup>e</sup>	119.06 <sup>d</sup>	25.91 <sup>e</sup>
S <sub>2</sub>	Williams*Chippewa	2803.12 <sup>a</sup>	140.39 <sup>a</sup>	43.87 <sup>a</sup>
S <sub>2</sub>	M <sub>9</sub>	2536.71 <sup>c</sup>	130.01 <sup>bc</sup>	33.04 <sup>c</sup>
S <sub>3</sub>	L <sub>17</sub>	2081.14 <sup>d</sup>	123.68 <sup>b</sup>	24.19 <sup>d</sup>
S <sub>3</sub>	Clean	2192.30 <sup>c</sup>	122.63 <sup>b</sup>	26.50 <sup>c</sup>
S <sub>3</sub>	T.M.S	1503.48 <sup>e</sup>	96.51 <sup>c</sup>	21.02 <sup>e</sup>
S <sub>3</sub>	Williams*Chippewa	2584.45 <sup>a</sup>	135.76 <sup>a</sup>	37.41 <sup>a</sup>
S <sub>3</sub>	M <sub>9</sub>	2398.58 <sup>b</sup>	129.87 <sup>a</sup>	31.59 <sup>b</sup>

(i) Levels of irrigation: S<sub>1</sub>; optimum condition of irrigation, S<sub>2</sub>; mild water deficit stress level, S<sub>3</sub>; high water deficit stress level.(ii) For a given means within each column of each section followed by the same letter are not significantly different ( $p < 0.05$ ). (iii) u mg<sup>-1</sup> protein: International Units of activity per milligram protein.

## Total chlorophyll

Total chlorophyll content was altered by intensification in water deficit stress and decreased significantly in all of cultivars (Table 5). Among cultivars and at the optimum conditions of irrigation, the highest total chlorophyll content was observed in L<sub>17</sub>. Although, differences among cultivars of Clean, T.M.S, Williams\*Chippewa and M<sub>9</sub> as well as L<sub>17</sub> and Clean were not significant. At both mild and high water deficit stress, Williams\*Chippewa had more total chlorophyll content and least percent of declined compared with optimum condition of irrigation. Also, differences between cultivars of Clean and L<sub>17</sub> at both conditions were not significant (Table 5). Assessment of correlation tables indicated that, there was a positive and significant correlation between total chlorophyll content and seed yield at the optimum condition of irrigation and high water deficit stress. Such a positive and significant correlation was observed

among total chlorophyll and measured enzyme activities (SOD, CAT, and GPX) in different irrigation levels of this experiment (Tables 7, 8 and 9)

## Field experiments

### Number of pods per plant

The analysis of variance indicated that irrigation levels, cultivars and interaction of cultivars\*irrigation levels had significant effect on number of pods per plant. The number of pods per plant decrease significantly at mild and high water deficit (Table 6). At the optimum condition of irrigation and mild water deficit stress, cultivars of L<sub>17</sub> and M<sub>9</sub> had the highest and lowest number of pods per plant, whereas, at the high water deficit stress, the highest and lowest number of pods per plant were obtained from L<sub>17</sub>, Williams\*Chippewa and T.M.S. At the

**Table 5.** The mean squares of ANOVA for effect of irrigation levels on total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index in soybean cultivars.

Features	Df	Total Chlorophyll	Number of pods per plant	Thousand seed weight	Seed yield	Harvest index
Year	1	Ns	ns	ns	ns	ns
Irrigation levels	2	**	**	**	**	**
Year* Irrigation levels	2	Ns	ns	ns	ns	ns
Cultivars	4	**	**	**	**	**
Cultivars * Irrigation levels	8	**	**	**	**	**
Year * Cultivars	4	Ns	ns	**	ns	ns
Year * Cultivars * Irrigation levels	8	Ns	**	ns	ns	*

\*, and \*\*: Significant, at the 5% and 1% levels of probability, respectively.

optimum condition of irrigation, the differences among cultivars of T.M.S and Williams\*Chippewa and at the high water deficit stress differences among cultivars of L<sub>17</sub> and Williams\*Chippewa as well as Clean and M<sub>9</sub> were not significant. A noticeable point was that, a positive and significant correlation between number of pods per plant and seed yield was observed only at the optimum condition of irrigation (Table 7).

### Thousand seed weight

Assessment of variance analysis and mean comparison tables indicated that, seed thousand weight decreased with intensification in water deficit stress in all of cultivars significantly (Table 5). The differences in thousand seed weight among cultivars were significant in all of irrigation levels. At the optimum condition of irrigation and high water deficit stress, the highest and lowest thousand seed weight were from Williams\*Chippewa and T.M.S, respectively. Furthermore, the highest and lowest thousand seed weight were in cultivars of Williams\*Chippewa and L<sub>17</sub>, T.M.S, respectively (Table 6). There was a positive and significant correlation between thousand seed weight and GPX content, total chlorophyll, harvest index and seed yield at the high water deficit stress (Table 9).

### Seed yield

Analysis of variance for Seed yield indicated significant differences ( $p < 0.01$ ) among irrigation levels, soybean cultivars and their interactions (Table 5). Seed yield decreased from optimum condition of irrigation to mild and high water deficit stress levels in all of cultivars, significantly. At the optimum conditions of irrigation, the highest and lowest seed were by cultivars of L<sub>17</sub> and T.M.S whereas, at the mild and high water deficit stress conditions, the highest and lowest seed yield were observed in cultivars of Williams\*Chippewa and T.M.S

(Table 6). Also within this period, the highest and the lowest percent of decrease in seed yield were in cultivars of T.M.S (87.39%) and Williams\*Chippewa (71.72%).

### Harvest index (HI)

There were significant differences ( $p < 0.01$ ) between irrigation levels, cultivars and interaction of cultivar\*irrigation levels (Table 5). Mean comparison showed that, harvest index decreased with increase in intensity of water deficit stress in all of the cultivars (Table 6). At the optimum condition of irrigation, the highest and lowest harvest index were in cultivars of Williams\*Chippewa and Clean. In this condition, the differences among cultivars of M<sub>9</sub>, T.M.S and L<sub>17</sub> were not significant. The same trend was observed in mild water deficit stress. Although, the difference in harvest index among L<sub>17</sub> and Clean was not significant. At the high water deficit stress, cultivars of M<sub>9</sub> and T.M.S had the highest and lowest harvest index, too. From the correlation aspect, a positive and significant correlation was observed between harvest index and GPX content, thousand seed weight and seed yield at the high water deficit stress (Table 9).

## DISCUSSION

The present findings revealed that all of the cultivars had varying ability to deal with oxidative stress that might govern their differential sensitivity to water deficit stress. They did differ significantly for water deficit stress injury in their seed yield, harvest index, thousand seed weight, number of pods per plants, antioxidant enzymes SOD, CAT and GPX and total chlorophyll contents at moderate and high water deficit stress levels (S<sub>2</sub>, S<sub>3</sub>). However, the differences between them became evident as the degree of the stress increased to moderate and higher levels. The water deficit stress levels (S<sub>2</sub>, 100 and S<sub>3</sub>, 150 mm evaporation from the Class "A pan" evaporation)

**Table 6.** Effects of irrigation levels on total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index in soybean cultivars.

Levels of irrigation	Cultivar	Seed yield (kg.ha <sup>-1</sup> )	Harvest index (%)	Thousand seed weight (g)	Number of pods per plant	Total Chlorophyll (mg/g fw)
S <sub>1</sub>		2339.31 <sup>a</sup>	46.43 <sup>a</sup>	146.76 <sup>a</sup>	27.65 <sup>a</sup>	5.33 <sup>a</sup>
S <sub>2</sub>		1019.52 <sup>b</sup>	38.034 <sup>b</sup>	116.77 <sup>b</sup>	19.67 <sup>b</sup>	4.49 <sup>b</sup>
S <sub>3</sub>		468.82 <sup>c</sup>	27.92 <sup>c</sup>	90.41 <sup>c</sup>	14.45 <sup>c</sup>	3.65 <sup>c</sup>
	L <sub>17</sub>	1490.70 <sup>a</sup>	34.70 <sup>d</sup>	111.08 <sup>d</sup>	24.51 <sup>a</sup>	4.59 <sup>b</sup>
	Clean	1359.03 <sup>b</sup>	32.46 <sup>e</sup>	112.51 <sup>c</sup>	21.61 <sup>b</sup>	4.48 <sup>d</sup>
	T.M.S	870.64 <sup>d</sup>	35.12 <sup>c</sup>	103.05 <sup>e</sup>	17.92 <sup>e</sup>	4.03 <sup>e</sup>
	Williams*Chippewa	1375.54 <sup>b</sup>	43.39 <sup>a</sup>	135.52 <sup>a</sup>	20.41 <sup>c</sup>	4.82 <sup>a</sup>
	M <sub>9</sub>	1283.49 <sup>c</sup>	41.63 <sup>b</sup>	127.72 <sup>b</sup>	18.49 <sup>d</sup>	4.53 <sup>c</sup>
S <sub>1</sub>	L <sub>17</sub>	2869.17 <sup>a</sup>	45.80 <sup>c</sup>	148.50 <sup>c</sup>	33.41 <sup>a</sup>	5.65 <sup>a</sup>
S <sub>1</sub>	Clean	2458.74 <sup>b</sup>	42.87 <sup>d</sup>	142.97 <sup>d</sup>	29.58 <sup>b</sup>	5.43 <sup>ab</sup>
S <sub>1</sub>	T.M.S	2002.83 <sup>e</sup>	46.96 <sup>b</sup>	130.15 <sup>e</sup>	25.82 <sup>c</sup>	5.12 <sup>b</sup>
S <sub>1</sub>	Williams*Chippewa	2245.03 <sup>c</sup>	50.10 <sup>a</sup>	158.00 <sup>a</sup>	25.39 <sup>c</sup>	5.26 <sup>b</sup>
S <sub>1</sub>	M <sub>9</sub>	2120.80 <sup>d</sup>	46.43 <sup>bc</sup>	154.18 <sup>b</sup>	24.04 <sup>d</sup>	5.21 <sup>b</sup>
S <sub>2</sub>	L <sub>17</sub>	1184.72 <sup>b</sup>	33.25 <sup>d</sup>	103.59 <sup>d</sup>	23.11 <sup>a</sup>	4.57 <sup>b</sup>
S <sub>2</sub>	Clean	1161.83 <sup>c</sup>	33.05 <sup>d</sup>	109.09 <sup>c</sup>	20.39 <sup>b</sup>	4.39 <sup>bc</sup>
S <sub>2</sub>	T.M.S	356.47 <sup>d</sup>	38.40 <sup>c</sup>	101.79 <sup>d</sup>	19.53 <sup>c</sup>	4.21 <sup>c</sup>
S <sub>2</sub>	Williams*Chippewa	1246.63 <sup>a</sup>	43.98 <sup>a</sup>	140.76 <sup>a</sup>	18.48 <sup>d</sup>	4.80 <sup>a</sup>
S <sub>2</sub>	M <sub>9</sub>	1147.92 <sup>c</sup>	41.46 <sup>b</sup>	128.63 <sup>b</sup>	16.82 <sup>e</sup>	4.48 <sup>b</sup>
S <sub>3</sub>	L <sub>17</sub>	418.22 <sup>d</sup>	25.05 <sup>c</sup>	81.17 <sup>d</sup>	17.02 <sup>a</sup>	3.56 <sup>c</sup>
S <sub>3</sub>	Clean	456.52 <sup>c</sup>	21.45 <sup>d</sup>	85.49 <sup>c</sup>	14.85 <sup>b</sup>	3.60 <sup>c</sup>
S <sub>3</sub>	T.M.S	252.62 <sup>e</sup>	20.01 <sup>e</sup>	77.21 <sup>e</sup>	8.42 <sup>c</sup>	2.75 <sup>d</sup>
S <sub>3</sub>	Williams*Chippewa	634.97 <sup>a</sup>	36.08 <sup>b</sup>	107.81 <sup>a</sup>	17.35 <sup>a</sup>	4.40 <sup>a</sup>
S <sub>3</sub>	M <sub>9</sub>	581.75 <sup>b</sup>	37.00 <sup>a</sup>	100.36 <sup>b</sup>	14.59 <sup>b</sup>	3.91 <sup>b</sup>

(i) Levels of irrigation: S<sub>1</sub>; optimum condition of irrigation, S<sub>2</sub>; mild water deficit stress level, S<sub>3</sub>; high water deficit stress level. (ii) For a given means within each column of each section followed by the same letter are not significantly different ( $p < 0.05$ ). (iii) mg/g fw: Milligram per gram fresh weight.

decreased total chlorophyll, number of pods per plants, thousand seed weight, seed yield and harvest index in all of the assessed cultivars. The decrease in yield and yield components in different soybean cultivars due to water deficiency has also been reported by other researchers (Dominique et al., 2007; Vicki et al., 2007; Ohashi et al., 2006). The results indicated that, cultivars of L<sub>17</sub> and Williams\*Chippewa had the highest seed yield in optimum condition of irrigation and both water deficit stress levels, respectively (Table 6). Also, Larry and Heatherly (2000) in their experiment showed, thousand seed weight is positively associated with seed yield.

Induction of oxidative stress in drought-stressed plants is well known in several cases (Borrmann et al., 2009; Manavalan et al., 2009) and its magnitude indicates the stress sensitivity of the genotype (Nayyar and Kaushal, 2002; Selote and Khanna-Chopra, 2004). Our results indicated that, activities of all measured antioxidants

(SOD, CAT, GPX) were increased in all of cultivars and both water deficit stress levels (S<sub>2</sub>, S<sub>3</sub>) but, antioxidants levels (degree of antioxidant activity) were higher at mild than high water deficit stress (S<sub>2</sub>>S<sub>3</sub>>S<sub>1</sub>).

This finding can be related to the ability of the crops against different intensities of water deficit stress. In other words, when crops are exposed in mild water deficit stress condition, their antioxidant defensive mechanism is activated and the content of antioxidants will raise in them. Results of this research indicate the same trend, too. Thus, the content of all three measured antioxidants increased in all of the cultivars (S<sub>2</sub>>S<sub>1</sub>).

Furthermore, it seems, when the intensity of water deficit stresses increase too much in crops, the physiological damages will increase, too. Thus, they can not promote their antioxidant defensive mechanism along with the intense of water deficit in parallel manner. In other words, in extreme water deficit stress condition,

**Table 7.** Correlation coefficient between antioxidant content, total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index at the optimum condition of irrigation (S<sub>1</sub>).

Features	Superoxide dismutase (SOD)	Catalase (CAT)	Glutathione peroxidase (GPX)	Total chlorophyll	number pods per plant	Thousand seed weight	Seed yield	Harvest index
Superoxide dismutase (SOD)	1.00 <sup>..</sup>							
Catalase (CAT)	0.96 <sup>..</sup>	1.00 <sup>..</sup>						
Glutathione peroxidase (GPX)	0.97 <sup>..</sup>	0.95 <sup>..</sup>	1.00 <sup>..</sup>					
Total chlorophyll	0.96 <sup>..</sup>	0.90 <sup>..</sup>	0.99 <sup>*</sup>	1.00				
number pods per plant	0.85	0.73	0.91 <sup>*</sup>	0.95 <sup>*</sup>	1.00			
Thousand seed weight	0.31	0.52	0.30	0.2	-0.11	1.00		
Seed yield	0.93 <sup>*</sup>	0.89 <sup>*</sup>	0.99 <sup>**</sup>	0.99 <sup>**</sup>	0.94 <sup>*</sup>	0.23	1.00	
Harvest Index	-0.53	-0.31	-0.38	-0.44	-0.50	0.40	-0.36	1.00

<sup>\*</sup>, and <sup>\*\*</sup>: Significant, at the 5% and 1% levels of probability, respectively.

**Table 8.** Correlation coefficient between antioxidant content, total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index at the mild water deficit stress (S<sub>2</sub>).

Features	Superoxide dismutase (SOD)	Catalase (CAT)	Glutathione peroxidase (GPX)	Total chlorophyll	Number of pods per plant	Thousand seed weight	Seed yield	Harvest index
Superoxide dismutase (SOD)	1							
Catalase (CAT)	0.97 <sup>**</sup>	1						
Glutathione peroxidase (GPX)	0.94 <sup>*</sup>	0.97 <sup>**</sup>	1					
Total chlorophyll	0.94	0.99 <sup>**</sup>	0.97 <sup>**</sup>	1				
number pods per plant	0.06	0.03	0.16	0.55	1			
Thousand seed weight	0.62	0.69	0.59	0.75	-0.69	1		
Seed yield	0.9 <sup>*</sup>	0.85	0.74	0.78	0.04	0.53	1	
Harvest Index	0.22	0.31	0.28	0.43	-0.81	0.84	0.006	1

<sup>\*</sup>, and <sup>\*\*</sup>: Significant, at the 5% and 1% levels of probability, respectively.

the antioxidant defensive mechanism of crops will be activated as well and the antioxidants content will increase as compared to the full-irrigated. But, due to excessive physiological damages resulted of water deficit stress, the antioxidant activities are less than mild water deficit level (S<sub>2</sub>>S<sub>3</sub>>S<sub>1</sub>).

Previously, an increase in the level of antioxidants was reported with increase in stress intensity in maize and soybean by Vasconcelos et al. (2009) and Jiang and Zhang (2002) which might be attributed to inhibitory effects of water stress on protein turnover causing depletion of antioxidants

(Bartoli et al., 1999). Also, Lee et al. (2009) reported a positive and significant correlation between catalase, superoxide dismutase and ascorbate peroxidase in both well irrigated and water deficit stress conditions. Furthermore, Silva Lobato et al. (2008) have also been found a



**Table 9.** Correlation coefficient between antioxidant content, total chlorophyll content, number of pods per plant, thousand seed weight, seed yield and harvest index at the high water deficit stress (S<sub>3</sub>).

Features	Superoxide dismutase (SOD)	Catalase (CAT)	Glutathione peroxidase (GPX)	Total chlorophyll	Number pods per plant	Thousand seed weight	Seed yield	Harvest index
Superoxide dismutase (SOD)	1							
Catalase (CAT)	0.98 <sup>**</sup>	1						
Glutathione peroxidase (GPX)	0.91 <sup>**</sup>	0.85 <sup>**</sup>	1					
Total chlorophyll	0.99 <sup>**</sup>	0.97 <sup>**</sup>	0.94 <sup>*</sup>	1				
number pods per plant	0.85 <sup>*</sup>	0.92 <sup>*</sup>	0.64 <sup>**</sup>	0.85 <sup>*</sup>	1			
Thousand seed weight	0.88 <sup>*</sup>	0.81 <sup>*</sup>	0.99 <sup>**</sup>	0.91 <sup>*</sup>	-0.56	1		
Seed yield	0.99 <sup>**</sup>	0.95 <sup>*</sup>	0.95 <sup>*</sup>	0.98 <sup>**</sup>	0.77	0.94 <sup>*</sup>	1	
Harvest Index	0.82	0.77	0.89 <sup>*</sup>	0.83	0.54	0.93 <sup>*</sup>	0.89 <sup>*</sup>	1

\*, and \*\*: Significant, at the 5% and 1% levels of probability, respectively.

positive and significant correlation between content of antioxidants with accumulation of abscisic acid (ABA) and seed yield in soybean cultivars. Among the various antioxidants examined, GPX content relatively showed larger increase than others, suggesting its vital involvement in deciding the oxidative response. Among cultivars, antioxidants contents were more in Williams\*Chippewa at both water deficit stress levels (mild and high) . As well as, the highest percent of increase in antioxidants content (with the exception of CAT) was observed in this cultivar. Considering that, the cultivar of Williams\*Chippewa had the highest total chlorophyll content, thousand seed weight and seed yield in both water deficit stress levels, it seems that, this cultivar have more effective alternative mechanisms for defense against free radicals and oxidative stress.

## Conclusion

In conclusion this study has shown that, all of the

soybean cultivars responded to different water deficit stress levels and activated antioxidant defensive mechanism against free radical by a significant increase in antioxidants content. Also there was observed that, cultivars with higher antioxidants levels had more yield and yield components in water deficit stress. In other words, antioxidants enzymes could increase the survival capacity of soybean cultivars under conditions of water deficit stress.

Finally, the present findings revealed that, Cultivars of L<sub>17</sub> and Williams\*Chippewa are more suitable than others for sowing at the optimum.

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