Impact of Antioxidant Enzymes and Physiological Indices as Selection Criteria for Drought Tolerance in Sesame Populations

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Abstract: In this study, we sought to determine whether the increases in peroxidase (POX), catalase activities (CAT), normalized differential vegetation index (NDVI), chlorophyll pigments as (SPAD reading), proline and relative water content (RWC) as selection criteria for drought tolerance in sesame and how to improve water use efficiency (WUE) under drought stress. Four sesame populations were derived from crossing among six parents i.e., population 1 (Sandaweel 3* 375* Sandaweel 3), population 2 (Lines 237*217* 241), population 3 (Sandaweel 3* lines 241* 237) and population 4 (Lines 241* 217* 220) for two growing seasons. Measurements were taken under various of water deficit levels (100 % ETo, 80 % ETo, 60 % ETo). The highest seed yield was belonging to population No.4 while, population No.1 and 3 were the lowest among populations. The NDVI index was sensitive to changes in plant biomass, vigor, and leaf size, which varies from water deficit level to another and from population to another. The activities of peroxidase and catalase antioxidant enzymes were altered when plants were subjected to stress. POX and CAT activity increased significantly in all populations for both drought stress Levels. CAT activity increased in Pop. No.4 more than 20 folds due to water stress. Results suggest that water deficit induces oxidative stress in growing sesame plants and that peroxidase and catalase could serve as important components of antioxidative defense mechanism against drought. Proline, RWC, chlorophyll content and NDVI are powerful tools for the study of spatial and temporal heterogeneity of leaf transpiration and photosynthetic performance. The highest values of WUE of seed or oil yields (kg/m3) were obtained by irrigating population 4 under sever water stress. The correlations between NDVI and grain yield within individual trials varied depending on crop stage, moisture availability, and genotypes composition. The genotypes were accumulated more proline due to stress had the same genotypes which gave the highest RWC, POX and CAT enzymes.

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1. Introduction:

Egyptian water resources are very limited, especially for irrigation practice (80% of water share), therefore, irrigation water saving is very needed in Egypt. Sesame (Sesamum indicum L.) is an important oilseed crop in Egypt as well as in many parts of the world with great commercial attributes by virtue of its oil having an edible quality and medicinal value. It yields 50-60% oil and 35-50% protein and the oil is highly stable against rancidity due to the presence of the natural antioxidants sesamin and sesamolin Kobayashi et al., (1990).

In sesame breeding programs, selection for seed yield, a polygenic trait, often leads to changes in other characters. Therefore, improvement through breeding should realistically assess the contribution of various yield components (Adebisi, 2004). Correlation studies enable the breeder to know the strength of the relationship between various characters as well as the magnitude and direction of changes expected during selection (Ariyo, 1995). Drought limits the sesame production by preventing the crop plants from expressing their full genetic potential. Different breeding approaches for drought resistance have emerged, with their merits and demerits.

Efficient screening techniques are pre-requisite for success in selecting desirable genotype through any breeding program. Any effort for genetic improvement in drought resistance utilizing the existing genetic variability requires an efficient screening technique, which should be rapid and capable of evaluating plant performance at the critical developmental stages. Drought is known to cause oxidative damage to plants either directly or indirectly by triggering an increased level of production of reactive oxygen species (ROS) (Ma³ecka et al., 2001). These ROS include superoxide radical (O2+), hydroxyl radical (OH+) and hydrogen peroxide (H2O2) that are produced as by products during membrane linked electron transport activities as well as by a number of metabolic pathways (Becana et al., 2000).

To combat the oxidative damage plants, have the antioxidant defense system comprising of enzymes. Catalases are involved in scavenging H2O2 generated during the photo-respiration and b-oxidation of fatty acids. Some researchers have recently argued that the peroxidases are a unique form of the resistance enzyme in that multiple substrate–enzyme products can promote resistance through several different mechanisms (Dowd et al., 2000). Peroxidases may be also involved in insect resistance in maize. In addition to the potential use in marker assisted breeding, the enhanced expression of this anionic peroxidase through breeding or genetic engineering may lead to an enhanced insect or disease resistance as reported by some researchers (Dowd et al. 2010). Remote sensing of vegetation is a non-invasive methodology to monitor physical and physiological characteristics of plants and to evaluate the effects of environmental stresses on leaves plant performance.

In remote sensing applications, Normalized difference vegetative index (NDVI) is becoming increasingly important as innovative techniques for selecting for drought tolerance. This approach is a nondestructive, rapid and reliable method for monitoring of whole plant response to water stress Bayoumi et al., (2016). In the present study, an attempt has been made to evaluate the role of antioxidant enzymes in sesame genotypes to drought tolerance; to find the effective selection criteria for drought tolerance and to determine the water use efficiency for sesame genotypes under water deficit.

2. Materials and Methods:

2.1. Genetic material and experimental field

This research was conducted to study the effects of water stress on sesame genotypes. Two field experiments were conducted for two consecutive seasons (2014 and 2015) to select sesame genotypes from four populations resulting from six parents to drought stress. The experiments were applied in the Experimental Farm of the Ismailia Research Station, Oil Crops Section, Agricultural Research Center (ARC). The breeding materials that used in this study consisted from four F2 populations of crosses established between six genotypes. The first population was derived from the cross (Sandaweel 3* line 375* Sandaweel 3), the second population was derived from the cross lines (237*217* 241), the third population was derived from the cross (Sandaweel 3* lines 241* 237) and the fourth population was derived from the cross lines (241* 217* 220). Irrigation water was supplied by sprinklers to provide the three water regimes which were well-watered (100% from ETo), intermediate (80% from ETo) and severe water stress (60% from ETo). The experiment was separated by 6 m to prevent the overlapping of sprinklers for each water regime.

The amount of water which needed for irrigation was calculated according to Penman-Monteith equation (Allen et al., 1998). The area of each plot was 10×3x0.6 m. Seeds were sown on the flat in rows at the rate of 3.5 kg/fad and at a spacing of 60 cm between rows and 20 cm between plants. The crop was grown on the 15th of May in each season. The fertilizers were applied at sowing by banding on one side of the row at 5 cm depth. After three weeks from sowing, plants were thinned to two plants/hole. At harvest, random samples of ten plants from each replicate and each moisture level were taken to determine seed yield and the following characters.

Oil extraction: Dried seeds were ground and oil was extracted using light petroleum ether (60 $_{o}$C) by Soxhlet method according to (de Peña & Arredondo, 1992)

Water use efficiency: At the end of the growing season, water use efficiency was calculated (kg m-3) according to Vites (1996).

Relative water content

Leaf relative water content (RWC) was proposed as a better indicator of water status. RWC, through its relation to cell volume, may more closely reflect the balance between water supply to the leaf and transpiration rate. RWC was determined according to (Mitra. and Pal, 1999).by the following equation:

$$RWC\,\% = \frac{\text{Fresh weight - dry weight}}{\text{Turgid weight - dry weight}} \times 100$$

SPAD chlorophyll reading

Leaf Chl content was measured to evaluate leaf senescence. A hand-held leaf Chl meter (SPAD-502 plus; Spectrum Technologies, Plainfield, IL) was used to measure Chl content on three subsamples taken per plant. The Chl meter gives an index of total leaf Chl content.

The Normalized Difference Vegetation Index (NDVI) determination

The NDVI of the total plant biomass in each plot was measured at heading stage by means of a portable Green Seeker TM Spectro radiometer (Trimple, USA). The sensor head was placed 70 cm above the surface of the plot, covering the total area of the plants and about 10 NDVI measurements were taken at each plot. The averaged NDVI measurements were soil-adjusted by subtracting NDVI measurements taken in an empty plot. The NDVI, in the range of -1 to 1, is derived from red and near-infrared bands of remotely sensed images - (NIR – RED)/ (NIR + RED).

Proline determination

Proline was determined in fully expanded leaves according to Pesci and Beffagna (1984). The samples (50 mg fresh weight) were extracted with 10 ml of sulphosalicylic acid solution for 1 hour at room temperature and filtered on Whatman fiber glass paper. A part of the extract was added to 4 ml ninhydrin reactive and 4 ml of acetic and incubated in boiling water for 1 hour. After fast cooling in ice, the samples were added to 5 ml of toluene and strongly shaken. The toluene phase, containing the colored complex was used to measure the absorbance at 515 nm versus toluene. From obtained absorbance values it has been calculated the proline amount of each sample by means of a calibration curve, made by starting from known amount of proline.

Peroxidase activity:

Peroxidase (POx) activity was determined as described by Liu & Kogan (2002). The POD reaction solution (3ml) contained 50mM potassium phosphate buffer (pH 7.8), 20mM guaiacol, 40mM H2O2, and 100 l enzyme extract. Changes in absorbance of the reaction solution at 470nm were determined every 20 sec. One unit of peroxidase activity was defined as an absorbance change of 0.01 units per min.

Catalase activity:

The assay of catalase activity was carried out in a total volume of 3 ml of 50 mM Na phosphate buffer (pH 7.0) containing 4.51 μl of H2O2 (30%) and 50μl of enzyme extract. The decrease in absorbance at 240 nm because of degradation of H2O2 was monitored every 30 sec for 2 min, using a spectrophotometer U-1800 (Hitachi, Japan). Catalase activity was expressed as nano moles of decomposed per milligram of protein per minute.

Statistical analysis:

All data were subjected to analysis of variance (ANOVA) using SAS software (Anonymous, 1996). The significance of the treatment effect was determined using F-test, and mean separation was analyzed by LSD test.

3. Results and Discussions:

3.1. Effect of water stress on Yield and seed oil %

Water stress is the most important limitation to sesame productivity in semiarid regions. Therefore, the development of sesame populations that use available water more efficiently and that are able to tolerate is the main objective of the research. An important objective in most sesame breeding programs is to enhance the genetic potential for seed yield. Because of the low heritability, it has been suggested that indirect selection based on one or more of its components (number of capsules or 1000-seed weight) might be more effective than direct selection for seed yield itself. According to the results showed in (Tables 1, 2and 3) the variance analysis indicated that water stress effect was significant on the yield and its attributes. There was evidence of significant genotypic variations for drought tolerance among the studied populations. Population No.4 had the heaviest seeds with 1000-seed weights of approximately 3.46g for100% ETo, 3.29g for 80% ETo and 2.96 g for 60 % ETo in the first season (2014). While, in the season (2015) 1000-seed weights were 5.04 g for 100% ETo, 3.51 g for 80% ETo and 3.39 g for 60% ETo. The results clearly indicated that any change in the amount of irrigation water less than optimum condition reduces the1000-seed weights.

Where, Water deficit reduces plant photosynthesis by closing stomata, decreasing leaf area, stomata gravity, chloroplast, protoplast hydration, protein and chlorophyll synthesis. However, reducing of photosyntate transport accumulates the products in leaves results in a diminution in photosynthesis, limiting growth and crop yield (Baker and Rosenqvist, 2004). Sesame populations in non-drought stress (100% ETo) had an average yield of 508.9 g/m2 in the first season (2014) and enhanced into 634.9 g/m2 in the second season (2015). The increase in yield and its attributes might be due to the availability of water at a reproductive phase when the plant needs more moisture.

Table (1). *Performance of yield and its attributes traits in sesame populations under 100% ET_o moisture level*

Pops.	Seed yield pl^{-1} (g)	Seed yield (g) /m^2	1000-seed weight (g)	Oil %	Seed yield pl^{-1} (g)	Seed yield(g) /m^2	1000-seed weight (g)	Oil %
	Season (2014)				Season (2015)			
Pop. 1	30.5	440.3	3.03	50.5	49.4	824.1	4.68	56.6
Pop. 2	27.1	451.4	3.17	50.4	46.1	768.1	4.40	53.2
Pop. 3	26.4	457.0	3.07	51.1	38.6	643.2	4.36	53.5
Pop. 4	27.4	508.9	3.46	54.4	50.6	844.1	5.04	57.3
MP	25.6	426.7	3.48	51.24	38.1	634.9	3.63	56.1
LSD0.05	1.05	15.10	0.10	0.84	3.24	8.98	0.18	0.69

The highest seed yield was belonging to population No.4 for both seasons. The maximum effect of reduction belonged to population No.1 for the first season

Table 2: *Performance of yield and its attributes traits in sesame populations under 80% ETO moisture level.*

Pops.	Seed yield /Plant (g)	Seed yield(g) /m2	1000-seed weight (g)	Oil %	Seed yield /Plant (g)	Seed yield(g) /m2	1000-seed weight (g)	Oil %
	Season (2014)				Season (2015)			
Pop.1	18.3	269.9	2.81	49.0	31.01	528.0	3.45	51.7
Pop.2	21.8	304.2	2.90	49.5	28.84	480.6	3.02	50.7
Pop.3	16.2	345.8	3.07	48.9	26.29	438.1	3.24	50.5
Pop.4	20.8	363.9	3.29	51.2	31.67	528.1	3.51	53.4
MP	16.50	275.0	2.78	47.14	24.15	402.4	3.05	52.5
LSD 0.05	1.06	16.95	0.29	0.34	1.38	5.09	0.15	1.98

Table 3: *Performance of yield and its attributes traits in sesame populations under 60 % ETO moisture level.*

Pops.	Seed yield /Plant (g)	Seed yield(g)/m2	1000-seed weight (g)	Oil %	Seed yield /Plant (g)	Seed yield(g) /m2	1000-seed weight (g)	Oil %
	Season (2014)				Season (2015)			
Pop. 1	11.65	194.2	2.27	46.3	20.44	340.7	2.69	50.2
Pop. 2	13.42	223.7	2.61	46.4	22.32	372.1	3.13	49.0
Pop. 3	12.32	205.4	2.92	46.4	19.33	322.1	2.73	50.8
Pop. 4	13.88	231.3	2.96	47.1	25.33	422.1	3.39	51.6
MP	9.84	164.1	2.20	46.03	17.34	288.9	2.71	50.8
LSD0.05	0.21	7.92	0.20	0.66	1.34	14.84	0.09	0.96

While population No.3 was the lowest among populations in the second season. Data in (Table 2) showed that sesame populations in moderate-drought stress (80% ETo) had an average yield of MP. 275 g/m2 in the first season (2014) and 402.4 g/m2 in the second season (2015). Results in (Table 3) represented mean seed yield of sesame populations under sever water stress (60% ETo) ranged from 194.2 to 231.3 g/m2 in the first season (2014) and enhanced from322.1 to 422.1 g/m2 in the second season (2015).

Concerning populations ranking under drought stress (60% ETo), pop. No. 4 was the best whereas, the maximum effect of reduction belonged to population No.1 for the first season and population No.3 was the lowest among populations in the second season as shown under non-stress (100% ETo). The results obtained corresponded with the results of Jaleel et al. (2009) and study were done by Farooq and Azam, (2002) that reported a yield of sesame cultivars was reduced under drought stress.

The results obtained in this study indicated that a change in the mean value of a population frequently reflected the actual status of mean values for the studied trait. In other words, a population with the highest mean value for a given trait usually was the population with the highest gain in relation to the previous generation. It had been expected that the population with the highest genetic gain would also have the highest mean value.

However, in the case of the lowest trait, seed yield, the population changed from the first season from No.1 to No.3 in the second season. A possible explanation for this disagreement could be sought in different levels of variability in the populations from the previous generation. It appeared that an increased intensity of selection tended to reduce the genetic variability in a population, which resulted in lower mean values of the studied trait.

The same trend of results could be observed for 1000-seed weight. Sesame is affected negatively by water stress. The present study provides comprehensive insight into the genetic response of sesame populations to water stress over intensity water stress gradually suppresses the expression of sesame genes, with approximately half being significantly induced or suppressed.

3.2. Effect of water stress on SPAD values

Virtually all metabolic processes are affected by water stress if the stress is severe or of long duration. Photosynthesis is one of the most important processes which influenced by water stress. However, when stress is involved, the ability of plants to continue a relatively high rate of photosynthetic activity may contribute well to yield. Photosynthesis may be affected by drought stress which influenced by chloroplast activity. The amount of chlorophyll in a leaf is normally expressed in terms of either concentration or content and traditionally determined by a classical wet chemical method which considered the standard method for Chl determination and extraction. This method requires destructive sampling and is relatively time consuming.

More recently, nondestructive optical methods, based on the absorbance and /or reflectance of light by the intact leaf, have been developed. Optical methods generally yield a 'chlorophyll index' (SPAD value) that expresses relative chlorophyll content but not absolute Chl content per unit leaf area, or concentration per gram of leaf tissue. These newer methods are nondestructive, very quick, and now possible in the field. The change in leaf chlorophyll content (measured by SPAD meter) were presented in (Table 4) for the four sesame populations under various moisture levels. SPAD values ranged from 36.63 to 40.70 for 100% ETo. Chlorophyll content decreased sharply due to water stress, where it ranged from 35.79 to

38.61 under 80 % ETo moisture level and from 31.52 to 36.18 under 60% ETo moisture level. Population No.4 surpassed other populations in chlorophyll content or SPAD values under all moisture treatments in the both seasons. Recently, While, SPAD values ranged from 41.97 to 47.85 for 100% ETo. Chlorophyll content decreased sharply due to water stress, where it ranged from. 40.34 to 45.20 under 80% ETo moisture level and from 36.19 to 44.61 under 60% ETo moisture level. Population No.4 surpassed other populations in chlorophyll content or SPAD values under all moisture treatments. Chlorophyll fluorescence is used as one of the sensitive parameters for biosensors using thylakoid membranes or plant cells as the transducers.

Table 4: *Mean performance of SPAD values, normalized difference vegetative index (NDVI) for sesame populations under various moisture levels*

Pops.	SPAD value						NDVI					
	2014			2015			2014			2015		
	100 % ETo	80 % ETo	60 % ETo	100% ETo	80 % ETo	60 % ETo	100 % ETo	80 % ETo	60 % ETo	100 % ETo	80 % ETo	60 % ETo
Pop.1	37.17	35.79	33.84	43.50	40.34	41.45	0.723	0.587	0.423	0.759	0.69	0.56
Pop.2	39.47	37.96	33.75	44.19	42.80	41.21	0.747	0.613	0.455	0.771	0.70	0.58
Pop.3	36.63	36.20	31.52	41.97	42.28	36.19	0.740	0.630	0.305	0.761	0.75	0.38
Pop.4	40.70	38.61	36.18	47.85	45.20	44.61	0.767	0.723	0.575	0.777	0.76	0.62
Mp	39.77	39.59	36.24	46.37	45.28	43.65	0.747	0.674	0.650	0.771	0.70	0.67
LSD0	0.25	0.18	0.40	2.19	0.38	2.27	0.01	0.01	0.01	0.01	0.02	0.02

Besides this fast Chl fluorescence can be used as a sensitive device for detection of water deficit sensitivity and other environmental stress factors. As it is known, the chlorophyll plays the major role in the conversion of photo energy to chemical energy which is important for carbohydrate biosynthesis as well as for nitrogen assimilation which the major constituent of seeds. Several authors have reported decreases in leaf chlorophyll content when water stress imposed (Liu & Kogan, 2002).

3.3 Effect of water stress on Normalized Difference Vegetation Index (NDVI)

NDVI is closely correlated with green biomass and leaf area, and thus is one of the most widely used indices for agriculture monitoring. The NDVI, in the range of (-1 to 1) is derived from red and near-infrared bands of remotely sensed images. The notion behind NDVI is that plants' chlorophyll absorbs sunlight, which is captured by the red-light region of the electromagnetic spectrum, whereas a plant's spongy mesophyll leaf structure creates considerable reflectance in the near-infrared region of the spectrum. For this reason, greener and dense vegetation has low red-light reflectance and high near-infrared reflectance, and thus high NDVI values. The result in Table (4) indicated that sesame populations were healthier for 100% ETo moisture level than for 80% and 60 % ETo moisture levels. Where it was around 0.7 approximately for 100% ETO. While it was decreased moderately for population No.4 but decreased sharply up to 0.305 and 0.387 for pop.No.3 for 60% ETo moisture level in the both seasons, respectively. In short, the NDVI index was sensitive to changes in plant biomass, vigor, and leaf size, which varies for water deficit treatment to another and from population to another.

On the other hand, this index could be confirmed the results obtained by SPAD values and gave a fast and easy indicator for plant canopy. Moreover, the average NDVI for sesame crop was greater near the end of the growing season and the increases of monthly NDVI varied depending on how healthy and the dense crop was developing, crop condition ratings could plunge in a poor harvest year. These results are in agreement with Jensen, (2000), Pedroni, (2003) and Marti et al., (2007).

3.4. Effect of water stress on Relative water content (RWC)

Relative water content was determined to give an indication the plant water status during the experiment. There were significant differences among sesame populations in relative water content, moreover, water stress decreased it significantly. RWC varied from 63.3 to 87.7 % for 100 % ETo moisture level, from 33.4 to 65.6 % for 80 % ETo moisture level and from 24.2 to 40.4 % for 60 % ETo moisture level in the first season (2014) and, RWC varied from 71.4 to 91.7 % for 100 % ETo moisture level, from 36.9 to 69.8 % for 80 % ETo moisture level and from 25.3 to 42.5 % for 60 % ETo moisture level in the (2015) in (Table 5)It is worth to mention that population No.4 which had high RWC under non stress gave nearly the highest RWC under stress conditions. Where RWC were responded consistently among their plants. Accordingly, the breeders can easily identify such genotypes without critically needs to put his materials under stresses. In this case, RWC, SPAD and NDVI can be described as a constitutive trait. A character is said to be constitutive when its expression is environment- independent, i.e. differences between genotypes are relatively constant in a range of environments. Although a constitutive character is not expected to show high GE interaction, therefore constitutive characters can be of advantage in some environments as a tool for selection to drought under optimal conditions (Marti et al., 2007; Furbank & Tester, 2011).

Table 5: *Mean performance of relative water content (RWC) and proline content for sesame populations under various moisture levels.*

Pops	RWC (%)						PC (mg/g)					
	2014			2015			2014			2015		
	100%	80%	60%	100%	80%	60%	100%	80%	60%	100%	80%	60%
Pop.1	64.5	33.4	28.5	75.4	36.9	30.6	4.1	5.2	9.7	4.4	5.7	11.2
Pop.2	63.3	35.5	24.2	71.4	38.6	25.3	4.5	5.1	8.5	5.0	6.1	10.1
Pop.3	81.8	39.6	29.6	87.3	42	31.4	4.4	5.3	9.3	4.6	5.7	13.3
Pop.4	87.7	56.6	40.4	91.7	69.8	42.5	5.0	5.8	11.3	5.4	7.5	15.1
Mp	64.4	40.6	26.61	68.7	43.1	28.34	4.47	6.07	7.55	4.78	6.21	8.18
LSD0.05	1.93	0.37	1.56	2.24	2.14	1.59	0.15	0.21	0.15	0.17	0.26	0.26

3.5. Effect of water stress on Proline content (PC)

The phenomenon of proline accumulation by plant tissue during water deficit has attracted considerable attention since it was first described. In this work, the changes in the concentration of free proline accumulation was shown in (Table 5). Proline content differed slightly between populations under 100 % ETo. Water stress increased proline accumulation more 2 to 3 folds than normal water treatment (100 % ETo). population No.4 accumulated more proline (11.3 mg/g) under sever water stress followed by population No.3 (9.3 mg/g) in the first season (2014) and population No.4 accumulated more proline (15.1 mg/g) under sever water stress followed by population No.3 (13.3 mg/g) in the second season (2015).

It is worth to note that populations which more accumulated free proline due to stress had the same genotypes which gave the highest relative water content (RWC). As well as, populations which relatively accumulated less proline associated with lower R.W.C. Consequently, differences in proline accumulation rate among these populations must be due principally to genetic differences in the capacity to maintain water status during severe stress. These results indicated that accumulated proline acts as a compatible solute regulating and reducing water loss from the cell during episodes of water deficit. This finding was in agreement with Claussen, (2005) and Mabhaudhi and Modi, (2011) Bayoumi et al (2015).

De Ronde et al. (2000) confirmed that subjecting sesame plants to water stress increased free proline and it can be used as a selection criterion under water stress. Free proline accumulation in water stressed tissue and net proline synthesis to come from carbohydrates via a- ketoglutarate and glutamate. Oxidation of proline occurs rapidly in turgid tissue suggested that proline oxidation could act as a control mechanisms to maintain low levels of proline in turgid tissue. Under water stress conditions, proline oxidation was inhibited and this was thought to maintain the high level of proline in the stressed tissue (Li et al., 2002).

3.6. Water use efficiency (WUE)

Water availability is a major constraint for the production of crops in Egypt and improving water use efficiency is a primary target for growers, breeders and agronomists'. Plants are losing its water as they fix Co2 from the air. The loss is inevitable because Co2 must dissolve in water before it becomes available to the Cells. The wet cell surface must be exposed to the atmosphere inside the leaf, and evaporation will occur. As a result, the photosynthesizing cells dehydrate to varying degree depending on how rapidly the water evaporates and how readily the lost water can be replaced. Water use efficiency (WUE) was defined as the ratio of total dry matter produced to the total amount of water consumed (Ling, 1995). The results were showed in Fig. (1 and 2) provide an overview for WUE in sesame populations comparing with mid parents. The production of sesame biomass is proportional to the amount of water, radiation and nutrients captured by crop which was increased by increasing WUE under non-stress (100% ETo). WUE ranged from 0.452 to 0.603 for sesame populations under 100% ETo in the first season. While WUE ranged from 0.494 to 0.761 for sesame populations under 100% ETo. While it reduced up to 0.198 for Pop.No.1 under 60% ETo in 2015.

The equation of regression which describes the relation of WUE among populations was Y=0.0154 x +0.206 with a coefficient of determination (R2) about 0.575. Populations tended to fluctuate in WUE under the various water treatments. Generally, Stresses of water reduced growth and consequently sesame biomass through two processes reducing of resources captured by the crop and reducing the efficiency in the use of resources. Sesame biomass and seed yield depend on photosynthesis. Photosynthesis involves the uptake of carbon dioxide (CO2) through stomata, which are pore-like, specialized cells the surface of leaves. However; open stomata required for CO2 uptake but it is an open gate for water loss. Therefore, there is a tight trade-off between uptake of CO2 and water loss and this explains the close link between crop production and water use efficiency. These results are in agreement with (Shahidi et al., 2006).

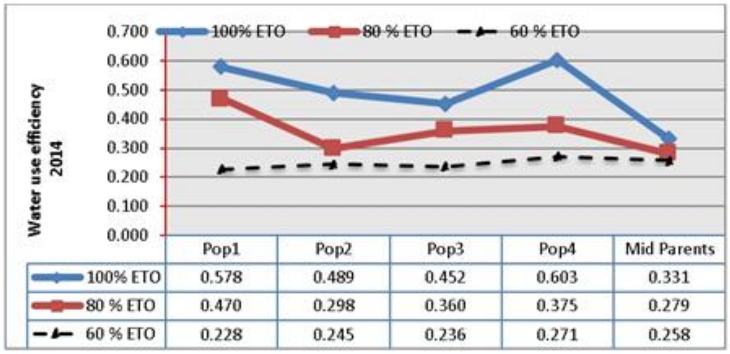

Figure 1. Effect of water stress on water use efficiency (WUE) for sesame populations and mid parents for (2014).

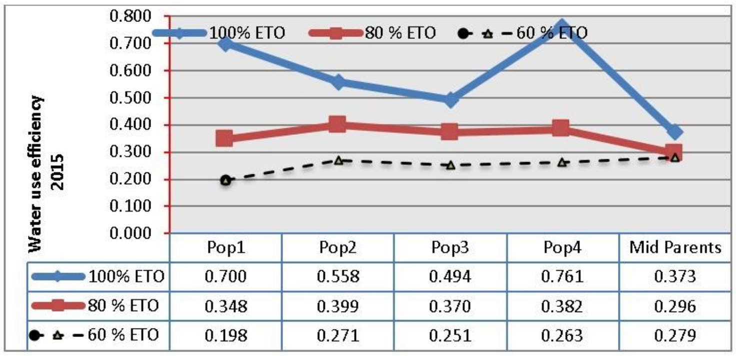

Figure 2. Effect of water stress on water use efficiency (WUE) for sesame populations and mid parents for (2015).

3.7. Effect of water stress on peroxidase (POX) and catalase (CAT) enzymes.

In order to analyze the changes of peroxidase (POX) enzymes in sesame under drought stress, POX activity was determined in this experiment. It was noticed that enzymes activity increased significantly in all populations for both drought stress treatments. POX activity increased in all drought treatments when compared with the control. The results showed that the lowest peroxidase was seen under normal conditions in Pop. No.1 (11.4 m mol peroxidase oxidation / mg FW) in C1. While in Pop. No.2 (18.7) in 2015 and the highest peroxidase was seen in Pop. No.4 (41.1 m mol peroxidase oxidation per mg FW) under high stress conditions (60% ETo) in (Figure 3) at 2014 and61.1 in 2015 at the same population in (Figure 4).

Higher levels of enzyme activities in the tolerant population could be due to its higher resistance. Under drought stress CO2 fixation and NADP+ recovering at the Calvin cycle decrease and cause the production of harmful free radicals and damage to the cell membrane (Jun & Junying, 1994). As can be seen in (Figure 3 and 4), significant differences (P ⩾ 0.01) were observed between populations and different levels of stress in leaves. Catalase activity (CAT) was measured in four sesame populations and their parents during vegetative stage (Figures 5 and 6). Compared with the control, there was significantly higher in CAT activity upon exposure to drought stress in all four populations during the vegetative stage. Catalase activity ranged from 0.103 to 0.217 m mol/mg FW under 100% ETo. While it increased up to 4.43 m mol/mg FW under severe water stresses (60% ETo).

The equation of regression which describes the relation of enzymes activity among populations Y=1.176 x + 22.7 with a coefficient of determination (R2) about 0.047 for peroxidase activity and Y=0.087 x + 2.351 with a coefficient of determination (R2) about 0.0158 for catalase activity in the first season.CAT activity increased in Pop. No.4 more than 20 folds due to water stress. But Catalase activity ranged from 0.231 to 0.561 m mol/mg FW under 100% ETo. While it increased up to 4.62 m mol/mg FW under severe water stress (60% ETo) in the second season. CAT activity increased in Pop. No.4 more than 8, 20 folds due to water stress in 2015 and 2014.The equation of regression which describes the relation of enzymes activity among populations Y=2.41 x + 28.17 with a coefficient of determination (R2) about 0.066 for peroxidase activity and Y=0.141 x + 2.709 with a coefficient of determination (R2) about 0.061 for catalase activity.

These results suggest that POX and CAT activities play an essential protective role against drought stress in sesame. Antioxidants act as a major defense against radical mediated toxicity by protecting the damages caused by free radicals.

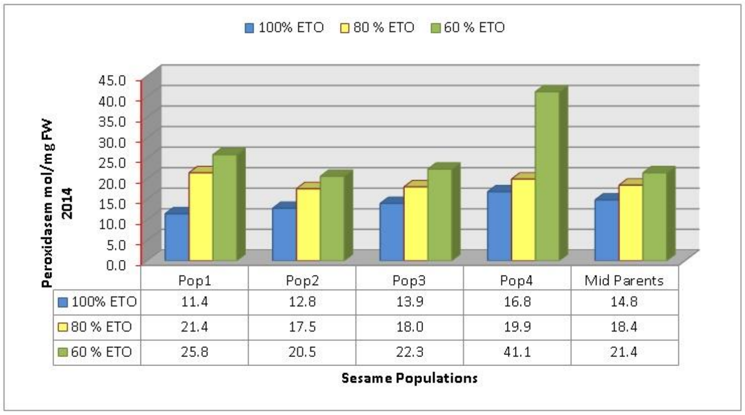

Figure 3. Effect of water stress on peroxidase activity for sesame populations and mid parents for (2014).

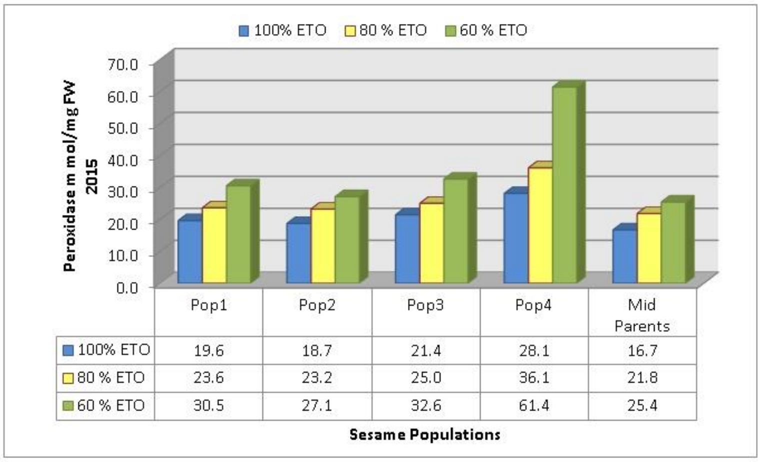

Figure 4. Effect of water stress on peroxidase activity for sesame populations and mid parents for (2015).

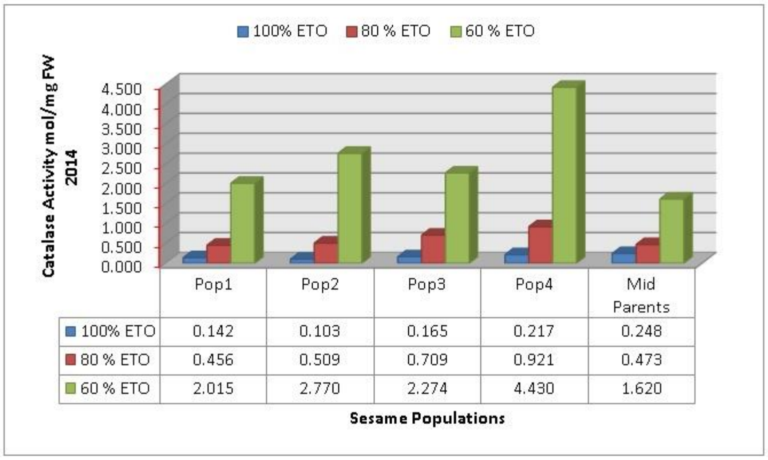

Figure 5. Effect of water stress on catalase activity for sesame populations and mid parents in (2014).

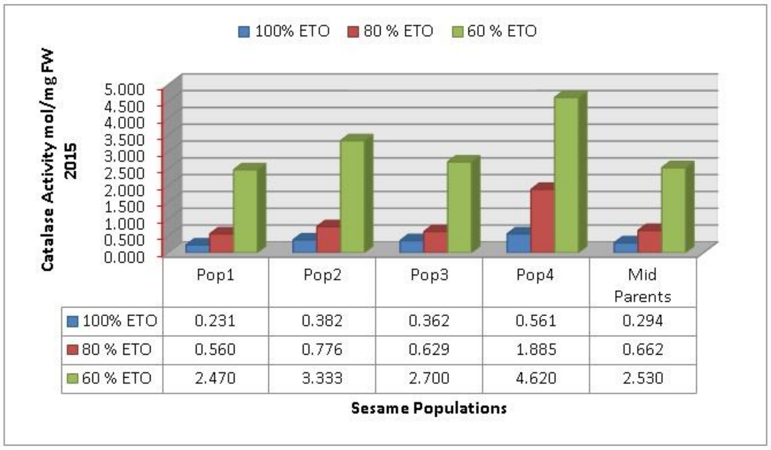

Figure 6. Effect of water stress on peroxidase activity for sesame populations and mid parents in (2015).

3.8. Correlation among traits

Plant breeders have devoted considerable attention to breed for yield under stresses. It is also true, however, that plant breeders have for decades sought to select for yield by manipulating what they call physiological components of yield under water stress. The close relation between the developments of different parts of the plant is evident from the way in which their size changes as growth proceeds. Therefore, the correlation between physiological characters and seed yield was calculated to find out, whether a character can be used as an indicator for seed yield under water stress. In plant breeding, correlation analysis measures the joint relationship between various plant traits and determines the component traits on which selection can be based genetic improvement in yield. Data in Table (6) showed that non-stress moisture (100 % ETo) level correlated negatively and significantly between seed yield / m2 and PC, RWC, POX and CAT. AT 80% ETo seed yield correlated positively and significantly with1000-SW, oil content, SPAD value and NDVI except POX and CAT enzymes correlated negatively, Enzymes activity (peroxidase and catalase) correlated positively and significantly under sever water (60 % ETo) they were 0.87** for POX and 0.81** for CAT.

Moreover, they were correlated positively and significantly with SPAD meter values(r=-0.86**), NDVI (r=-0.63**) I, Proline content(r=-0.67**) and RWC (r= 0.72**). These results suggest that selection for higher these previous traits would tend to increase seed yield in sesame under water stress. This situation will favor accumulating proline content, peroxidase and catalase and shortening of the length of the reproductive period by developing early genotypes without a reduction in seed yield, where, plants adjust their growth patterns to maximize the yield in the presence of drought. The present results can be expected that improvement of water use efficiency, chlorophyll content (SPAD) and NDVI (green biomass) should to greater dry matter production and/or an economic yield per unit of water used in a particular evaporative environment Balaghi et al., (2008).

Table 6: *Simple correlation between seed yield and morpho-physiological characters for sesame populations under different water stress treatments.*

Traits vs. Seed yield / m2	100 % ETo	80 % ETo	60 % ETo
1000-seed weight	0.54**	0.69 **	0.88**
Seed yield / plant	0.99**	0.91**	0.99**
Oil content	0.55**	0.56**	0.64**
SPAD meter value	0.70**	0.65**	0.86**

NDVI	0.94**	0.63**	0.63**
Proline content	-0.94**	0.44ns	0.67 **
RWC	-0.86**	0.83**	0.72**
Peroxidase	-0.33ns	-0.84**	0.87**
Catalase	-0.23ns	-0.60**	0.81**

4. Conclusions

It is concluded from the results of this study that sesame genotypes respond differentially to drought stress. Plant breeders in order to optimize the use of inputs and genetic diversity were required to identify the selection criteria for drought tolerance. To increase water use efficiency under field condition, researchers should increase transpiration efficiency and photosynthetic pigments which increase the capacity of genotypes. There was a strong correlation between yield under stress and WUE, NDVI, SPAD reading, POX and CAT, when subjected to drought stress, plants responded through alteration in physiological and biochemical processes. Additionally, enzymatic antioxidant systems including POX, and CAT played an important role in scavenging harmful oxygen species. Irreversible damage occurred when the enzymatic antioxidant system under drought stress was overwhelmed

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