

## Salt Tolerance Mechanisms in Some Halophytes from Saudi Arabia and Egypt

Ashraf Mohamed Youssef

Department of Botany, Faculty of Science, Ain Shams University, Cairo, Egypt.

---

**Abstract:** Halophytes residing in coastal areas of the semi-arid regions are often subjected to intense and varying environmental stresses. In order to adapt with non-permissive conditions, they developed growth, physiological and biochemical changes for survival that allow them to grow in saline habitats. Five succulent halophytic species were selected during summer from the coastal zone along each of Al-Qatif on the Arabian Gulf in Saudi Arabia (Site I) and south of Safaga on the Red Sea in Egypt (Site II). These included: *Halocnemum strobilaceum*, *Arthrocnemum macrostachyum*, *Halopeplis perfoliata*, *Suaeda vermiculata* and *Seidlitzia rosmarinus*. Their response to salinity was studied in both sites in respect to habitat conditions. The involvement of photosynthetic pigments, ions, free amino acid, soluble protein, soluble sugar and proline, as well as activities of certain antioxidant enzymes activation in salt tolerance of these halophytes were investigated. Plants obtained from Site II were characterized by higher values of TWC and RWC concomitantly with high contents of photosynthetic pigment fractions (chl.a, chl.b and carotenoids). Results pointed to a prominent feature in the mechanism of the protective adaptive response mechanisms of halophytes. It was observed that halophytes of Site I tended to retain higher soluble protein, soluble sugar, proline and total organic osmolytes as well as higher activity levels of CAT and GR enzymes, while the halophytic species of Site II tended to accumulate high contents of photosynthetic pigments, free amino acids and higher levels of POD activity. It is of interest to observe that the accumulation of total organic osmolytes of most studied halophytes were associated with the increase of succulence ratio attained concurrently with higher values of Cl<sup>-</sup>, Na<sup>+</sup> and SO<sub>4</sub><sup>2-</sup> determined in each of soil and plants either collected from Site I or site II.

**Key words:** Salt marshes, Osmotic adjustment, Red Sea, Al-Qatif, Photosynthetic pigments, Organic osmolytes, Proline, Antioxidant enzymes

---

### INTRODUCTION

In arid and semiarid climate zones, desertification, land degradation and declining precipitation rates increasingly limit crop cultivation<sup>[15]</sup>. It has been estimated that two-thirds of the potential yield of major crops are usually lost due to adverse growing environments<sup>[8]</sup>. Most climate change scenarios predict a worldwide increase in arid areas, including the coastal zones<sup>[32]</sup>. Over 90% of the planet's living and nonliving resources are found within a few hundred kilometers of the coast around the world<sup>[1]</sup>.

There is an increasing interest in organisms that are capable of colonizing extreme environments<sup>[25,65]</sup>. In order to cope with non-permissive conditions, they developed unusual physiological and biochemical adaptations for survival that allow them to grow in habitats that are near the extremes of life<sup>[19,61]</sup>. Understanding the mechanisms by which native plants cope with naturally saline conditions is a logical starting point for selection and development of salt-

tolerant native species for the rehabilitation of land affected by salinity<sup>[64]</sup>.

Salinity and drought are among the major stresses that adversely affect plant growth and crop productivity. These constraints remain the primary causes of crop losses worldwide, reducing average yields by more than 50%<sup>[12,67]</sup>. Soil salinization today affects about 7% of the global total land area<sup>[41]</sup> and 20–50% of the global irrigated farmland. Desertification and salinization also result in a further shortage of the already limited fresh water resources<sup>[27]</sup>. Simultaneously, the world population is presently growing by 80 million people every year<sup>[18,52]</sup>, so that the requirement of cultivable farmland and of fresh water will continually increase.

Halophytes grow in a wide variety of warm, arid to semi-arid saline habitats, from coastal sand dunes, salt marshes and mudflats to inland deserts, salt flats and steppes<sup>[20]</sup>. These plants are characterized by high specialized modifications not only for their salt tolerance limits, but also for the climatic zone from

which they originate. A geographical classification differentiates between hydro-halophytes, typical from brackish wetlands, and xero-halophytes, that are particularly well-adapted to deserts and low-moisture environments<sup>[63]</sup>.

Soil salinity is a major factor limiting plant growth, development and productivity in many areas of the world<sup>[22,34]</sup>. In salty ecosystems, halophytes are often subjected to salinity and drought. Accumulation of compatible osmolytes plays an important role in their tolerance to these two constraints. Hester *et al.*<sup>[31]</sup> demonstrated that intraspecific variation in morphological and physiological traits expressed under salinity stress was as great as interspecific variation in their study on several halophytic grasses, .

Salt induces osmotic stress by limiting absorption of water from soil, and ionic stress resulting from high concentrations of potentially toxic salt ions within plant cells. Plants have evolved a variety of protective mechanisms to allow them to cope with these unfavorable environmental conditions for survival and growth, including the accumulation of ions and osmolytes such as proline. The accumulation of these compounds prevents water loss and ion toxicity<sup>[6]</sup>. One adaptive plant response to salt stress is synthesis and accumulation of low-molecular weight organic compounds in the cytosol and organelles<sup>[5,9,58]</sup>. These compounds are collectively called compatible osmolytes because they accumulate and function without perturbing intracellular biochemistry, such as enzyme or protein activities in the cytoplasm.

Under salt stress conditions, plants accumulate several kinds of compatible solutes such as proline, soluble protein, soluble sugar and amino acid. These organic osmolytes contribute to the (osmotic adjustment) OA and also protect the structural integrity of cell membranes and proteins, but do not have negative effects on plant metabolism even when present at high concentrations in the cytoplasm<sup>[73,16]</sup>. In halophytes such as *A. halimus*, OA in response to salinity or drought, which also cause cellular dehydration, involves vacuolar accumulation of inorganic ions; simultaneously, compatible solutes accumulate in the cytoplasm to maintain an osmotic equilibrium across the tonoplast<sup>[45-47]</sup>. Another function of compatible osmolytes that may occur at lower concentrations is osmoprotection, which includes protection of thylakoid and plasma membrane integrity, stabilizing proteins, a sink for energy or reducing power, a source of carbon and nitrogen for recovery, or scavenging of reactive oxygen species that are byproducts of salinity stress<sup>[958]</sup>.

Exposure of plants to salinity, drought or extreme temperatures commonly results in a water deficit. Maintaining osmotic homeostasis requires an increase

of osmotica in cells either by uptake of soil solutes or by the synthesis of metabolically compatible compounds<sup>[62]</sup> that can accumulate to high concentrations without interfering with plant metabolism<sup>[72]</sup>. These organic osmolytes are most commonly carbohydrates (such as sugars), amino acids, protein and proline<sup>[75]</sup>. Apart from their role in osmotic adjustment, compatible solutes have also osmoprotective functions. Due to their specific hydrophilic structure, they are capable of replacing water on the surfaces of proteins, protein complexes or membranes, thus preserving their biological functions<sup>[28]</sup>. Most compatible solutes also seem to play an important role in hydroxyl radical scavenging<sup>[4]</sup>, thus defending plants against oxidative damage, which is a common consequence of many abiotic stresses<sup>[33]</sup>.

Al-Qatif, the first area of our investigation, is a large city and oasis in the northeastern part along the coast of the Arabian Gulf in the Kingdom of Saudi Arabia. Al-Qatif lies at the northern end of a large metropolitan and industrial area, where the other cities are Dammam, Khobar and Dhahran. Al-Qatif enjoys a continental climate, with a very hot and humid weather especially in summer<sup>[70]</sup>. The second study area (south of Safaga), is located along the coastal zone of the Red Sea in Egypt. The Red Sea lies between arid land, desert and semi-desert. Salt marshes is one of the major groups of the rich coastal habitat which inhabiting the coastal zone in each of the Arabian Gulf<sup>[77]</sup> and Red Sea<sup>[76]</sup>. Therefore, the purpose of this study was to understand and compare some ecophysiological aspects of selected salt marshes from coastal areas along the Arabian Gulf in Saudi Arabia (Al-Qatif) and the Red Sea in Egypt (south of Safaga), to live under the high salinity of the different studied habitats. Particular interest was paid to the involvement of photosynthetic pigments, ions, free amino acid, soluble protein, soluble sugar and proline, as well as some antioxidant enzymes activation in salt tolerance of these investigated halophytes.

## MATERIALS AND METHODS

The selected samples were obtained from the coastal areas along each of Al-Qatif on the Arabian Gulf in Saudi Arabia and south of Safaga on the Red Sea in Egypt during July, 2007.

**Description of the Study Sites:** Al-Qatif or Qatif (also spelled Qateef or Al-Qateef) is a historic, coastal oasis region located on the western shore of the Arabian Gulf in the Eastern Province of Saudi Arabia. It extends from Ras Tanura and Jubail in the north to Dammam in the south, and from the Arabian Gulf in the east to King Fahd International Airport in the west.

This region includes the town of Qatif as well many smaller towns and villages<sup>[59]</sup>. The selected halophytes of the first location (Site I) were collected from the coastal area of Al-Qatif along the Arabian Gulf 26°56 034'N 50°01 861'E (Fig.1).

The Red Sea lies between arid land, desert and semi-desert. The main reasons for the better development of coastal species along the Red Sea is because of its greater depths and an efficient water circulation pattern. The Red Sea water mass exchanges its water with the Arabian Sea, Indian Ocean via the Gulf of Aden. These physical factors reduce the effect of high salinity caused by evaporation and cold water in the north and relatively hot water in the south<sup>[76]</sup>. The selected salt marshes representing the second location (Site II), were collected from the coastal region of the area south of Safaga 26°45 018'N 33°56 410'E (Fig. 2).

Description of the studied areas with some climatic parameters from the nearest weather stations for the studied sites from Dammam (Saudi Arabia) and Safaga (Egypt) during 2007 were picked<sup>[24]</sup>. Altitude was determined using a Global Positioning System (GPS) at the two localities of the area under investigation.

**Plant Material Collection:** Plant materials used in the present investigation were obtained during summer from selected succulent halophytic species which grow naturally along the coast in the two studied areas. Two different habitats were studied and included Site I, which extended along the coastal zone of Al-Qatif (26°56 034'N 50°01 861'E) on the Arabian Gulf in Saudi Arabia and Site II which located along the coast south of Safaga (26°45 018'N 33°56 410'E) on the Red Sea in Egypt (Figs.1 and 2). Five succulent halophytic species were selected from each of the study sites (I and II) which included: *Halocnemum strobilaceum* (Pall.) M. Bieb, *Arthrocnemum macrostachyum* (Moris.) Moris & Delpont., *Halopeplis perfoliata* (Forssk.) Bunge Ex Asch., *Suaeda vermiculata* Forssk. ex J.F.Gmel. and *Seidlitzia rosmarinus* Ehrenb.ex Bunge from the coastal zones along such sites. Leaves and young branches of each plant were collected and frozen with liquid nitrogen, and then they were deposited in a refrigerator at -15°C for the different analysis..

**Soil Analysis:** At both sites, soil samples were taken from each associated plants at a depth of 5- 30cm, mixed, air-dried and passed through a 2- mm mesh prior to the analyses. Soil textural analysis (%) was determined by the dry sieving method of Kilmer and Alexander (1949). Soil water contents were determined as in the following equation:  $SWC(\%) = (FW - DW)/DW \times 100$ , where FW was the fresh weight of

a soil and DW was the dry weight of the same soil portion after had been oven-dried at 105°C. Total soluble salt percentages (TSS), pH, electrical conductivity (EC) expressed as  $dSm^{-1}$  of the saturated soil extracts at a ratio of 1:5 of air-dried soil samples: water, were determined as described by Richards (1954). Soil samples were dried in an oven for 2 days at 105 °C. Concentration of  $Na^+$  and  $K^+$  were determined in soil water extracts by flame photometer as described by Wilde *et al.*,<sup>[69]</sup> and their values expressed as g/100g dry wt. Chloride ( $Cl^-$ ) was analyzed by precipitation as  $AgCl$  and titration according to Johnson and Ulrich<sup>[35]</sup> and its value expressed as g/100g dry wt. Sulfate ( $SO_4^{2-}$ ) was estimated gravimetrically according to Wilde *et al.*,<sup>[69]</sup> and expressed as g/100g dry wt.

#### **Plant Analyses:**

**Succulence:** Leaf succulence was estimated as the ratio of plant water content and dry weight as followed by Dehan and Tal<sup>[17]</sup>.

**Plant Water Status:** The plant material collected from both sites was first cleaned with distilled water. After the water on the plant was absorbed by tissue paper, fresh weight (FW) was measured. The dry weight (DW) was measured after the fresh material was dried at 60°C for 48 h. Tissue water content percentage of plant shoots was determined as  $TWC(\%) = 100 \times (FW - DW)/FW$ . The relative water content (RWC) was measured as the following equation:  $RWC(\%) = 100 \times (FW - DW)/(TW - DW)$ , where TW stands for the turgid fresh weight<sup>[14]</sup>. TW was obtained after soaking the plant shoot pieces in distilled water in test tubes for 12 h at room temperature (20°C) under low light condition. Then pieces were quickly and carefully blotted dry with tissue paper for determining turgid weight.

**Photosynthetic Pigment Determination:** Leaves and young branches used for photosynthetic pigment extraction were immersed in 5mL of 80% acetone and left in the dark at 4°C for tonight. After spectrophotometric measurements at 470, 652.4 and 665.2 nm, chlorophyll *a*, chlorophyll *b* and carotenoids, concentrations were calculated according to Linchtenthaler and Wellburn<sup>[43]</sup>. Values were expressed in  $mg\ g^{-1}\ F. Wt.$

**Sodium, Potassium, Chloride and Sulfate Determination:**  $Na^+$  and  $K^+$  were assayed by flame emission spectrophotometry after nitric acid extraction ( $HNO_3\ 0.5\%$ ) of the finely ground dry matter



Fig. 1: Location map of Al Qatif coast, Arabian Gulf, Saudi Arabia<sup>[68]</sup>



Fig. 2: Location map of Safaga area on the Red Sea coast, Egypt<sup>[48]</sup>

(Jenway, PFP-7) according to Williams and Twine<sup>[71]</sup>. Chloride was analyzed by precipitation as AgCl and titration according to Johnson and Ulrich<sup>[35]</sup>. Sulfate of the plant dry matter was determined gravimetrically as described in AOAC<sup>[7]</sup>. Values of ions were expressed in mg/100g dry wt.

**Organic Osmolytes:** Free amino acid was estimated according to the method of Moor and Stein<sup>[48]</sup>. The optical density was read at 570 nm on spectrophotometer (Spectronic Genesys ZPC, Rochester, NY, USA). Soluble protein was determined according to Bradford<sup>[13]</sup>. Soluble sugar was extracted by distilled water from the plant tissues and determined according to the anthrone sulphuric acid method<sup>[21]</sup>. Proline was determined according to the procedure of Bates *et al.*<sup>[10]</sup>. Values of all fractions of organic solutes were expressed in mg/100g d.wt.

**Antioxidant Enzyme Activities:**

**Enzyme Extraction:** The samples were prepared as described by Mukherjee and Choudhuri<sup>[50]</sup>. A leaf sample (0.5 g) was frozen in liquid nitrogen and finely ground by pestle in a chilled motor, the frozen powder was added to 10 ml of 100 mM phosphate buffer (KH<sub>2</sub>PO<sub>4</sub> / K<sub>2</sub>HPO<sub>4</sub>) pH 7.0, containing 0.1 mM Na<sub>2</sub>EDTA and 0.1 g of Polyvinylpyrrolidone. The homogenate was filtered through cheese cloth, then centrifuged at 15000 g for 10 min at 4°C. The supernatant was recentrifuged at 18000 g for 10 min, and then the resulted supernatant was collected and stored at 4°C for catalase (CAT), peroxidase (POD), and glutathione reductase (GR) assays.

**Catalase Activity:** Catalase (EC 1. 11. 1. 6) activity was assayed according to Aebi<sup>[2]</sup>. The activity of catalase was estimated by the decrease of absorbency

at 240 nm for 1 min as a consequence of H<sub>2</sub>O<sub>2</sub> consumption<sup>[29]</sup>. Catalase activity was expressed as  $\mu\text{mol H}_2\text{O}_2$  destroyed  $\text{gm}^{-1}$  F.wt.  $\text{hour}^{-1}$ .

**Peroxidase Activity:** Peroxidase (EC 1. 11. 1. 7) activity was determined according to Maehly and Chance<sup>[44]</sup> by the oxidation of guaiacol in the presence of H<sub>2</sub>O<sub>2</sub>. The increase in absorbance due to formation of tetraguaiacol was recorded at 470 nm<sup>[39]</sup>. The enzyme activity was expressed as the change in optical density  $\text{gm}^{-1}$  F.wt.  $\text{hour}^{-1}$ .

**Glutathione Reductase Activity:** The activity of glutathione reductase (EC 1. 6. 4. 2) was measured according to Foyer and Halliwell<sup>[23]</sup> which depends on the rate of decrease in the absorbance of NADPH at 340 nm. The enzyme activity was expressed as the change in optical density  $\text{gm}^{-1}$  F.wt.  $\text{hour}^{-1}$ .

## RESULTS AND DISCUSSION

According to the descriptive data for the studied sites, the locations from which plants were collected are shown in Table 1. Plant materials were obtained during summer 2007 at Site I in Al-Qatif along the Arabian Gulf coast, Saudi Arabia (altitude 3m asl; 26°56' 034"N 50°01' 861"E) and Site II at south of Safaga along the Red Sea coast, Egypt (altitude 1m asl; 26°45' 018"N 33°56' 410"E). The average minimum temperature during the period of study was almost the same for both locations I and II (29° and 28°C), while the average maximum and mean temperatures were varied between 43°C to 36 in Site I and 37°C to 32.5 in Site II, respectively. The two studied Sites were completely rainless during the study period. The relative humidity was high in both areas, however, it was more prominent in Site I (73%) than in Site II (67%).

Regarding the parameters of soil profiles associated with the selected plants at the two studied sites (Table 2), the soil texture was fine sand in both sites with more amounts of silt and clay in case of Site II (28.1%). Soil profile from Site II appeared to have higher amount of SWC (37.7%) than that which recorded in Site I (35.2%). Meanwhile, the soil profile collected from Site I was attained high values of TSS (10.8%) compared with those indicated by soil sample from Site II. Soil reaction (pH) was generally alkaline in the two areas and ranged between 7.52 to 7.78. Values of soil EC were relatively high during the period of study within both sites, however, it was much higher in Site I (1.21 dS m<sup>-1</sup>) than the value observed in Site II (0.65 dS m<sup>-1</sup>). Concerning the analyzed ions of the soil samples representing the studied sites, Table 2 clearly indicates that sodium ion

(Na<sup>+</sup>) was the dominant cation whereas chloride ion (Cl<sup>-</sup>) was the dominant anion within the two studied areas. It is notable that the concentrations of Na<sup>+</sup> and Cl<sup>-</sup> were much higher in Site I (2.48 and 4.31 g/100g dry wt., respectively) than those recorded in Site II (1.92 and 3.61 g/100g dry wt., respectively). The values of potassium (K<sup>+</sup>) and sulfate (SO<sub>4</sub><sup>-</sup>) ions were varied among the two sites and were ranged between 0.38 and 1.66 g/100g dry wt.

From Data indicated in Fig 3, it is clear that *Arthrocnemum macrostachyum* was characterized by apparently higher ratio of succulence (3.18 and 3.55) during the period of study in summer within the two investigated sites I and II. The highest values of succulence were attained by *Suaeda vermiculata* reaching its maximum of 4.43 at Site I. From data in Figs. 4 and 5, it is clear that percentages of TWC and RWC were varied between the different studied halophytes at the two sites. *Suaeda vermiculata* attained the highest value of TWC (65.2%) at Site II, whereas the lowest record of TWC (52.6%) was observed in *Seidlitzia rosmarinus* at the same Site. However, the maximum values of RWC were recorded by the halophytic species *Halopeplis perfoliata* at both sites (28.7 and 29.3%). Values of TWC and RWC which revealed by the other studied halophytes in the different locations were ranged between 55.1 and 63.8% for TWC and between 23.8 and 27.6% for the RWC parameters. In general, data of Figs. 4 and 5 indicated that all halophytes collected from Site II showed higher percentages of TWC and RWC compared with those recorded by plant species which were obtained from Site I, except in values of TWC which showed a reverse trend in case of *Seidlitzia rosmarinus*.

Concerning the photosynthetic pigments of the studied halophytes during the period of investigation in summer, it was found that higher values of chl.a, chl.b and carotenoid were attained by halophytes of Site II (Figs. 6A-C). The highest values of chl.a and chl.b constituents were observed in *Arthrocnemum macrostachyum* under the two sites (1.76 and 1.29 mg g<sup>-1</sup> F. Wt. at Site I and 2.44 and 1.54 mg g<sup>-1</sup> F. Wt. at Site II, respectively). However, the carotenoids reached its maximum amount in *Suaeda vermiculata* among all the studied halophytes at Site II (0.81 mg g<sup>-1</sup> F. Wt.). It is notable that *Halopeplis perfoliata* recorded the lowest values of chl.a and chl.b at the two studied Sites, whereas the minimum value of carotenoid constituent (0.17 mg g<sup>-1</sup> F. Wt.) was attained by *Halocnemum strobilaceum* at Site I (Fig. 6C).

The accumulation of mineral ions in the halophytic species of the study sites during summer season were illustrated in Figs. 7A-D. The sodium, chloride and sulfate contents constitute the highest proportion of ions in plant tissue of investigated halophytes. Data

**Table 1:** Description of the studied sites (I,II) from Saudi Arabia and Egypt during July 2007 (Freemeteo, 2007)

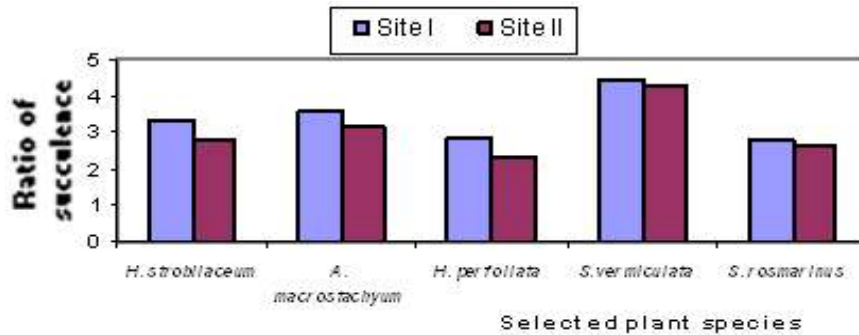
Location	Coordinates	Altitudem asl	Average max. Temp.(°C)	Average min. Temp.(°C)	Average mean Temp.(°C)	Rainfall mmmont h	RH (%)
Site I (Al-Qatif, Arabian Gulf, Saudi Arabia)	(26°56'034"N 50°01'861"E)	3m	43	29	36	0.0	73
Site II (South of Safaga, Red Sea, Egypt)	(26°45'018"N 33°56'410"E)	1m	37	28	32.5	0.0	67

Max. Temp.: maximum temperature, Min. Temp.: minimum temperature, Mean Temp.: mean temperature, RH: relative humidity

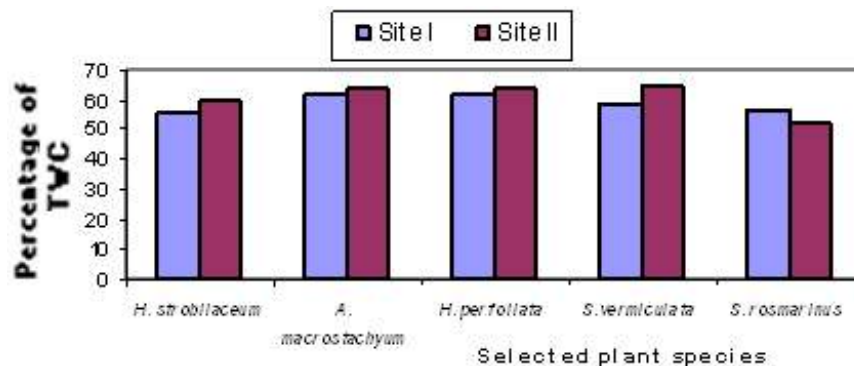
**Table 2:** Parameters of the soils associated with the selected species at the two sites

Parameter	Site I (Al-Qatif, Arabian Gulf, Saudi Arabia)	Site II (South of Safaga, Red Sea, Egypt)
Texture (%)	Fine-sandy	Fine-sandy-clay
Coarse sand	21.9	24.7
Fine sand	53.4	47.2
Silt and clay	24.7	28.1
SWC (%)	35.2	37.7
TSS (%)	10.8	7.6
pH	7.78	7.52
EC (dS m <sup>-1</sup> )	1.21	0.65
Na <sup>+</sup> (g/100g dry wt.)	2.48	1.92
K <sup>+</sup> (g/100g dry wt.)	0.54	0.38
Cl <sup>-</sup> (g/100g dry wt.)	4.31	3.61
SO <sub>4</sub> <sup>2-</sup> (g/100g dry wt.)	1.66	1.58

SWC: soil water content, TSS: total soluble salts, EC: electrical conductivity, dry wt.: dry weight



**Fig. 3:** Variations of succulence contents (Suc.) Of the selected plant species at the two sites.



**Fig. 4:** Variations of tissue water contents (TWC) of the selected plant species at the two sites.

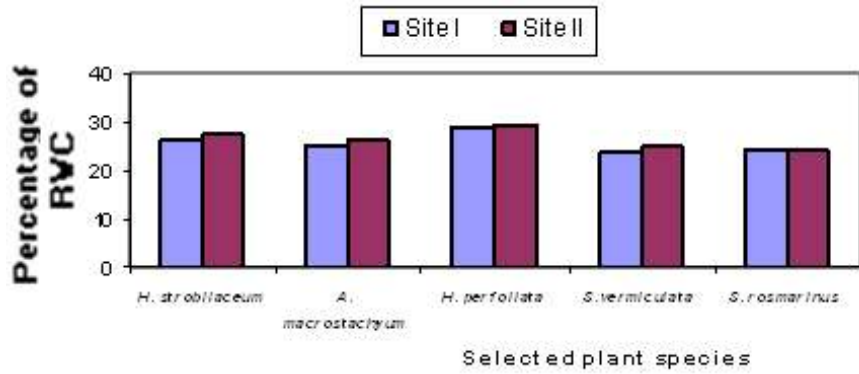


Fig. 5: Variations of relative water contents (RWC) of the selected plant species at the two sites.

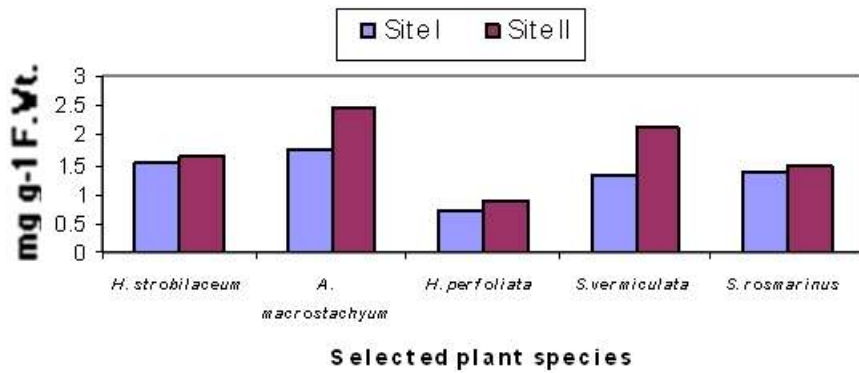


Fig. 6A: Variations of chlorophyll a contents (chl.a) of the selected plant species at the two sites.

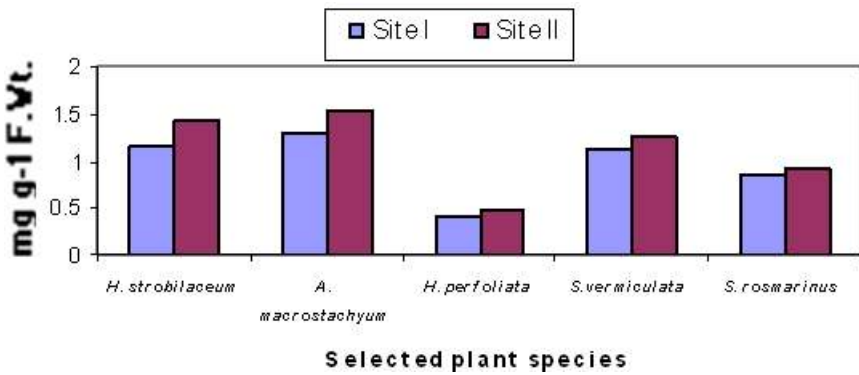


Fig. 6B: Variations of chlorophyll b contents (chl.b) of the selected plant species at the two sites.

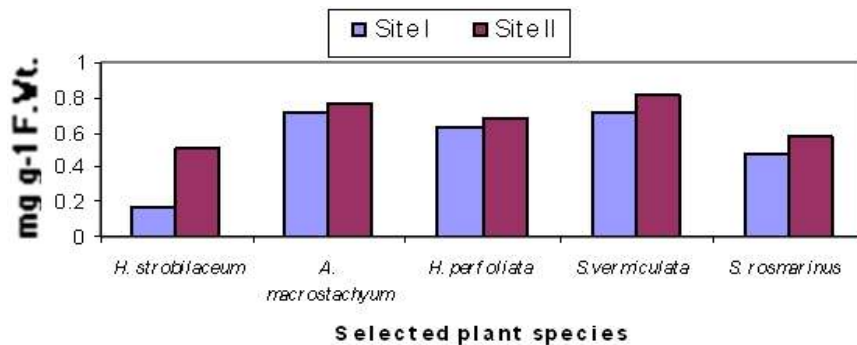


Fig. 6C: Variations of carotenoid contents (carot.) of the selected plant species at the two sites.

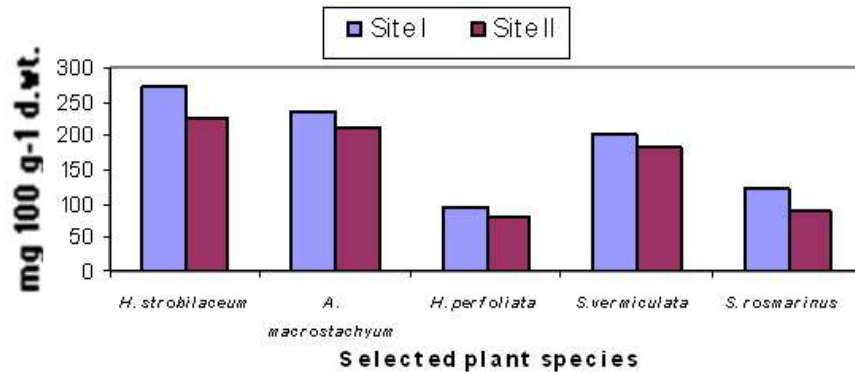


Fig. 7A: Variations of sodium ion contents (Na<sup>+</sup>) of the selected plant species at the two sites.

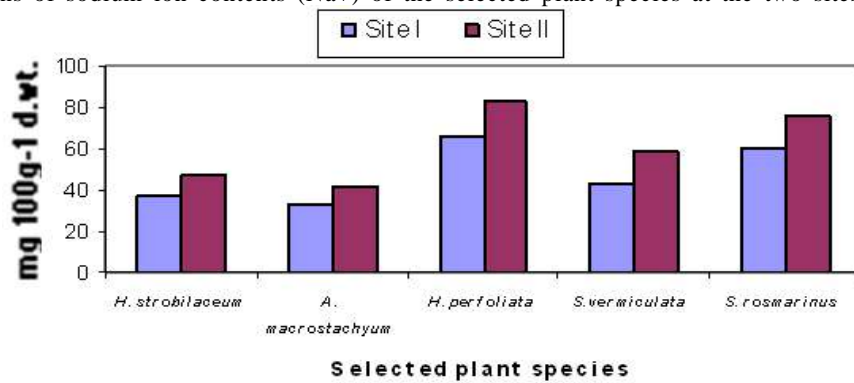


Fig. 7B: Variations of potassium ion contents (K<sup>+</sup>) of the selected plant species at the two sites.

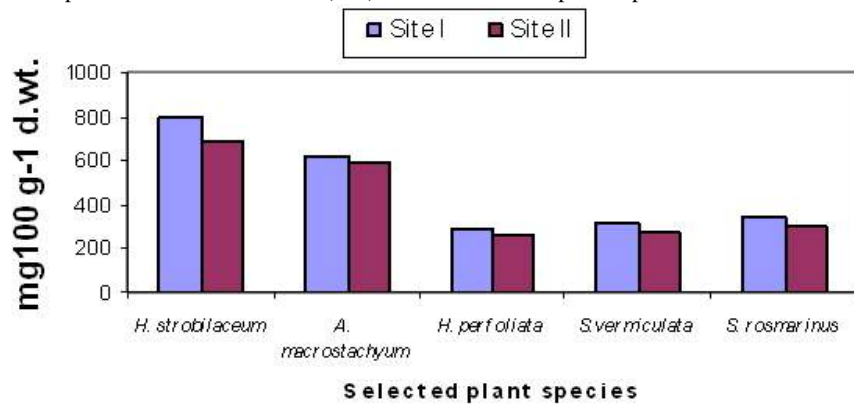


Fig. 7C: Variations of chloride ion contents (Cl) of the selected plant species at the two sites.

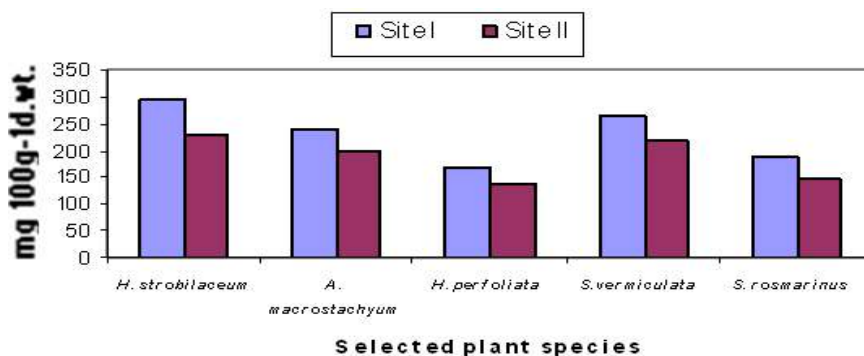


Fig. 7D: Variations of sulfate ion contents (SO<sub>4</sub>) of the selected plant species at the two sites.

presented in Figs.7(A, C and D) revealed that species collected from Site I exhibited much higher values of Na<sup>+</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> than species of the other site. The highest Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and Na<sup>+</sup> contents were shown in *Halocnemum strobilaceum* (792, 294 and 274 mg100g<sup>-1</sup> dry wt. at Site I and 681, 226 and 223 mg100g<sup>-1</sup> dry wt. at Site II, respectively). On the other hand, the lowest contents of the same fractions were attained by *Halopeplis perfoliata* at Site II. Potassium contents of the studied halophytic species revealed a reverse pattern to the other ion constituents (Fig.7B). The higher values of K<sup>+</sup> contents were recorded by plants collected from Site II reaching the maximum of 83 mg100g<sup>-1</sup> dry wt. in *Halopeplis perfoliata* at Site II. *Arthrocnemum macrostachyum* exhibited the lowest values of K<sup>+</sup> content (33 mg100g<sup>-1</sup> dry wt. at Site I) among all the studied plants (Fig.7B).

Regarding the variations in the organic osmolytes recorded by the studied halophytes, there were notable differences between the different organic solutes which were determined for the plants of the two selected habitats (8A-E). The accumulation of proline (P) was associated with an increase in the concentrations of soluble sugar (SS) and soluble protein (SP) in the studied plants. These constituents were attained remarkable high values in *Arthrocnemum macrostachyum* and reached their maximum values in *Suaeda vermiculata* (144, 1246 and 987 mg100g<sup>-1</sup> d.wt., respectively) at Site I (Figs.8B, C and D). It is of interest to observe that the accumulation of SS and P were much higher in plants collected from Site I, while plant species obtained from Site II were revealed higher amounts of free amino acid contents (FAA). However, the values of SP varied among the plants of the two sites (Fig.8B). The highest content of organic osmolytes was detected in *Suaeda vermiculata* at the two sites (3189 and 2944 mg100g<sup>-1</sup> d.wt.), followed by *Seidlitzia rosmarinus* (2806 mg100g<sup>-1</sup> d.wt.) at Site I. On the other hand *Arthrocnemum macrostachyum* at Site II accumulated the lowest amounts of organic solutes (2594 mg100g<sup>-1</sup> d.wt.) among all the studied plants (Fig.8E).

Data of the activities of the antioxidant enzymes for the studied plants were shown in Figs.9(A-C). It was indicated that catalase (CAT) and glutathione reductase (GR) enzymes attained the highest activity within plants collected from Site I (Figs.9A and C), conversely peroxidase (POD) activity was much higher with plants obtained from Site II (Fig. 9B). The highest values of (CAT) and (GR) activities were detected in *Halocnemum strobilaceum* (441 and 9.72 unit gm<sup>-1</sup>F.wt. hour<sup>-1</sup>) at Site I, while the activity of POD reached the maximum of 52.1 unit gm<sup>-1</sup>F.wt. hour<sup>-1</sup> in *Arthrocnemum macrostachyum* at Site II.

**Discussion:** The need for elucidation of the role of growth criteria, organic osmolytes and antioxidant activities in salt tolerance mechanisms of coastal halophytes are highlighted by the recent interest in different salt plants for forage and land reclamation schemes on saline sites<sup>[56]</sup>. All the plants under the present investigation from both Sites I and II, are belonging to succulent halophytes. Park *et al.*,<sup>[52]</sup> stated that many plant species which grow around the Arabian Gulf in Asia or along the Red Sea coast in Egypt<sup>[75]</sup> belong to succulent halophytes from family Chenopodiaceae<sup>[3,36]</sup>.

The present work indicates that soil parameters which determined for the profile collected from Site I, attained high values of TSS, EC and selected inorganic ion contents compared with the other studied profile from Site II. Such results may related with a reduction in the percentages of SWC. Results of the study also indicate that there was a general tendency in selected halophytes from Site I to accumulate high amounts of Cl<sup>-</sup>, Na<sup>+</sup> and SO<sub>4</sub><sup>2-</sup> ions while there was an increase in the concentration of K ion in halophytes collected from Site II. In this regard, Slama *et al.*<sup>[60]</sup> reported that some halophytes tended to accumulate Na<sup>+</sup> and Cl<sup>-</sup> ions in equivalent amounts, but sometimes they replace Na<sup>+</sup> ions with K<sup>+</sup> ions since plants have high requirements for K<sup>+</sup> ions where Na<sup>+</sup> ions are not necessary. Ksouri *et al.*<sup>[42]</sup> concluded that the inorganic ions (including Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>) exhibit well clarified roles in plant metabolism and osmotic adjustment of halophytes.

Data of the present study indicated that plants collected from Site I have high succulence contents, which were associated with higher values of Cl<sup>-</sup>, Na<sup>+</sup> and SO<sub>4</sub><sup>2-</sup> determined in each of soil and plants. Species collected from Site I were characterized by attaining high levels of succulence which were associated with higher TSS contents and reduction in SWC percentages. Youssef *et al.*<sup>[75]</sup> and Ben Ghanaya *et al.*<sup>[11]</sup> considered the attainment of high ratio of succulence in saline habitats as an adaptive response for the dilution of intercellular solution in halophytic plant species.

Results indicate that halophytes obtained from Site II were characterized by higher values of TWC and RWC compared with those recorded in Site I. This last data were also associated with high contents of photosynthetic pigment fractions (chl.a, chl.b and carotenoids). These results may be attributed to the fact that the study was conducted during the summer season, which is characterized with high average of temperature and relative humidity along the studied sites. In this concern, Youssef *et al.*<sup>[75]</sup>, Touchette<sup>[64]</sup> and Ksouri *et al.*<sup>[42]</sup> confirmed that most of halophytes which have succulent leaves and stems attained higher

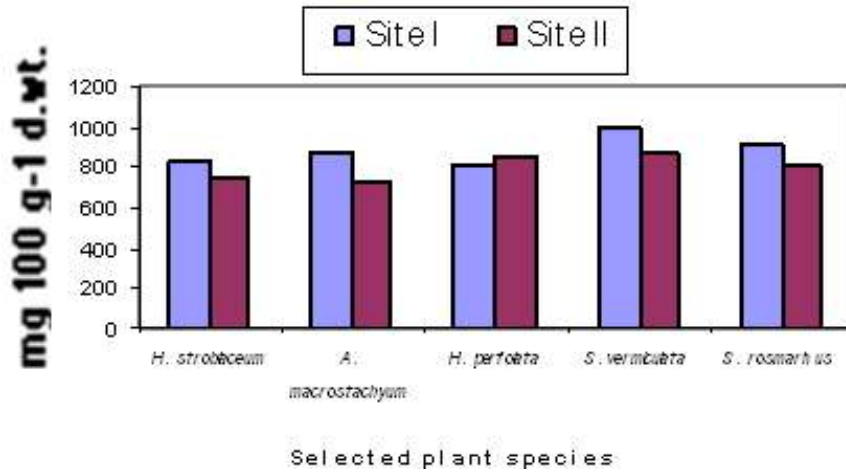


Fig. 8A: Variations of free amino acid contents (FAA) of the selected plant species at the two sites.

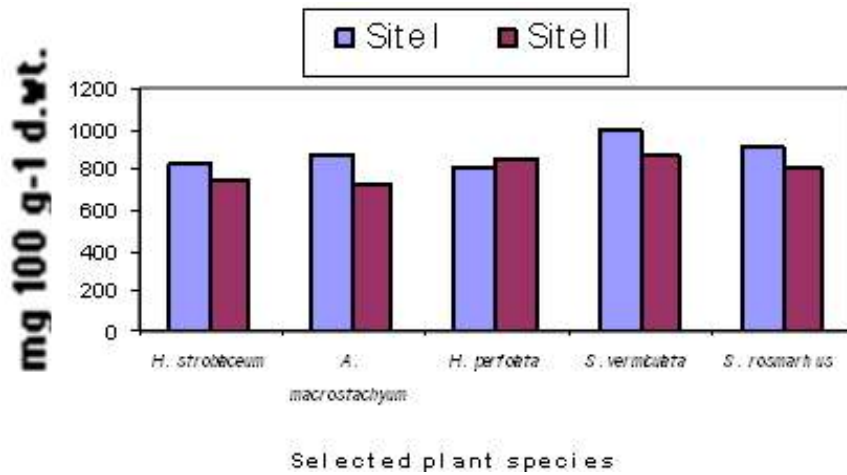


Fig. 8B: Variations of soluble protein contents (SP) of the selected plant species at the two sites.

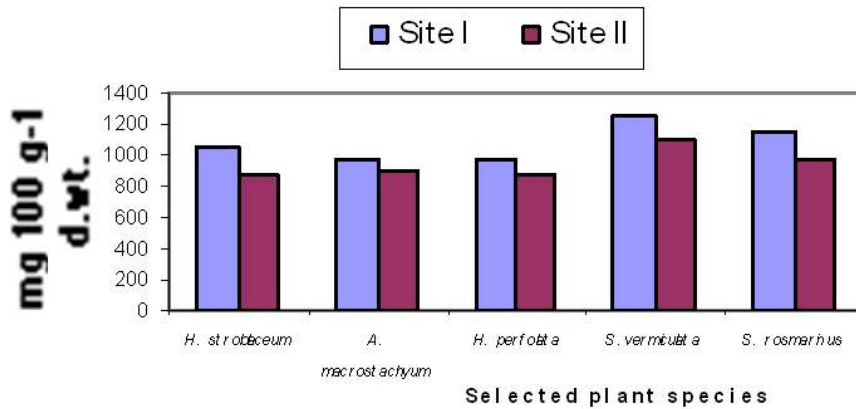


Fig. 8C: Variations of soluble sugars contents (SS) of the selected plant species at the two sites.

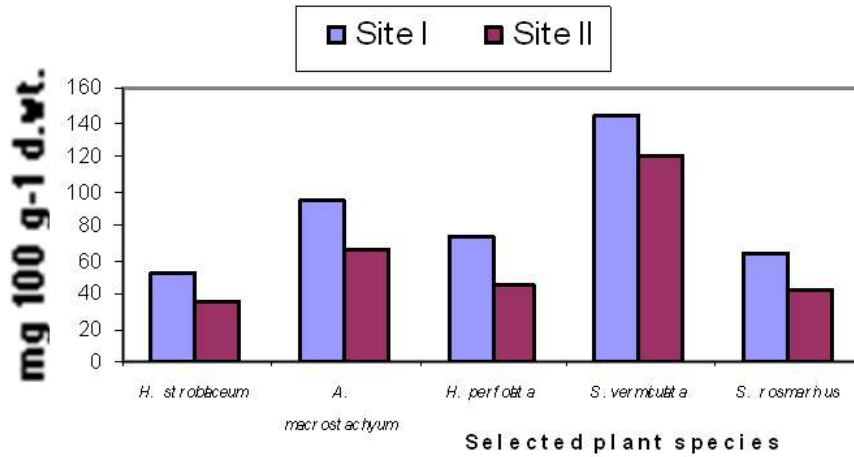


Fig. 8D: Variations of proline contents (P) of the selected plant species at the two sites.

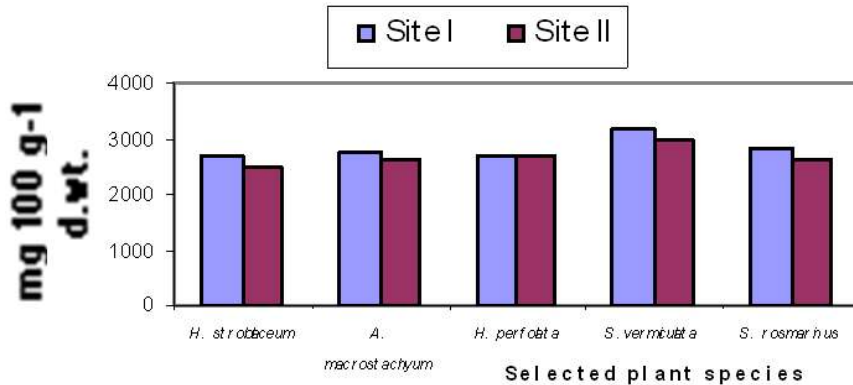


Fig. 8E: Variations of total contents of organic osmolytes (org. osmol.) of the selected plant species at the two sites.

values of relative water content, free water content, succulence ratio and photosynthetic pigment contents. Pennings *et al.*<sup>[53]</sup> and Park *et al.*<sup>[52]</sup> stated that under severe conditions of moisture stress or physiological dryness of the soil, halophytic species exhibited high RWC values. Succulence is considered as a mechanism through which certain halophytes are adapted to their salt environment<sup>[60]</sup>. Present results clearly show that fractions of photosynthetic pigment were reduced between the selected halophytes of Site I. This may be due to the humid and arid weather which is dominant during the period of study (summer season) in Site I. In this respect, Nunes *et al.*<sup>[51]</sup> reported that in saline habitats, soil salinity and arid climate greatly affect the synthesis of pigment components of plants. Moreover, Morsy *et al.*<sup>[49]</sup> on their study on the desert plants along Alamain Wadi El-Natron area, concluded that chl.a, chl.b and carotenoids were remarkably decreased in summer and increased during winter for all stressed plant species. On the other hand, Pennings *et al.*<sup>[53]</sup>

reported that the intrinsic photosynthetic water use efficiency tended to rise than decline as the water stress increases in natural habitats.

Results of the present work point to other feature in the mechanisms of the protective adaptive response mechanisms of halophytes. It was observed that all halophytes which were collected during summer from Site I tended to retain higher soluble protein, soluble sugar and proline as well as higher levels of total organic osmolytes, compared to those parameters of the other group of halophytes in Site II. Meanwhile, the halophytic species of Site II tended to accumulate high contents of free amino acids. In this regard, Walker *et al.*<sup>[66]</sup> reported that the accumulation of high levels of organic intermediates in plants was associated with the dry climate as well as other stress conditions. Moreover, a high level of proline (in particular) enables the plants to maintain an osmotic balance when growing under low water potentials. It is reported that proline protects higher plants against salt/osmotic

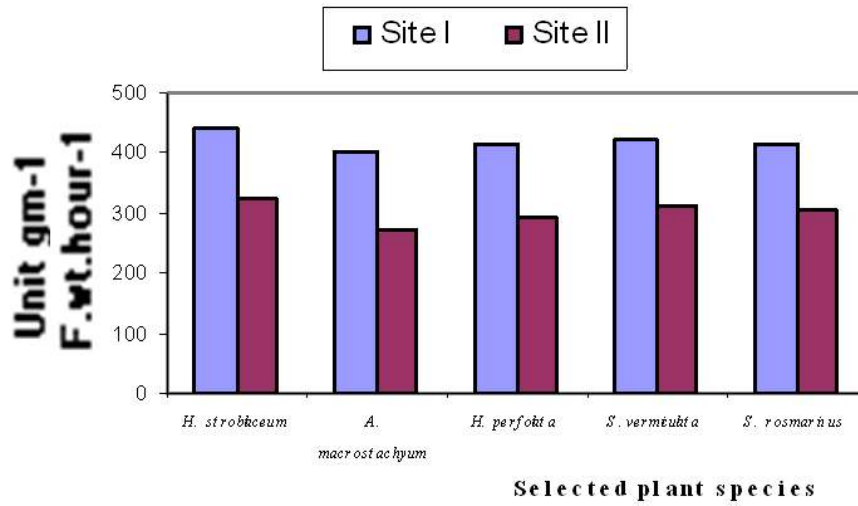


Fig. 9A: Variations of catalase activities (CAT) of the selected plant species at the two sites.

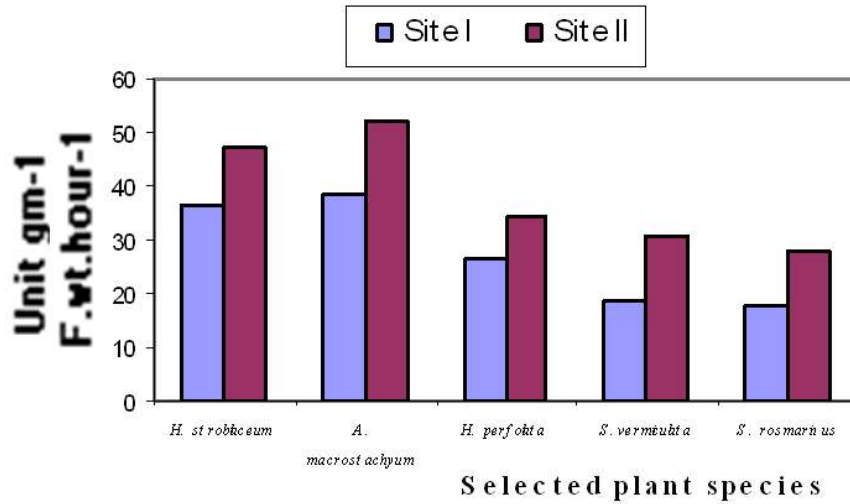


Fig. 9B: Variations of peroxidase activities (POD) of the selected plant species at the two sites.

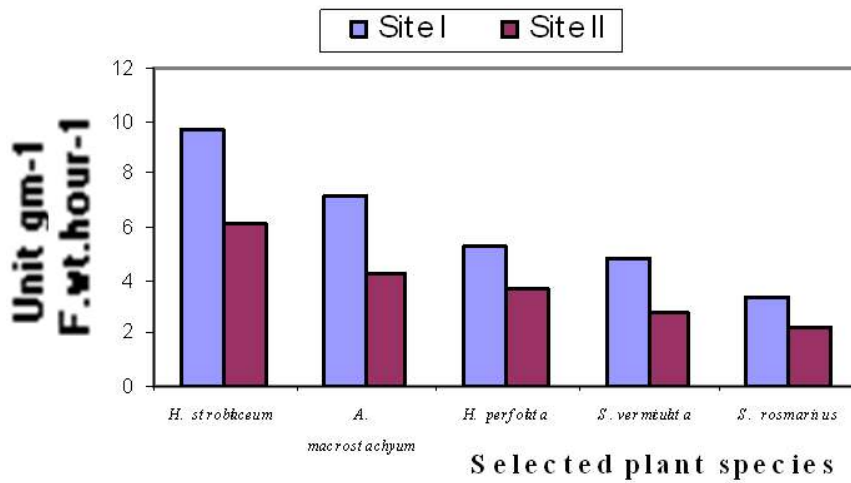


Fig. 9C: Variations of glutathione reductase activities (GR) of the selected plant species at the two sites.

stresses, not only by adjusting osmotic pressure, but also by stabilizing many functional units such as protein and enzymes<sup>[40]</sup>. Slama *et al.*<sup>[60]</sup> demonstrated that the osmotic adjustment of plants common to xeric and saline habitats depends on the kind of stress conditions. They clarified that these plants depend, to a large extent, on the accumulation of organic intermediates resulting in osmotic adjustment under saline conditions.

Results of the present investigation indicate that all the studied halophytes in both sites are succulent. It is of interest to observe from results that the accumulation of total organic osmolytes of the studied halophytic species were associated with the increase of succulence ratio attained by plant species collected from Site I or II. *Suaeda vermiculata* attained the highest amount of organic osmolytes which was associated with a prominent increase of its succulence ratio, among all the studied halophytes. Morsy *et al.*<sup>[49]</sup> referred to the essential role of organic intermediates in building up relatively higher osmotic pressure values in the succulent species inhabiting the most saline habitats. In many plants, salt stress has been shown to affect the organic solutes and metabolism, leading to the synthesis of new compounds<sup>[40]</sup>. The accumulation of organic solutes might be of importance for the adjustment of the cellular water potential under conditions of reduced water availability<sup>[77]</sup>.

Results of the present study indicated that CAT and GR enzymes attained their highest activities within plants collected from Site I, while POD activity was much higher with plants obtained from Site II. In this regard, Jaleel *et al.*<sup>[33,41]</sup> reported that salt stress increases the content of H<sub>2</sub>O<sub>2</sub> and peroxidation of lipid membrane leading to disrupter of its permeability or induce oxidative damage in plant tissues. Salt stress may induce a combination of negative effects on salt-tolerant plants including osmotic stress, ion toxicity and oxidative stress. The induction of antioxidant enzymes such as CAT and POD can be considered as one mechanism of salt tolerance in plants<sup>[30]</sup>. These antioxidant enzymes are involved in eliminating H<sub>2</sub>O<sub>2</sub> from the salt-stressed plants<sup>[38]</sup>. Data of the present work showed that the highest values of CAT and GR activities were detected in *Halocnemum strobilaceum* at Site I, which is associated with relatively lower content of soil water availability as well as higher values of TSS and EC. Catalase, which is localized in peroxisomes, decomposes hydrogen peroxide to water and molecular oxygen without consuming reductants and, thus, may provide plant cells with an energy-efficient mechanism to remove hydrogen peroxide (Ros-Barcelo *et al.*, 2006). Hydrogen peroxide can be removed also by peroxidases in the apoplast of lignifying tissues. These latter enzymes are involved in

various processes such as cell growth control and salt tolerance of environmental stress<sup>[44]</sup>.

**Conclusion:** The study point to a prominent feature in the mechanisms of the protective adaptive response of halophytes. It is of interest to observe that the accumulation of total organic osmolytes of most studied halophytes were associated with the increase of succulence ratio and values of Cl<sup>-</sup>, Na<sup>+</sup> and SO<sub>4</sub><sup>2-</sup> of soil and plants either collected from Site I or II. It may be concluded from the obtained results that halophytes from Site I seem to depend on osmotic adjustment (OA), driven by accumulation of Na, Cl, SO<sub>4</sub>, SP, SS and P as well as higher activity of CAT and GR enzymes, while those collected from Site II tended to accumulate high contents of photosynthetic pigments, K and free amino acids as well as higher levels of POD activity.

#### ACKNOWLEDGEMENT

The author would like to express his acknowledgment to Prof. Dr. Raifa A. Hassanein, Department of Botany, Faculty of Science, Ain Shams University, for her suggestions and valuable advices on revising the manuscript before its publication.

#### REFERENCES

1. AbdulAzis, P.K., I.A. Al-Tisan, M.A. Daili, T.N. Green, A.G.I. Dalvi, M.A. Javeed, 2003. Chlorophyll and plankton of the Gulf coastal waters of Saudi Arabia bordering a desalination plant. *Desalination*, 154: 291-302.
2. Aebi, H., 1984. Catalase *in vitro* Meth. Enzymol., 105: 121-126 DOI: 10. 1016 / S0076-6879(84) 05016-3.
3. Akhani, H., P. Trimborn, H. Ziegler, 1997. Africa, Asia and Europe with their ecological, phytogeographical and taxonomical importance, *Plant Syst. Evol.*, 206: 187-221.
4. Ashraf, M., 2009. Biotechnological approach of improving plant salt tolerance using antioxidants markers. *Biotech. Advan.*, 27: 84-93. PMID: 18950697 [PubMed - in process].
5. Ashraf, M. and P.J. Harris, 2004. Potential biochemical indicators of salinity tolerance in plants. *Plant Science*, 166: 3-16. ISSN 0306 4484.
6. Ashraf, M. and M.R. Foolad, 2007. Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environ. Exp. Bot.*, 59: 206-216. doi:10.1016/j.envexpbot.2005.12.006
7. Association of Official Agriculture Chemists (AOAC), 1975. *Official methods of Analysis*. 12<sup>th</sup> ed., Washington DC, USA.

8. Bajji, M., J.M. Kinet and S. Lutts, 1998. Salt stress effects on roots and leaves of *Atriplex halimus* L. and their corresponding callus cultures, Plant Sci. 137: 131–142. Cited By in Scopus (24).
9. Bartels, D. and R. Sunkar, 2005. Drought and salt tolerance in plants. Crit. Rev. in Plant Sci, 24: 1-36.
10. Bates, L.S., R.P. Waldren and L.D. Tear, 1973. Rapid determination of free proline for water-stress studies. Plant and Soil, 39: 205-207. 10.1007/BF00018060.
11. Ben Ghanaya, A., G. Charles, A. Hourmant, J.Ben Hamida and M. Branchard, 2009. Physiological behaviour of four rapeseed cultivar (*Brassica napus* L.) submitted to metal stress. C. R. Biologies: (In Process). doi: 10.1016/j.crv.2008.12.001.
12. Boyer, J.S., 1982. Plant productivity and environment, Science, 218: 443–448. Cited By in Scopus (595).
13. Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein– dye binding. Anal. Biochem., 72: 248–254. doi:10.1016/0003-2697(76)90527-3.
14. Catsky, J., 1960. Determination of water deficit in discs cut out from leaf blades. Biol. Plant, 2: 76-77.
15. Choukr-Allah, R., M.C. Harrouni, 1996. The potential use of halophytes under saline irrigation in Morocco (abstract). In: Symposium on the Conservation of Mangal Ecosystems. Al Ain, United Arab Emirates, 15–17.
16. Cushman, J.C., 2001. Osmoregulation in plants: implications for agriculture, Am. Zool. 41: 758–769.
17. Dehan, K. and M. Tal, 1978. Salt tolerance of the wild relatives of the cultivated tomato: Responses of *Solanum pennellii* to high salinity. Irrigation Sci., 1: 71.
18. Deutsche Stiftung Weltbevölkerung, 2008. DSW-Datenreport 2008. Soziale und demographische Daten zur Weltbevölkerung. Available on: [http://www.dsw-online.de/pdf/dsw\\_datenreport\\_08.pdf](http://www.dsw-online.de/pdf/dsw_datenreport_08.pdf).
19. Ebel, C. and G. Zaccai, 2004. Crowding in extremophiles: linkage between solvation and weak protein-protein interactions, stability and dynamics, provides insight into molecular adaptation, J. Mol. Recognit. 17: 382–389. Cited By in Scopus (7).
20. El Shaer, H.M., 2003. Potential of halophytes as animal fodder in Egypt, in: H. Lieth, M. Mochtchenko (Eds.), Part II: Chemical Contents. Cash Crop Halophytes: Recent Studies, Kluwer Academic Publishers, Dordrecht, Boston, London, 111–120.
21. Fales, F.W., 1951. The assimilation and degradation of carbohydrate by Yeast cells. J. Biol. Chem., 193: 113-124. PMID: 14907695 [PubMed – OLDMEDLINE].
22. Flowers, T.J., 2003. Single-cell measurements of the contributions of cytosolic Na<sup>+</sup> and K<sup>+</sup> to cell salt tolerance (with Carden, D.E., Walker, D.J. and Miller, A.J.), Plant Physiology, 131: 676-683.
23. Foyer, C.H. and B. Halliwell, 1976. The presence of glutathione and glutathione reductase in chloroplasts: A proposed role in ascorbic acid metabolism. Planta, 133: 21-25.
24. Freemeteo, 2007. Weather of Dammam, KSA and Safaga (Egypt), In : <http://freemeteo.com>.
25. Fujiwara, S., 2002. Extremophiles: developments of their special functions and potential resources, J. Biosci. Bioeng., 94: 518–525. Cited By in Scopus (19).
26. Gibbons, S., K.T. Mathew and Alexander I. Gray, 1999. A caffeic acid ester from *Halocnemum strobilaceum*. Photochemistry, 51: 465-467. doi: 10.1016/S0031-9422(99) 00007-02.
27. Hamdy, A., 2002. Sustainable use and management of non-conventional water resources in the arid regions. In: Aksoy, U., Anac, D., Anac, S., Beltrao, J., Ben-Asher, J., Cuartero, J., Flowers, T.J., Hepaksoy, S. (Eds.), Proceedings of the International Symposium on Techniques to Control Salination for Horticultural Productivity. Acta Hort. 573. Drukkerij Geers, Gent-Oostakker, 159–174.
28. Hasegawa, P.M., R.A. Bressan, J.K. Zhu and H.J. Bohnert, 2000. Plant cellular and molecular responses to high salinity. Annu. Rev. Plant Physiol. Mol. Biol., 51: 463–499.
29. Havir, E.A. and N.A. McHale, 1987. Biochemical and developmental characterization of multiple forms of catalase in tobacco leaves. Plant Physiol. 84: 450-455. PMID: 16665461 [PubMed - as supplied by publisher].
30. Hernandez, J.A., A. Aguilar, B. Portillo, E. Lopez Gomez, J.M. Beneyto and M.F. Legaz, 2003. The effect of calcium on the antioxidant enzymes from salt-treated loquat and anger plants. Funct. Plant Biol., 30: 1127-1137.
31. Hester, M.W., I.A. Mendelsohn and K.L. McKee, 2001. Species and population variation to salinity stress in *Panicum hemitomon*, *Spartina patens*, and *Spartina alterniflora*: morphological and physiological constraints. Environ. Exp. Bot., 46: 277–297.
32. IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007. The Physical Science Basis. Summary for Policymakers. Available on: [http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1\\_Pub\\_SPM-v2.pdf](http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf).

33. Jaleel, C.A., G.M.A. Lakshmanan, M. Gomathinayagam, R. Panneerselvam, 2008. Triadimefon induced salt stress tolerance in *Withania somnifera* and its relationship to antioxidant defense system. South Afric. J. Bot., 74 (1):126-132. doi:10.1016/j.sajb.2007.10.003.
34. Jiang, Y. and M.K. Deyholos, 2006. Comprehensive transcriptional profiling of NaCl-stressed Arabidopsis roots reveals novel classes of responsive genes. BMC Plant Biology, 6(25):20. doi: 10.1186/1471-2229-6-25: 20.
35. Johnson, C.M. and A. Ulrich, 1959. Analytical Methods for Use in Plant Analysis. California Agriculture Experiment Station Bulletin, CA USA.
36. Kahn, M.A. and M. Qaiser, 2006. Halophytes of Pakistan: characteristics, distribution and potential economic usages, in: M.A. Khan, G.S. Kust, H.-J. Barth, B. Boer (Eds.), Sabkha Ecosystems, Vol. II, 129–153.
37. Kilmer, V.J. and L.T. Alexander, 1949. Methods of makings mechanical analysis of soils. Soil Sci., 68: 15-24.
38. Kim, S.Y., J.H. Lim, M.R. Park, Y.J. Kim, T.I. Park, Y.W. Seo, K.G. Choi and S.J. Yon, 2005. Enhanced antioxidant enzymes are associated with reduced hydrogen peroxide in barley roots under salt stress. J. Biochem. Mol. Biol., 38: 218-224.
39. Klapheck, S., I. Zimmer and H. Cosse, 1990. Scavenging of hydrogen peroxide in the endosperm of *Ricinus communis* by ascorbate peroxidase. Plant Cell Physiol., 31: 1005-1013.
40. Kohler, J., J.A. Hernandez, F. Caravaca and A. Roldan, 2009. Induction of antioxidant enzyme is involved in the greater effectiveness of a PGPR versus AM fungi with respect to increasing the tolerance of lettuce to severe salt stress. Environ. Exp. Bot., 65: 245–252. doi:10.1016/j.envexpbot.2008.09.008.
41. Koyro, H.W., N. Geissler, S. Hussin, A. Debez and B. Huchzermeyer, 2008a. Strategies of halophytes to survive in a salty environment. In: N.A. Khan and S. Singh, Editors, Abiotic Stress and Plant Responses, I.K. International Publishing House, New Delhi, 83–104.
42. Ksouri, R., W. Megdiche, H. Falleh, N. Trabelsi, M. Boulaaba, A. Smaoui and C. Abdelly, 2008. Influence of biological, environmental and technical factors on phenolic content and antioxidant activities of Tunisian halophytes. C. R. Biologies 331: 865–873. doi:10.1016/j.crv.2008.07.024.
43. Linchtenthaler, H.K. and A.R. Wellburn, 1983. Determination of total carotenoids and chlorophyll a and b of leaf extract in different solvents. Biochem. Soci. Trans., 11: 591-592.
44. Maehly, A.C. and B. Chance, 1954. The assay of catalase and peroxidase. Meth. Anal. Biochem. (D. Glick, ed.), 1: 357-424. PMID: 13193536 [PubMed - indexed for MEDLINE].
45. Martínez, J.P., J.F. Ledent, M. Bajji, J.M. Kinet and S. Lutts, 2003. Effect of water stress on growth, Na<sup>+</sup> and K<sup>+</sup> accumulation and water use efficiency in relation to osmotic adjustment in two populations of *Atriplex halimus* L., Plant Growth Regul. 41: 63–73. Cited By in Scopus (15).
46. Martínez, J.P., S. Lutts, A. Schank, M. Bajji and J.M. Kinet, 2004. Is osmotic adjustment required for water stress resistance in the Mediterranean shrub *Atriplex halimus* L.?, J. Plant Physiol. 161: 1041–1051. Cited By in Scopus (21).
47. Martínez, J.P., J.M. Kinet, M. Bajji and S. Lutts, 2005. NaCl alleviates polyethylene glycol-induced water stress in the halophyte species *Atriplex halimus* L., J. Exp. Bot. 56: 2421–2431. Cited By in Scopus (9).
48. Moor, S., and W.H. Stein, 1948. Photometric ninhydrin method for use in the chromatography of amino acids. J. Biol. Chem., 176, 367–388.
49. Morsy, A.A., A.M. Youssef, H.A. Mosallam and A.M. Hashem, 2008. Assessment of selected species along Alamein-Wadi El-Natron desert road, Egypt. J. Appl. Sci. Res., 4(10): 1276-84.
50. Mukherjee, S.P. and M.A. Choudhuri, 1983. Implications of water stress-induced changes in the levels of endogenous ascorbic acid and hydrogen peroxide in *Vigna* seedlings. Plant Physiol., 58: 166-170. DOI::10.1111/j.1399-3054.1983.tb04162.
51. Nunes, C., S. de Sousa, J.M. da Silva, M.P. Fevereiro, A.B. da Silva, 2008. Physiological responses of the legume model *Medicago truncatula* cv. Jemalong to water deficit. Environ. Exp. Bot., 63: 289–296. doi:10.1016/j.envexpbot.2007.11.004.
52. Park, J., T.W. Okita and G.E. Edwards, 2009. Salt tolerant mechanisms in single-cell C4 species *Bienertia sinuspersici* and *Suaeda aralocaspica* (Chenopodiaceae) Plant Sci., (In Process). doi:10.1016/j.plantsci.2009.01.014.
53. Pennings, S.C., M.B. Grant, M.D. and Bertness, 2005. Plant zonation in low-latitude salt marshes: disentangling the roles of flooding, salinity and competition. J. Ecol., 93: 159–167.
54. Quiroga, M., C. Guerrero, M.A. Botella, A.R. Barcelo, M.I. Medina and F.J. Alonso, 2000. A tomato peroxidase involved in the synthesis of lignin and suberin. Plant Physiol., 122: 1119-1127.
55. Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils. US Dept. Agr. Handbook, 60.

56. Rogers, M.E., *et al.*, 2005. The potential for developing fodder plants for the salt-affected areas of southern and eastern Australia: an overview. *Aust. J. Exp. Agric.*, 45: 301-329.
57. Ros-Barcelo, A.L., V. Gomez-Ros, M.A. Ferrer and J.A. Hernandez, 2006. The apoplastic antioxidant enzymatic system in the wood-forming tissues of trees. *Trees-Struct. Funct.*, 20: 145-156.
58. Sairam, R. K., G.C. Srivastava, S. Agarwal and R.C. Meena, 2005. Differences in antioxidant activity in response to salinity stress in tolerant and susceptible wheat genotypes, *Biol. Plant.*, 49: 85–91. Cited By in Scopus (28).
59. Saudi Aramco World, 1974. InWikipedia.com, Saudi Aramcoworld, Vol.25 #5, sep./oct.
60. Slama, I., T. Ghnaya, D. Messedi, K. Hessini, N. Labidi, A. Savoure and C. Abdelly, 2007. Effect of sodium chloride on the response of the halophyte species *Sesuvium portulacastrum* grown in mannitol-induced water stress, *J. Plant Res.* 120: 291–299. Cited By in Scopus (5).
61. Stetter, K.O., 1999. Extremophiles and their adaptation to hot environments, *FEBS Lett.* 452: 22–25. Cited By in Scopus (127).
62. Tester, M. and R. Davenport, 2003. Na<sup>+</sup> Tolerance and Na<sup>+</sup> Transport in Higher Plants. *Annals of Botany*, 91: 503-527.
63. Tipirdamaz, R., D. Gagneul, C. Duhaze, A. Ainouche, C. Monnier, D. Zkuma, F. Larher, 2006. Clustering of halophytes from an inland salt marsh in Turkey according to their ability to accumulate sodium and nitrogenous osmolytes, *Environ. Exp. Bot.* 57: 139–153.
64. Touchette, B.W., 2006. Salt tolerance in a *Juncus roemerianus* brackish marsh: spatial variations in plant water relations, *J. Exp. Mar. Biol. Ecol.* 337: 1–12. Cited By in Scopus (7).
65. Van den Burg, B., 2003. Extremophiles as a source for novel enzymes. *Curr. Opin. Microbiol.*, 6: 213–218. Cited By in Scopus (50).
66. Walker, D. J., P. Romero, A. de Hoyos, Enrique Correal, 2008. Seasonal changes in cold tolerance, water relations and accumulation of cations and compatible solutes in *Atriplex halimus* L. *Environ. Exp. Bot.*, 64: 217–224. doi:10.1016/j.envexpbot.2008.05.012.
67. Wang, B., U. Lüttge, R. Ratajczak, 2004. Specific regulation of SOD isoforms by NaCl and osmotic stress in leaves of the C3 halophyte *Suaeda salsa* L., *J. Plant Physiol.*, 161: 285–293.
68. Wikimedia, 2008. Map of the World, In: <http://google.com/wikimedia.com/maps>.
69. Wilde, S.A., R.B. Corey, J.G. Lyer and G.K. Voigt, 1979. *Soil and Plant Analysis for Tree Culture*. Oxford and IBH Pub. Co., New Delhi, Bombay.
70. William, F., 1994. *The Story of the Eastern Province of Saudi Arabia*. ISBN 1 900988 18 6.
71. Williams, I.I. and Twine, B., 1960. Flame photometric method for sodium, potassium and calcium. – *In*: Peach, K. and M.V. Tracey, (eds.): *Modern Methods of Plant Analysis*. Vol. V. pp 3-5, Springer-Verlag., Berlin.
72. Williamson, R.E., J.E. Burn and C.H. Hocart, 2002. Towards the mechanism of cellulose synthesis. *Trends in Plant Science*, 7: 461-467.
73. Xin, Z. and J. Browse, 2000. Cold comfort farm: the acclimation of plants to freezing temperatures, *Plant Cell Environ.* 23: 893–902. Cited By in Scopus (91).
74. Youssef, A.M., 2008. Adaptive responses of some desert plants from different ecosystems of Suez road, Egypt. *Res. J. Agric. Biol. Sci.*, 4(5): 595-603.
75. Youssef, A.M., R.A. Hassanein, A.A. Hassanein and A.A. Morsy, 2003. Changes in quaternary ammonium compounds, proline and protein profiles of certain halophytic plants under different habitat conditions. *Pak. J. Biol. Sci.*, 6(10): 867-882. ISSN 1028-8880.
76. Youssef, A.M., A.F. Hamed and B.B. Salem, 2004. Spatial distribution of mangal-algal association in some sites along the Egyptian Red Sea coast by remote sensing technology. *Egyptian J. Biol.*, 6(1): 39-51.
77. Youssef, A.M. and M.A. Al-Fredan, 2008. Community composition of major vegetations in the coastal area of Al-Uqair, Saudi Arabia in response to ecological variations. *J. Biol. Sci.*, 8(4): 713-721. doi: 1727/jbs.3048.2008.8880.