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Seasonal variation in photosynthetic pigments, osmotic solutes and osmotic potential of *Capparis spinosa* L. var. inermis Turra

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ABSTRACT

The climate of the Mediterranean is characterized by mild winter, hot and dry summer and a long period of aridity. The osmotic adjustment is a known mechanism by which many plants can adapt to drought conditions. The investigation of the physiological responses and adaptation mechanism of wild plants can help identify metabolic products associated with improved tolerance to stress conditions. Thus, the aim of this study was to investigate the effect of seasonal variations in the climatic conditions at Mediterranean region on the photosynthetic pigments, content of osmotic solutes and their contribution to change the total osmotic potential of *Capparis spinosa* L. var. *inermis* Turra under stress condition in dry season. The results indicated that *Capparis spinosa* was rich in photosynthetic pigments in winter and the contents of Chl.a and carotenoid were significantly affected by seasonal variations in climatic conditions and decreased significantly in dry season. While the content of Chl. b showed no significant change by season. The content of proline tended to increase during a cold climate in winter, while proline betaine (stachydrine) was detected in high concentration during the dry period of summer. The results indicated that the Mediterranean evergreen plant *Capparis spinosa* responded to stress conditions in dry season through the accumulation of soluble sugar, water soluble stachydrine alkaloid and ions as compatible solutes to assist in decrease the osmotic potential and increase the water inlet to the cells. Determining the role of stachydrine in improving the tolerance of *Capparis spinosa* to stress conditions needs more investigations, also, the possibility of increasing the tolerance of economic plants to water deficit by enhancing the synthesis of these compounds is suggested for further studies.

Keywords: alkaloids, *Capparis spinosa*, compatible solutes, osmotic adjustment

1. Introduction

The Mediterranean Basin is one of the biodiversity hotspots (Médail and Myers 2004), comprising about 290 indigenous taxa of trees (species and sub species), including 201 endemics (Quezel and Médail 2003; Médail, 2008). The climate of the Mediterranean is characterized by mild winter, hot and dry summer and a long period of aridity which cause the expose of plants to severe drought stress. Mediterranean vegetation types vary greatly with environmental limitations e.g., climate, geology, geomorphology, and soil type. Many studies have attributed the effect of drought stress in the Mediterranean region to the low level of soil fertility, as the soils in these regions are often classified as poor in nutrients. According to Mooney (1983), the long dry period in summer season is considered the most unfavorable conditions of the year for plant growth, that characterized by high temperature, high irradiance, and no rainfall (Di Castri,1973). The plant responses to these adverse conditions by minimizing the effects and/or repairing the produced damage and improving water uptake.

The most important adaptation mechanism in desert plants is osmotic adjustment, which assist in maintaining the plant water potential more negative than the external medium to insure the water uptake. It helps also to maintain cell swelling through the accumulation of solutes and may reduce the effects of water stress in plant cells (Subbarao *et al.,* 2000).

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In Egypt, there were 6 species of *Capparis* was that recognized by Tackholm (1974), while Boulos (1999) classified the genus as 3 species and 4 varieties. *Capparis spinosa* L.var *inermis* Turra is one among three varieties present in Egypt included in *Capparis spinosa* that belong to Capparacaea. This variety is reported mainly on the seashore from Mersa Matrouh to Ras El Hekma. *Capparis spinosa* L.var *inermis* growing on maritime cliff in the western Mediterranean coast of Egypt. It is a shrub, permanent green, large succulent leaves, glabrous orbicular or ovate, 2-5cm long, 1.4-4.5 cm wide (Boulos 1999). Produces one of the deepest root systems (Ozkahraman, 1997), it reaches 10 meters in length (Sozzi, 2001). The young shoots of *Capparis* are used for human nutrition. In addition to its richness in carotenoids, flavonoids, tocopherols, and glucosinolates in different parts of this plant (Tlili *et al.,* 2010). Ecologically, it can be grown as a ground cover to cohere the loose soil, emend the microclimate of soil and in soil and water conservation programs (Suleiman *et al.,* 2009).

Capparis spinosa is well adapted to the adverse environmental conditions of the Mediterranean summer. As the development of most of its above-ground parts and the formation of flowers and fruits takes place in the absence of any precipitation (Levizou *et al.,* 2004). The osmotic adjustment and the decrease in osmotic potential in response to drought stress is a known mechanism by which many plants can adapt to drought conditions (Patakas & Noitsakis, 1999; Morgan, 1984). The types of osmoprotectant metabolites and their relative contribution to lower the osmotic potential varies greatly among plant species. Thus, the investigation of the physiological responses and adaptation mechanism of wild plants can help identify metabolic products associated with improved tolerance to stress conditions and assist in maintaining the uptake of water. Therefore, the aim of this study was to investigate the effect of seasonal variations in the climatic conditions at Mediterranean region on the photosynthetic pigments, content of osmotic solutes and their contribution to change the total osmotic potential of *Capparis spinosa* L. var. *inermis* Turra under stress conditions in dry season.

2. Materials and Methods

2.1. Plant material

Arial parts of *Capparis spinosa* L. var. *inermis* plant were collected from Wadi Halazien,45Km west Mersa Matrouh, Egypt in January 2018 and July 2018 (Figure 1). The plant was authenticated and identified In the Herbarium of Desert Research Center.

Fig. 1: *Capparis spinosa* L. var *inermis* Turra

2.2. Ecological studies

2.2.1. Climatic Factors:

The Meteorological data of temperature and rainfall were obtained from the Desert Research Center (DRC) Applied Agricultural Meteorological Laboratory.

2.2.2. Soil analysis

Soil samples were collected at a depth of (0-20cm) in Wadi Halazien. The physical properties of soil including electrical conductivity (EC) and pH of the soil water suspension (1:1) were estimated according to Page (1987). The content of chloride (Cl^-) was determined according to Jackson (1967),

while the concentrations of Na^+ and K^+ in the soil solution were measured using flame photometer (Jenway, PFP-7). The concentrations of carbonate (CO_3) and bicarbonate ions (HCO_3), magnesium (Mg^{2+}), sulphate (SO_4^{2-}) and calcium (Ca^{2+}) in the soil solution were determined according to the method of Rowell (1994).

2.3. Physiological studies

2.3.1. Plant water content

The percentage of plant water content (WC) was estimated according to the method described by (Rybak-Chmielewska 2003).

$$\text{Plant water content (\%)} = \frac{\text{Fresh wt.} - \text{Dry wt.}}{\text{Dry wt.}} \times 100 \quad \ldots\ldots (1)$$

The percentage of ash was calculated according to (Momin and Kadam 2011) on a dry weight basis, then Organic matter and Ash contents were calculated according to the following equations:
The organic matter content = (wt. of crucible - plant sample)- (wt. of the crucible + plant ash).

$$\text{The organic matter (\%)} = \frac{\text{wt.of organic matter}}{\text{wt.of dry plant}} \times 100 \quad \ldots\ldots (2)$$

Ash content = (wt. of crucible + plant ash) – wt. of empty crucible

$$\text{Ash (\%)} = \frac{\text{wt.of ash}}{\text{wt.of dry plant}} \times 100 \quad \ldots\ldots (3)$$

2.3.2. Determination of plants osmotic potential

Sample preparation was done according to Simmelsgaard (1976). The fresh plants were collected in liquid nitrogen, and then stored at-20˚C until the time of measurement. Plant samples were thawed at room temperature and pressed to free the cell sap. The osmotic potential of the expressed sap was measured with freezing point osmometer (Osmomat 030 - Gonotec - Berlin - Germany) which was calibrated with KCl. The osmotic potential of a given solute was calculated as: Ψs = nRT/Where n is the number of solute molecules; R. the universal gas constant; T, temperature in K; and V, volum in liter (Baker,1984).The contribution of salts to the total osmotic potential can be calculated according to the following equation: Osmotic potential (MPa) = $-0.04 \times EC(dSm^{-1})$ according to Rowell (1994).

2.4. Plant Chemical Analysis

2.4.1. Preparation of samples

The aerial parts of plant samples were dried in the oven at 60 °C and ground to fine powder, then subjected to chemical analyses.

2.4.2. Chlorophyll and carotenoid determination

The contents of chlorophyll-a (Chl. a), chlorophyll-b (Chl. b) and carotenoids were determined by spectrophotometric method according to Sumanta *et al.* (2014). Half gram of fresh plant leaf sample was homogenized in tissue homogenizer with 10 ml of 80% Acetone. The homogenate was centrifuge for 15 min at 4°C at 10,000 rpm for 15 min, then 0.5 ml of supernatant was mixed with 4.5ml of solvent. The absorbance was read at 663, 644 and 452.5 nm (using UV/VIS spectrophotometer ChromTech CT-2400). The content of Chlorophyll-a, Chlorophyll-b and Carotenoids were calculated according to the following equations:

Chl. a=12.25A663.2 – 279A646.8……..... (1)
Chl. b=21.5A646.8 – 5.1A663.2 ……..…… (2)
C x+c= (1000A470 – 1.82Ca –85.02Cb)/198 ……..……..... (3)

Where: A = Absorbance, Chl.a = chlorophyll a, Chl. b = chlorophyll b, C x+c = carotenoids) and the results were expressed as (mg/100gFW).

2.4.3. Mineral Analysis

The dried samples (0.5g) were digested according to Baker and Smith (1974), with 10ml concentrated sulphuric acid and 2-4 ml of perchloric acid. The mixture was heated until the mixture become clear, then diluted with distilled water to 100ml and used for mineral analysis. The contents of Ca, Mg, K and Na in this solution were determined according to the method of Rowell (1994). Plant ash powder was used to determine P concentration by using phosphomolybdate method (Rowell,1994) and Cl concentration according to Jackson and Thomas (1960). The concentrations of manganese, copper, zinc, and iron were determined by using ICP emission spectroscopy (Jones, 1977). Nitrogen (N) content of sample was determined according to Kjeldahl (1983), and crude protein was calculated by multiplying the total content of nitrogen by the traditional conversion factor of 6.25 (James, 1995).

2.4.4. Determination of free proline

Half gram dry samples were homogenized in 10 ml of 3% aqueous sulfosalicylic acid. Two ml of the filtrate was mixed with equal volume of acetic acid ninhydrin reagent and incubated for 1hour at 100 ° C. The tube was incubated in an ice bath and the reaction mixture was extracted with 4ml toluene. The color containing toluene was aspirated from the aqueous phase and the absorbance was read at 520 nm according to Bates *et al.,* (1973). Proline concentration was determined by a calibration curve of L-proline using equation $Y = 0.0113\times - 0.0052$($R2 = 0.998$) and was expressed as (µmole g^{-1} DW).

2.4.5. Determination of Stachydrine by HPLC

2.4.5.1. Sample preparation

One gram of plant powder was extracted with 10 mL of 80% methanol by sonication for 40min at room temperature then diluted and filtrated through 0.45mm membrane filters. The sample solution was transferred into chromatography vials and stored at $-20^{\circ}C$ for subsequent analyses.

2.4.5.2. HPLC conditions

A high-performance liquid chromatographic method was applied to the determination of stachydrine hydrochloride concentration in *Capparis spinosa* according to (Junbo Xie *et al.,* 2015). The determination was performed by Thermo, Dionex UHPLC UltiMate 3000 and methanol-0.1%formic acid solution (20:80) was used as mobile phase at a flow-rate of 0.2 ml /min. The mobile phase was filtered through a Millipore 0.45 µm filter and degassed prior to use. The detection wavelength was set at 282 nm and the injection volume was 10µml.

2.4.6. Determination of soluble sugar

The plant sample was extracted twice in 40 ml of boiling water and twice in 40 ml of aqueous boiling ethanol (80%v/v) and clarified using saturated neutral lead acetate solution (AOAC method 2000). The total soluble sugar was estimated using the general phenol–sulfuric acid method (Buysse and Merck, 1993).

2.5. Statistical analysis

Physiological parameters assessed by numerical analysis performed by t test using SPSS for Microsoft Windows (Ver. 10.0, SPSS Inc., USA).

3. Results and Discussion

3.1. Description of the study area and climatic data

Wadi Halazien is a rocky wadi located at the Northwest coast of Matrouh Governorate, Egypt, about 45 km west of Matrouh city at latitudes of 31° 25' 21" N and longitudes of 26° 51' 43" E (Figure 2). The Northern coast region of Egypt extends around 1000 km along the Mediterranean Sea and 30 km inland. This region is characterized by an arid Mediterranean climate that has a limited rainfall (UNESCO, 1977). The annual rainfall in Egypt shows a maximum rate over the Mediterranean coast with a rapid decrease toward the south. Average annual rainfall was 150 mm/year. The dry period extended to four months (from June to September). Most precipitation falls in January, with an average of 36 mm. The highest average temperature of 25.3 °C was recorded in August, as is considered the is

the warmest month. The average high temperature during winter fluctuated between 18-20 °C, the average temperature is 13.1 °C in January.

Fig. 2: Wadi Halazein at 45km west Mersa Matrouh in Egypt

3.2. Soil properties

The physical and chemical properties of the soils associated with *Capparis spinosa* at Wadi Halazien indicated that the soil texture was sandy clay loam (Tables 1&2). The percentages of coarse sand and fine sand were 7.95 and 53.2%, while silt, and clay were 18.5 and 20.34%, respectively.

Table 1: Soil physical properties

Soil Depth (cm)	Soil Particles Distribution				Soil Texture Class
	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	
0-20	7.95	53.21	18.5	20.34	Sandy clay loam

As shown in Table (2), the value of pH was 7.05 in winter and 7.97 in summer season. Electric conductivity (EC) value and most ions concentrations tended to decrease in the summer season. Where the concentrations of calcium, sodium and chloride were 4 $meql^{-1}$, 18.5 $meql^{-1}$and 13 $meql^{-1}$in winter and decreased to 3.5 $meql^{-1}$, 9.1$meql^{-1}$and 8 $meql^{-1}$ in summer. The concentration of sulphate also decreased by more than two-fold in summer, while the percentage of total calcium carbonate ($CaCO_3$%) was 28.35% in winter and 25.48% in summer. According to Moore *et al.,* (1990), the availability of manganese, copper, phosphorus, and zinc may be affected due to the presence of high percentages of calcium carbonate with high percentages of silt and clay particles, which may activate the carbonate and consequently decrease the availability of these minerals. The percentage of soil moisture content was 7.44 % in winter and decreased to 3.44% in summer season.

Table 2: Soil chemical properties and soil moister content in winter and summer seasons

Soil depth	pH 1:1	EC dS/m	Cation (milliequivalent/Liter)				Anion (milliequivalent/Liter)				$CaCO_3$%	Soil moisture
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3		
Winter	7.05	2.95	4	1.5	18.5	1.07	13	10.57	1.5	Traces	28.35	7.44
Summer	7.97	1.93	3.5	1.5	9.1	1.09	8	4.19	3	Traces	25.48	3.44

3.3. Effect of season on photosynthetic pigments

As shown in Table (3), the contents of Chl.a and carotenoid were significantly affected by seasonal variations in climatic conditions and decreased significantly ($p<0.05$) from 39.2±1.55 and 16.4± 0.36 mg/100g FW in summer to 24.6±1.42 and 5.67±0.55 mg/100g FW in winter. The decline in total chlorophyll content under stress conditions was also reported in other species due to the sensitivity of these pigments to the environmental stress (Ladjal *et al.,* 2000; Terzi *et al.,* 2010; El-lamey, 2020a; El-lamey *et al.,* 2021). The content of Chl.b was not significantly affected by seasons. Whereas the ratio of Chl.a to Chl.b was slightly decreased under stress conditions, a decrease in chlorophyll a/b under drought stress was also reported in the resistant species of tomato under water stress (Ghorbanli *et al.,* 2013) and also in some species of plants inhabiting the same region like *Ajuga iva* (El-lamey,2020a), *Atriplex nummularia* and *Atriplex halimus* (El-Lamey, 2021),which may indicate that photosystem II may protect plants against of heat and water stresses.

Table 3: The content of photosynthetic pigments in *Capparis spinosa* in winter and summer seasons

Seasons	Chlorophyll a (mg/100g FW)	Chlorophyll b (mg/100g FW)	Carotenoid (mg/100g FW)	Chl. a/Chl. b
Winter	39.2±1.55[a]	13.8±0.93a	16.4±0.36[a]	2. 84±0.15[a]
Summer	24.6±1.42[b]	10.3±1.84[a]	5.67±0.55[b]	2.43±0.36[a]

Values are expressed as mean ± SD (n = 3). In each column values followed by different letters are significantly different at $p < 0.05$

3.4. Effect of season on the content of minerals

As shown in Table (4), The contents the contents of nitrogen, phosphorus and sodium were not significantly affected by seasonal variation while the content of calcium, magnesium, chloride, iron and manganese were significantly different between seasons ($p < 0.05$), their values were significantly lowered in dry season. These results agree with Bista *et al.,* (2018), who reported that water deficiency decreases the availability of total nutrients in the soil, which reduce the uptake of nutrient by root and consequently decrease the content of minerals in plant tissues and affect the homeostasis of ions in plant cells as reported by Akhtar and Nazir (2013).

The significant decrease in the contents of Ca^{2+}, $Mg^{2+}$and Mn^{2+} in *Capparis spinosa* could be attributed to the high proportion of silt and clay in the root-associated soil particles in the rhizosphere, which may enhance the activity of calcium carbonate resulting in lower the availability of these nutrients.

Table 4: The content of minerals in *Capparis spinosa* in winter and summer seasons

Minerals		Seasons	
		Winter	**Summer**
Nitrogen	**g /100g**	1.81±0.23[a]	1.34±0.26[a]
Sodium	**g /100g**	1.03±0.03[a]	1.22±0.10[a]
Potassium	**g /100g**	2.04±0.12[a]	2.18±0.26[a]
Calcium	**g /100g**	2.90±0.05[a]	1.25±0.01[b]
Magnesium	**g /100g**	1.98±0.027[a]	1.32±0.01[b]
Phosphorus	**g /100g**	0.07±0.005[b]	0.10±0.011[a]
Chloride	**g /100g**	0.43±0.01[a]	0.19±0.02[b]
Iron	**mg /100g**	17.5±0.25[a]	12.1±0.42[b]
Manganese	**mg /100g**	3.47±0.03[a]	2.44±0.32[b]
Zinc	**mg /100g**	0.29±0.03[b]	0.41±0.10[b]
Copper	**mg/100gm**	0.35±0.15[b]	0.66±0.22[a]

Values are expressed as mean ± SD (n = 3). In each column values followed by different letters are significantly different at $p < 0.05$.

3.5. Effect of season on plant water content, Ash and organic matter contents

As shown in Table (5), Fig. (3), the plant water content was significantly higher ($p < 0.05$) in summer when compared with winter, as its value was 71.81±0.1ml/100g DW in summer, while in winter it was 68.92±0.17ml/100gDW.

Ash content was significantly higher ($p < 0.05$) in the summer sample, its value was 18.04±0.40 g/100g in winter and increased to 19.51±0.16 g/100g in summer. Whereas the content of organic matter was significantly higher ($p < 0.05$) in the winter sample.

Regarding the results of total protein, it was found that the content of total protein was significantly affected by season. Its values were significantly decreased under the climatic conditions of summer season.

Table 5: Plant water content, ash, organic matter, and total protein contents in *Capparis spinosa* in winter and summer seasons

Season	Plant water content (ml/100gDW)	Ash (g/100g)	Organic matter (g/100g)	Total protein (g/100g)
Winter	68.92 ±0.17^{b}	18.04 ±0.40^{b}	81.9 ±0.40^{a}	11.3±1.44^{a}
Summer	71.83 ±0.1^{a}	19.51±0.16^{a}	80.5 ±0.16 ^{b}	8.37±1.62^{a}

Values are expressed as mean ± SD (n = 3). In each column values followed by different letters are significantly different at $p < 0.05$.

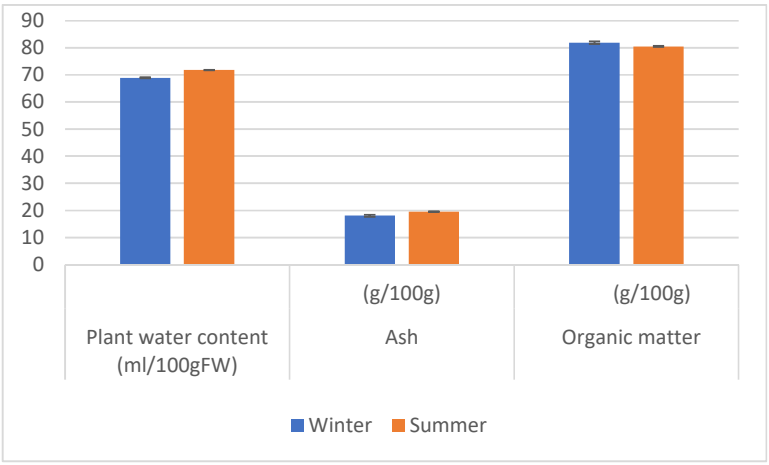

Fig. 3: Plant water content, ash, organic matter in *Capparis spinosa* in winter and summer seasons

3.6. Effect of season on the contents of proline, stachydrine, total soluble sugars and osmotic potential

The obtained results indicated that the content of proline was significantly different between seasons ($p < 0.05$) (Table 6), its values were 9.61±0.18 µmol g^{-1} DW in winter and decreased significantly to 5.17±0.17 µmol g^{-1} DW in summer season. The accumulation of proline in response to cold stress has been reported in many higher plants as reported by Delauney and Verma (1993). It prevents the damage of cell membrane and protein denaturation during severe drought stress (Hare *et al.,* 1998; Ain-Lhout *et al.,* 2001) and also facilitates the continued synthesis of nitrogenous compatible solutes using excess photochemical energy available when stomata are closed (Smirnoff and Stewart, 1985). Whereas the content of proline derivative; water-soluble stachydrine alkaloid, also known as proline betaine, was detected in high value in summer samples (3.49±0.07 µmole /g DW), which may be attributed to the synthesis of stachydrine from proline to contribute to osmotic pressure, which may explain the decrease in the value of proline in dry season. It was evident by Parameshwara (1984) that stachydrine act as compatible solute and was synthesized from proline under stress in alfalfa seedling, this may be mediated by the co-factor such as pyridoxine, methionine, and folic acid. The pre-treatment of stachydrine also protects the photofunction of alfalfa leave when exposed to stress and high intensity of light. Also, chemotaxonomy evidence from Plumaginaceae indicates that the evolution of proline

betaine was associated with an improvement in stress tolerance (Hanson *et al.,*1994) and is considered a more effective osmoprotectant than proline (Amin *et al.,*1995; LeRudulier *et al.,*1984).
Water stress has shown to increase alkaloid percentage in a variety of plants including *Ephedra alata* (El-Lamey, 2005) *Retama raetam* (El-Lamey, 2020b) *Nicotiana tabacum* (Aveytan & Kazanchyan, 1973; Waller & Nowacki, 1978), *Lycopersicon esculentum* (Azizbekova *et al.,* 1973), and *Phalaris aquatica* and *P. tuberose* (Williams, 1972). The increased alkaloids reported in these studies ranged from 5% to 500%. In *Catharanthus roseus* G. Don the highest alkaloidal contents as vincaleukoblastine in different plant organs were obtained by 50% followed by 75% soil moisture deficit (Talha *et al.,* 1975).

Table 6: The content of proline, stachydrine, total soluble sugars and osmotic potential in *Capparis spinosa* in winter and summer seasons

Seasons	Proline (µmol g^{-1} DW)	Stachydrine (µmol g^{-1} DW)	T. soluble sugars (mmol l^{-1})	Osmotic content (mOsoml l^{-1})	Osmotic Potential (MPa)
Winter	9.61±0.18[a]	Not detected	576.9±17.9[a]	732.3±7.09[b]	-1.81±0.18[b]
Summer	5.17±0.17[b]	3.49±0.07	653.7±18.9[b]	833.3±21.9[a]	-2.06±0.05[a]

Values are expressed as mean ± SD (n = 3). In each column values followed by different letters are significantly different at $p < 0.05$

The mechanisms by which water deficits increase the alkaloid levels have been the subject of some speculations. One possible explanation is that water deficits raise the levels of amino acids and amides which can serve as biosynthetic precursors to alkaloids. This accumulation has been attributed to a decline in protein synthesis (Hsiao, 1973; Hsiao *et al.,* 1976).

On the other hand, the content of total soluble sugars showed a significant increase under the climatic condition in summer season, its values were 576.9±17.9 mmol l^{-1} in winter and significantly increased to 653.7±18.9 mmol l^{-1} in summer. Such an increase in the content of soluble sugars under drought conditions is considered as an adaptive mechanism to drought stress that gives the plants a competitive trait, makes them more adaptable to the desert environment (Pelah *et al.,* 1997). Besides the role of sugars in providing the carbon and energy needed to regulate plants growth and development, they act as osmoprotectants, which regulate the cell osmotic status, protect membranes by maintaining integrity of membrane structure during hydration (Crowe *et al.,* 1988; Crowe and Crowe, 1992), and contribute to the scavenging of free radicals in plant cells (Koyro *et al.,* 2012).Also, they have a role in protecting the chloroplast from being damaged under water deficit conditions (Santarius, 1973). Therefore, it has been used as a marker for selecting tolerant varieties against water as reported by Al Hakimi *et al.,* (1995).

Regarding the results of osmotic potential, its values were significantly affected by seasons and decreased significantly (become more negative than the external medium) under the climatic conditions of dry season. Its value was -1.81±0.18 MPa in winter and -2.06±0.05 MPa in summer. The results indicated that the value of osmotic content per liter in cell sap of *Capparis* was significantly affected by season, its value increased under the climatic condition of summer season to (833.3±21.9 mOsmol l^{-1}). The accumulation of compatible osmolytes assists in maintaining tissue turgor and generates low values of plant water potential (more negative than the external medium) to insure the water uptake (Kan *et al.,* 2000; Kamel, 2007).

According to the values of the concentrations of osmotic solutes and calculated solute potential by Boyle - van 't Hoff equation, the assumed contribution of total soluble sugars to the total osmotic potential under climatic conditions of summer season was more than 77%, and the contribution of ions was more than 20% when the measured EC value(10.953 dSm^{-1}) of the cell sap was converted to the unit of osmotic potential (-0.44MPa), while proline and stachydrine can act as compatible solutes when accumulated in the cytoplasm of the cell (Nolte and Hanson,1997). These results agree with those found by other investigators, since sugars are the major osmolytes of osmoregulation in expanded leaves of many species (Jones *et al.,* 1980; Boyer, 1983). However, in leaf tissues of acclimated periwinkle, polar water-soluble alkaloids formed the major fraction of the osmotic solutes (Talha *et al.,* 1975).
In conclusion, the results of this study indicated that the Mediterranean evergreen plant *Capparis spinosa* is well adapted the adverse climatic conditions of summer season and responded to these conditions through the accumulation of soluble sugar, stachydrine alkaloid and ions. It is likely that the

selective accumulation of these solutes as osmolytes might contribute to the decrease in osmotic potential and increase the water inlet to the cells, which eventually leads to normal cell functions, that was deduced from the high-water content in the plant in the dry season. The role of stachydrine in improving the tolerance of *Capparis spinosa* to stress conditions in summer seasons as compatible solutes and osmotic regulatory substances to alleviate drought stress hasn't been reported in this species in other studies and needs more investigations, also the possibility of increasing the tolerance of economic plant to water deficit by enhancing the syntheses of these compounds is suggested for further studies.

References

Ain-Lhout, F., M. Zunzunegui, M.C., Diaz Barradas, R. Tirado, A. Clavijo and F. Garcia Novo, 2001. Comparison of proline accumulation in two Mediterranean shrubs subjected to natural and experimental water deficit. Plant Soil, 230: 175–183

Akhtar, I. and N. Nazir, 2013. Effect of waterlogging and drought stress in plants. International Journal of water Resources and Environmental Sciences, 2(2): 34-40.

Al Hakimi, A., P. Monneveux, and G. Galiba, 1995. Soluble Sugars, proline and relative water content (RWC) as traits for improving drought tolerance and divergent selection for RWC from *T. polonicum* into *T. durum*. J. Genet. Breed., 49: 237-244.

Amin, U.S., T.D. Lash and B.J. Wilkinson, 1995. Proline is a highly effective osmoprotectant for *Staphylococcus aureus*. Arch. Microbiol., 163:138-142.

AOAC, 2000. Official Methods of Analysis, 17th Ed. Association of Official Analytical Chemists. Washington D.C., U.S.A.

Aveytan, E.M. and O.K., Kazanchyan, 1973. Effect of watering conditions on the chemical composition of tobacco leaves and its smoke. Tabak 51-52 (cited in Chem Abst. 81:10998t)

Azizbekova, Z.S., S. Aslanov, and Z.A. Babaeva, 1973. Effect of sodium chloride on the levels of glucoalkaloids and free amino acids in tomatoes. Dokle Akad-Azerb, SSR. 29: 58-61 (Cited in Chem. Abst., 80: 104457X

Baker, A.S. and R.L., Smith, 1974. Preparation of solutions for atomic absorption analysis of Fe, Mn, Zn and Cu in plant tissue. Journal of Agriculture and Food Chemistry, 22, 103.

Baker, D.A., 1984. Water relations. In: advanced plant physiology. (Wilkins, M. 13th Ed.). Longman Scientific & Technical, Harlow, UK, 297-318.

Bates, L.S., R.P. Waldren, and I.D., Teare, 1973. Rapid determination of free proline for water-stress studies. Plant and Soil. 39(1): 205-207.

Bista D.R., S.A. Heckathorn, D.M. Jayawardena, S. Mishra, J.K. Boldt, 2018. Effects of Drought on Nutrient Uptake and the Levels of Nutrient-Uptake Proteins in Roots of Drought-Sensitive and -Tolerant Grasses. Plants, 7: 28. doi: 10.3390/plants7020028

Boulos, L., 1999. Flora of Egypt. Volume 1, Al Hadara Pub., Cairo, Egypt, 419.

Boyer, J.S., 1983. Subcellular mechanisms of plant response to lower water potential. Agriculture and Water Management, 7: 239-248.

Buysse, J. and X.R., Merck, 1993. An improved colorimetric method to quantify sugar content of plant tissue. Journal of Experimental Botany, 44 (267): 1627-1629.

Crowe, J.H. and L.M. Crowe, 1992. Membrane integrity in anhydrobiotic organisms toward a mechanism for stabilizing dry cells. In: Somero, G. N.; Osmond, C. B. and Bolis, C. L. (Eds), water and life. Springer Verlag, Berlin, pp. 87-103.

Crowe, J.H., L.M. Crowe, J.F. Carpenter, A.S. Rudolph, C.A. Wistrom, B.J. Spargo, and T.J., Anchordoguy, 1988. Interactions of sugars with membranes. Archives of Biochemsitry and Biophysics, 947: 367-384.

Delauney, A.J., 1993.Verma DPS. Proline biosynthesis and osmoregulation in plants. Plant J., 4: 215–223.

Di Castri, F., 1973. Climatographical comparisons between Chile and the western coast of North America. – In: Di Castri F. and H.A. Mooney, (ed.): Mediterranean Type Ecosystems. Pp. 21-36. Springer-Verlag, Berlin 1973.

El-Lamey, T.M., 2005. The effect of some ecological factors on the chemical compounds in some plant xerophytes for enhancing their use. Ph.D. Thesis, Institute of Environmental Studies and Research, Ain Shams University, Cairo, Egypt.

El-Lamey, T.M., 2020a. Seasonal impact on photosynthetic pigments, antioxidant activity and total phenolic content in *Ajuga iva* (L.) Schreb. grown in Sidi Barrani Desert. Egypt International Journal of Environment, 9(2): 104-117

El-Lamey, T. M., 2020b. Changes in some chemical compounds of *Retama raetam* (Forssk.) Webb & Berthel. in response to different environmental conditions. Journal of Biodiversity and Environmental Sciences, 16(2):78-91.

El-Lamey, T.M., S.A. Elmeleigy and A.A.A. El-Henawy, 2021. Comparative study of anatomical characteristics and chemical composition of essential oils of *Deverra tortuosa* (Desf.) DC. grown under different environmental conditions. Current Science International, 10 (4): 729-749.

El-Lamey, T.M., 2021. Comparative study of the physiological performance of two species of Atriplex growing in the same ecological conditions. Middle East Journal of Applied Sciences. 11(4): 959-974.

Ghorbanli, M., M. Gafarabad, T. Amirkian and B.A. Mamaghani, 2013. Investigation of proline, total protein, chlorophyll, ascorbate and dehydroascorbate changes under drought stress in Akria and Mobil tomato cultivars. Iran. J. Plant Physiol., 3: 651-658.

Hanson, A.D., B. Rathinasabapathi, J. Rivoal, M. Burnet, M.O. Dillon and D.A. Gage, 1994. Osmoprotective compounds in the Plumbaginaceae: A natural experiment in metabolic engineering of stress tolerance. Proc. Natl. Acad. Sci., USA91:306-310.

Hare, P.D., W.A. Cress, J. van Staden, 1998. Dissecting the roles of increased calcium for potassium nutrition and salt tolerance. osmolyte accumulation during stress. Plant, Cell and Environment 21: 535–553.

Hsiao, T.C., 1973. Plant responses to water stress. Annu. Rev. Plant. Pysiol., 24: 519-570.

Hsiao, T.C., E. Acevedo, E. Fereres, and D.W. Henderson, 1976. Stress metabolism, water stress, growth and osmotic adjustment. Phil. Trans. R. Soc. London. 273: 479-500.

Jackson, M.L., 1967. Soil Chemical Analysis. Hall of India Private, New Delhi, India. Printice. Hall Inc., N.J., 248.

Jackson, W.A. and G.W. Thomas, 1960. Effect of KCl and dolometric limestone on growth and ion uptake of sweet potato. Soil Science 89: 347-352.

James, C.S., 1995. Analytical chemistry of foods (Blackle Academic and Professional Publisher. An imprint of Champman and Hall) 178.

Jones J.B., 1977. Elemental analysis of soil extracts and plant tissue ash by plasma emission spectroscopy, Commun. Soil Sci. Plant Analy., 8:349-365.

Jones, M.M., C.B. Osmond, N.C. Truner, 1980. Accumulation of solutes in leaves of sorghum and sunflower in response to water deficits. Aust. J. Plant Physiol., 7: 193-205.

Junbo, X., S. Lintao, Z. Yanqing, F. Leilei and L. Yaxin, 2015. Determination of Stachydrine and Leonurine in Herba Leonuri and Its Succedaneum-Herba Lagopsis-with a Sensitive HPLC–MS/MS Method, Journal of Liquid Chromatography & Related Technologies, 38(7):810-815, DOI: 10.1080/10826076.2014.973965

Kamel, M., 2007. Osmotic adjustment in three succulent species of Zygophyllaceae, Afric. J. Ecol., 46: 96-1 04.

Kan, M.A., I.A. Ungar and A.H. Showalter, 2000. The effect of salinity on growth, water status and ion content of leaf succulent perennial halophytes, *Suaeda fruticosa* (L.) Forssk., J Arid Environ., 45: 73-84.

Kjeldahl, J., 1983. The Kjeldahl determine of nitrogen: retrospect and prospect. Trends in analytical Chemistry 13(4): 138.

Koyro, H.W., P. Ahmad and N. Geissler, 2012. Abiotic stress responses in plants: an overview. In: Ahmad P, Prasad MNV, editors. Environmental adaptations and stress tolerance of plants in the era of climate change. New York (NY): Springer Science and Business Media, 1–28

Ladjal, M., D. Epron and M. Ducrey, 2000. Effects of drought preconditioning on thermotolerance of photosystem II and susceptibilityof photosynthesis to heat stress in cedar seedlings. Tree Physiol., 20: 1235–1241.

LeRudulier D., A.R. Strom, A.M. Dandekar, L.T. Smith, and R.C. Valentine, 1984. Molecular biology of osmoregulation. Science, 224: 1064–1068

Levizou, E., P. Drilias, and A. Kyparissis, 2004. Exceptional Photosynthetic Performance of *Capparis spinosa* L. Under Adverse Conditions of Mediterranean summer. https://doi.org/10.1023/B:PHOT.0000040594.85407.F4

Médail, F., 2008. Ecosystems: Mediterranean. In: Jørgensen SE, Fath B (eds) Encyclopedia of ecology, vols 3, 5. Elsevier, Oxford, 2296–2308

Médail, F. and N. Myers, 2004. Mediterranean Basin. In: Mittermeier RA, Robles Gil P (eds) Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions. CEMEX (Monterrey), Conservation International. Washington and Agrupación Sierra Madre, 144–147

Momin, R.K. and V.B. Kadam, 2011. "Determination of ash values of Some Medicinal Plants of Genus Sesbania of Marathwada Region in Maharashtra" Journal of Phytology, 3(2):52-54.

Mooney, H.A., 1983. Carbon-gaining capacity and allocation patterns of Mediterranean-climate plants. – In: Kruger, F.J., Mitchell, D.T., Jarvis, J.U.M. (ed.): Mediterranean-type Ecosystems. The Role of Nutrients. Pp. 103-119. Springer-Verlag, Berlin – Heidelberg – New York.

Moore, T.J., R.C. Hartwig and R.H. Loeppert, 1990. Steady-state procedure for determining the effective particle-size distribution of soil carbonates. Soil Sci. Soc. Am. J. 54: 55–59.

Morgan, J. M., 1984. Osmoregulation and water stress in higher plants. Ann. Rev. plant physiol., 35: 299-319.

Nolte, K.D. and A.D. Hanson, 1997. Proline Accumulation and Methylation to Proline Betaine in *Citrus* Implications for Genetic Engineering of Stress Resistance. J.Amer.Soc.Hort.Sci., 122(1):8-13

Özkahraman, I. 1997. Caper. Forest Ministry, AGM Publications, Various Publication Series, No: 2. Ankara-Turkey

Page, A.L., 1987. Methods of Soil Analysis, part 2. chemical and microbiological properties - agronomy monograph. No.9. American Society of Agronomy Inc., Madison. 167.179.

Parameshwara, G., 1984.Stress effects in Alfalfa (*Medicago sativa*) seedlings in relation to proline and betaines Thesis (Ph.D.) University of Adelaide.

Patakas, A. and B. Noitsakis, 1999. Mechanisms involved in diurnal changes of osmotic potential in grapevines under drought conditions, J. Plant Physiology, 154: 767-774.

Pelah, D., W. Wang, A. Altman, O. Shoseyov and D. Bartels, 1997. Differential accumulation of water stress-related proteins, sucrose synthase and soluble sugars in Populus species that differ in their water stress response. Physiologia plantarum, 99: 153-159

Quézel, P. and F. Médail, 2003. Ecologie et biogéographie des forets du bassin méditerranéen. Elsevier, Paris. http://www.lavoisier.fr/livre/environnement/ecologie-et-biogeographie-des-forets-du-bassin-mediterraneen/quezel/descriptif-9782842994518

Rowell, D.L., 1994. Soil science: methods and application. Longman Publishers, Singapore. 350 p.

Rybak-Chmielewska, 2003. H. Honey In: TOMASIK, P. Chemical and functional properties of food saccharides. Boca Raton: CRC, 73-80.

Santarius, K.A., 1973. The protective effect of sugars on chloroplast membranes during temperature and water stress and its relationship to frost, desiccation on heat resistance. Planta, 113: 105-114.

Simmelsgaard, S.E., 1976. Adaptation to water stress in wheat. Physiol. Plant, 37: 167-174.

Smirnoff, N. and G.R. Stewart. 1985. Nitrate assimilation and translocation by higher plants: Comparative physiology and ecological consequences. Physiol. Plant, 64:133–140.

Sozzi G.O., 2001. Caper bush: Botany and horticulture -Horticult. Rev. 27: 125-188, 2001.

Subbarao, G.V., N.H. Nam, Y.S. Chauhan, C. Johansen, 2000. Osmotic adjustment, water relations and carbohydrate remobilization in pigeonpea under water deficits. Journal of Plant Physiology. 157: 651-659.

Suleiman, M.K., N.R. Bhat, M.S. Abdal, S. Jacob, R.R. Thomas, S. Al-Dossery, G. D'Cruz, and R. Bellen, 2009. Growth of *Capparis spinosa* var. *Inermis* under different irrigation levels. Journal of Horticulture and Forestry, 1(2): 17-21.

Sumanta, N., C.I. Haque, J. Nishika, R. Suprakash, 2014.Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. Research Journal of Chemical Sciences, 4(9): 63.69.

Täckholm, V., 1974. Student Flora of Egypt. Pub. Cairo Univ. Printed by Cooperative Printing Co., Beirut.

Talha, M., A.S. Radwan, and S. Negm, 1975. Effect of soil moisture deficit on growth and alkaloid content of *Catharanthus roseus* (L.) G. Don. Current Science, 44: 614-616.

Terzi, R., A. Sağlam, N. Kutlu, H. Nar, and A. Kadıoğlu, 2010. Impact of soil drought stress on photochemical efficiency of photosystem II and antioxidant enzyme activities of *Phaseolus vulgaris* cultivars. Turk J. Bot., 34: 1-10. doi:10.3906/bot-0905-20

Tlili, N., N. Nasri, E. Saadaoui, A. Khaldi, S. Triki, 2010. Sterol composition of caper (*Capparis spinosa*) seeds. Afr. J Biotechnol 9:3328-3333.

UNESCO, 1977. Map of the World Distribution of Arid Regions, MAB, Paris.

Waller, G.R. and E.K. Nowacki, 1978. Alkaloid biology and metabolism in plants. Plenum Press, New York.

Williams, J.D., 1972. Effects of time of day, moisture stress, and frosting on the alkaloid content of *Phalaris tuberose.* Aust. J. Agric. Res., 23: 611-621.