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Mechanisms of Drought Tolerance in *Cornulaca monacantha* Del.

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Abstract

Samples of shoot system of *Cornulaca monacantha* were collected from two sand embankments location; Rommana (North Sinai) and Khamisa (Siwa Oasis) in Egypt during wet and dry seasons. Degree of succulence, chlorophyll a, chlorophyll b, carotenoids, total carbohydrate, soluble and non-soluble carbohydrates, crude protein, total soluble protein, proline, glycinebetaine, total phenols, Na^+, K^+, Ca^{++} and Mg^{++} were determined. Degree of succulence, chlorophyll a, chlorophyll b, carotenoids, soluble carbohydrate, soluble protein, total phenols, Ca^{++} and Mg^{++} were decreased in dry season. On the other hand, total carbohydrate, non-soluble carbohydrate, proline, glycinebetaine, Na^+ and K^+ were increased in dry season. *Cornulaca monacantha* inhabiting Rommana was higher in degree of succulence, chlorophyll b, glycinebetaine, total phenols, soluble protein, Ca^{++} and Mg^{++} and lower in the other characters (except in Na^+ was non-significant) than that inhabiting Khamisa.

1. Introduction

Drought stress is one of the premier limitations to global agricultural production due to complexity of the water-limiting environment and changing climate. To overcome water deficit, plants have included a series of mechanisms; morphological, physiological, biochemical, cellular and molecular levels (Fang and Xiong 2015). Drought tolerance is the ability of plant to withstand with reduced water potential of the plant tissue. Drought tolerance mechanisms allow the plant to function or at least survive, at reduced water potential (Verslues *et al.,* 2014). The overproduction of different types of compatible solutes is one of the most common stress tolerance strategies in plants (Serraj and Sinclair 2002). Compatible solutes are highly soluble, low molecular weight and non-toxic even at high concentration. They protect plants from stress by different means viz., contribution in osmoregulation, scavenging reactive oxygen species and stabilization of membranes (Farooq *et al.,* 2009). In addition to compatible solutes, inorganic ions accumulation reduce the osmotic potential and improve cell water retention in response to water stress (Morgan 1984; Rhodes and Samaras 1994).

Glycinebetaine as an organic osmolyte plays an im-

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portant role in enhancing plant tolerance under abiotic stress including drought (Quan *et al.,* 2004). Beside the direct protective roles of glycinebetaine either through positive effects on enzyme and membrane integrity or as an osmoprotectant, it may protect cells from environmental stresses indirectly by participating in signal transduction pathways (Subbarao *et al.,* 2000). Also, proline acts as an osmoprotectant in plants subjected to drought conditions (Yamada *et al.,* 2005). Relative water content and total protein were decreased by water stress, while free amino acids were increased in *Morus alba* L. (Ramanjulu and Sudhakar, 1997). Soluble carbohydrates are considered as important metabolites in plants under drought stress (Arabzadeh, 2012). Drought stress imposed a significant increase in soluble carbohydrate and decrease in soluble protein in Cicer arietinum cultivars (Mafakheri *et al.,* 2011).

Cornulaca monacantha is a desert plant, woody shrub, richly branched, usually with long internodes, that is now included in family Amaranthaceae (formerly Chenopodiaceae). This study aims to shed the light on the adaptive responses of *C. monacantha* as drought tolerance plant. In this study, succulence degree, plant pigments (chl. a, chl. b and carotenoids), total carbohydrate, soluble carbohydrate, crude protein, soluble protein, total phenols, proline, glycine betaine, Na^+, K^+, Ca^{++} and Mg^{++} were determined in shoot system of *C. monacantha* growing naturally at Rommana (North Sinai) and Khamisa (Siwa Oasis) during wet and dry season.

2. Materials and methods

2.1. Study area

The two studied locations (Rommana and Khamisa)

are sandy embankments habitat. The first one lies on the western part of North Sinai, farthest by about 35 km from Suez Canal. The second one lies on the western part of Siwa Oasis, farthest by about 60 km from the Lybian boarder. The geographical position of the collected samples and meteorological data were represented in Table 1. Meteorological data for Rommana (L1) and Khemaisa (L2) were collected from the nearest station from each one during 2013-2014 as represented in Table 2 using ETo calc Program according to Francisco Catalán (2015).

2.2. Soil analyses

Two depths of soil (0-30 cm and 30-60 cm) supporting *C. monacantha* were collected (three replicates for each depth) to determine physical and chemical properties. Samples of plant shoot system were collected in three replicates from the two locations; Rommana and Khamisa during wet (March) and dry (August) seasons in 2014. The soil samples were air-dried, sieved through 2mm meshes and granulometric analysis was determined as described by Jackson (1967) and illustrated in Table 3. Electrical conductivity (EC), Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^{--} and HCO_3^- were estimated and determined in soil water extract (1:1). Soil water content, EC, Na^+, K^+, Ca^{++} and Mg^{++} were determined following the methods described by Rowell (1994). Chlorides were determined as described by Jackson (1967). Sulphates were determined by the turbidity method according to Rainwater and Thatcher (1960). Bicarbonate was determined by titration with sulphuric acid 0.01N according to Reitemeier (1943). All studied soil chemical analyses were represented in Table 4.

Table 1. The geographical position (GPS) of the collected plant samples and meteorological data.

Locations	GPS of the collected samples	GPS of the collected meteorological data
Rommana (L1)	31° 00` 583 ″ latitude 32° 39` 352 ″ longitude	30° 40` 156″ latitude 32° 36` 287″ longitude
Khamisa (L2)	29° 12` 470 ″ latitude 25° 24` 828 ″ longitude	29° 12` 72″ latitude 25° 31` 839″ longitude

Table 2. Meteorological data covering studied locations during 2013-2014.

Months	Precipitation mm/m		Temperature °C		Relative humidity %		Sun shine %		ETo mm/m	
	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
January	9	3	13.2	12.4	61.4	55.1	67.7	76.9	73	85
February	8	1	14.1	14.0	59.1	49.2	70.3	79.6	85	102
March	8	2	16.1	17.2	56.6	43.4	71.0	73.6	122	152
April	5	1	20.1	21.7	51.4	36.0	74.0	74.5	158	197
May	2	0	22.9	25.3	51.3	33.6	79.4	77.7	193	231
June	0	0	25.9	28.7	53.6	32.6	87.8	86.3	210	248
July	0	0	27.5	29.2	55.6	38.3	86.6	89.5	216	252
August	0	0	27.6	29.1	57.6	40.9	87.5	89.3	202	229
September	0	0	25.8	26.9	59.6	43.0	83.4	84.9	163	184
October	2	0	22.9	22.8	60.1	47.6	83.2	83.5	135	143
November	7	2	18.8	17.5	61.2	55.1	76.9	82.0	92	97
December	9	2	14.6	13.4	63.1	56.9	65.7	77.4	71	81
Total	50	11							1 720	2 001

Table 3. physical analysis of soil supporting *C. monacantha*.

Location	Depth cm	2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-125 mm	0.125-0.063 mm	< 0.063 mm	texture
Rommana	0-30	0.1	3.76	51.73	39.49	4.5	0.42	Sandy
	30-60	0	1.23	43.24	52.46	3.02	0.05	Sandy
Khamisa	0-30	0.45	4.14	29.66	47.87	17.76	0.12	Sandy
	30-60	0.2	16.72	56.75	23.82	2.45	0.06	Sandy

Table 4. Chemical analysis of soil supporting *C. monacantha*.

seasons	location	Depth Cm	Moisture content %	EC Mmhos	Cations meq/L				Anions meq/L		
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	SO_4^-
Wet	Rommana	0-30	2.30	0.666	2.43	0.23	2.00	2.50	2.7	0.7	4.1
Wet	Rommana	30-60	1.22	0.825	3.35	0.26	2.25	3.25	4.3	1.0	3.5
Wet	Khamisa	0-30	0.66	0.813	6.04	0.72	1.75	1.25	4.2	1.1	3.9
Wet	Khamisa	30-60	0.53	0.495	3.74	0.31	1.00	0.50	2.5	0.9	2.3
Dry	Rommana	0-30	0.70	1.025	4.87	0.27	2.50	4.00	4.4	0.7	5.9
Dry	Rommana	30-60	0.83	0.655	2.70	0.21	2.00	2.00	2.0	0.7	4.1
Dry	Khamisa	0-30	0.07	0.435	3.04	0.28	1.00	0.25	1.0	1.0	2.6
Dry	Khamisa	30-60	0.11	0.405	2.80	0.26	1.00	0.50	1.0	1.5	2.0

2.3. Plant analyses

Plant samples were divided into two parts for analyses, in the first part fresh samples were used to determine degree of succulence, chlorophyll a, chlorophyll b, carotenoids and soluble protein, the second part plant samples were dried at till constant weight, then ground to fine powder to determine contents of total carbohydrate, soluble and non-soluble carbohydrate, crude protein, proline, glycinebetaine, total phenols, Na^+, K^+, Ca^{++} and Mg^{++}.

Degree of succulence was calculated as fresh/dry weight according to Dehan and Tall (1978). The photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids) were determined quantitatively as described by Metzner *et al*. (1965). Soluble protein concentrations were determined by the method of Bradford (1976) using bovine serum albumin as a standard. Total and soluble carbohydrates were extracted and estimated calorimetrically by applying the general phenol-sulphoric acid method as adopted by Chaplin and Kennedy (1994). Values were expressed as g/100g dry wt. Crude protein was estimated by Kjeldahl method as described by Pregle (1945). Free proline was measured by the sulfosalicylic acid- ninhydrin method according to Bates *et al*. (1973). Glycine-betaine content was estimated colorimetrically as described by Grieve and Grattan (1983). Total phenols were determined using Folin-Denis reagent as described by Shahidi and Nacz (1995). A known weight of plant sample was extracted by 80% ethanol, 1 ml of the extract, 0.5 ml of Folin reagent were mixed well, 1 ml of saturated Na_2CO_3 and mixed well then 3 ml of dist. water were added. After 1 hour read the developed blue color at 725 nm by spectrophotometer using catechol as a standard. Sodium and potassium were measured by flame photometer and Calcium and magnesium by atomic absorption spectrophotometer as described by Kalra (1998).

2.4. Statistical analysis

Data obtained from the experiment of plant analysis were subjected to the proper statistical analysis of variance of the split plot design according to the procedure obtained by Snedecor and Cochran (1969). Mean values of treatments were differentiated by using L.S.D at 5 % level as mentioned by Steel (1960).

3. Results

Degree of succulence increased significantly in *Cornulaca* monacantha during wet season, recorded the highest value (3.16) in plants inhabiting Rommana (Table 5). *C. monacantha* at Rommana was higher in degree of succulence than that at Khamisa.

Regarding plant pigments, chlorophyll a, chlorophyll b and carotenoids were decreased in dry season in *C. monacantha* as shown in Table 5. *C. monacantha* inhabiting Khamisa was higher in chlorophyll a and carotenoids, while that inhabiting Rommana was higher in chlorophyll b. The highest contents of chlorophyll a and b were recorded in *C. monacantha* growing at Khamisa in wet season 24.67 and 11.47 mg/100g fr. wt., respectively. While the highest carotenoids content was recorded in *Cornulaca* inhabiting Rommana in wet season (4.3 mg/100g fr. wt.).

In general, total carbohydrate and non-soluble carbohydrate in *C. monacantha* increased in dry season, recorded the highest values 43.73% and 39.98% in the plant of Rommana during dry season but the interaction was non-significant in total carbohydrate as illustrated in Table 5. Soluble carbohydrate generally increased in the plant during wet season (4.57%).

Proline was significantly elevated in dry season in *C. monacantha*, it increased by 35% and elevated in *C. monacantha* of Khamisa by 89% compared to that in Rommana (Table 6). The highest value of proline (112 µg/g dry wt.) was noticed in *C. monacantha* inhabiting Khamisa during dry season. As proline glycinebetaine was elevated significantly in dry season, it increased by 70% (Table 6). Glycinebetaine increased by 12% in C. monacantha at Rommana compared to that at Khamisa. The highest value of glycinebetaine (301.2) was noticed in the plant at Rommana in dry season.

A significant accumulation of total phenols in *C. monacantha* was noticed in wet season as shown in Table 6. *Cornulaca* at Rommana was higher in total phenols than that at Khamisa. The highest value of total phenols (224.1 mg/100g dry wt.) was recorded in the

plant at Rommana in wet season, followed by that at Khamisa in dry season (192.1 mg/100g dry wt.), Rommana in dry season (170.3 mg/100g dry wt.) and Khamisa in wet season (166.7 mg/100g dry wt.).

Crude protein had non-significant change seasonally (Table 6). It was higher accumulation in *C. monacantha* at Rommana than that at Khamisa. The highest value of crude protein (11.49%) was noticed in the plant at Rommana in wet season. Soluble protein in the plant was affected significantly by seasons and locations while the interaction between them was non-significant. Generally, it increased in wet season and was higher in *C. monacantha* at Rommana than that at Khamisa.

Sodium content was elevated significantly in dry season (Table 7). There was no significant change in the studied plant between the two locations. The highest sodium content was recorded in *Cornulaca* at Khamisa in dry season (3.62%), and the lowest content was record-

ed in *Cornulaca* at the same location in wet season (1.38%). Like sodium, potassium in *Cornulaca* was elevated significantly in dry season (Table 7). It was higher in *Cornulaca* growing at Rommana than that growing at Khamisa. Potassium content in *Cornulaca* can be arranged in descending order as those growing at Rommana in wet season (0.57%), those growing at Rommana in dry season (0.51%), those growing at Khamisa in dry season (0.39%), those growing at Khamisa in wet season (0.19%).

Calcium and magnesium in *C. monacantha* were increased significantly in wet season (Table 7). They were higher in the plant growing at Rommana than that at Khamisa. The highest calcium content was noticed in the plant growing at Rommana in wet season (3.02%), while the highest magnesium was noticed in the plant growing at Khamisa in wet season (1.82%).

Table 5. Succulence (fr.w/dry W.), chlorophyll a, b and carotenoids (mg/100g fr. W.), total, soluble and non-soluble carbohydrate (g/100g dry w.) in *Cornulaca monacantha*.

Season							
	Succulence	Chlorophyll a	Chlorophyll b	Carotenoids	Total carbohydrate	Soluble carbohydrate	Non-soluble carbohydrate
Wet (W)	2.44	18.31	10.53	4.12	39.64	4.57	35.16
Dry (D)	2.24	11.43	7.48	1.57	40.97	3.74	37.26
L.S.D at 5%	s	s	s	s	s	s	s
locations							
Rommana (L1)	2.97	10.41	9.56	2.67	37.62	3.41	34.24
Khamisa (L2)	1.72	19.33	8.46	3.00	42.99	4.90	38.11
L.S.D at 5%	s	s	s	s	s	s	s
Interaction between locations and seasons							
W* L1	3.16	11.95	9.60	4.30	37.03	3.12	33.91
W* L2	1.73	24.67	11.47	3.89	42.26	6.02	36.24
D* L1	2.77	8.87	9.51	1.03	38.22	3.69	34.53
D* L2	1.70	13.99	5.45	2.11	43.73	3.78	39.98
L.S.D at 5%	0.03	1.18	0.16	0.14	n.s	0.10	1.18

Where s = significant   n.s. = non-significant

Table 6. Proline (µg/g dry wt.), glycinebetaine (Mmole/g dry wt.), total phenols (mg/100g dry wt.), crude protein (g/100 g dry wt.) and soluble protein (mg/100g fr. Wt.) in *Cornulaca monacantha*.

seasons					
	Proline	**Glycine betaine**	**Total phenols**	**Crude protein**	**Soluble protein**
Wet (W)	63.5	173.6	197.7	8.23	156.09
Dry (D)	85.5	295.3	179.3	8.21	131.61
L.S.D at 5%	s	s	s	n.s	s
locations					
Rommana (L1)	51.5	247.4	195.9	8.23	126.37
Khamisa (L2)	97.5	221.5	181.2	8.21	161.57
L.S.D at 5%	s	s	s	s	s
Interaction between locations and seasons					
W* L1	44	193.7	225.1	11.49	136.64
W* L2	83	153.4	170.3	4.96	175.45
D* L1	59	301.2	166.7	9.36	116.11
D* L2	112	289.5	192.1	7.06	147.6
L.S.D at 5%	2.4	7.9	13.6	0.29	n.s

Where s = significant   n.s. = non-significant

Table 7. Sodium, potassium, calcium and magnesium (g/100g dry wt.) in *Cornulaca monacantha*.

Seasons				
	Sodium	**Potassium**	**Calcium**	**Magnesium**
Wet (W)	2.04	0.38	2.94	1.78
Dry (D)	3.04	0.45	2.20	1.68
L.S.D at 5%	s	s	s	s
Locations				
Rommana (L1)	2.58	0.54	2.78	1.76
Khamisa (L2)	2.50	0.29	2.36	1.70
L.S.D at 5%	n.s	s	s	s
Interaction between locations and seasons				
W* L1	2.70	0.57	3.02	1.74
W* L2	1.38	0.19	2.86	1.82
D* L1	2.47	0.51	2.54	1.77
D* L2	3.62	0.39	1.86	1.59
L.S.D at 5%	0.11	0.01	0.12	0.15

4. Discussion

From meteorological data, it became known that Rommana location lies on arid area affected by Mediterranean weather, while Khamisa location lies on hyper-arid area (the Western Desert). Soils supporting *C. monacantha* are non-saline usually lower than 1Mmhos except at the first depth (0-30 cm) of Rommana, slightly higher than 1 Mmhos in dry season. The higher moisture content in Rommana soil due to the high precipitation and lower evapotranspiration compared with that in Khamisa especially in wet season. These climatic conditions reflected on degree of succulence to increase in *C. monacantha* growing at Rommana. A decline in succulence degree was recorded in dry season. However, *C. monacantha* growing at Khamisa showed a non-significant decrease. Gorai *et al.* (2015) noticed the decrease in relative water content in *Ephedra alata* by 17% and 30% compared with control plants after 7 days and 14 days of the drought stress treatment respectively. The decrease in chlorophyll a and b in dry season agreed with the studies of (Morsy *et al.*, 2008; Mafakheri *et al.*, 2010; Din *et al.*, 2011). The production of reactive oxygen species under drought conditions can disturb the chlorophyll biosynthesis (Herbinger *et al.*, 2002). Drought stress stimulates inhibition of photosynthetic activity in plant tissues due to imbalance between light capture and its utilization (Foyer and Noctor, 2000). Liu *et al.* (2011) found that drought stress significantly decreased chl. a+b in *Cinnamomum bodinieri*, *Broussonetia papayrifera* and *Platycarya longipes* and also decreased carotenoids in *Platycarya longipes* and Pteroceltis tatarinowii. Sai *et al.* (2012) reported that water deficit decreased the contents of carotenoids and anthocyanin in *Atriplex hortensis*. The accumulation of total carbohydrate and non-soluble carbohydrate in dry season agreed with Nour El-Din and Ahmed (2004). They found that carbohydrate content in *Crotalaria aegyptiaca* tend to decrease in the rainy season and to increase at the end of the dry season. Abd El-Maboud (2006) concluded that *Deverra tortuosa* as a xerophyte plant depends to large extent on the accumulation of organic intermediates; particularly carbohydrate in building osmotic potential. Soluble carbohydrate responded negatively by drought in *C. monacantha*. Similar results were obtained by Morsy *et al.* (2008). On the other hand, many authors found the reverse trend (Choluj *et al.*, 2008; Liu *et al.*, 2011; Mafakheri *et al.*, 2011).

Proline accumulation in *C. monacantha* in response to drought and temperature stresses is a good indicator of drought tolerance mechanism. Many researchers suggest a positive correlation between proline accumulation and drought stress in plants (Liu *et al.*, 2011; Hayat *et al.*, 2012; Cha-um *et al.*, 2013; Gorai *et al.*, 2015). In this respect, Anjum *et al.* (2012) reported that progressive stress reduced the relative water content but increased proline concentration in the two maize cultivars; dog dan-60 and nong da-95. Proline act as an osmolyte, a reactive oxygen species scavenger and a molecular chaperone stabilizes proteins structure (Szabados and Savoure 2010). Like proline, glycinebetaine accumulated in response to drought stress. Similar results were obtained by Sankar *et al.* (2007). Glycinebetaine and proline are two major organic osmolytes that accumulate in a variety of plant species in response to environmental stresses including drought. Both compounds are thought to have positive effects on enzyme and membrane integrity along with adaptive roles in mediating osmotic adjustment in plant grown under stress conditions (Ashraf and Foolad, 2007). Hoque *et al.* (2008) reported that betaine reduce oxidative damage in tobacco suspension cells by enhancing reactive oxygen species detoxification system. It has been reported that glycinebetaine in *Salsola tetrandra* is more effective as a defense against free radicals under drought than salinity stress (Abd El-Maboud and Eisa, 2016). Cha-um *et al.* (2013) concluded that exogenous application of glycinebetaine significantly alleviates water-deficit in indica rice and maintain grain yield. Total phenols are affected negatively by drought stress. It was lower in *C. monacantha* growing at Khamisa which is subjecting to more drought conditions than that growing in Rommana. A decrease of total phenols in dry season agreed with Król *et al.* (2014) who found that total phenolics were decreased in leaves and roots of grapevine when subjected to drought stress.

An increase in crude protein of *C. monacantha* inhabiting Khamisa and a decrease in that inhabiting Rommana in dry season neglected seasons effect. Regarding locations effect, *C. monacantha* inhabiting Khamisa decreased significantly in crude protein by 42% compared to that in Rommana. That decrease may be return to the reduction in soil moisture content supporting the plant at Khamisa location. Davies (1987) interpreted the decrease of protein under drought stress to might be the result of increased protease activity or due to fragmentation of proteins resulted from reactive oxygen species effect. The decrease of soluble protein in dry season agreed with those in Mafakheri *et al.* (2011).

It is noteworthy that Na^+ and K^+ contents of the plant increased in dry season by 1.5 and 1.2 fold. That increase may contribute to decrease the osmotic potential in plant cell in response to drought stress and help in water uptake along a soil-plant gradient. In spite of growing at poor sand dunes, non-saline soil, *C. monacantha* was able to take up large quantities of Na^+ from soil and accumulate it in aboveground tissue. In addition to the reduction in K^+ accumulation in the plant indicates that K^+ can be substituted by Na^+ as cation exchange of monovalent ions. It has been reported that Na^+ could substituted for K^+ in some cellular functions especially in a terrestrial life under limited K^+ supply, but in others it is toxic. In the vacuole, Na^+ is not toxic and can do osmotic functions, reducing the total K^+ requirements and improving growth when K^+ is a limiting factor (Navarro and Rubio, 2006). Epstein *et al.* (1973) concluded that Na^+ competes with K^+ for uptake by plant roots, supporting that K^+ transporters are also the gates for Na^+ entry. Na^+ ions inter root cells through HKT proteins and non-selective voltage-independent cation channels, some of which (labeled CNGC) are inactivated by cyclic neucleotides (cAMP and cGMP) Pardo and Quintero (2002). Potassium is not only an essential nutrient for plant growth and development, but also contributes to the survival of plants exposed to various biotic and abiotic stresses (Wang *et al.,* 2013). The decrease of Ca^{++} and Mg^{++} levels of *C. monacantha* in dry season could be attributed to the competition between them and monovalent cations in the soil such as Na^+ which reduce Ca^{++} and Mg^{++} intake by the plant. It has been reported that Mg^{++} and Ca^{++} availability increased steadily throughout the wet season, and then decreased rapidly in dry season for three constitutive years on Barro Clorado Island (Mulkey e*t al.,* 1996). In this trend, Abd El-Maboud (2006) found that Mg^{++} ions were higher in winter than summer in *Panicum turgidum* and *Deverra tortuosa*.

5. Conclusion

Cornulaca monacantha is an example of drought tolerant plants, can grow in arid and hyper arid zones. The plant was able to overcome drought stress by the accumulation of total carbohydrate, an organic osmolytes like proline and glycinebetaine. In addition to the accumulation of Na^+ as inorganic osmolyte, that may displace K^+ in some metabolic processes.

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الملخص العربى

أليات تحمل الجفاف فى نبات الحاد

محمد محمد عبد المعبود

قسم البيئة النباتية والمراعى – مركز بحوث الصحراء

تم تجميع عينات من المجموع الخضرى لنبات الحاد من موقعين للتكوينات الرملية: رمانة بشمال سيناء وخميسة بواحة سيوة بمصر. تم تقدير درجة العصارية ، كلوروفيل أ، كلوروفيل ب ، الكاروتينويد ,الكربوهيدرات الكلية ، الكربوهيدرات الذائبة والغير ذائبة, البـروتين الخام ,البـروتين الكلى الذائب ,البـرولين ,الجلايسـين بيتاين ,الـفيـنـولات الكليـة ,الصوديوم ,البـوتـاسـيـوم ,الكـالـسـيـوم والماغنسيوم. أظهرت النتائج انخفاض كل من درجة العصارية ، كلوروفيل أ، كلوروفيل ب، الكاروتينويد ، السكريات الذائبة ,البروتين الذائب ,الفينولات الكلية ,الكالسيوم والماغنسيوم فى موسم الجفاف وعلى الجانب الأخر ازداد كل من الكربوهيدرا ت الكلية والغير ذائبة ، البرولين، الجلايسين بيتاين ,الصوديوم والبوتاسيوم فى موسم الجفاف.

تفوق نبات الحاد النامى بمنطقة رمانة على نظيره بمنطقة خميسة فى كل من درجة العصارية ,كلوروفيل ب ، الجلايسين بيتاين, الفينولات الكلية ,البروتين الذائب ، الكالسيوم والماغنسيوم بينما حدث العكس فى باقى الصفات فيما عدا الصوديوم حيث كان الاختلاف بين الموقعين غير معنوى.

Mechanisms of Drought Tolerance in *Cornulaca monacantha* Del.

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Reprint