Original Research Article

Effect of different habitats conditions on *Citrullus colocynthis* (L.) Schrad. growing naturally in Egypt and Kingdom of Saudi Arabia

Abstract

Harsh environmental conditions are major factors limiting plants production and development, including *Citrullus colocynthis* L. (*C. colocynthis*). The present investigation provides an analysis of soil properties and plant compounds of *C. colocynthis* in Wadi Hebran, Saint Katherine, South Sinai, Egypt and Wadi Al-Akhder, Tabuk Province, KSA at dry and wet seasons, and focuses on the relationship between the environmental factors and phytochemical compounds using principal component analysis (PCA). According to ANOVA, the experimental factors (locations, depths, seasons and their interactions significantly influenced the physico-chemical properties of soil and chemicals present in *C. colocynthis* ($P < 0.05$ or 0.01). Wadi Hebran at both seasons significantly promoted most mechanical and chemical properties in soil and most chemical compositions in *C. colocynthis* compared with Wadi Al-Akhder. While the significantly positive highest impact on photosynthetic pigments contents was found in Wadi Al-Akhder at both seasons. The dry season in the two locations significantly increased the total carotenoids, Chl.a/b, total pigment, P %, total carbohydrate, proline, catalase enzyme, peroxidase enzyme, ascorbic acid and malondiadehyde compared to the wet season. Based on PCA analysis, the first two PCs explain more than 84% of the total variance in the original variables and mainly distinguished the soil and plant variables in different groups during each location or between the two locations at both seasons. The first PC showed the highest positive correlation with some soil variables (EC, K^+, and Cl^-) and plant variables (P, total carbohydrate, proline, catalase enzyme, peroxidase enzyme and malondiadehyde). While the second PC exhibited a highly positively correlated with Ca^{2+}, S^- and water content in soil and with Chl.b, K^+, Ca^{2+}, N, water content, crude protein, crude fiber, total ash and superoxide enzyme in *C. colocynthis* plants. Positive correlations among most soil and plant variables were found, but they differed in their degree and consistency in quantity. PCA application indicated that the above soil variables are related closely to the above plant variables of *C. colocynthis* in the two locations. The results of PCA could be useful and used as a suitable method for studying the stresses tolerance mechanisms of plants under hard environmental conditions.

Key words: *Handal, soil properties, phytochemical compounds, PCA.*

1. Introduction

Climate changes could play a major role in modifying species distribution in desert areas controlling environmental heterogeneity and disturbances effects on plant species diversity [1]. Ackerly et al. [2] stated that ecophysiological studies have been powerful in elucidating plant function and identifying traits that are adaptive in specific environmental conditions. Drought stress is a major factor limiting plant growth, production and development, thus, water is essential for plant growth. High drought stresses led to decreased photosynthesis, disrupted physiological processes and reduced plant biomass, at last, expected plant death [3,4]. Drought stress tolerance is a complex trait, due to interaction among several factors [5]. To adapt and thrive to drought stress, plant species have developed various strategies to deal with extreme changes in the environment in all kinds of climates and terrains [6]. Aldamegh et al. [7] mentioned that dry weather conditions may activate the production of secondary phytochemical compounds with high concentrations. Also, Pradhan et al. [8] and Salama et al. [9] added that stress conditions induce the accumulation of numerous reactive oxygen species and osmolytes such as proline, soluble proteins, soluble sugars, and betaine, which will play a critical role during stress acclimatization in plants. Maybe, these compounds made these plants more capable of resistance to salinity and drought stresses [10]. In desert plants, drought tolerance is due to the plant's ability to preserve turgidity and water absorption [11]. Also, it is achieved by morphological, physiological and molecular changes in plants [12,13].

The Sinai Peninsula is an arid to the extremely arid region and has a varied heritage of plant diversity, which is about 1285 species [14]. Because of the high rainfall, South Sinai is one of the three richest places in Egypt in terms of biodiversity, in addition to, the Mediterranean coast and Jebel Elba in the far southwest of the country [15]. In South Sinai, the flora consists of about 472 species; of which 19 species are Egyptian endemic species and 115 are of medicinal interest and about 170 are used in folk medicine [16]. Saint Katherine Protectorate is one of the most floristically varied spots in the Middle East [17], with 410 species have been reported by Shaltout et al. [18].

The Kingdom of Saudi Arabia (KSA) is an arid region and it has a varied heritage of plant diversity [19]. KSA contains 2290 plant species belonging to 855 genera in 131 families, of which 9 species are Gymnosperms and 27 are Pteridophytes, with about 200 regional endemics [20]. Some of these plants are showing important genetic resources of medicinal [21]. According to the theory of biogeography, KSA flora has strong ties with those of North Africa, East Africa and Mediterranean countries [22]. The climate of Tabuk is considered an arid region [23] and it had remarkable floristic diversity [24]. Moawed and Ansari [25] released a checklist on Tabuk area flora that includes 82 wild plant species belonging to 66 genera and 30 families. Alghanem et al. [26] identified plant species of Al-Wadi Al-akhder from Tabuk region, which registered 30 species belonging to 23 genera and 15 families.

The Cucurbitaceae family is considered as one of the families that possess economically important species that are used as food or fodder [27]. This family comprises about 110 genera and 560-850 species of plants [28]. *Citrullus colocynthis* (L.) Schrad (*C. colocynthis*) belongs to the Cucurbitaceae family, it is an uncultivated and annual useful plant that commonly grows in the desert regions of the world (as Egypt and Saudi Arabia), possess great tolerance to salinity and drought stresses as well as desert extreme conditions [29,30]. Wang et al. [6] reported that *C. colocynthis* can survive in arid environments by maintaining its water content at sharp stress conditions. Previous studies on *C. colocynthis* reported many medicinal benefits against different ailments including decrease blood sugar and against breast cancer [31], diabetes type II [32], anti-inflammatory and anti-bacterial activities [33] and against colorectal cancer cell lines [29]. In addition to its important medicinal applications a source of valuable oil [34], seeds oil can be used as low-cost biodiesel [35], natural insecticide [36], and a viable source of genes for promoting pest and disease resistance for the commonly cultivated watermelon cultivars [37].

Soil pH also affects the physical, chemical and biological properties of the soil as well as plant growth [38]. Since soil and plant are interrelated, the soil organic matter content and nature and type of vegetation influence the physical, chemical, and biological properties of soil [39,40]. The influence of soil variables on the plant species had been studied by several workers/studies, such as Al-Ghamdi [10], Al-Mutairi [19], Salama et al. [41] in *C. colocynthis* plants and El-Ghani and Amer [42] in other plant species.

Several authors indicated a positive correlation between proline accumulation and drought stress in plants. Proline plays three major roles during stress, i.e., as a metal chelator, an antioxidative defense molecule and a signaling molecule [43]. The plants produce a huge number of metabolites to adapt to the stress conditions as chlorophylls and carotenoids [44,45]. Some studies have investigated metabolites in *C. colocynthis*, the results suggest that osmotic adjustment was the main water relationship adaptation to cope with drought stress [6,11,41]. El-Absy [45] explained that most of the chemical compounds in the plant were significantly affected by seasonal changes. This may reflect seasonal changes in physiological needs and effort, rather than availability in plant content [46].

The principal component analysis (PCA) is one of the Multivariate statistical techniques tools that can be used to study the relationship between the environmental parameters and plant variables. Many researchers have used the PCA to assess the relationship and diversity between measured soil properties and vegetation [42,45,47-52].

The present study aims to identify the responses of the *C. colocynthis* growing in the arid desert regions in different environments (Egypt and KSA) and to show its adaptive mechanism to drought tolerance through: a) calculating soil physico-chemical properties associated with plants, b) measuring morphological, anatomical and physiological parameters in the plants and (c) estimating the relation between the environmental factors and phytochemical compounds using PCA, to understand its adaptive behavior and the possibility of osmotic adjustment adopted by these plants to tolerate of harsh environmental conditions during the wet and dry seasons.

2. Materials and methods

2.1. Study area

The present study was carried out along two sites: Wadi Hebran, Saint Katherine, South Sinai, Egypt and Wadi Al-Akhder, Tabuk Province, Saudi Arabia. The two sites were visited from August 2019 (dry) to January 2020 (wet). Wadi Al-Akhdar is the most important regional wadis in Tabuk region, and is situated about 120km from the Tabuk and does not directly cross Tabuk city. It lies located southeast of Tabuk at the intersection of 28° 1' 4'' N and 36° 39' 19'' E. This site is created from Ghawanim Mountains in the east and is 68 km long and connected to Wadi Mishash Bani Atiyah and Tuus Al Arqanah in the upland. This site is characterized by a hot deserts climate, also has unique plant species communities due to its location in North part of KSA [26,53]. Wadi Hebran is part of the route from El Tur on the Gulf of Suez to Mount Sinai, and runs parallel to but north of Wadi Isla, and which opens onto the Plain of El Qa'a. This site lies at the intersection of 28°25′35.9″ N and 33°35′20.9″ E [54,55].

The Meteorological data of temperature, relative humidity and rainfall were provided by the Applied Agricultural Meteorological Laboratory of the Desert Research Center, Egypt (Table 1). The grand mean of average temperature, relative humidity and rainfall in Wadi Hebran were higher than in Wadi Al-Akhder. The highest temperatures occur in August at both locations. The highest percentage of relative humidity were registered in May and January across Wadi Hebran and Wadi Al-Akhder, respectively. In the two locations, the rainfall rates were increased in December and January compared with other months.

Table 1. Monthly average temperature (°C), relative humidity (%) and rainfall (mm) at each location in both seasons.

	Wadi Hebran			Wadi Al-Akhder		
Months	Average temperature (°C)	Relative humidity (%)	Rainfall (mm)	Average temperature (°C)	Relative humidity (%)	Rainfall (mm)
Jan	14.7	59	3.4	12	48	3.7
Feb	15.2	58	2.3	13	37	2.8
Mar	17.8	63	2.2	16	28	0.6
Apr	25.7	69	0.2	23	21	0.8
May	29.1	70	0.2	28	18	1.8
Jun	26.7	69	0.0	31	17	0.0
Jul	28.8	64	0.0	31	19	0.0
Agu	30.3	63	0.0	33	21	0.0
Sep	29.4	65	0.0	30	23	2.2
Oct	24.5	60	1.7	26	28	0.0
Nov	21.1	59	1.9	14	41	0.0
Dec	17.4	55	3.6	15	46	2.9
Grand mean	23.39	62.83	1.29	22.67	28.92	1.23

2.2. Description of C. colocynthis **(L.) Schrad***:*

Handal (*C. colocynthis*) is a very scabrid herb with long trailing branches growing in the arid region with perennial nature (Fig. 1 and 2). It has long, fleshy and perennial rootstock. The stems are spread in all directions for some things over which to climb and rough in texture with prominent rough hairs at 3 meters in length. Leaves are deeply lobed arranged alternatively on the petioles length 5-10 cm and width 1.5-2 cm. The flowers are small yellow. Each plant produces 15 to 30 fruits very bitter, round in shape, smooth textured, fleshy mottled with dark-green, turning dry and yellow when ripe, each one contains seeds of about 200-300. Seeds small, smooth textured, brown. Reproduction by seeds and vegetative buds in rootstocks. The plants flourish in sandy loam, sub-desert soils, along sandy seacoasts, as well as when the annual temperature and annual rainfall averages range from 23°C to 27°C and from 25 cm to 37 cm, respectively [56-59].

Fig. 1. *C. colocynthis* in Wadi Al-Akhder, Tabuk Province, Saudi Arabia.

Fig. 2. *C. colocynthis* in Wadi Hebran, Saint Katherine, South Sinai, Egypt.

2.3. Soil physical and chemical properties

Soil samples were collected from the soil associated with *C. colocynthis* carefully made from three random points at the two depths 0-20 cm and 20-40 cm from the two Wadis studied. The soil samples were carried to the laboratory in closed tins to be used for soil physical and chemical analyses. Soil samples were air-dried, sieved and used for mechanical analysis of soil particles as suggested by Jackson [60] and Rowell [61] for soil texture, and they are expressed as a percentage of the original weight. The soil moisture content was calculated according to the method described by Rowell [61]. The electrical conductivity (EC) and pH value for each sample were carried out using soil-water paste, according to Jackson [62], EC was expressed as ds/m. The mineral contents of soil including sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfur (S^-) and chlorides (Cl^-; meq/L) were determined using a saturation paste described by Tuzuner [63].

2.4. Plant analysis

The samples of *C. colocynthis* were collected manually in triplicates at random from the two sites studied during the dry and wet seasons of 2019 and 2020, respectively. The samples were placed in plastic bags at the sites, then transferred immediately to the laboratory for preparation. Drying of collected plant materials was done in oven at 70°C to a constant weight after which dried samples were milled to a fine powder and stored in brown bags at room temperature pending minerals and metabolites determinations.

The concentrations of Sodium (Na^+), potassium (K^+) and calcium (Ca^{2+}), magnesium (Mg^{2+}), and phosphorus (P) were determined by atomic absorption spectrophotometry (GBC Avanta E, Victoria, Australia) [64]. Total nitrogen (N) content was determined using the micro-Kjeldahl method [65]. The photosynthetic pigments parameters were quantified spectrophotometrically, and using the wavelengths of 663, 645 and 470 nm, the chlorophyll a (Chl.a), chlorophyll b (Chl.b) and total carotenoids were calculated by equations of Lichtenthaler [66], respectively. The crude protein % was determined by multiplying the total nitrogen by 6.25 according to Allen [67]. The plant water content was obtained following the equation described by Jin et al. [68]. The proline and the total available carbohydrate contents were determined according to the methods of Bates et al. [69] and Chaplin and Kennedy [70], respectively. Total ash and crude fiber were determined by AOAC [71] methods. Soluble proteins were extracted according to Beauchamp and Fridovich [72] and used in the assay of catalase (CAT; EC 1.11.1.6), peroxidase (POX; EC 1.11.1.7) and superoxide dismutase (SOD; 1.15.1.1) according to Kato and Shimizu [73]. Enzyme activities were expressed in μM of the substrate converted $min.^{-1}$ g^{-1} fresh weight. Ascorbic acid concentration was determined according to Rai [74] and expressed in mg $100ml^{-1}$. Malondialdehyde (MDA); a peroxidation product of the unsaturated fatty acid linolenic acid, 18:3) was estimated as μM g^{-1} fresh weight using the method of Heath and Packer [75].

2.5. Statistical analysis:

The normality of data distribution was verified using the Komolgorov-Smirnov test. Then, the measured data were subjected to a two and three-way ANOVA test and the coefficient of variation (CV%) to determine the significant differences ($p \leq 0.05$ and $p \leq 0.01$) of the effect of experimental factors and their interactions according to the method of Steel & Torrie [76]. The obtained data were expressed as mean ± standard error (SE) and multiple comparisons were determined using the least significant difference test (L.S.D) at 0.05 level of probability [76]. Principal component analysis (PCA) was applied for a better understanding of the relationship among traits studied across experimental factors. The ANOVA and PCA were performed using the computer software programs SPSS version 20, PAST version 4.03 and OriginPro 2018 b9.5.0.193.

3. Results

3.1. Soil analysis

Table 2 outlines the detailed results of two-way ANOVA for the effects of locations (L), depths (D) and their interaction (LD) on mechanical properties % of the adjoining soil samples of *C. colocynthis*. All mechanical properties % in *C. colocynthis* soil were significantly affected ($P < 0.05$ or 0.01) by L, D and interaction LD, except D on very fine sand. Significant differences between the two depths in the two wadis were found for mechanical properties % at *C. colocynthis* soil. The highest percentage of coarse sand was found in the soil associated soil of *C. colocynthis* in 0 - 20 depth at KSA location, followed by fine and medium sands, compared with 20 - 40 depth at Egypt location. Compared with other interactions LD, the maximum fine sand % and coarse sand % were registered by interactions Wadi Hebran x 20 - 40 depth and Wadi Al-Akhder x 0 - 20 depth, respectively.

Table 2. Effect of the locations, depths and their interaction on mechanical properties % of the adjoining soil samples of *C. colocynthis*.

Factors	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Clay and Silt	Soil Texture Class
			Locations				
WH	9.02±0.40b	6.41±0.52b	23.54±0.71a	29.16±0.52a	22.51±0.37a	9.36±0.38a	Sandy
WAA	51.82±0.62a	25.11±0.35a	16.36±0.84b	2.37±0.40b	3.08±0.31b	1.26±0.21b	Sandy
P–Values	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	
			Depths				
0 – 20 (D1)	31.29±3.69a	16.39±4.11a	18.40±1.73b	15.06±5.95b	12.78±4.29a	6.08±1.88a	Sandy
20 – 40 (D2)	29.54±3.45b	15.13±4.28b	21.50±1.55a	16.47±6.05a	12.81±4.42a	4.55±1.59b	Sandy
P–Values	0.00**	0.00**	0.00**	0.00**	0.81ns	0.00**	
			Locations x Depths				
WH x D1	9.64±0.48c	7.24±0.62c	22.19±0.65b	28.34±0.38b	22.34±0.52a	10.25±0.39a	Sandy
WH x D2	8.39±0.31d	5.58±0.46d	24.89±0.47a	29.98±0.46a	22.68±0.67a	8.48±0.42b	Sandy
WAA x D1	52.94±0.54a	25.54±0.39a	14.61±0.35d	1.78±0.64d	3.22±0.44b	1.91±0.31c	Sandy
WAA x D2	49.69±0.67b	24.68±0.33b	18.11±0.40c	2.95±0.29c	2.95±0.37b	1.62±0.34d	Sandy
P–Values	0.04*	0.05*	0.01*	0.09*	0.06*	0.00**	
C.V.%	1.09	1.83	0.98	1.92	1.80	0.75	

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test

The results of three-way ANOVA revealed a significant effect (P < 0.05 or 0.01) of the locations, depths, seasons as well as their first and second-order interactions on the water content % in *C. colocynthis* soil (Fig. 3). Significantly, the water content increased with Wadi Al-Akhder soil and decreased with Wadi Hebran soil. Also, the water content in soil is significantly increased in 20 - 40 depth compared to 0 - 20 depth. Naturally, it is significantly increased with the wet season than with the dry season. The interaction of 20-40 depth in Wadi Hebran during the wet season recorded a significantly higher water content % compared with the other interaction among factors studied. In contrast, when comparing all interactions, minimum water content % were found in 0-20 depth at the Wadi Hebran during the dry season.

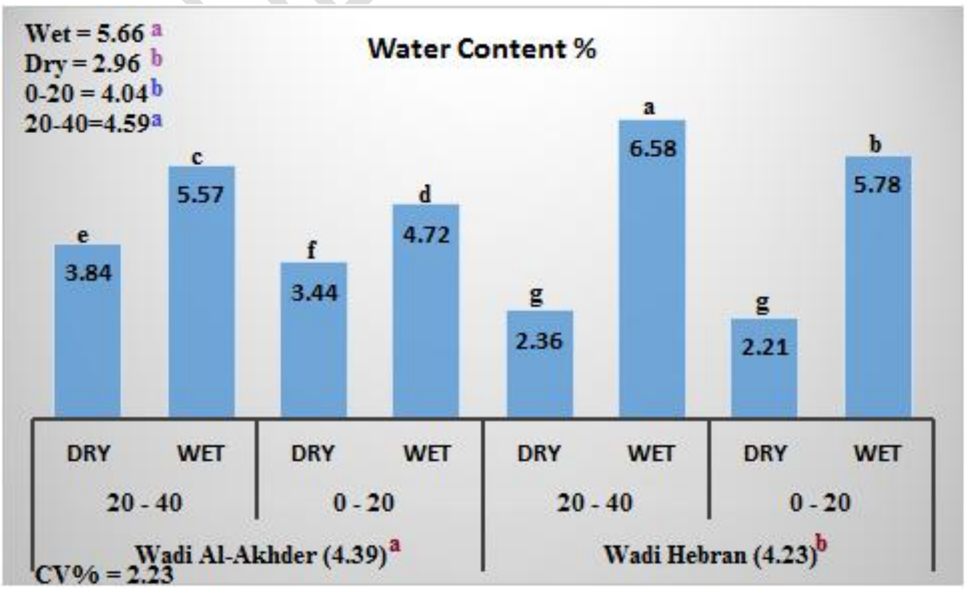

Fig.3. Water content % at the soil associated with *C. colocynthis* in the two depths and the two seasons during Wadi Hebran; WAA: Wadi Al-Akhder. Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test

The ANOVA generally showed a significant effect (P < 0.05 or 0.01) of L, D and interaction LD on all chemical properties in *C. colocynthis* soil (Table 3). The two wadis and depths differently influenced the chemical properties in soil of *C. colocynthis*. In the Wadi Hebran, a significantly higher Ec, Na^+, K^+, Ca^{2+}, S^- and Cl^- were noticed with respect to the Wadi Al-Akhder. As for the two depths, Ec, Na^+, K^+, Mg^{2+} and Cl^- contents were higher in 20 - 40 than in 0 - 20. The highest Ec, Na^+, K^+ and Cl^- in the Wadi Hebran x 20-40 interaction, the highest Ca^{2+} and S^- in the Wadi Hebran x 0-20 interaction and the highest pH and Mg^{2+} in the Wadi Al-Akhder x 20-40 interaction were observed.

Table 3. Effect of the locations, depths and their interaction on soil chemical properties of the adjoining soil samples of *C. colocynthis*.

Factors	Ec (ds/m)	pH	Na^+ (meq/L)	K^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	S^- (meq/L)	Cl^- (meq/L)
Locations								
WH	2.91±0.11a	6.88±0.04b	7.75±1.26a	2.10±0.07a	8.43±0.85a	87.72±1.86b	2.36±0.65a	14.61±1.00a
WAA	1.53±0.22b	7.45±0.01a	6.27±1.23b	0.74±0.14b	5.20±0.20b	89.73±2.18a	1.46±0.22b	8.71±0.12b
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
Depths								
0 – 20 (D1)	1.87±0.38b	7.21±0.10a	4.19±0.33b	1.19±0.34b	7.54±1.24a	88.36±1.57b	2.38±0.64a	10.67±0.76b
20 – 40 (D2)	2.56±0.24a	7.12±0.15b	9.83±0.34a	1.64±0.27a	6.09±0.20b	89.09±2.47a	1.43±0.24b	12.65±1.88a
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
Locations x Depths								
WH x D1	2.71±0.14b	6.98±0.04b	4.94±0.09c	1.96±0.02b	10.32±0.17a	91.88±0.52b	3.81±0.09a	12.36±0.15b
WH x D2	3.11±0.12a	6.78±0.03c	10.57±0.18a	2.24±0.04a	6.53±0.19b	83.57±0.67d	0.91±0.10c	16.85±0.19a
WAA x D1	1.03±0.10d	7.45±0.02a	3.45±0.04d	0.43±0.02d	4.76±0.23d	84.85±0.49c	0.96±0.08c	8.97±0.09c
WAA x D2	2.02±0.11c	7.46±0.01a	9.09±0.02b	1.04±0.03c	5.64±0.10c	94.60±0.62a	1.96±0.11b	8.45±0.11d
P–Values	0.01^{*}	0.00^{**}	0.09^{*}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
C.V.%	5.52	0.26	2.21	3.54	0.57	2.64	2.36	0.62

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test.

3.2. Plant analysis

The effects of locations (L), seasons (S) and their interaction (LS) on all photosynthetic pigments contents in *C. colocynthis* were significant (P < 0.05 or 0.01) (Table 4). The photosynthetic pigments contents of *C. colocynthis* growing in Wadi Al-Akhder were significantly greater than that of Wadi Hebran. A significant increase of Chl.a, Chl.b and Chl.a+b contents were observed in the wet season compared to the dry season. While, in the dry season a significant increase of the total carotenoids, Chl.a/b (more than 1) and total pigment contents were noticed than in the wet season. Relative to the effect of interaction LS, Wadi Al-Akhder in both seasons displayed significantly higher photosynthetic pigments contents compared with Wadi Hebran in both seasons.

Table 4. Effect of the locations, seasons and their interaction on photosynthetic pigments contents (g/100g fr. wt.) of *C. colocynthis*.

Factors	Chlorophyll a (Chl.a)	Chlorophyll b (Chl.b)	Total Carotenoids	Chl.a+b	Chl.a/b	Total Pigment

			Locations			
WH	5.57±0.28b	4.73±0.81b	389.81±2.93b	10.30±1.07b	1.32±0.17b	400.10±3.90b
WAA	8.47±0.46a	5.31±0.82a	472.96±9.31a	13.78±1.28a	1.74±0.19a	486.74±8.05a
P–Values	0.00^{**}	0.02^{*}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
			Seasons			
Wet	7.84±0.74a	6.82±0.19a	423.87±12.67b	14.66±0.89a	1.14±0.09b	438.52±13.55b
Dry	6.21±0.56b	3.22±0.15b	438.90±24.57a	9.43±0.69b	1.92±0.12a	448.32±25.26a
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
			Locations x Seasons			
WH x Wet	6.19±0.10c	6.50±0.29a	395.57±0.90c	12.69±0.19b	0.96±0.06d	408.26±0.72c
WH x Dry	4.96±0.09d	2.95±0.12b	384.04±2.99d	7.90±0.12d	1.69±0.10b	391.94±3.02d
WAA x Wet	9.49±0.08a	7.13±0.07a	452.16±0.94b	16.62±0.15a	1.33±0.03c	468.78±1.08b
WAA x Dry	7.46±0.11b	3.49±0.16b	493.76±0.41a	10.95±0.27c	2.15±0.07a	504.70±0.18a
P–Values	0.01^{*}	0.03^{*}	0.00^{**}	0.08^{*}	0.07^{*}	0.00^{**}
C.V.%	2.30	6.41	1.65	3.01	8.15	0.63

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test.

In Table 5, the statistical evaluation exhibited a significant effect (P < 0.05 or 0.01) of L, S and interaction LS on all mineral compositions of *C. colocynthis*, except Na^+ was not significantly affected by the seasons. The contents of Na^+, K^+, Ca^{2+}, N and P showed a significant increase in Wadi Hebran than in Wadi Al-Akhder. Moreover, Na^+, K^+, Ca^{2+}, Mg^{2+} and N contents displayed a significant increase in the wet season compared to the other season. The highest values were registered for K^+, Ca^{2+} and N contents in the interaction Wadi Hebran x Wet, for Na^+ and P in the interaction Wadi Hebran x Dry and for Mg^{2+} in the interaction Wadi Al-Akhder x Wet.

Table 5. Effect of the locations, seasons and their interaction on mineral compositions of *C. colocynthis*.

Factors	Na^+ %	K^+ %	Ca^{2+} %	Mg^{2+} %	N %	P %
			Locations			
WH	1.10±0.06a	2.03±0.07a	1.96±0.25a	1.56±0.15b	1.21±0.11a	0.70±0.08a
WAA	0.78±0.07b	1.47±0.25b	1.89±0.17b	2.05±0.07a	0.75±0.09b	0.33±0.05b
P–Values	0.00^{**}	0.00^{**}	0.04^{*}	0.00^{**}	0.00^{**}	0.00^{**}
			Seasons			
Wet	0.95±0.01a	2.10±0.05a	2.39±0.05a	2.03±0.08a	1.20±0.12a	0.37±0.07b
Dry	0.93±0.13a	1.40±0.22b	1.46±0.03b	1.58±0.16b	0.77±0.10b	0.65±0.10a
P–Values	0.39^{ns}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
			Locations x Seasons			
WH x Wet	0.97±0.03b	2.18±0.08a	2.50±0.04a	1.89±0.05b	1.45±0.06a	0.52±0.08b
WH x Dry	1.23±0.02a	1.89±0.12b	1.41±0.03d	1.23±0.03c	0.98±0.04b	0.87±0.10a
WAA x Wet	0.92±0.05c	2.02±0.10b	2.27±0.05b	2.17±0.06a	0.94±0.03b	0.22±0.04d
WAA x Dry	0.63±0.04d	0.91±0.09c	1.50±0.02c	1.93±0.01b	0.56±0.05c	0.44±0.06c
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.09^{*}	0.00^{**}
C.V.%	2.61	4.33	2.27	4.23	3.87	0.95

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test.

The statistical evaluation showed highly significant effects (P < 0.05 or 0.01) of L, S and interaction LS on water content, crude protein, crude fiber, total ash, total carbohydrate and proline contents of *C. colocynthis* (Table 6). Significant higher these chemical compositions of *C. colocynthis* were observed in Wadi Hebran than in Wadi Al-Akhder. Moreover, water content, crude protein, crude fiber and total ash contents were significantly higher during the wet season compared to the dry season. While, total carbohydrate and proline contents were significantly higher in the dry season than in the wet season. Regarding the effect of interaction LS and according to statistical significance, the highest water content, crude protein, crude fiber and total ash contents, as well as total carbohydrate and proline contents, were identified in the interactions of Wadi Hebran with the wet and dry seasons, respectively.

Table 6. Effect of the locations, seasons and their interaction on some chemical compositions of *C. colocynthis*.

Factors	Water Content %	Crude Protein	Crude Fiber	Total Ash	Total Carbohydrate	Proline
			Locations			
WH	59.70±3.25a	7.67±0.63a	32.46±2.90a	23.17±0.88a	41.52±0.40a	13.22±0.99a
WAA	51.12±2.68b	4.70±0.52b	23.41±0.39b	19.83±0.48b	35.90±1.33b	6.90±1.06b
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
			Seasons			
Wet	63.15±2.71a	7.46±0.72a	30.96±3.56a	22.91±0.99a	37.07±1.83b	7.81±1.48b
Dry	47.68±1.15b	4.90±0.62b	24.91±0.65b	20.08±0.59b	40.35±0.81a	12.31±1.37a
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
			Locations x Seasons			
WH x Wet	69.19±0.23a	9.07±0.07a	38.83±1.17a	25.07±0.39a	41.10±0.49b	11.08±0.50b
WH x Dry	50.21±0.39c	6.27±0.19b	26.10±0.54b	21.26±0.32b	41.95±0.61a	15.37±0.31a
WAA x Wet	57.10±0.28b	5.86±0.09c	23.09±0.52c	20.76±0.29b	33.04±0.53d	4.54±0.09d
WAA x Dry	45.15±0.33d	3.53±0.03d	23.72±0.64bc	18.90±0.47c	38.76±0.62c	9.26±0.16c
P–Values	0.00^{**}	0.04^{*}	0.00^{**}	0.01^{*}	0.00^{**}	0.06^{*}
C.V.%	2.31	2.58	4.78	2.12	2.47	5.24

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \le 0.05$ and $**p \le 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \le 0.05$ according to the LSD test.

As can be observed in Table 7, L, S and interaction LS exhibited statistically significant effects ($P < 0.05$ or 0.01) on some antioxidant enzymes, ascorbic acid and malondiadehyde contents of *C. colocynthis*. The contents of catalase enzyme, peroxidase enzyme, superoxide enzyme, ascorbic acid and malondiadehyde have increased significantly during Wadi Hebran compared with their values in Wadi Al-Akhder. As for the seasons, catalase enzyme, peroxidase enzyme, ascorbic acid and malondiadehyde contents were significantly higher in the dry season than in the wet season. As for interaction LS, these contents in *C. colocynthis* were increased significantly in Wadi Hebran in both seasons.

Table 7. Effect of the locations, seasons and their interaction on some antioxidant enzymes (µM/g fr. wt. $mint.^{-1}$), ascorbic acid (mg/100 ml.) and malondiadehyde (MDA) contents (µM/g fr.wt min^{-1}) of *C. colocynthis*.

Factors	Catalase enzyme	Peroxidase enzyme	Superoxide enzyme	Ascorbic Acid	MDA
			Locations		
WH	1.97±0..36a	4.02±0.37a	1.37±0.17a	1.63±0.16a	2.55±0.16a
WAA	0.76±0.18b	1.75±0.22b	0.93±0.09b	1.57±0.20b	2.04±0.20b
P–Values	0.00^{**}	0.00^{**}	0.00^{**}	0.06^{*}	0.00^{**}
			Seasons		
Wet	0.77±0.19b	2.22±0.43b	1.31±0.20a	1.55±0.20b	1.89±0.13b
Dry	1.96±0.37a	3.54±0.58a	1.00±0.06b	1.65±0.17a	2.71±0.10a

P–Values	0.00**	0.00**	0.00**	0.02*	0.00**
Locations x Seasons					
WH x Wet	1.17±0.04b	3.18±0.06b	1.75±0.03a	1.99±0.01a	2.19±0.06c
WH x Dry	2.77±0.05a	4.85±0.08a	1.00±0.05b	1.28±0.02b	2.92±0.02a
WAA x Wet	0.37±0.03c	1.26±0.04d	0.86±0.03c	1.11±0.06c	1.59±0.04d
WAA x Dry	1.15±0.04b	2.24±0.05c	1.00±0.06b	2.02±0.03a	2.49±0.03b
P–Values	0.00**	0.00**	0.00**	0.00**	0.00**
C.V.%	3.91	1.08	2.70	3.19	0.58

WH: Wadi Hebran; WAA: Wadi Al-Akhder; Statistically significant differences at $*p \leq 0.05$ and $**p \leq 0.01$; ns: indicate the non-significant difference. Different lowercase letters in the same column indicate statistically significant differences at $p \leq 0.05$ according to the LSD test.

3.3. Principal component analysis (PC):

The principal component analysis (PC) was used for an evident understanding of relationships between soil and plant variables in each site and between sites under this study. Out of all PCs, the two first main PCs (PC1 and PC2) were kept for the final analysis, in which, it has eigenvalues greater than one. The similarities and dissimilarities relationships between the soil and plant variables in each site are graphically displayed in a biplot of PC1 and PC2 (Fig. 4). The PC1 and PC2 contributed 96.87% and 95.01% of the total variation existing among soil and plant variables regarding Wadi Hebran and Wadi Al-Akhder sites, respectively. The PC1 only describes 93.21% and 88.70% of the measured data total variability under each Wadi Hebran and Wadi Al-Akhder sites in both seasons, respectively. Mg^{2+} soil and plant variables i.e., carotien, total pigment, total carbohydrate and water content of *C. colocynthis* contributed to the PC1under each Wadi Hebran and Wadi Al-Akhder in both seasons. Thus, Mg^{2+} in soil had positively correlated with carotien, total pigment, total carbohydrate and water content in *C. colocynthis*. While the PC2 has lower positive correlations with Ca^{2+}, Mg^{2+} and S^{-} in Wadi Hebran and all soil variables except Cl^{-} in Wadi Al-Akhder site as well as most plant variables of *C. colocynthis* in the two sites. The soil and plant variables inside each site were positively or negatively associated with each other.

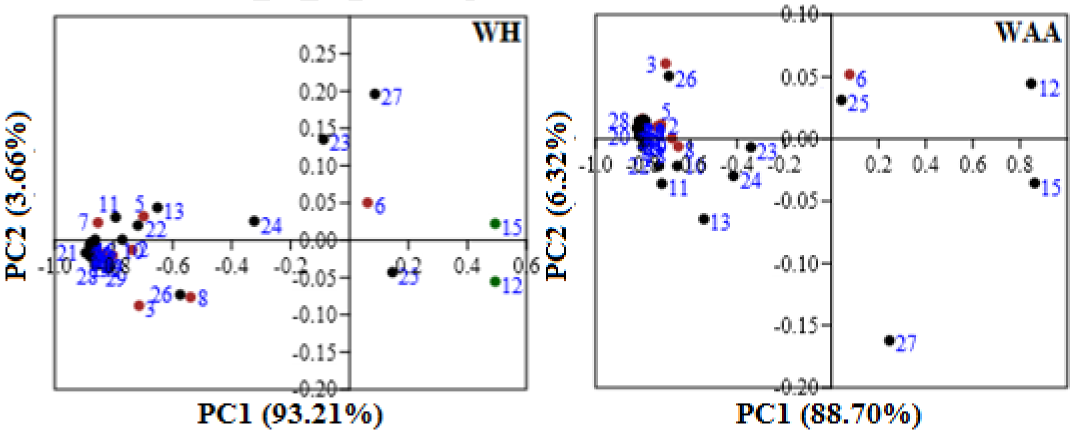

Fig.4. Biplot diagram between PC1 and PC2 shows similarities and dissimilarities relationships between soil and plant variables during Wadi Hebran (WH) and Wadi Al-Akhder (WAA) in both seasons. 1: Ec; 2: pH; 3: Na^{+}; 4: K^{+}; 5: Ca^{2+}; 6: Mg^{2+}; 7: S^{-}; 8: Cl^{-}; 9: water content; 10: Chl.a; 11: Chl.b; 12: total arotenoids; 13: Chl.a+b; 14: Chl.a/b; 15: total pigment; 16: Na^{+}; 17: K^{+}; 18: Ca^{2+}; 19: Mg^{2+}; 20: N; 21: P; 22: water content; 23: crude protein; 24: crude fiber; 25: total ash; 26: total carbohydrate; 27: proline; 28: catalase enzyme; 29: peroxidase enzyme; 30: superoxide enzyme; 31: ascorbic acid; 32: malondiadehyde.

The PCA biplot in Fig. 5 identifies the relationships among soil and plant variables under the two sites in both seasons. The two first PCs explains 84.78% of the total variance in the original variables of *C. colocynthis* in Wadi Hebran and Wadi Al-Akhder at both seasons. The PC1 and PC2 accounted for more than 48.64% and 36.14% of the total variance, respectively, and discriminated well the soil and plant variables of *C. colocynthis* on the two sites in both seasons. The PC1 and PC2 have positive correlations with most soil and plant variables in Wadi Hebran and Wadi Al-Akhder sites at both seasons, where PC1 is located in the first and fourth quarters and PC2 in the second and third quadrants. The highest positive correlations of PC1 were found with soil variables i.e., EC, K^+, and Cl^- as well as plant variables i.e., P, total carbohydrate, proline, catalase enzyme, peroxidase enzyme and malondiadehyde. While the PC2 is highly positively correlated with Ca^{2+}, S^- and water content in soil and with Chl.b, K^+, Ca^{2+}, N, water content, crude protein, crude fiber, total ash and Superoxide enzyme in *C. colocynthis* plants (Fig. 5).

Regarding relationships among soil properties, a positive correlation was found among EC, Na^+, K^+ and Cl^- and among Ca^{2+}, Mg^{2+}, S^- and water content. Ca^{2+} showed positive correlations with EC, K^+ and Cl^-. pH is positively correlated with Mg and water content. S^- has a positive correlation with EC and K^+. As for relationships among plant analysis, most plant variables in *C. colocynthis* had positive correlations across the two sites in the two seasons. Highest positive correlation had observed among Chl.a, Chl.b, Chl.a+b, Ca^{2+} and Mg^{2+}, between carotenoids and total pigment, between N and K^+, between Na^+ and P, between Ca^{2+} and water content, among N, water content, crude protein, crude fiber, total ash and superoxide enzyme, among total carbohydrate, proline, catalase enzyme, peroxidase enzyme and malondiadehyde, as well as between superoxide enzyme and ascorbic acid.

The data of soil and plant variables studied displayed a positive correlation among most studied variables, but they differed in their degree and consistency in quantity. Strong positive correlations were observed for EC, Na^+, K^+ and Cl^- in soil with Na^+, P, total carbohydrate, proline, catalase enzyme, peroxidase enzyme and malondiadehyde in plant, for soil pH with Chl.a, carotenoids, total pigment and Mg in plant, for Ca^{2+} and S^- in soil with N, crude protein, cruse fiber, total ash, superoxide enzyme and ascorbic acid, for soil Mg with plant ascorbic acid, as well as for soil water content with Chl.b, Ca^{2+} and water content in *C. colocynthis* under Wadi Hebran and Wadi Al-Akhder locations.

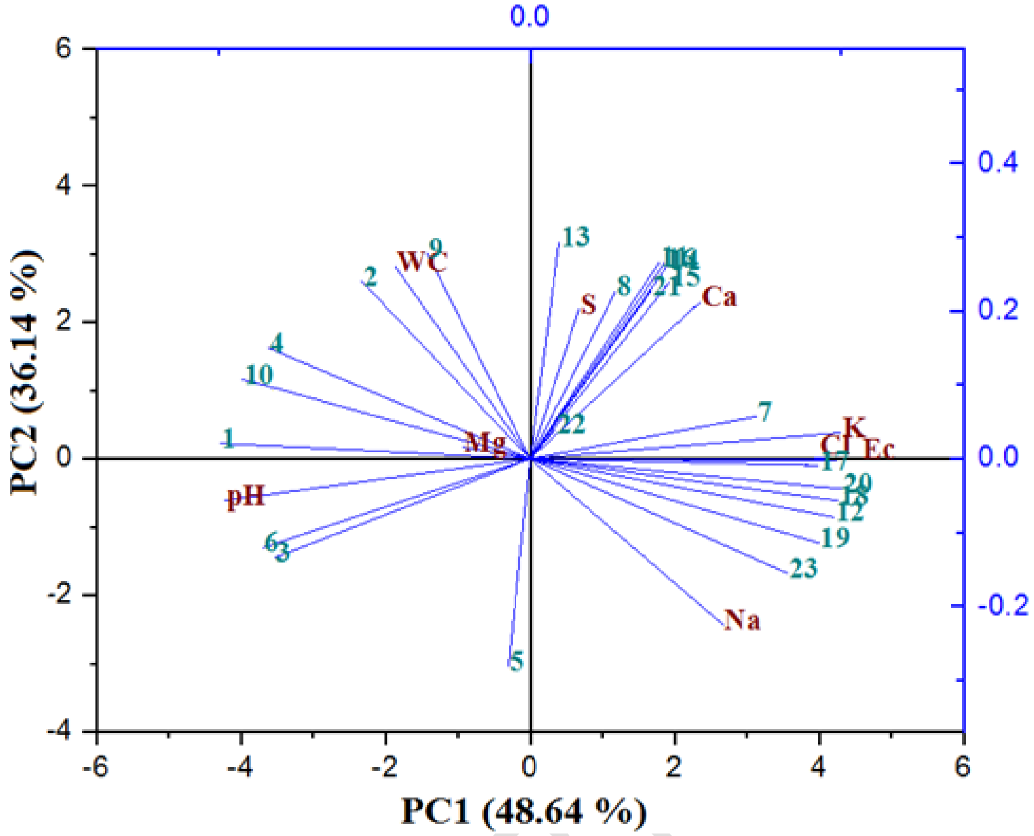

Fig.5. Biplot diagram between PC1 and PC2 shows similarities and dissimilarities relationships between soil and plant variables during Wadi Hebran and Wadi Al-Akhder in both seasons. Ec; pH; Na^+; K^+; Ca^{2+}; Mg^{2+}; S^-; Cl^-; WC: water content; 1: Chl.a; 2: Chl.b; 3: total arotenoids; 4: Chl.a+b; 5: Chl.a/b; 6: total pigment; 7: Na^+; 8: K^+; 9: Ca^{2+}; 10: Mg^{2+}; 11: N; 12: P; 13: water content; 14: crude protein; 15: crude fiber; 16: total ash; 17: total carbohydrate; 18: proline; 19: catalase enzyme; 20: peroxidase enzyme; 21: superoxide enzyme; 22: ascorbic acid; 23: malondiadehyde.

4. Discussion

The current study evaluated the soil proprieties and plant analysis and their relationships of *C. colocynthis* under the two locations (Wadi Hebran and Wadi Al-Akhder) in the two seasons. Statistically, most mechanical and chemical properties of the adjoining soil samples of *C. colocynthis* were significantly affected ($p<0.05$ or 0.01) by the locations, depths, and their interaction. Salama et al. [41] and Midhat *et* al. [77] confirm that significant differences in chemical properties of the soil supporting *C. colocynthis*. Also Al-Mutairi [19] stated that there is variation in measured soil properties of *C. colocynthis* by locations, especially for pH and calcium. The present study revealed that most mechanical and chemical properties of the adjoining soil samples of *C. colocynthis* were significantly higher in Wadi Hebran location than in Wadi Al-Akhder location, regardless of the two depths. During the LD interactions, the highest values of most mechanical and chemical properties soil were found in 20-40 depths at Wadi Hebran location. In agreement with Al-Ghamdi [10] and Bhasin et al. [59], the pH of soil associated with *C. colocynthis* tended to be somewhat alkaline. Alkalinity may be due to the increase in total soluble salts in plant soil [9]. Generally, the adjoining soil of *C. colocynthis* and collected from the two depths in Wadi Hebran and Wadi Al-Akhder are sandy in texture, as already reported by Al-Zahrani and Al-Amer [78] and Bhasin et al. [59]. Significant differences in environmental variables reflect the variance in the soil characteristics and texture [19]. Shaltout et al. [79] reported that the diversity in plant species had been brought about by local differentiation in soil characteristics around individual plants. The plants can adapt and thrive in locations with different soil properties [80]. Also, the soil chemical and physical characteristics have a marked influence on the vegetation patterns of *C. colocynthis* [78], through their effect on the water resources [81].

Significantly, the highest values of water content % were found by the interaction Wadi Hebran in 20-40 depth under the wet season compared to the other location in both seasons. These results may be due to the high seasonal rainfall rates during the studied period, and the extent of increase was 2.31% in Wadi Hebran than in Wadi Al-Akhder, thus enabling the plants to adapt to drought conditions. Also, due to increase silt and clay content in Wadi Hebran than in Wadi Al-Akhder, thus increase available water storage capacity, then increases the vegetation. These results similar to those described by Al-Ghamdi [10] and Salama et al. [41] in soil *C. colocynthis*. Generally, the appearance and disappearance of plants species as *C. colocynthus* depend on affect microclimatic conditions like soil texture, soil water content and temperature [57,59,82].

The locations, seasons and their interaction had highly significant effects on most chemical compositions measured in *C. colocynthis*. In the study by Al-Zahrani and Al-Amer [78], the locations significantly affected mineral compositions (N, P, K^+, Mg^{2+}, Ca^{2+}, Na^+ and Cl^-) in *C. colocynthis*. Also, Salama et al. [41] mentioned that the seasons showed significant effects on photosynthetic pigments, water content, ionic composition and metabolic components of *C. colocynthis*. The differences between seasons and locations were oftentimes weather-related. Thus, can be assumed that weather conditions were the cause of the significant differences for studied contents of *C. colocynthis*. In other species, similar results were recorded in the study of Salama et al. [9] and Kamel and El-Absy [83].

Results of plant analysis exhibited that there was a significant effect of increasing photosynthetic pigments contents of *C. colocynthis* in Wadi Al-Akhder during the two seasons. While, Wadi Hebran in the wet season showed significantly increased most chemical compositions studied of *C. colocynthis* compared to the Wadi Al-Akhder location in the two seasons. The contents of total carotenoids, Chl.a/b, total pigment, P%, total carbohydrate, proline, catalase enzyme, peroxidase enzyme, ascorbic acid and malondiadehyde have been significantly increased in the dry season than in the wet season in both locations. While the highest values of other components contents studied were registered in the wet season compared with their values in the dry season. Seasonal changes are the main factor affecting the chemical composition of plants [84], as these reflect seasonal changes in physiological needs and efforts, rather than availability in plant content [46].

Salama et al. [41] the highest concentration of photosynthetic pigments and Chl.a/b ratio (more than 1) in the summer season were observed at *C. colocynthis*. Huang et al. [85] cleared that increased ratio of Chl.a/b may be due to the Chl.a content was higher than Chl.b content. During dry conditions and due to adaptive mechanisms, the desert plants attained higher concentrations of chlorophyll and carotenoids [86], enabling the plants to adapt to light conditions changes and stresses. While, Ait Said et al. [87] has hypothesized that a decrease in Chl.a can be considered as a protective adaptive mechanism that prevents increased photon absorption.

The plant species differ in the content of the minerals as well as the reactions under adverse conditions in the same region [88]. The highest values of mineral compositions were of K^+ and Ca^{2+} in Wadi Hebran, and Mg^{2+} in Wadi Al-Akhder. Some previous studies reported similar conclusions with the present results, for example, Salama et al. [41] in *C. colocynthis* and Kamel and El-Absy [83] in *Lycium showii*. An increased concentration of Ca^{2+} and Mg^{2+} without reaching toxic levels counteracts the inhibitory effect of Na^{+} and may contribute to its physiological salt tolerance mechanisms, have also a role in large responsibility in physiological reactions within plant cells [89-91]. The Na^{+} and Cl^{-} are often stored in the vacuoles resulting in increased osmotic pressure [92] and avoid Na^{+} toxicity [9], K^{+} ions are essential for reducing the uptake of Na^{+}. Concentrations of Na^{+} and K^{+}, as well as ion balance play important roles in plant salt tolerance [93]. Salama et al. [94] stated that the absorption and removal of inorganic osmoregulatory ions like K^{+}, Na^{+}, Ca^{+2} and Mg^{+2} are useful means of osmotic gradient re-adjustment in stressed plants.

Our results are as well in agreement with Salama et al. [41] for water content, with Gonzalez-Hernandez et al. [95] for crude protein, with Abebe et al. [96] for crude fiber and total ash, with Al-Qahtani et al. [97] for total carbohydrates and with Pouris et al. [98] for proline. The water content of *C. colocynthis* decreased due to the high temperature, where the transpiration rate increases in summer than in the winter [41], thus the plants tend to reduce their internal water potential under abiotic stresses [99]. Kasim et al. [100] reported that the protein types synthesis rich in certain amino acids may be the key to survival for species plants, where, the osmotic modification under stress conditions may be accompanied by protein accumulation to improve the plant species to drought stress tolerance [9]. Similarly, in studies by several researchers such as Al- El-Absy [45], Qahtani et al. [97] and Dhaka and Meena [101], the highest accumulation of total carbohydrates and proline observed in the dry season, which can be used as an indicator of disturbed physiological conditions as drought and salinity stresses in most plant species. The total carbohydrates and proline have a more intimate association with the survival adaptability of plants, which play an important role during drought by acting as compatible osmolytes to maintain cell turgor and favorable plant water status, thereby sustaining biological processes and soil water uptake [102].

In line with this study, Kasim et al. [100] have already stated, *C. colocynthis* plants showed significantly higher levels of contents of catalase enzyme, peroxidase enzyme, ascorbic acid and malondiadehyde in the dry season than in wet season, while the opposite was found in case of superoxide enzyme. These results indicated increased activities of these compositions can be considered as a defense mechanism in *C. colocynthis* during the two locations at the dry seasons in this study. Such a decrease in uperoxide enzyme activity can be due to the formation of H_2O_2 as a by-product which should be a potentially damaging agent at higher salt concentrations in the dry season [100]. Sarker and Oba [103] reported that the catalase, superoxide dismutase and ascorbate-glutathione cycle enzymes play a vital role in the tolerance of *Amaranthus tricolor* and major ROS detoxification in the tolerant genotype.

Principal component analysis (PC) has been used to decrease the number of comparisons between variables and to estimate the similarities and dissimilarities relationships between soil and plant variables in each site and between sites under this study. The first two PCs explain more than 95% and 84% of the total variance of all variables investigated in each location and between locations, respectively. The PC1 explained above 88% and 48% of the measured data total variability in the original variables under each location and between locations, respectively, in our research and other studies like and El-Absy [45], Kooch et al. [48], Ferraz et al. [50] and Metwally et al. [51]. Thus, it explains variance more than an individual attribute and it expresses more variability and support to select the variable with a positive loading factor. It is evident that the PC1 and PC2 can be interpreted as a response related to the soil and plant variables and which possess positive and negative contributions to locations and seasons in this study. Therefore, the PC1 is considered very important to increase the soil and plant variables studied under drought stress conditions. In agreement with Gil et al. [91] and El-Absy [45], the first PC is correlated with soil variables i.e., Na^+, Ca^{2+}, Mg^{2+} and Cl^-, as well as with contents of water, crude protein, proline, total pigment, Chl.a+b and carotenoids in plants, and which related to water stress and to salt stress. Likewise, PC1 and PC2 characterized some soil variables and the PCA displayed noticeable variations of soil properties under the study region [48]. Similar conclusions with this study were published by Khafagi et al. [1] and Al-Mutairi [19], where the soil variables EC, Ca^{2+}, K^+, Na^+, Mg^{2+} and Cl^- as well the soil variables EC, Na^+, S^- and Cl^- were the most important factors controlling the community structure of plants in the region under study, respectively. The PC1 and PC2 had strongly correlated with some soil and plant variables investigated [91].

The highest and strong positive correlations among EC, K^+ and Cl^- as well as between Ca^{2+} and S^- in soil were observed in this study. Our results are as well in agreement with El-Absy [45], Ferraz et al. [50], Abdel-Fattah et al. [52] and Neina [104], who reported that positive or negative significant correlations among soil properties. The results of PCA showed high positive correlations among plant variables measured in this study and other studies by Uvalle Sauceda et al. [105], Kaspary et al. [106], Sadeghi and Robati, [107], Nejat and Sadeghi [108] and Yinping et al. [109]. Highest and strong positive correlations between Chl.b and Ca^{2+} as well as among P, proline, catalase enzyme and peroxidase enzyme were found in this study. The positive correlation among most plant variables such as between total chlorophyll and carotenoid concentrations plays an important role in protecting plants from stresses through photo-oxidation [110] and evaluating the ability of plants to capture light during shade [111].

The biplot showed the degree of correlation amongst most soil and plant variables measured regarding each Wadi Hebran and Wadi Al-Akhder as well as between them in the two seasons. Most soil variables have strong positive correlations with most plant variables, for example, total carbohydrate, proline, catalase enzyme, peroxidase enzyme and malondiadehyde in *C. colocynthis* during Wadi Hebran and Wadi Al-Akhder at both seasons. These findings were consistent with El-Absy [45] and Gil et al. [91]. Using PCA, El-Absy [45], Gil et al. [91,112] reported that positive correlations among most soil variables and the plant variables (Ca^{2+}, Mg^{2+}, proline and total carbohydrate), indicating the functional role of proline in the stress tolerance mechanisms of the plant species under study. Salama et al. [113] cleared that significant negative relationships were noticed for the plant species richness with the soil variables (EC, Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-). High correlation results between soil and plant variables indicate an effect of soil chemical variables on plant variables, where, increasing these soil variables will increase plant variables. These results indicate that *C. colocynthis* and through their adaptive behavior and the possibility of osmotic adjustment adopted can survive and endure a wide range of environmental conditions during the dry season.

5. Conclusions

According to ANOVA, significant effects ($P < 0.05$ or 0.01) by the locations, depths and their interaction on most soil mechanical and chemical properties, and by the locations, depths and their interaction on most plant compositions were found. Most mechanical and chemical properties in soil and most chemical compositions in *C. colocynthis* were significantly increased in Wadi Hebran at both seasons than that of Wadi Al-Akhder. Wadi Al-Akhder in both seasons had the positive highest impact on photosynthetic pigments contents. The dry season significantly increased proline and other chemical compositions compared to the wet season. According to PCA, the first two PCs had highly and positively associated with the most soil and plant variables, and showed a strong positive correlation amongst most soil and plant variables investigated under the two locations in both seasons. Using PCA, estimating the relation between the environmental factors and phytochemical compounds might help to understand adaptive behavior and mechanisms in *C. colocynthis* to a tolerance of harsh environmental conditions.

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