



Seasonal Effects on Some Eco-Morphological and Physiological Characters of *Tamarix nilotica* (Ehrenb) Bunge Growing Naturally in Egyptian Northern Coastal Salt Marshes

Aya M Mehanny^{1*}, Gamal S Khalifa¹, Ola H Abd Elbar¹, Maryam Abba Dawud², Sami A Habib¹

1- Botany Dept, Fac of Agric, Ain Shams Univ, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt

2- Cereals Dept, Lake Chad Research Institute, Maiduguri, Nigeria

*Corresponding author: AyaMahmoud42@agr.asu.edu.eg

<https://doi.org/10.21608/AJS.2022.108934.1439>

Received 1 December 2021; Accepted 27 March 2022

Keywords:

Seasonal changes,
Salinity,
Drought,
Salt marches,
Tamarix nilotica

Abstract: *Tamarix nilotica* is a perennial halophyte growing naturally at the Mediterranean coastal salt marshes. Vegetative parts were collected in two successive winters and summers to investigate the seasonal effects on the ecomorphological and physiological responses of *T. nilotica*. The results indicated that either in winter or summer seasons, *T. nilotica* can reduce the effect of soil salinity by excreting salts outside its body through salt glands. Summer season was characterized by low content of soil moisture (due to rare rainfall), high soil EC, high light intensity and high temperature; therefore, plant induced certain morphoanatomical changes in leaves and stem to face the previously mentioned adverse conditions. The most remarkable changes to reduce the transpiration process were found by decreasing leaf area and increasing cuticle thickness and mesophyll tissue thickness. In addition, the most marked physiological changes in summer were the significant increase in total phenols, proline, free amino acids and total soluble sugars. These compounds can work as osmotic regulators and/or antioxidants. These features enhance the defensive mechanism against dehydration and permit *T. nilotica* to tolerate the stress conditions in salt marsh habitats.

1 Introduction

The climate of Egypt varies from semiarid to extremely arid climate; it is divided into three types: the Red Sea climate, the Mediterranean climate of the northern coastal areas and the desert climate (El-Marsafawy et al 2019). The North-western section of the Mediterranean coast (Mariut coast) runs from the Libyan border to Alexandria. The area is distinguished by semiarid conditions with seasonal drought in the warm summer months and cold with sudden high rainfall in the winter months. The flora on the North-western coast is comparatively rich and it contains

around 50% of the total flora of Egypt (Zahran and Willis 2009, Abd El-Gawad and Shehata 2014). There are various types of habitats in the Western Mediterranean region such as salt marshes which is a widespread habitat in the area. Predominant plant species in this habitat are adapted to dominant salinity or drought stress. Salt marshes are remarkable habitats, inhabited by a considerable number of halophytes which have many economic uses. (El-Shaer and El-Morsy 2008, Abd el-gawad and Shehata 2014).

The ability of plants to adapt to stressful environments is related to the plasticity of morpho-anatomical structure combined with the physiological factors. Studies of plant adaptation to environmental stresses

are important for understanding the adaptive mechanisms of plant species. It is indispensable to quantify the tolerance variances among halophytic species to salinity as a foundation for evaluating their potential utilization (Salsinha et al 2020). One of the distinctive plants of salt marches is *Tamarix nilotica* which is a halophytic shrub or tree belonging to the family of Tamaricaceae. Tamarix plants can secrete salts by salt glands as a mechanism of salt tolerance. *T. nilotica* has many pharmacological activities, including the effects as antidiabetic, antioxidant, anti-tumor, antimicrobial and antiviral activity. The wood can be used to make charcoal, as a fuel, and sometimes used for some inferior carpentry and to stabilize sand (Brock 1994, Abdelgawad 2017). *T. nilotica* is rich in bioactive compounds e.g. phenols, ascorbic acid and natural pigments (Abd El-Maboud 2019). This work aims to study the morphological, physiological and biochemical adaptations of *Tamarix nilotica* collected from salt march under stress conditions.

2 Materials and methods

2.1 Collection of plant materials from the study area

Fresh shoot samples of *Tamarix nilotica* were collected randomly from 20 plants during the end of winter (wet season) in March and the end of summer (dry season) in September for two successive years 2018-2019. Samples were collected from the salt marsh habitat of the Northwestern coast of Egypt at the city of Borg Al-Arab; the geographical position system (GPS) reading perusing is 30°55.259 N, 29°31.425 E.

2.2 Climate data

According to Abdel Moghith et al (2015), the study area belongs to the subtropical Mediterranean climate. Climate data of the study area was taken from Borg Al-Arab meteorological station, the central laboratory for agriculture climate. Maximum and minimum average values of temperature (°C), rainfall (mm/month), relative humidity (%) and solar radiation (MJ/m²/day) were documented for the selected area.

2.3 Soil analysis

Soil samples were collected from the study area at a depth of 0-50 cm. Mechanical analysis was

executed by the method described by Kilmer and Alexander (1949). Electrical conductivity in soil water extract (1:5) was determined; pH values, cations including (sodium and calcium) and anions including (chloride, bicarbonate and Sulphate) were determined according to Estefan et al (2013). The results of cations and anions were expressed as meq/L.

2.4 Morphological and anatomical examinations define the location of samples

Fresh middle parts of the wintry and summery new shoots were separated to assay the morphological and anatomical traits of *Tamarix nilotica* as follows: 40 leaves were used to measure the leaf area (mm²) by ImageJ software. For the anatomical features, small samples (about 0.5 to 0.1 cm in length) were cut from the wintry and summery shoots and fixed in FAA solution (Formalin, Acetic acid, 50% ethyl alcohol 5:5:90 by volume) for 24 h. The Paraffin method of Abd Elbar (2017) was used. Serial of transverse sections at 10-12 µm were made by LEICA rotary microtome model RM 2125 RTS. The sections were double-stained with safranin and fast green. Anatomical observations were performed using a LEICA light microscope model DM-500 supplied with a digital camera. The following measurements were taken: the cuticle thickness, epidermis thickness, palisade tissue thickness on both abaxial and adaxial surfaces, the spongy tissue thickness and the lamina thickness were measured (in the middle zone).

2.5 Physiological parameters

2.5.1 Determination of water content and degree of succulence

Water content was determined according to the following equation:

Water content = $100 \times ((\text{Fresh weight} - \text{Dry weight}) / \text{Fresh weight})$ the degree of succulence was calculated according to the method described by Holbrook and Putz (1996), as the initial fresh weight/dry weight ratio.

2.5.2 Determination of photosynthetic pigments

To extract chlorophylls (ch. A and ch. B) and carotenoids, Moran's (1982) method was used as follows: 0.1g of *T. nilotica* frozen shoots was ground by a mortar and pestle with 10 ml *N,N*-dimethyl formamide. The resulting extract was left in the dark overnight. The pigments were determined using a UV/Vis spectrophotometer (T60 PG instrument limited, China) at 664, 647 and 470 nm for chl. A, chl. B and carotenoids respectively. The chlorophyll A, B concen-

trations were determined by using the Lichtenhaler and Wellburn (1983) formula, while the carotenoid concentration was calculated using Shlyk (1971) formulas:

Chlorophyll a = $9.784 * A_{664} - 0.990 * A_{647}$ = mg/L

Chlorophyll b = $21.426 * A_{647} - 4.650 * A_{664}$ = mg/L

Carotenoids = $[(4.695 * A_{470}) - 0.268 (Chl. a + b)]$ = mg/L

The data were stated as mg/g fresh weight.

2.5.3 Determination of total phenols

The shoot (0.5 g) was mixed with 5 mL ethanol 80% and kept for 24 h at 0°C. Sample extraction was repeated three times, and then filtered. To determine total phenols content, Singleton and Rossi's (1965) method was followed. Absorbance was documented at 650 nm in a UV/Vis spectrophotometer. The concentration of total phenols was determined using a standard curve of catechol and calculated as mg catechol/g fresh weight.

2.5.4 Determination of proline

The concentration of proline was estimated according to the method of Troll and Lindsley (1955) modified by Petters et al (1997). The color was documented at 515 nm in UV/Vis spectrophotometer. The concentration of proline was calculated using L-proline as a standard curve and expressed as μ mole proline/g fresh weight.

2.5.5 Determination of total soluble sugars

Fresh parts of the shoot were used to extract the soluble sugars with ethanol 80% according to AOAC (2007). The total soluble sugars were determined by the method of Dubois et al (1956). The absorbance of the extract was documented at 490 nm in a UV/Vis spectrophotometer. Total soluble sugar concentration is estimated using D-glucose as the calibration standard and calculated as mg/g fresh weight.

2.5.6 Determination of free amino acid

Free amino acids were extracted from the shoot with ethanol 80% according to AOAC (2007). It is determined by the method of Jayaraman (1981). The absorbance was documented at 570 nm in a UV/Vis spectrophotometer. Free

amino acid concentration is estimated using glycine as the calibration standard and calculated as mg/g fresh weight.

2.6 Statistical analysis

The obtained results were analyzed by statistical one-way analysis of variance (ANOVA) using (Costas software, Version 6.4, 2008) computer program. The significance between means was tested by LSD at 5% significant level.

3 Results and Discussion

3.1 Climate data

In accordance with metrological data of the study area from 2018 to 2019 (Table 1), the region is characterized by higher temperature, light intensity and solar radiation in summer than in winter. The winter season was rainy while the summer season was almost rainless. So, the climate of the region belongs to the warm coastal desert.

3.2 Soil characters of the study habitat

Table 2 shows that the soil texture of the site of *Tamarix nilotica* was sandy clay loam. Also, the habitat of the investigated species was alkaline (pH ranging between 9.8 and 10). The soil moisture content was lower in summer. In general, electrical conductivity was high and higher in summer, indicating a high salinity. Also, sodium, chloride and calcium increased in summer.

3.3 Morphological and anatomical responses

T. nilotica is a perennial shrub that has many thin branches (Fig 1 A) with chestnut bark. The young branches are cylindrical and solid while cladophyll has a reddish-green color. The leaf is scaly, simple, sessile, whorled, oblong-lanceolate, has a green color, entire margin with acute apex (Figs 1 B&C). The lamina cross-section of both the winter and summer seasons (Figs 2 A, B, C & D) revealed that the leaf consists of a uniseriate epidermis. The epidermal cells of the adaxial surface have tangentially elongated shapes while the abaxial cells are slightly isodiametric. Some epidermal cells are papillose (especially the adaxial cells). Several stomata and salt glands were observed (Figs 2 E&F). The mesophyll differentiates into palisade tissue toward adaxial and abaxial surfaces and isodiametric chlorenchymatous cells. The palisade cells of the abaxial surface (facing the light) are more

Table 1. The climate data of the study area in winter and summer season

	2018						2019					
	average temperature (°c)			Solar Radiation (MJ/m ² /day)	Relative Humidity (%)	Rainfall (mm/month)	average temperature (°c)			Solar Radiation (MJ/m ² /day)	Relative Humidity (%)	Rainfall (mm/month)
	max.	min.	mean				max.	min.	mean			
January	18.11	10.25	13.73	12.53	69.10	40.98	17.08	7.82	11.83	13.42	61.45	10.13
February	20.72	10.82	15.18	15.06	65.21	11.60	18.92	8.71	13.17	15.68	64.10	10.56
March	20.72	10.82	15.18	15.06	55.56	1.27	20.63	10.55	15.02	19.72	63.52	18.06
April	27.06	14.49	20.15	24.43	54.67	5.63	24.58	12.83	18.22	24.54	56.36	4.26
May	30.88	18.70	24.19	26.95	54.13	0.02	31.42	17.31	23.86	27.52	46.09	0.01
June	32.97	21.21	26.71	29.54	51.97	0.00	32.84	21.51	26.77	28.80	56.96	0.00
July	33.93	22.81	27.86	29.47	58.14	2.42	34.17	23.06	28.15	29.42	55.89	0.00
august	33.66	23.51	27.99	27.18	59.98	0.00	34.31	23.09	28.19	27.36	58.09	0.00
September	32.26	22.33	26.58	23.34	60.57	0.00	31.64	21.79	26.07	23.61	60.46	0.00
October	28.98	19.82	23.69	18.96	61.38	3.06	29.89	20.20	24.32	18.54	62.52	25.34
November	24.46	16.06	19.69	14.23	63.13	20.73	26.57	16.54	20.73	14.90	61.77	0.09
December	19.38	12.60	15.52	12.60	67.21	11.25	20.31	12.54	15.78	11.89	67.61	28.67
Annual	26.93	16.95	21.37	20.78	55.78	96.96	26.86	16.33	21.01	21.28	59.57	97.12

Table 2. Physical and chemical properties of soil supporting *T. nilotica* in winter and summer seasons

Sand %	Silt %	Clay %	texture					
47	25.5	27.5	Sandy clay loam					

Season	Moisture content (%)	pH	EC (ds/m)	SO ₄ ²⁻ (meq/L)	CL ⁻ (meq/L)	HCO ₃	Na ⁺ (meq/L)	Ca ⁺ (meq/L)
Winter	26	10	47.84	61.68	371.19	2.12	269.57	66.67
Summer	17.5	9.8	54.28	202.98	426.27	2.36	410	74.24

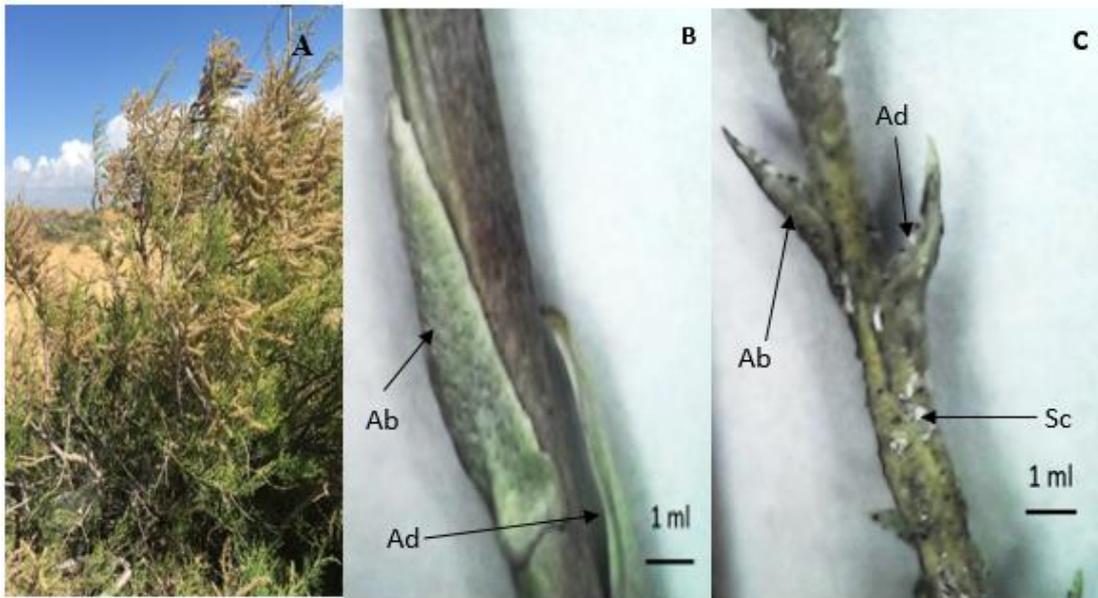


Fig 1. A *T. nilotica* in its habitat, B wintery shoot, arrow reveals to wintery leaf, C summery shoot, arrows reveal to Ad: adaxial surface of a leaf, Ab abaxial surface of a leaf, and Sc: salt crystals scattered on the summery stem

elongated than the adaxial ones (Figs 2 A&B). The midvein has a vascular bundle that consists of approximately 2 or 3 rows of xylem elements, phloem and phloem fibers (Figs 2 C&D). Data in Table 3 show that there is a significant decrease in the average leaf area, leaf length and summery leaf width. Also, there are significant increases in leaf thickness (Figs 2 A&B), spongy tissue thickness, palisade tissue on adaxial and abaxial surfaces and cuticle thickness of abaxial surface in summery leaves. In addition, the palisade tissue cells had a more columnar shape in summer (Figs 2 B&D).

Generally, both the wintry and summery stem of *T. nilotica* (Figs 2 G & H) consist of uniseriate epidermis. The epidermis cells have a slightly isodiametric shape and some cells are papillose. Several stomata and salt glands were observed (Fig 2 G). Under the epidermis, there is the cortex consists of outer layers of palisade tissue and inner

non-photosynthetic parenchyma tissue followed by a vascular cylinder that includes collateral vascular bundles. It is noticeable in the summery stem that each vascular bundle contains phloem and 1-3 radial rows of xylem elements and phloem fibers (Fig 2 H). In the summery stem, the cuticle is thicker, palisade cells are more elongated and vascular bundles are more lignified (Figs 2 G&H).

3.4 Chemical parameters

Table 4 reveals that there is a significant decrease in water content percentage and degree of succulence. While there is a significant increase in total phenols, proline, free amino acids and total soluble sugars in the summer season. A reversible relationship was observed between water content and each of proline, free amino acid and total soluble sugar concentrations. On the other hand, seasonal changes had non-significant changes in the chlorophyll A, B and carotenoid concentrations in both winter and summer seasons.

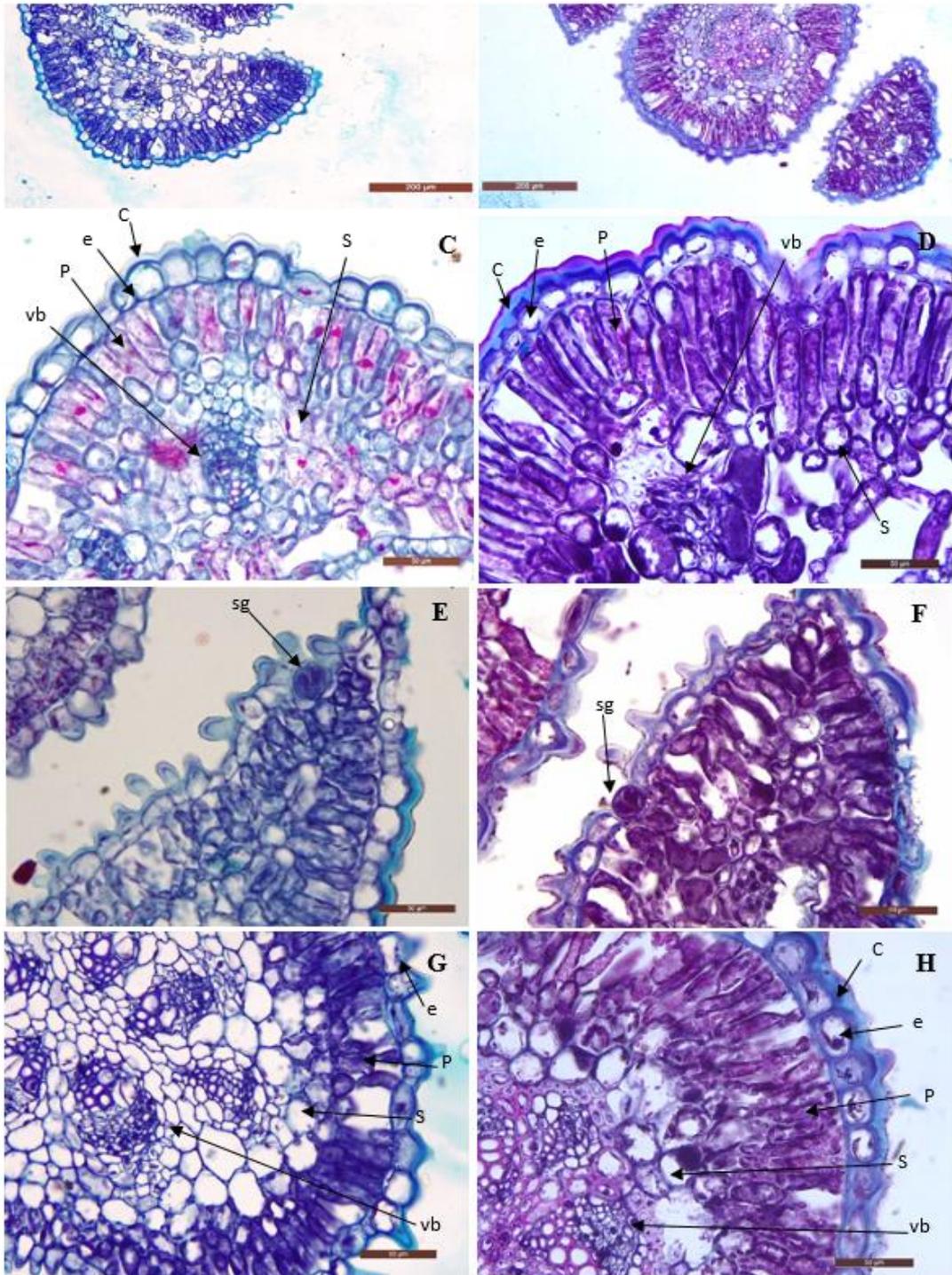


Fig 2. Cross-sections of *T. nilotica* young shoots. A. the wintery shoot, B the summery shoot. C, D, E and F magnifications of leaf transections. C, E reveal the wintery leaf with moderately thick cuticle and obvious intercellular spaces in the mesophyll layers. D and F illustrate transactions in the summery leaf. Note the thicker cuticle and compacted elongate palisade cells. G, H magnifications of stem transections. G. the wintry stem structure, H the summery stem structure, note an increase in lignification in xylem elements and phloem fibers surrounding the vascular bundles also increasing in cuticle thickness covered the summery stem and accumulation of tannins in cortex cells. c: cuticle, arrows reveal to e: epidermis, p: palisade tissue, s: spongy tissue, vb: vascular bundle, sg: salt gland

Table 3. Morpho-anatomical characteristics of *T. nilotica* leaves in different seasons

Characters	Winter	Summer	LSD at 5%
Leaf length (mm)	1.9 ^a ± 0.64	1.3 ^b ± 0.49	0.25
leaf width (mm)	0.58 ^b ± 0.19	0.07 ^a ± 0.02	0.06
Leaf area (mm ²)	1.31 ^a ± 0.52	0.95 ^b ± 0.37	0.20
Leaf thickness (µm)	235.9 ^b ± 19.3	297.8 ^a ± 40.2	27.08
Adaxial surface			
Thickness of cuticle (µm)	3.64 ^a ± 0.73	3.75 ^a ± 0.7	n.s
Thickness of epidermis (µm)	19.11 ^a ± 3.2	18.93 ^a ± 3.4	n.s
Radial diameter of epidermis cell (µm)	14.82 ^b ± 3.1	15.67 ^a ± 2.2	1.72
Tangential diameter of epidermis cell (µm)	18.35 ^a ± 3.1	18.00 ^a ± 2.9	n.s
Palisade thickness (µm)	33.58 ^b ± 6.2	48.86 ^a ± 6.1	3.95
Abaxial surface			
Thickness of cuticle (µm)	5.70 ^b ± 1.6	8.29 ^a ± 1.1	0.94
Thickness of epidermis (µm)	24.89 ^b ± 3.6	28.79 ^a ± 4.2	2.51
Radial diameter of epidermis cell (µm)	19.44 ^a ± 3.5	18.00 ^a ± 2.1	n.s
Tangential diameter of epidermis cell(µm)	19.93 ^a ± 4.6	21.54 ^a ± 2.5	n.s
Palisade thickness (µm)	47.49 ^b ± 6.1	58.26 ^a ± 9.6	5.12
Spongy thickness (µm)	69.00 ^b ± 11.3	78.41 ^a ± 5.2	8.62

Data in **Table 3** are shown as average ± standard deviation, averages with the different letters in rows are significant statistically by LSD test ($p \leq 0.05$), n.s: non-significant

Table 4. Physiological and chemical parameters of *Tamarix nilotica*

	Winter	Summer	LSD at 5%
Water content (%)	67.8 ^a ± 1.5	54.3 ^b ± 4.5	7.6
Degree of succulence	3.16 ^a ± 0.2	2.21 ^b ± 0.2	0.46
Chlorophyll a (mg/g)	0.57 ^a ± 0.06	0.55 ^a ± 0.09	ns
Chlorophyll b (mg/g)	0.29 ^a ± 0.02	0.28 ^a ± 0.01	ns
Carotenoids (mg/g)	0.26 ^a ± 0.01	0.23 ^a ± 0.01	ns
Total phenols (mg/g)	137.32 ^b ± 5.8	148.9.3 ^a ± 1.3	9.7
Proline (mg/g)	0.96 ^b ± 0.09	2.46 ^a ± 0.05	0.16
Total soluble sugars (mg/g)	2.94 ^b ± 0.6	6.9 ^a ± 0.8	1.59
Free amino acid (mg/g)	15.3 ^b ± 0.7	60.4 ^a ± 3.5	5.7

Data in **Table 4** are shown as mean ± standard deviation, means with the different letters in columns are statistically significant according to the LSD test ($p \leq 0.05$), n.s: non-significant

Climate and soil analyses (**Tables 1, 2**) show that *T. nilotica* has been exposed to more salinity, drought and light intensity in the summer season. Plants growing in saline soils may face many abiotic stresses they may suffer from water stress and accumulation of some toxic ion concentrations such as chloride and sodium (Koyro et al 2009).

Tamarix growing naturally among halophytes was found to be a quite long-living plant resistant to a diversified of environmental stresses such as salinity and drought (Saïdana et al 2008). The present study shows that *Tamarix nilotica* can survive under environmental stresses. A set of adaptation mechanisms includes morpho-anatomical adaptations such as the existence of salt glands on aerial parts. These salt glands may remove a lot of quantities of salts by secretion to the plant surface (Koyro et al 2009). Moreover, *T. nilotica* is char-

acterized by some xeromorphic properties such as decreasing leaf area, and increasing cuticle thickness in stem and abaxial leaf surface in the summer season. Hameed et al (2010) reported that xeromorphic features have appeared in many halophytes to survive under environmental stresses. Reduction in leaf area aims to limit water loss *via* transpiration since smaller leaves diminish the need for evaporative cooling. In addition, small leaves can avoid the harmful effect of increasing solar radiation. Also, the increase of cuticle thickness reduces the harmful effects of drought, salinity, and high radiation *via* limited water loss caused by transpiration. Thus, limits reaching salts in the photosynthetic tissues (Reef and Lovelock 2015, Koyro et al 2008).

The present results indicated a significant increase in the lamina thickness in the summer season due to an increase in both palisade and spongy tissue thick-

ness. Galmés et al (2013) suggested that the increase in the thickness of the palisade and the spongy could improve the distribution of chloroplasts and then increase the chloroplast area and number of CO₂ assimilation sites per leaf area unit. On the other hand, according to Vogelmann and Martin (1993), most leaves developed under conditions of increased light intensity are comparatively thick and have well-developed palisade tissue with a high amount of columnar cells. These columnar cells facilitate more uniform light distribution to chloroplasts within the leaf. This may allow for improvement in the vertical position of the chloroplasts and may respond to internal carbon dioxide concentration in the leaf. Thus, improving the entire photosynthesis process that may depend on the balance between the concentrations of both light and carbon dioxide. This balance could be achieved partly by controlling the level of palisade development. The anatomical results showed that the increase in the palisade tissue thickness was due to the palisade cells becoming more columnar not due to the increase in the palisade cell row number.

Increasing the lignification in the summery stem of *T. nilotica* can be explained according to Abd Elbar (2015) as increasing lignification provides mechanical support to the cell wall. The presence of sclerenchyma tissue surrounding the vascular bundle may confer resistance of phloem against destruction caused by abiotic stresses.

Chlorophyll (Chl) is the most important chloroplast component for photosynthesis. Since there is a direct proportion between the chlorophyll concentration and the photosynthetic rate. While carotenoids (Car) are important for photosynthesis photoprotection and they play a substantial role during plant growth under abiotic stresses. Generally, stressful environments cause a decrease in pigment concentrations (Ashraf And Harris 2013, Ansari et al 2019). There was no significant change in the concentration of chlorophyll A and B and carotenoids due to seasonal change.

Usually, the reactive oxygen species (ROS) are formed due to oxidative damage from environmental stresses. ROS can cause inactivation of enzymes, damage to the cell membrane and alter gene expression. Various organic molecules, including phenols and proline, can be used to scavenge the ROS (Abobatta 2020). Phenolics are known as antioxidants that help to prevent cellular damage induced by oxidative stress. They can directly scavenge molecular species of active oxygen or act as metal chelators (Bautista et al 2016).

This could explain the significant increase in total phenols in the summer season. Since lignin is synthesized from phenolic precursors (Selmar 2008), this may explain the increase in lignification in the summery stem.

A higher value of proline in shoot parts of *T. nilotica* in the summer season was observed. It may be used for several purposes including function as antioxidants by facilitating ROS scavenging, ensuring osmotic adjustment as well as protection of plasma membrane integrity, cellular structures and proteins. Proline can be used as a source of energy or reducing power. These results are in agreement with those reported by Per et al (2017) and Ansari et al (2019). Likewise, there was a significant increase in both free amino acids and total soluble sugars in the summer season in the shoot parts of *T. nilotica*. According to Yeo (1998), Couee et al (2006) and Abobatta (2020) organic molecules, such as free amino acids and soluble sugars improve the cell sap concentration and maintain the resistance of plants by acting as osmotic regulation. They have a stabilizing effect on the cell membrane, proteins and enzymes as an Osmo protectant.

4 Conclusion

Tamarix nilotica growing naturally in Egyptian salt marches has the ability to withstand the seasonal environmental stresses by many adaptation mechanisms. These mechanisms include salt secretion by salt glands as well as reducing water loss and increasing water use efficiencies by reduction of scaly leaf size, increasing cuticle, epidermis thickness and palisade tissue thickness. In addition to the physiological adaptive mechanisms (osmotic adjustment and antioxidant activity), increasing concentrations of proline, amino acids and total soluble sugars.

Abbreviations: Chl, chlorophyll; Car, Carotenoids; ROS, Reactive Oxygen Species.

Acknowledgment

The authors thank the Desert Research Center (DRC) for supporting the field experiments of this work.

References

- Abd Elbar OH (2015) Development of the successive cambia in *Sesuvium verrucosum* Raf (Aizoaceae). *Annals of Agricultural Science* 60, 203–208. <https://doi.org/10.1016/j.aos.2015.07.001>

- Abd Elbar OH (2017) Histological analysis of the developmental stages of direct somatic embryogenesis induced from in vitro leaf explants of date palm. In: Alkhayri JM, Mohan JS, Johnson DV (Eds), Date Palm Biotechnology Protocols Tissue Culture Applications (Vol. I). Springer, Berlin, pp 145–162.
https://doi.org/10.1007/978-1-4939-7156-5_13
- Abdelgawad AAM (2017) *Tamarix nilotica* (Ehrenb) Bunge: A review of phytochemistry and pharmacology. *Journal of Microbial & Biochemical Technology* 9, 1.
<https://doi.org/10.4172/1948-5948.1000340>
- Abd El-Gawad AM, Shehata HS (2014) Ecology and development of *Mesembryanthemum crystallinum* L. in the Deltaic Mediterranean coast of Egypt. *Egyptian Journal of Basic and Applied Sciences* 1, 9.
<https://doi.org/10.1016/j.ejbas.2014.02.003>
- Abd El-Maboud MM (2019) Seasonal variations effect on antioxidant compounds and their role in the adaptation of some halophytes at Wadi Gharandal, Southwest Sinai. *Annals of Agricultural Sciences* 64, 161-166.
<https://doi.org/10.1016/j.aoas.2019.11.001>
- Abdel Moghith SM, Salah M, Morad NA, et al (2015) Climate change detection in the northwestern coastal zone (Egypt) and its possible impact on water resource. *Egyptian Journal of Desert Research* 65, 233–255.
<https://doi.org/10.21608/EJDR.2015.5952>
- Abobatta WF (2020) Plant responses and tolerance to combined salt and drought stress. In: Hasanuzzaman M, Tanveer M (eds), Salt and Drought Stress Tolerance in Plants, Signaling and Communication in Plants. Springer Nature Switzerland AG, pp 17-53.
<https://doi.org/10.1007/978-3-030-40277-87>
- Ansari WA, Atri N, Pandey M, et al (2019) Influence of drought stress on morphological, physiological and biochemical attributes of plants: A Review. *Biosciences Biotechnology Research Asia* 16, 697-709.
<http://dx.doi.org/10.13005/bbra/2785>
- AOAC (2007) Official Methods of Analysis, 18th Ed. Association of Official Agriculture Chemists, Washington, DC, USA.
- Ashraf M, Harris PJC (2013) Photosynthesis under stressful environments: An overview. *Photosynthetica* 51, 163-190.
<https://doi.org/10.1007/s11099-013-0021-6>
- Bautista I, Boscaiu M, Lidon A (2016) Environmentally induced changes in antioxidant phenolic compounds levels in wild plants. *Acta Physiologiae Plantarum* 38, 9.
<https://doi.org/10.1007/s11738-015-2025-2>
- Brock JH (1994) *Tamarix* spp. (Salt Cedar), an invasive exotic woody plant in arid and semi-arid riparian habitats of western USA. *Ecology and Management of Invasive Riverside Plants* 4, 28-44.
- Couee I, Sulmon C, Gouesbet G, et al (2006) Involvement of soluble sugars in reactive oxygen species balance and responses to oxidative stress in plants. *Journal of Experimental Botany* 75, 449–459.
<https://doi.org/10.1093/jxb/erj027>
- Dubois M, Gilles KA, Hamilton JK (1956) Colorimetric method for determination of sugars and related substances. *Analytical Chemistry* 23, 350-356.
<https://doi.org/10.1021/ac60111a017>
- El-Marsafawy S, Bakr N, Elbana T, et al (2019) Climate. In: El-Ramady H, Alshaal T, Bakr N, et al (Eds), The Soils of Egypt, World Soils Book Series. Springer Nature Switzerland AG, pp 69-92.
<https://doi.org/10.1007/978-3-319-95516-2>
- El-Shaer HM, El-Morsy MHM (2008) Potentiality of salt marshes in north Mediterranean coastal area of Egypt. In: Abdelly CH, Öztürk M, Ashraf M, Grignon C (Eds), Biosaline Agriculture and High Salinity Tolerance, Veriage Birkhäuser Press, Switzerland, pp 207-219.
https://doi.org/10.1007/978-3-7643-8554-5_19
- Estefan G, Sommer R, Ryan J (2013) methods of soil, plant, and water analysis: A Manual for the West Asia and North Africa Region. 3rd ed, ICARDA, Beirut, Lebanon, pp 61-120.
<https://doi.org/20.500.11766/7512>
- Galmés J, Ochogavía JM, Gago J, et al (2013) Leaf responses to drought stress in Mediterranean accessions of *Solanum lycopersicum*: anatomical adaptations in relation to gas exchange parameters. *Plant Cell and Environment* 36, 920–935.
<https://doi.org/10.1111/pce.12022>

- Hameed M, Ashraf M, Ahmad MSA, et al (2010) Structural and functional adaptations in plants for salinity tolerance. In: Ashraf, M; Ozturk, M; Ahmad, MSA (eds), *Plant Adaptation and Phytoremediation*, Springer Science & Business Media BV, pp 151-170.
https://doi.org/10.1007/978-90-481-9370-7_8
- Holbrook NM, Putz FE (1996) From Epiphyte to tree: differences transition in growth forms in eight species of hemiepiphytes. *Plant Cell and Environment* 19, 631-642.
<https://doi.org/10.1111/j.1365-3040.1996.tb00398.x>
- Jayaraman J (1981) *Laboratory manual in biochemistry*. Wiley Eastern Ltd, New Delhi, 64 p.
<https://rb.gy/y7q7k>
- Kilmer NJ, Alexander LT (1949) Methods of making mechanical analysis of soils. *Soil Science* 68, 15-24.
<http://dx.doi.org/10.1097/00010694-194907000-00003>
- Koyro HW, Geissler N, Hussin S (2009) Survival at extreme locations: Life strategies of halophytes. In: Ashraf M, Ozturk M, Athar HR (Eds), *Salinity and Water Stress*, Springer Science & Business Media, pp 167-177.
https://doi.org/10.1007/978-1-4020-9065-3_17
- Koyro HW, Geissler N, Hussin S, et al (2008) Strategies of halophytes to survive in a salty environment. In: Khan NA, Singh S (eds), *Abiotic Stress and Plant Responses*, IK International Publishing House, New Delhi, pp 83-104.
- Lichtenthaler HK, Wellburn AR (1983) Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochemical Society Transactions* 11, 591-592.
<https://doi.org/10.1042/bst0110591>
- Moran R (1982) Formulae for determination of chlorophyllous pigments extracted with N, N-dimethylformamide. *Plant Physiology* 69, 1376-1381. <https://doi.org/10.1104/pp.69.6.1376>
- Per TS, Khan NA, Reddy PS, et al (2017) Approaches in modulating proline metabolism in plants for salt and drought stress tolerance: Phytohormones, mineral nutrients and transgenics. *Plant Physiology and Biochemistry* 115, 126-140.
<https://doi.org/10.1016/j.plaphy.2017.03.018>
- Petters W, Piepenbrock M, Lenz B, et al (1997) Cytokinin as a negative effector of phosphoenolpyruvate carboxylase induction in *Mesembryanthemum crystallinum*. *Journal of Plant Physiology* 151, 362-367.
[https://doi.org/10.1016/S0176-1617\(97\)80266-0](https://doi.org/10.1016/S0176-1617(97)80266-0)
- Reef R, Lovelock CE (2015) Regulation of water balance in mangroves. *Annals of Botany* 115, 385-395. <https://doi.org/10.1093/aob/mcu174>
- Saïdana D, Mahjoub MA, Boussaada O, et al (2008) Chemical composition and antimicrobial activity of volatile compounds of *Tamarix boveana* (Tamaricaceae). *Microbiological Research* 163, 445-455.
<https://doi.org/10.1016/j.micres.2006.07.009>
- Salsinha YCF, Maryani E, Indradewa D, et al (2020) Leaf physiological and anatomical characters contribute to drought tolerance of Nusa Tenggara Timur local rice cultivars. *Journal of Crop Science and Biotechnology* 24, 337-348.
<https://doi.org/10.1007/s12892-020-00082-1>
- Selmar D (2008) Potential of salt and drought stress to increase pharmaceutical significant secondary compounds in plants. *Landbauforsch Volkenrode* 58, 139-144. <https://rb.gy/pq1y2>
- Shlyk AA (1971) Determining chlorophylls and carotenoids in extracts of green leaves. *Biokhimicheskie metody v fiziologii rastenii (Biochemical Methods in Plant Physiology)* Pavlinova OA, (Ed), Moscow: Nauka, pp 154-170.
- Singleton VL, Rossi JA (1965) Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16, 144-158.
<https://www.ajevonline.org/content/16/3/144>
- Troll W, Lindsley J (1955) A photometric method for the determination of proline. *The Journal of Biological Chemistry* 215, 655-660.
<https://rb.gy/vox6u>
- Vogelmann TC, Martin G (1993) The functional significance of palisade tissue: penetration of directional versus diffuse light. *Plant Cell and Environment* 16, 65-72. <https://doi.org/10.1111/j.1365-3040.1993.tb00845.x>
- Yeo AR (1998) Molecular biology of salt tolerance in the context of whole-plant physiology. *Journal of Experimental Botany* 49, 915-929.
<https://doi.org/10.1093/jxb/49.323.915>
- Zahrán AM, Willis AJ (2009) *The Vegetation of Egypt*. 2nd Ed, Springer Science & Business Media BV, Cairo, pp 31-75.
<https://doi.org/10.1007/978-94-015-8066-3>