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RESEARCH ARTICLE

Morphological and anatomical changes in stems of *Aeluropus littoralis* under salt stress

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ABSTRACT: Salinity is one of the most important agricultural issues causing considerable yield reduction in agricultural crops. The main adverse effects of salinity are due to excess amount of sodium ions that is toxic to plant cells. Most halophytes are equipped with defense mechanisms enabling them to tolerate the salty habitats. Among grass plants, *Aeluropus littoralis* is a known monocots halophyte that can tolerate harsh saline conditions. In this study, salt treatment was applied in three levels of 0, 200 and 400 mM NaCl after 45 days and biological samples were collected at 7, 14 and 21 days after treatment (DAT). For microscopic analysis, the tissues were cross-sectioned and stained using methylene blue for lignified tissues and Congo red for cellulosic tissues. The amounts of Na^+ and K^+ were measured by flame photometer and the content of lignin was measured by polymeric thioglycolic acid derivatives method. The results showed that the amount of Na^+ increased 13-fold, while the stem length, stem diameter, vascular bundle number, metaxylem diameter, phloem diameter, K^+, fresh weight and dry weight decreased significantly by 35%, 48%, 59%, 19%, 25%, 45%, 64% and 55% under salt treatment, respectively. The amount of lignin in stem did not significantly change under salinity. According to these results, *A. littoralis* can tolerate saline habitats by different adaptation strategies like the limitation of minerals transition and reduction of plant biomass. Furthermore, the concentration of lignin in metaxylem tissues and stele parenchyma led to increased resistance of halophytes in excess amounts of Na^+.

Keywords: *Aeluropus littoralis*, K^+, lignin, Na^+, stele parenchyma, stem

Abbreviations: DAT, days after treatment; SL, stem length; SD, stem diameter; VBN, vascular bundle number; MD, metaxylem diameter; PD, phloem diameter; Lig, lignin; FW, fresh weight; DW, dry weight.

INTRODUCTION

Salinity is one of the most important environmental stresses that reduce growth and development of plants. The land under saline conditions in Iran is about 55.6 million hectares about 34% of the whole country (22). It was reported that saline soils contain large amounts of soluble cations (e.g. Na^+, K^+, Ca^+ and Mg^+) and anions (e.g. Cl^-, NO_3^-, SO_4^{-2} and HCO_3^{-1}) (28). In arid and semi-arid regions, soluble salts in the soil are mainly composed of chloride and sulfate of Na^+, Ca^+ and Mg^+, but bicarbonates are present partially or in trace amounts. Sodium ion is one of the toxic elements that cause poisoning in plant. The concentration of Na^+ is often

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associated with Cl^- that is found mostly in dicotyledonous plants stems. It has been reported that selectivity of K^+ is higher than Na^+ in monocotyledonous compared to dicotyledonous plants (30). Nowadays, due to the unrestricted use of natural resources and improper applications of technology in crop productions, especially unsuitable irrigation, the agricultural lands exposed to saline phenomena (17, 21). After treatment with 600 mM NaCl, the amount of Na^+ increased by 4-fold in root and 9.9-fold in shoot tissues of *Aeluropus lagopoides* (14). At cellular level, high ratio of K^+/Na^+ in the cytosol is essential for normal function. Uptake of Na^+ competes with K^+ through the symporters and Na^+ may block the K^+ selective carrier in the roots. Certainly, depending on plant species these processes are different (6). In other study, the effects of saline condition and silicone application on the amount of Na^+ and K^+ ions were reported in *Puccinellia distans* (3). This study revealed that salinity can increase Na^+ in both aerial and underground organs, but silicone treatment can reduce the sodium ions in shoot and root tissues. Changes in fresh weight and dry weight represent the biomass production of plants as an important physiological parameter. The dry weight of *A. littoralis* was significantly decreased under 800 mM NaCl salt stress (4). Another study showed that *A. littoralis* in comparison with *Puccinellia distans* has more dry weight in concentrations higher than 200 mM NaCl (26). A study on *Salsola dendroides*, *Alhagi persarum* and *Aeluropus lagopoides* revealed that dry weight, fresh weight, shoot length, number of branches and internodes of treated plants were mostly reduced under salt stress. It was reported that the amount of sclerotic vascular bundles of *A. lagopoides* increases in 200 mM NaCl treatment (31). Besides, some sclerenchyma tissues are developed around the vascular bundles of *A. littoralis* leaf under salinity (26). Due to the special cytophysiological characteristics of *A. littoralis* to enhance salt tolerance, this study was conducted to shed more light on some anatomical modifications in halophile plants in achieving salt tolerance. *A. littoralis* is a perennial grass distributed in many saline areas of Iran. It is an important economic plant having notable impact for use as forage and for biological reclamation of saline wastelands (2, 16). It is well-known that endodermis and exodermis may prevent the influx of Na^+ in root. In comparison, there are other strategies in the stem tissues of halophytes such as sclerification and lignification of stele parenchyma to increase the tolerance in salinity (25). Therefore, the main aim of the present work was to study the changes in morphological and anatomical features of stem tissues *A. littoralis* under salt stress.

MATERIALS AND METHODS

Plant growth and treatment

Whole plant and seeds of *A. littoralis* were collected from Miankaleh coast of the protected regions in the summer 2011. The plants were then grown in a phytotron with 210 μmoles/m^2/s, 16-h light, 60% relative humidity and 27 °C average temperature. The seeds were surface sterilized with hypochlorite sodium 10% and were sown in a soilless culture system in peat moss (32) with 1/2 Hoagland solution. Fertigation was performed with Hoagland solution twice a day (12). After 45 days, when the plants reached the stage of 7 to 8 leaves, the salt treatment was started. In order to osmotic balance of the plants, 25 to 50 mM NaCl was added to Hoagland solution gradually during a week up to 200 and 400 mM NaCl. To keep the salt concentration constant in the pots, three times irrigation with nutrient solution and the salt treatment were daily carried out. In order to prevent salt accumulation, the pots were washed with sufficient water at the end of each week. Sampling was performed during three weeks with 3 replications.

Morphohistological measurements

The length of stem was measured using a digital camera (Creative 900, 3 MP). For histological studies the cross-sections were prepared with a sharp razor blade. The tissues were stained with methylene blue for lignified tissues and Congo red for cellulosic tissues (24). Microscopic observations were carried out using a digital camera with a resolution of 740 × 430 pixels (Isfahan Optic Industries). Morphological and anatomical measurements were performed by Digimizer 4.1.1.0 software.

Physiological assessments

Fresh and dry weights of stems were recorded after exposing in an oven at 75 °C for 72 h. For measuring the concentrations of Na^+ and K^+, the shoots (0.5 g) were rinsed with distilled water and then were dried in an oven at 75 °C for 72 h. The powder of shoots was placed into the electric furnace at 550 °C for 16.5 h. The ash was moisturized with a few drops of distilled water and 2.5 ml of HCl (2N) was added for each 0.5 g of ash. The mixture was poured into a 50 ml balloon and then distilled water was added to bring the volume up to the

final 50 ml. The amounts of Na^+ and K^+ were measured by flame photometer (Sherwood, 410-UK) (23).

Lignin content

Lignin content was measured by polymeric thioglycolic acid derivatives method (8). Accordingly, fresh stem (0.05 g) was extracted in 0.4 ml ethanol 80%. The precipitation was mixed with 1 ml methanol and then was suspended in 0.5 ml thioglycolic acid (10%) and HCl 2N (v/v) (8). The solution was boiled at 100 °C for 4 h. After cooling, it was centrifuged at 14000 g for 6 min. The flocculent reddish-brown precipitate was rinsed with deionized water and then was dissolved in 0.5 ml NaOH (1N) for 16 h using a shaker (Rotator, Labnet). The suspension was centrifuged in 18000 g for 6 min and the supernatant was dissolved in 0.2 ml HCl (10N) and the suspension was cooled on ice bath for 1 h. After centrifugation, the precipitate was dissolved in NaOH 0.5N and the absorbance of the orange solution was recorded at 335 nm by a spectrophotometer (UV-Visible-1800 pc, Mapada) as a measure of phenolic polymer deposition.

Statistical analysis

All experiments were done in factorial randomized block design with three replications. The first factor was salt treatment in 200 and 400 mM NaCl and control plants and the second factor was the time. The data were analyzed by excel 2007 and SAS 9.1.3 software. The significance of the mean differences was determined by Duncan's multiple range tests at $P \leq 0.01$.

RESULTS

Morphohistological changes

The length of stem showed a 35.5% decrease in plants treated with 400 mM NaCl at 7 DAT compared to control plants (13 vs 20 cm). The subsequent decrease was observed by 33% and 25% in 200 and 400 mM NaCl at 21 DAT, respectively (Tables 1, 2). The stem diameter was decreased significantly from 1.16 to 0.61 mm (by 48%) in plants treated with 400 mM NaCl at 21 DAT (Tables 1, 2; Fig. 2). This decrease was recorded by about 30% in plants in 200 and 400 mM NaCl at 7 DAT. Vascular bundle numbers were decreased significantly from 39 to 17 at 14 DAT. It decreased by 35% and 41% at 7 DAT and by 58% and 50% at 14 DAT in 200 and 400 mM NaCl, respectively (Tables 1, 2). Metaxylem diameter decreased from 28 to 23 mm by 19% in plants treated with 400 mM NaCl at 14 DAT, while it decreased by 15% in 200 mM NaCl at 14 DAT. This reduction was observed by 12% and 14% in 200 and 400 mM NaCl at 21 DAT, respectively (Tables 1, 2; Fig. 3). The mean length and width of phloem was decreased by 25% in 400 mM NaCl at 21 DAT (Tables 1, 2).

Physiological characteristics

Fresh weight decreased from 0.66 to 0.24 g (by 64%) in plants treated with 400 at 21 DAT (Table 1). It was decreased by 52% and 58% in plants treated with 400 mM NaCl at 7 and 14 DAT. In 200 mM NaCl treatments, it

Table 1. The compare mean procedure for the changes in stem length (cm), stem diameter (mm), vascular bundle number, metaxylem diameter (µm), phloem diameter (µm), fresh weight (g) and dry weight (g) in 200, 400 mM NaCl treatments and control plants of *A. littoralis* at 7, 14 and 21 DAT.

Sampling time	Salt treatment	Stem length	Stem diameter	Vascular bundles number	Metaxylem diameter	Phloem diameter	Fresh weight	Dry weight
7 DAT	Control	20.20±1.35^{a}	0.98±0.012^{b}	34.67±0.67^{a}	26.92±1.23^{a}	33.20±1.26^{bc}	0.49± 0.05^{ab}	0.08± 0.01^{abc}
	200 mM	20.46±0.48^{a}	0.71± 0.02^{ef}	22.67±0.33^{bc}	25.20± 0.64^{a}	32.43±2.54^{bc}	0.43±0.04^{bc}	0.09± 0.01^{ab}
	400 mM	13.03±0.60 ^{b}	0.65±0.02f^{g}	20.33±0.33^{bc}	25.34± 0.97^{a}	42.20± 0.89^{a}	0.23±0.03^{cde}	0.05±0.01^{bcd}
14 DAT	Control	14.93±0.90 ^{b}	0.90± 0.01^{c}	38.67± 2.4^{a}	27.86± 0.94^{a}	35.55± 0.73a^{bc}	0.35±0.06^{bcde}	0.06±0.01^{bcd}
	200 mM	15.43± 1.07^{b}	0.73±0.02^{e}	16.00± 0.33^{c}	23.43± 0.3^{a}	28.78±1.62^{bc}	0.18±0.01^{de}	0.03±0.01^{d}
	400 mM	15.60± 0.90^{b}	0.73± 0.02^{e}	19.33±0.88^{bc}	22.52± 0.56^{a}	29.82±1.21^{bc}	0.14±0.02^{e}	0.04±0.01^{cd}
21 DAT	Control	21.83±0.45^{a}	1.15± 0.01^{a}	23.67±3.18^{b}	26.89± 3.79^{a}	36.62± 3.37^{ab}	0.66± 0.06^{a}	0.12±0.01^{a}
	200 mM	16.36± 0.88^{b}	0.80± 0.02^{d}	19.66±0.33^{bc}	23.61± 1.39^{a}	33.08±0.94^{bc}	0.37±0.09^{bcd}	0.08± 0.02^{ab}
	400 mM	14.60±1.01^{b}	0.60± 0.01^{g}	17.00±2.08^{bc}	23.08±1.96^{a}	27.57± 1.75^{c}	0.23±0.02^{cde}	0.05±0.01^{bcd}

Means ± SE followed by same letters are not significantly different ($P < 0.01$).

Table 2. Analysis of variance (ANOVA) for the effects of salinity and time, and their interaction on different parameters including stem length (cm), stem diameter (mm), vascular bundle number, metaxylem diameter (μm), phloem diameter (μm), fresh weight (g) and dry weight (g) in NaCl-treated and control plants of *A. littoralis* at 7, 14 and 21 DAT.

Source of variance	DF	Stem length	Stem diameter	Vascular bundle number	Metaxylem diameter	Phloem diameter	Fresh weight	Dry weight
Salinity	2	5.59*	33.38**	18.95**	5.15*	1.06	9.81**	4.97*
Time	2	0.66	0.02	0.11	1.16	0.14	0.03	0.02
Salinity × Time	4	0.17	0.01	0.69	1.17	0.52	0.30	0.50
Error	18	156.74	0.16	496.6	119.77	522.61	0.36	0.012
CV	-	17.42	12.54	22.25	10.32	16.2	40.96	41.31

** and * indicate a significant difference at $P < 0.01$ and at $P < 0.05$, respectively.

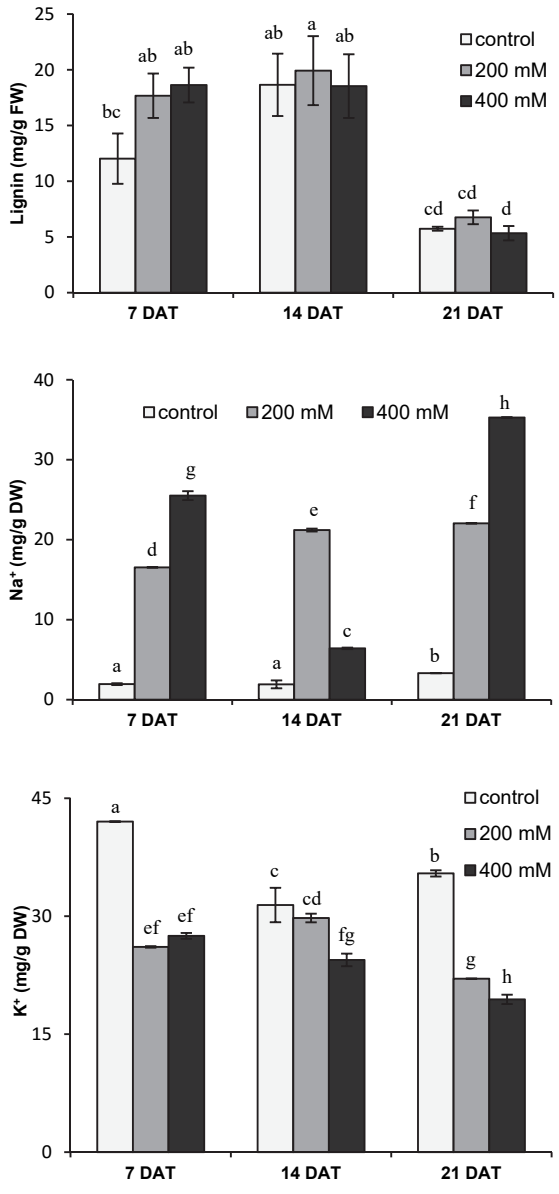

Fig. 1. Changes of lignin, Na^+ and K^+ in lowermost segment of *A. littoralis* stem in NaCl-treated and control plants at 7, 14 and 21 DAT.

was decreased by 47% and 42% at 14 and 21 DAT, respectively (Tables 1, 2). Dry weight was decreased from 0.07 to 0.03 g by 55% in 400 mM NaCl at 14 DAT. It was reduced by 33% and 53% in 400 mM NaCl at 7 and 21 DAT, respectively, while it was decreased by 42% in 200 mM NaCl at 14 DAT (Tables 1, 2). The maximum Na^+ increase by 13-fold from 2 to 25.5 (mg/g DW) was observed in plants treated with 400 mM NaCl at 7 DAT. The increasing trend was observed by about 11-fold in 200 and 400 mM NaCl at 14 and 21 DAT. In spite of Na^+, the lowermost K^+ was observed by a decrease of 45% from 35.5 to 19.5 (mg/g DW) in 400 mM NaCl at 21 DAT and was decreased by 38% in 200 mM NaCl at 7 and 21 DAT (Fig. 1).

Changes in lignification pattern

Lignin content of stem was increased from 12 to 17.5 and 18.5 (mg/g FW) by 55% and 47% in 200 and 400 mM NaCl at the beginning of salt stress (7 DAT), respectively, but the increasing trend was gradually reduced to 5.5 (mg/g FW) by 7% during the time (Fig. 1). Totally, the amount of lignin did not show significant differences under salt stress with time, but the methylene blue staining indicated that the lignin concentration was enhanced in the parenchyma tissues around the vascular bundles by increasing of salt concentration (Fig. 2, 3).

The correlation of characteristics

The Na^+ concentration showed reverse relation with most of the phenotypic parameters (e.g. stem length, stem diameter, vascular bundle number, metaxylem diameter and fresh weight). In comparison, the K^+ concentration had direct relation with most of measured characteristics (e.g. stem length, stem diameter, vascular bundle number, metaxylem diameter and fresh weight). There was a direct relation between the stem length and stem diameter with

Table 3. Correlation of stem length (SL), stem diameter (SD), number of vascular bundles (VBN), metaxylem diameter (MD), phloem diameter (PD), lignin (Lig), Na^+, K^+, fresh weight (FW) and dry weight (DW) 200 and 400 mM NaCl treatments and control plants of *A. littoralis* at 7, 14 and 21 DAT.

	SL	SD	VBN	MD	PD	Lig	Na^+	K^+	FW	DW
SL	1									
SD	0.651**	1								
VBN	0.217ns	0.531**	1							
MD	0.254ns	0.404*	0.418*	1						
PD	ns0.024	0.226ns	0.264ns	0.523**	1					
Lig	-0.287ns	-0.226ns	0.099ns	0.017ns	0.048ns	1				
Na^+	-0.486**	-0.776**	-0.696**	-0.391*	-0.183ns	-0.164ns	1			
K^+	0.515**	0.737**	0.607**	0.447*	0.272ns	0.104ns	-0.723**	1		
FW	0.715**	0.731**	0.337ns	0.564**	0.306ns	-0.405*	-0.451*	0.555**	1	
DW	0.617**	0.578**	0.201ns	0.501**	0.301ns	-0.461*	-0.259ns	0.347ns	0.954**	1

**Indicates a significant difference at $p < 0.01$, * significant difference at $p < 0.05$ and ns no significant difference.

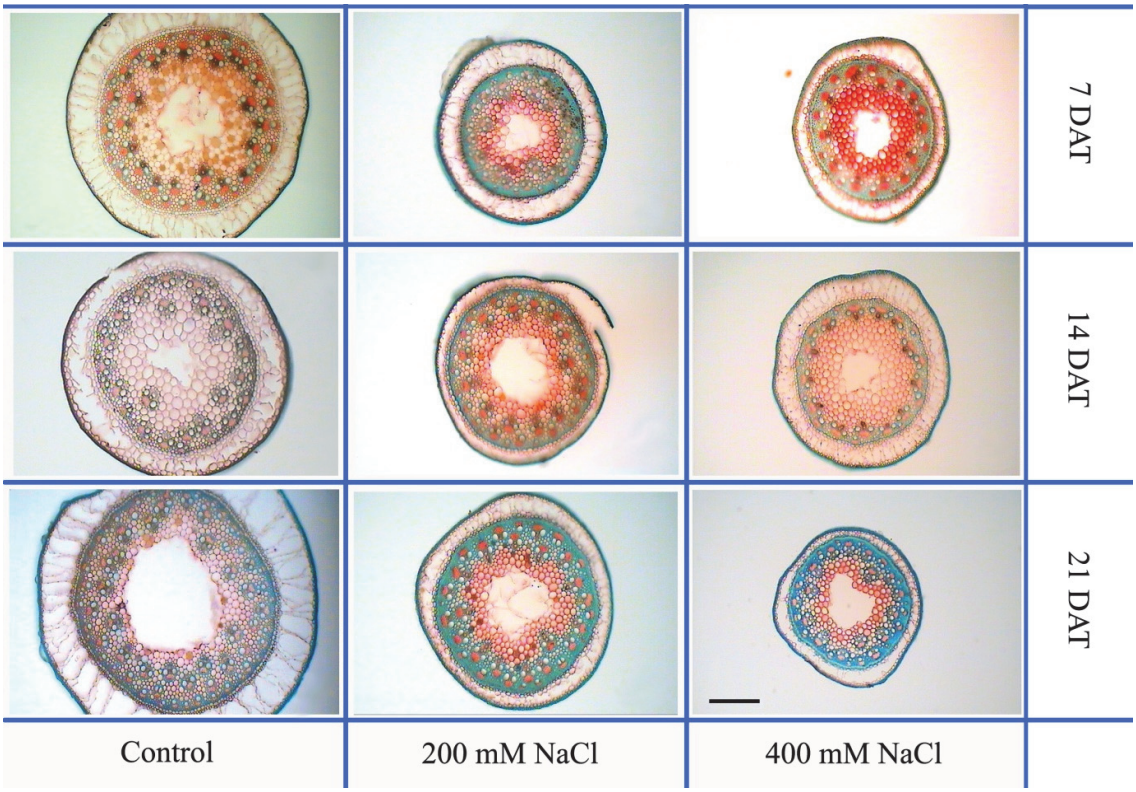

Fig.2. Cross-sections of lowermost segments of *A. littoralis* stem presenting lignification patterns (methylene blue) in control, 200 and 400 mM NaCl treatments at 7, 14 and 21 DAT. Scale = 0.2 mm.

significant differences at $P < 0.01$. There was a direct relation between fresh weight and dry weight (Table 3). Metaxylem diameter showed significant relation with phloem diameter at $P < 0.01$. Further, the most important correlation was observed between Na^+ and K^+ in direct relation with significant differences at $P < 0.01$.

DISCUSSION

In this study, shoot length was reduced predominantly up to 400 mM NaCl. In 5 different ecotypes of *Aeluropus lagopoides*, stem length decreased with salt increase in different habitats (25). In *Sesbania sesban*, the roots have limited growth compared to stems under salt stress. Generally, root length, leaf size and stem length were decreased in this plant species (18). In another study on four plant species including *A. littoralis*, the stem length was significantly reduced (13). However, it is also reported that salinity did not cause significant differences on root length on *A. littoralis* and the interaction between salinity and drought did not show specific trend (1). In *Sporobolus ioclados*, the shoot length decreased under

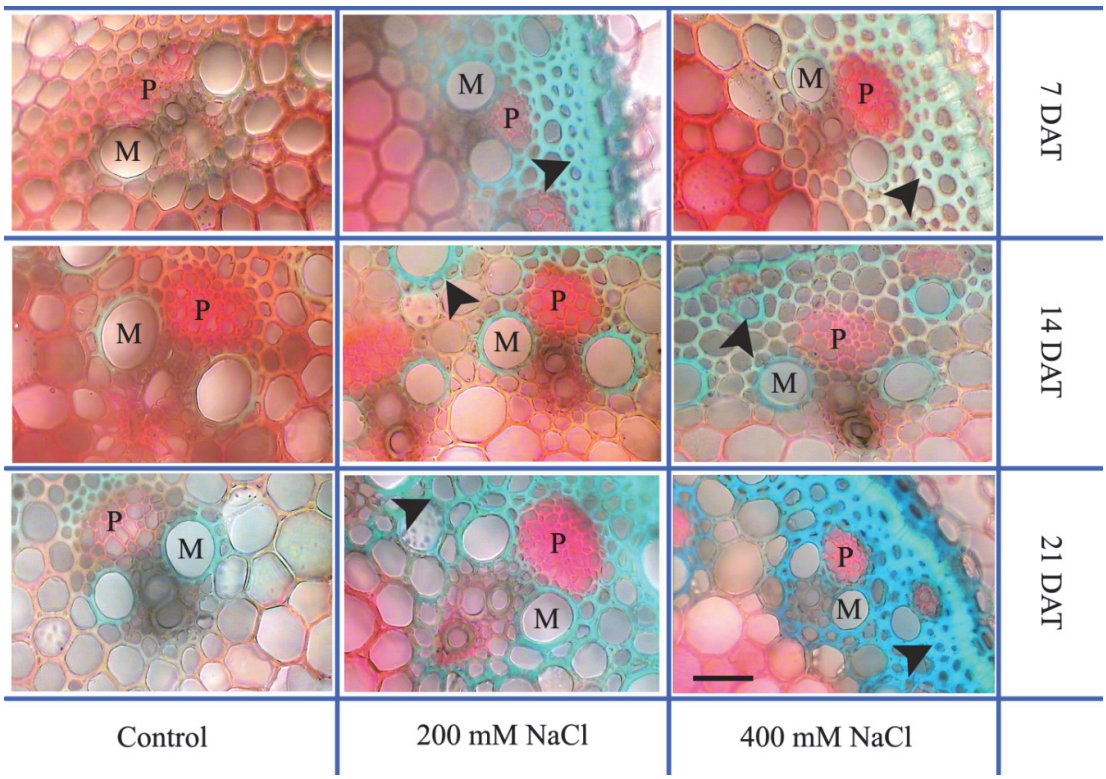

Fig. 3. Cross-sections of lowermost segments of *A. littoralis* stem showing metaxylem diameter, phloem diameter and lignification patterns (methylene blue) in control, 200 and 400 mM NaCl treatments at 7, 14 and 21 DAT. M; metaxylem, P; phloem. Black arrows; lignification of stele parenchyma. Scale = 25 µm.

NaCl treatments up to 500 mM (10). Probably, the restriction of stem length leads to the reduction in metabolism of halophytes, which is necessary for surviving. In our study, the stem diameter decreased significantly. In some halophytes, e.g. *Nitraria retusa* and *Atriplex halimus*, the stem cross-sections areas were decreased at NaCl concentrations up to 800 mM (5). The numbers of vascular bundles were reported to be decreased under salt stress in stem of *A. littoralis* (16). The metaxylem area of 5 ecotypes of *A. lagopoides* was decreased by increase in salt concentration at different habitats (25). In some halophytes, the xylem vessel diameter was decreased after NaCl treatments up to 800 mM (5) and the phloem diameter reduced similarly in salt stress. For Instance, in *Imperata cylindrical* the phloem area decreased under salinity (11).

As mentioned, most of the morphological and anatomical parameters like stem length, stem diameter, vascular bundles, metaxylem diameter and phloem diameter were decreased under salt stress in *A. littoralis* and other halophytes. Accordingly, the halophytes diminish the most crucial physiological functions like transition of mineral and organic materials in stems. Moreover, *A. littoralis* as a halophyte probably inhibits the Na^+ influx to the plant tissues in this manner (33).

Fresh and dry weights indicate the biomass production by plants. Halophytes may improve their resistance to saline stress with diminishing fresh and dry weight (26). The fresh and dry weights were decreased by an increase in salt concentration in 5 ecotypes of *A. lagopoides* in different habitats (25). In a research on the halophyte *Puccinellia distans*, salinity just affected shoot fresh weight and despite the moderate decline, it did not significantly affect other growth phenotypes (3).

In the current study the amount of Na^+ was enhanced in roots of *A. littoralis* under salinity (up to 400 mM NaCl), although the content of K^+ was simultaneously reduced. Similarly, in *Aeluropus littoralis* stems the amount of Na^+ increased at NaCl concentrations up to 800 mM, but the K^+ content was decreased (7, 20). The maximum amount of K^+ (128.6 mg/g) was observed in root tissues of *A. lagopoides* in natural conditions. Apparently, competition between uptake of K^+ and Na^+ has significant differences (14). In *Sporobolus ioclados,* the Na^+ content of shoot

increased at NaCl concentrations of 0 to 200 mM and then decreased up to 500 mM NaCl (10). The Na:K ratio in *Urochondra setulosa* was increased at treatments up to 800 mM NaCl and then decreased at concentrations up to 1000 mM NaCl (9). It is well-known that the salt-tolerant plants accumulate these ions mostly in the vacuole. Osmotic balance of vacuoles, cytosol and the apoplastic pathway are the reason of accumulation of K^+ and some compatible osmolytes such as proline in cytosol. However, the accumulation of Na^+ and Cl^- in cytosol of salt-sensitive plants causes the poisoning, reduction of enzymes activity, water efflux and deficiency in the cells (19). The Na^+ competes with K^+ through Na-K carriers and even more, the K^+ can probably block these carriers. In this way, the carriers have an effective role under salt stress in homeostasis of K^+/Na^+ ratio (33).

Lignification of cell walls plays many important roles in terrestrial plants. For example, it acts as a mechanical barrier against physical injuries and penetration of the pathogens (27). It improves wood properties for pulp and papermaking and biofuel productions (15). In addition, increasing the lignin biosynthesis is one of the adaptive reactions to saline conditions. Excess amounts of Na^+ affect the process of lignin biosynthesis in saline conditions. A variety of enzymes and genes are involved in lignification process induced by salt stress. Lignification usually occurs in large vessels and fibers which their elongation is stopped (28). Based on our findings, lignification was exceeded in stele parenchyma in addition to the metaxylem and fibers of stem under salt stress.

CONCLUSION

Most of morphological and anatomical features were altered in *A. littoralis* under salt stress. Actually, the halophyte decreases the most crucial physiological functions in stem by limiting the growth progress. Consequently, *A. littoralis* inhibits the Na^+ influx to the plant tissues. *A. littoralis* responses lead to energy saving with decreasing the biomass by lowering the growth of tissues and organs under salt stress. The amount of Na^+ was increased in salt stress but the K^+ was decreased in *A. littoralis* stems. Lignification was intriguingly exceeded in stele parenchyma in addition to the metaxylem and fibers of stem in salinity. Lignifying a cell has an apathetic role in plants. In fact, the halophytes move towards control of life span in saline condition.

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تغییرات مورفولوژیک و آناتومیک در ساقه گیاه چمن شور ساحلی (*Aeluropus littoralis*) تحت تنش شوری

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چکیده

شوری یکی از عوامل مهم مطرح در کشاورزی است که موجب کاهش قابل توجه در محصولات کشاورزی می گردد. اثرات متعدد مهم شوری از مقدار بالای یون سدیم ناشی می شود که برای سلول های گیاهی سمی می‌باشد. اغلب گیاهان شوررُست مجهز به سیستم‌های دفاعی هستند تا قادر به تحمل زیستگاه‌های شور گردند. در این میان گیاه چمن شور یک گیاه تک لپه‌ای مقاوم به شوری شناخته شده می‌باشد که شرایط سخت شوری را تحمل می‌کند. در این تحقیق، تیمار شوری در سه سطح ۰، ۲۰۰ و ۴۰۰ میلی‌مولار کلرید سدیم اعمال گردید و پس از ۴۵ روز تنش شوری، نمونه برداری بعد از ۷، ۱۴ و ۲۱ روز انجام پذیرفت. در بررسی‌های میکروسکوپی، برش‌های عرضی تهیه و با متیلن بلو برای بافت‌های لیگنینی و قرمز کنگو برای بافت‌های سلولزی رنگ آمیزی گردیدند. مقدار سدیم و پتاسیم بوسیله دستگاه فلیم فتومتر و مقدار لیگنین با استفاده از روش سنجش مشتقات پلیمری اسید تیوگلیکولیک اندازه گیری شد. بر اساس نتایج بدست آمده، تحت تنش شوری مقدار یون سدیم (Na^+) ۱۳ برابر افزایش یافت، در حالیکه طول ساقه، قطر ساقه، تعداد دسته‌های آوندی، قطر متازایلم، قطر بافت آبکش، مقدار یون پتاسیم (K^+)، وزن تر و وزن خشک بطور معنی‌دار به ترتیب ۳۵٪، ۴۸٪، ۵۹٪، ۱۹٪، ۲۵٪، ۴۵٪، ۶۴٪ و ۵۵٪ کاهش یافت. مقدار لیگنین ساقه تحت تنش شوری تغییرات معنی‌دار نشان نداد. بر اساس این نتایج، گیاه چمن شور ساحلی می‌تواند زیستگاه‌های شور را با راهبردهای تطبیقی مختلفی نظیر محدود کردن انتقال مواد و کاهش زیتوده گیاهی تحمل نماید. علاوه بر این، تجمع لیگنین در بافت‌های متازایلم و پارانشیم استوانه‌ای به افزایش مقاومت گیاهان شوررُست در فزونی Na^+ منتج می‌گردد.

کلمات کلیدی: گیاه چمن شور ساحلی، یون پتاسیم، لیگنین، یون سدیم، پارانشیم استوانه‌ای، ساقه