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Tolerance of Beach Bean, *Canavalia maritima* MART. to Foliar Salt Stress

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Abstract: Tolerance of *Canavalia maritima* MART to foliar salt stress was examined in the greenhouse study to have an insight into its ecophysiological adaptations in the strandline. Seedlings were subjected to different foliar spray with seawater at: two sprays per week (2SS), four sprays per week (4SS) or six sprays per week (6SS), which equaled on average 4, 8 and 12 mg NaCl dm^{-2} leaf area day^{-1} respectively. Seedlings sprayed with de-ionized water served as control (CSS). Salt spray did not alter plant survival but suppressed growth. It significantly reduced the growth parameters taken, except stem girth, number of roots and root length, that did not significantly differ from control. Leaf total chlorophyll also declined significantly under salt spray. Fresh and dry mass values of leaves and stem of seawater-sprayed seedlings were significantly lower than control. Shoot mass and total biomass likewise reduced, but root: shoot ratio increased significantly under salt spray. Plants sprayed with seawater reduced ion toxicity by increasing stem and leaf succulence for ion dilution and decreased xylem water potential to minimize water stress. Seawater-treated plants accumulated Na^+ and Cl^- ions in the aerial parts leading to ion toxicity but lowered $Ca^{2+,}$ Mg^{2+}, K^+ and Fe^{2+} essential for growth. Increased N in the shoot under salt spray was suggestive of the quaternary amino compounds for osmotic adjustment. Salt spray application increased total nutrient and percentage ash, contributed mainly by Na^+ and Cl^- ions. Na: K ratio values were elevated by sea spray. Seedlings exposed to seawater spray minimized water loss through reduced leaf area and stomata density/stomata number per leaf. Salt spray caused necrotic leaf damage and reduction in plant visual ratings but at a non-significant level. Seawater spray negatively affected *Canavalia maritima* growth, but it has developed some adaptations to withstand seawater spray-related stress in the strandline. Its high aesthetic value makes it suitable for use in beach landscaping.

Key words: Seawater spray · Beach bean · Strandline · Growth · Ion accumulation · Necrosis · Stomata · Visual ratings

INTRODUCTION

Strandlines are areas where litter, debris and many discarded items are left behind by the previous receding tide, above the high water mark [1]. Strandline is a unique habitat because only (i) few species occupy this zone and those that are dominant are found only within this zone and (ii) the environment is characterized by the most extreme environmental conditions [2]. Consequently, morphological, growth, anatomical and physiological adaptations are likely to have been emphasized by selection and hence may be more easily recognized and quantified.

Despite that strand vegetation has ecological, social and economic values; it has received considerably little attention. Many of the studies on salt tolerance in strandline plants have been limited to saline soil or saline irrigation [3-4], while little information specific to strand plants and salt sprays-related growth and quality under non-saline irrigation conditions exists in the scientific literature, particularly in Africa. Unlike the salt marsh where plant species are exposed to tidal inundation and thus to high salinity [5], the strandline is out of reach of mean high tide and only rarely flooded with seawater [6]. Thus, salt exposure at the strandline is mainly composed of salt sprays and plants are often more sensitive to saline

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spray than to salt applied at the root zone [6-10]. Salt spray suppresses plant growth and disrupts water balance, membranes and enzyme systems [6]. It inhibits nutrient uptake [11] and causes necrotic damage [8, 12]. Air-borne salt led to a reduction in shoot and root growth in *Triplasis purpurea* [13], *Leymus mollis* [14], *Myrica pensylvanica* [12], Crambe maritima [10]. *Diodia maritima* [15] and *Commelina erecta* subsp *maritima* [16]. Studies on salinity tolerance have offered some explanations of species abilities to grow on the strandlines [5, 17]. For example, Crambe maritima minimize water loss through a reduction in leaf surface area available for transpiration. Salt spray increases water content in some plants, which is an adaptation for ion dilution [6, 10]. Also, salt spray disrupts water balance in plants and only the tolerant species can adjust osmotically through reduced xylem water potential [9, 12]. Thus, plant species growing in the strandline have adapted to salt spray in various ways [6].

Canavalia maritima is a strandline plant that is dominant and widely spread along the coast of West Africa. It is commonly called beach bean or bay bean and belongs to Fabaceae family. It is an herbaceous perennial legume. It is a ground vine with elliptical dark green with a network of veins. It has small racemes of purple flowers and the fruits are woody thick pods; each pod consists of 4-9 large greenish brown to dark brown seeds. It is ecologically important in shoreline stabilization, erosion control and serves as food and spawning sites to some coastal animals. It is has medicinal uses as well as making incense, especially when blended with other incense herbs. Since it is dominant and confined to the strandline, it is hypothesized that it has some adaptations to withstand sea spray-related stress. A greenhouse experiment was therefore conducted to determine the tolerance of *Canavalia maritima* to salt spray and to have an insight into the ecophysiological adaptations underlying the responses.

In addition, the death and low aesthetic values of ornamental plants due to scorching effect of seawater spray, are major challenges to ornamental growers and residents of coastal communities [11, 21] and landscape value is largely determined by the physical appearance rather than survival of individual plants [23]. In view of this, leaf necrosis, an aesthetically important symptom of damage and visual ratings were also determined on the leaves of the plant in order to ascertain its suitability for landscape projects in coastal beaches.

MATERIALS AND METHODS

Seedling Preparation and Experimental Set up: Seeds of *Canavalia maritima* collected from Arogbo Ijaw Seaside Beach, Ondo State, Nigeria were mechanically scarified to break dormancy and sown in 20 X 26 cm perforated plastic pots containing 2:1 mixture (v/v) of river sand to topsoil [13, 18]. The soil had 5.48 pH, 20.42 ppm N, 3.56 ppm P, 3.56 (meq/100g) K, 2.32 (meq/100g) Ca, 2.60 (meq/100g) Mg, 8.2 (meq/100g) CEC, 3.67% C, 80.68% sand, 12.06% silt and 8.36% clay [15-16, 19-20]. The experiment was conducted in the greenhouse of Plant Science and Biotechnology Department, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria (Lat. 7° N 28^1, Long. 5°S 44^1 E). Sea spray water was collected by the conventional method along the shore at Arogbo Ijaw Seaside Beach, Ondo State, Nigeria on a single day in late September, 2013. Seawater spray collectors were arranged parallel to the coastline at about 10 m from mean seawater level (mean tide line). Each seawater spray collector was made up of polypropylene filter gauze wrapped over a 30 cm long plastic tube placed vertically in a beaker. The collectors were fixed on the ground with about 20 cm of the upper part exposed. The beaker was to collect precipitation and prevent loss of trapped water [10, 12, 21]. The seawater was stored in a plastic keg and kept at 4°C. It had salinity of 31 ppt, with sodium and chloride accounting for approximately 86% of the ions present. Spray treatments commenced in late September 2013 and lasted for 12 weeks. Plants were sprayed twice/week (on Mondays and Thursdays) with seawater at: 2 sprays/week (2SS) - 1 spray on each of the two days), 4 sprays/week (4SS) - 2 sprays on each of the two days or 6 sprays/week (6SS) - 3 sprays on each of the two days. The plants under control were sprayed with de-ionized water 3 times on each of the two days, to account for any mechanical or physical effects of the misting process. Individual plants were taken outside and sprayed to run-off with all the aerial parts equally exposed, using a plant mist bottle held about 20 cm from the shoot. Plants were sprayed at 4-hour interval from 08:00 am. The salt loads at each level of spray were estimated following 13. Five plants not used in the experiment but grown with the experimental plants were each immersed in 150 ml of de-ionized water and the conductivity determined. The same shoot was sprayed once with seawater, immersed into 150 ml of de-ionized water and the conductivity increase was recorded. The conductivity increase was also recorded after the same shoot was sprayed twice and thrice respectively following immersion in 150 ml of de-ionized water. This was repeated for all the 5 plants. Salt deposition was estimated per square decimeter of leaf area surface for each of the three seawater treatments at each application. The accumulated salt onto shoot for 1 spray, 2 sprays and 3 sprays equaled on average 4, 8 and 12 mg NaCl dm^{-2} leaf area day^{-1}, which fall within the levels found in the natural habitat of strandline plants [9, 17]. Plastic discs were placed over the soil surface and around the base of each plant before spraying to prevent salt deposition on the soil, to ensure that the relative level of airborne salt deposited onto the shoots would be the primary cause of any observed effect rather than soil salinity or combined effect of substrate and air-borne salt [1, 9, 13]. Weekly, plants were watered from the top of the soil surface at the base of the plants, which did not remove the salts deposited onto the shoots, to flush out any salts that might have been deposited onto the soil during misting. Salt spray was allowed to accumulate throughout the experiment, which is realistic in the field because in years with infrequent rain, salt spray is not washed off during the summer growing season [13, 22].

Growth Measurement: At the end of the study, plant survival was recorded while plant height, leaf area and stem girth were measured with meter rule, leaf area meter (LI-COR 300 model) and digital vernier caliper (model 0-200 mm) respectively. Number of leaves and branches were counted. Number of roots was counted, while their length measured after harvest. Fresh and dry mass of plant parts were weighed, while root: shoot ratio and relative growth rate (RGR) were calculated with the commonly used formulae: root mass/shoot mass and (ln mass2-ln mass1)/ time respectively.

Determination of Water Status: Moisture content and xylem water potential were the two aspects of water status determined. Moisture content was calculated with the commonly used formula: [(fresh mass– dry mass)/dry mass] x 100, while plant xylem water potential was measured with a plant moisture-stress instrument (PMS Instrument Co., Oregon, USA) on six randomly selected stems from each treatment. Pre-dawn xylem water potential was measured between 06.00 and 07.00 am while mid-day xylem water potential was measured between 12:00 noon and 1:00 pm.

Leaf Chlorophyll and Mineral Content Determination: Leaf total chlorophyll was extracted with 80% acetone and calculated with the formula: $(20.2 \times D_{645} + 8.02 \times D_{663}) \times (50/1000) \times (100/5) \times ½$, where D = absorbance [24]. Soil physicochemical parameters and plant nutrient content were assayed following the standard methods of the Association of Official Analytical Chemists [25] in the Central Laboratory of The National Institute for Oil Palm Research (NIFOR), Nigeria.

Estimation of Stomata, Necrotic Leaf Area and Visual Ratings: Stomata number and necrotic damage were estimated following the conventional method [26]. The stomata number per leaf was estimated as the product of stomata density and leaf area. The area of leaf tissue with necrotic damage was measured using a dot grid and expressed as the percentage of total leaf area showing necrosis [8, 12] at 2-week interval to know the stage at which necrotic damage occurred. Visual ratings were conducted by six observers based on foliage appearance, with 1 = no green foliage, 2= 25% green foliage, 3 = 50% green foliage, 4= 75% green foliage and 5 = all green foliage [11]. Although quality standards differ, researchers deem ratings of 1 and 2 as unacceptable, 3 as marginally acceptable and ratings of 4 and 5 as acceptable in most professionally maintained landscape situations [11].

Statistical Analysis: Data were subjected to single factor ANOVA and means were separated with Tukey Honest Significant Difference (HSD) test using SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA) at 95% level of significance.

RESULTS

Plant survival was not altered by seawater spray but growth was inhibited (Table 1). Internode length, plant height, leaf area, number of leaves, number of branches and relative growth rate were significantly reduced ($p \leq 0.05$) by sea spray compared to the control. Stem girth, number of roots and root length were not affected by seawater spray. Leaf total chlorophyll was significantly lower in plants exposed to salt spray than in those sprayed with de-ionized water. Dry and fresh mass values for leaf, stem and shoot declined with increasing level of seawater spray, which significantly differ ($p \leq 0.05$) from control (Table 2). Root mass was however not

Table 1: Percentage survival, growth parameters and leaf total chlorophyll of *Canavalia maritima* after 12 weeks of exposure to different levels of salt spray

	Level of salt spray			
Growth parameter	CSS	2SS	4SS	6SS
Survival at harvest (%)	100	100	100	100
Number of nodes/plant	10.40^{a}	7.60^{a}	8.40^{a}	7.00^{a}
Internode length (cm)	3.25^{a}	2.18^{ab}	2.13^{ab}	1.73^{b}
Plant height (cm)	29.98^{a}	19.1^{b}	17.00^{b}	14.88^{b}
Stem girth (cm)	3.46^{a}	3.47^{a}	3.34^{a}	3.32^{a}
Leaf area (cm^2)	33.50^{a}	26.19^{b}	23.32^{b}	25.87^{b}
Number of leaves/plant	15.60^{a}	10.60^{b}	8.80^{b}	7.00^{b}
Number of branches/plant	6.20^{a}	4.60^{b}	3.80^{b}	3.60^{b}
Number of roots/plant	18.14^{a}	16.23^{a}	15.62^{a}	14.56^{a}
Root length (cm)	24.32^{a}	25.53^{a}	21.01^{a}	22.65^{a}
Relative growth rate (mgg-1 dry mass)	0.054^{a}	0.042^{b}	0.038^{b}	0.039^{b}
Leaf total chlorophyll (mgg^{-1} fresh weight	0.82^{a}	0.78^{b}	0.79^{b}	0.76^{b}

Each value is a mean of 6 replicates. For each parameter, means with the same letter(s) in superscript in the same row are not significantly different at $P \geq 0.05$ (Turkey HSD). CSS = deionized water sprays (control), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week.

Table 2: Biomass accumulation and water status of *Canavalia maritima* after 12 weeks of exposure to different levels of salt spray

		Level of salt spray			
	Plant part	CSS	2SS	4SS	6SS
Fresh	Leaf	7.38^{a}	3.68^{b}	3.25^{b}	3.28^{b}
mass (g)	Stem	5.93^{a}	4.54^{b}	4.56^{b}	4.45^{b}
	Root	4.81^{a}	4.68^{a}	4.76^{a}	4.59^{a}
	Shoot	13.40^{a}	8.25^{b}	7.64^{b}	7.57^{b}
Dry	Leaf	3.51^{a}	1.92^{b}	1.71^{b}	1.70^{b}
mass (g)	Stem	3.20^{a}	2.51^{b}	2.52^{b}	2.46^{b}
	Root	2.87^{a}	2.79^{a}	2.81^{a}	2.71^{a}
	Shoot	6.71^{a}	4.43^{a}	4.23^{a}	4.16^{a}
Biomass		9.59^{a}	7.22^{b}	7.03^{b}	6.86^{b}
Root: shoot		0.43^{b}	0.63^{a}	0.66^{a}	0.65^{a}
Moisture	Leaf	52.48^{a}	47.77^{b}	47.53^{b}	48.29^{b}
Content (%)	Stem	45.98^{a}	44.77^{ab}	44.68^{ab}	44.73^{ab}
	Root	40.23^{a}	40.45^{a}	41.05^{a}	41.03^{a}
Water potential (-MPa)	Predawn	3.12^{c}	5.33^{b}	7.14^{a}	7.41^{a}
	Mid day	3.12^{c}	5.52^{b}	7.23^{a}	8.02^{a}

Each value is a mean of 6 replicates. For each parameter, means with the same letter(s) in superscript in the same row are not significantly different at $P \geq 0.05$ (Turkey HSD). CSS = deionized water sprays (control), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week.

affected by seawater spray. Leaf and stem succulence was induced by seawater spray but One-way ANOVA showed that only the leaf was significant ($p \leq 0.05$) in comparison to control treatment. Seawater spray caused a significant ($p \leq 0.05$) decline in plant xylem water potential as the treatment level increased. The values obtained at mid-day were slightly lower than at predawn (Table 2).

Except Fe^{2+} in the stem with a slight increase, other nutrients including Ca^{2+}, Mg^{2+}, K^{+} and Fe^{2+} had less values in the aerial parts of salt-treated plants than did control (Table 3). No significant difference ($p \leq 0.05$) was obtained in the nutrients between the control and seawater sprayed seedlings. Seedlings sprayed with seawater had higher N in leaf and stem but One-way ANOVA showed a significant difference only in the leaf in comparison to those sprayed with de-ionized water. Seawater-treated plants accumulated more Na^{+} and Cl^{-} ions in leaf and stem than did control. This accumulation was increased with increasing level of seawater application, which culminated in significantly ($p \leq 0.05$) higher total nutrient and percentage ash. Also in the shoot, seawater spray resulted in a significant increase ($p \leq 0.05$) of Na: K ratio values over the control. In the root however, seawater spray had no effect on the nutrient composition of the test plant.

Seawater spray resulted in a more scattered stomata on the abaxial leaf surface (Plate A) bringing about a decrease in stomata density and consequently on number

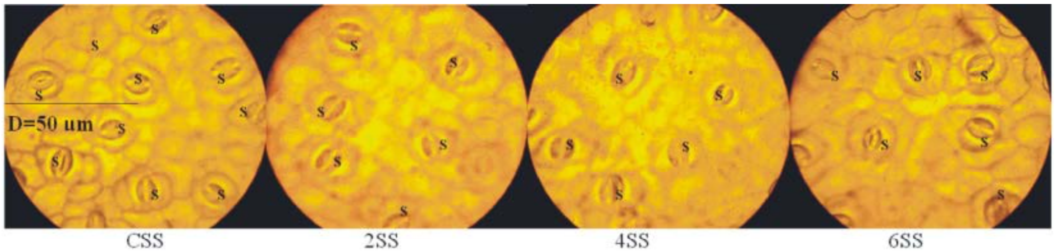

Plate A: Stomata appearance on the abaxial leaf surface of *Canavalia maritima* after 12 weeks of exposure to salt spray. S= stoma, D= diameter, CSS = deionized water sprays (control), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week.

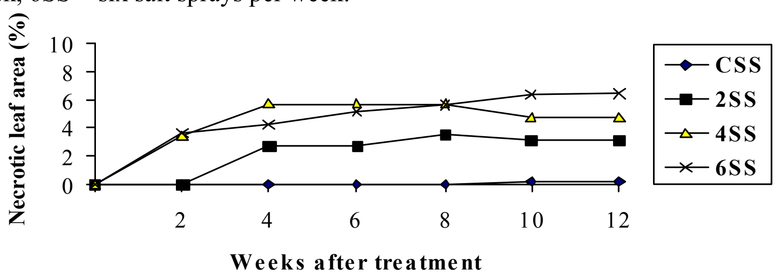

Fig. 1: Necrotic leaf area (%) taken at 2-week interval, of *Canavalia maritima* exposed to salt spray for 12 weeks. Each value is a mean of 3 replicates. CSS = control spray (deionized water sprays), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week.

Table 3: Nutrient content (mmolg^{-1} dry weight), ash content (% dry weight) and Na: K ratio in leaf, stem and root of *Canavalia maritima* after 12 weeks of exposure to different levels of salt spray

Plant Part	Salt Spray level	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe^{2+}	Cl^{-}	N	Total	Na: K	Ash
	CSS	1.17^{a}	0.38^{a}	0.03^{d}	1.39^{a}	2.34^{a}	0.14^{d}	0.95^{b}	6.4^{d}	0.02^{d}	7.75^{c}
	2SS	0.89^{b}	0.35^{a}	3.33^{c}	1.21^{a}	1.43^{b}	4.64^{c}	2.31^{a}	14.16^{c}	2.75^{c}	12.13^{ab}
Leaf	4SS	0.85^{b}	0.32^{a}	6.37^{b}	0.89^{ab}	1.51^{b}	8.92^{b}	2.42^{a}	21.28^{b}	7.16^{b}	15.34^{ab}
	6SS	0.60^{b}	0.24^{b}	11.41^{a}	0.78^{ab}	1.33^{b}	15.61^{a}	2.37^{a}	32.34^{a}	14.63^{a}	19.23^{a}
	CSS	0.98^{a}	0.36^{a}	0.03^{d}	1.32^{a}	2.03^{a}	0.14^{d}	0.9^{ab}	5.71^{d}	0.02^{d}	6.11^{c}
Stem	2SS	0.87^{a}	0.33^{a}	2.31^{c}	1.17^{a}	2.03^{a}	3.57^{c}	1.34^{a}	11.62^{c}	1.97^{c}	10.34^{b}
	4SS	0.83^{a}	0.31^{a}	4.36^{b}	0.87^{ab}	2.16^{a}	6.78^{b}	1.95^{a}	17.1^{b}	5.01^{b}	14.62^{ab}
	6SS	0.59^{ab}	0.19^{ab}	9.41^{a}	0.74^{ab}	2.03^{a}	11.42^{a}	1.95^{a}	26.33^{a}	12.72^{a}	17.68^{a}
	CSS	1.23^{a}	0.40^{a}	0.28^{a}	1.43^{a}	1.32^{a}	0.93^{a}	0.59^{a}	5.18^{a}	0.22^{a}	4.56^{a}
Root	2SS	0.92^{a}	0.36^{a}	0.35^{a}	1.25^{a}	1.34^{a}	0.71^{a}	0.49^{a}	5.42^{a}	0.28^{a}	4.37^{a}
	4SS	0.97^{a}	0.34^{a}	0.38^{a}	0.92^{a}	1.4^{a}	0.99^{a}	0.56^{a}	5.46^{a}	0.41^{a}	4.82^{a}
	6SS	0.93^{a}	0.29^{a}	0.45^{a}	0.79^{ab}	1.36^{a}	1.32	0.48^{a}	5.57^{a}	0.57^{a}	4.77^{a}

Each value is a mean of 3 replicates. For each parameter, means with the same letter(s) in superscript in the same row are not significantly different at $P \geq 0.05$ (Turkey HSD). CSS = deionized water sprays (control), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week.

Table 4: Number of stomata and visual ratings measured on the leaf of *Canavalia maritima* after 12 weeks of exposure to salt spray

Level of salt spray	Stomata density (no./cm^{2})	Number of stomata /leaf)	Visual ratings
CSS	127307.40^{a}	4264798.17^{a}	5.00^{a}
2SS	95480.59^{b}	2500637.46^{b}	4.44^{a}
4SS	94207.51^{b}	2296919.54^{b}	4.58^{a}
6SS	94080.20^{b}	2433855.66^{b}	4.11^{a}

Each value is a mean of 6 replicates. Means with the same letter(s) in superscript in the same column are not significantly different at $P \geq 0.05$ (Turkey HSD). CSS = deionized water sprays (control), 2SS = two salt sprays per week, 4SS = four salt sprays per week, 6SS = six salt sprays per week. Visual ratings scale: 1 = no green foliage, 2= 25% green foliage, 3 = 50% green foliage, 4= 75% green foliage and 5 = all green foliage

of stomata per leaf (Table 4). The higher level of seawater application, the faster the initiation of necrotic damage. Necrotic damage was initiated at 2 weeks after treatment at 4SS and 6SS but was delayed till 4 weeks at 2SS (Fig. 1). At the end of the experiment, necrotic leaf area increased with increasing level of seawater application. Plant visual ratings declined under seawater treatment, but did not differ significantly ($p \geq 0.05$) when compared to the control treatment (Table 4).

DISCUSSION

Plant survival under air-borne salinity has been linked with ability to cope with salt stress [14]. Seawater spray tolerant plants occupy sea-side, while sensitive species are eliminated and are found inland far away from the beach [11, 27]. It was reported that the death of *Impereta cylindrica* and *Miscanthus sinensis* transplanted to beach was as a result of salt spray inhibiting them from becoming established on the front dunes [27]. The high level of the death of sea side horticultural plants has been attributed largely to seawater spray [11, 21]. They concluded that seawater spray was among the non-negligible factors controlling the distribution of plants in sand dune vegetation. Decreased height in *C. maritima* was as a result of reduced internode length. Growth reduction in *Leymus mollis* has earlier been attributed to inhibition of stem elongation [14]. Decrease in leaf area in this study agrees with the earlier results on Crambe maritima [10], *Diodia maritima* [15], *Commelina erecta* var. *maritima* [16] and *Kyllinga peruviana* [19]. Leaf size decrease in *Myrica*. *pensylvanica* was linked with reduction in leaf expansion [12]. Seawater spray inhibited production of lateral branches, similar to reduced number of tillers reported on *Triplasis purpurea* [13] and *Kyllinga peruviana* [19]. Reduction in number of leaves by seawater spray was also recorded in *Miscanthus sinensis* and *Pennisetum alopecuroides* [11], Crambe maritima [10] and *Diodia maritima* [15]. The reduction in number of leaves was as a result of early leaf senescence and defoliation imposed by ion toxicity caused by Na^+ and Cl^- accumulation. Similar results have been obtained in an earlier study on *Pinu rigida* seedlings [28]. Fewer leaves and reduced leaf size have direct effect on the leaf surface available for light interception for photosynthetic activities, with consequential effect on growth [10]. However, reduced height and an absence of trees are mechanisms through which the characteristic dwarf stature of strand vegetation is maintained [12]. Reduced leaf size also lowers the leaf surface available for salt deposition and water loss through transpiration, which are adaptations against excessive salt accumulation and water stress respectively [29]. Reduction in chlorophyll content was as a result of foliage-induced damage by Na^+ and Cl^- ions. Salt spray usually results in foliage induced fragmented cuticles, disrupted stomata, collapsed cell walls, coarsely granulated cytoplasm, disintegrated chloroplasts and nuclei and disorganized phloem in plants [30]. Decrease in certain elements such as Mg^{2+} and $Fe^{2+,}$ which are part of chlorophyll ultrastructure [30], must have led to a decline in chlorophyll formation. Besides, reduction in total leaf chlorophyll was largely due to damage induced by salt, caused by Na^+ and Cl^- ions toxicity, leading to necrosis on the leaf surface. The necrotic spots on leaf must have resulted in a decrease in total photosynthesis and carbohydrate stored in the plant [30]. *Scaevola sericea* seedlings had reduced stem mass, leaf mass, shoot mass and total biomass with increasing level of sea spray [31]. Reduced chlorophyll negatively affected photosynthetic activities thereby limiting food resources including carbohydrate stored in the plant, which must have led to biomass reduction. High values of root: shoot ratio is indicative of the shoot being mare negatively impacted upon by salt spray than the root; the former being in direct contact with seawater.

Induced stem and leaf succulence in sea-sprayed *C. maritima* conforms to the findings on Crambe maritima [10]. Increase in moisture content of stem and leaf in the presence of salt is an adaptation for ion dilution [6]. Salt spray has been reported to cause water stress and only the salt-tolerant species reduce their water potential. Xylem water potential was also reduced under salt spray in *Solidago puberula*, *Solidago rugosa*, *Gaylussacia baccata*, *Myrica pensylvanica*, *Pinus rigida* and *Quercus ilicifolia* (12, *Kyllinga peruviana* [19] and *Alternanthera maritima* [20]. Salt spray led to Na^+ and Cl^- accumulation, which might lead to ion toxicity [1]. Na^+ toxicity for instance disrupts nutrient uptake and induces water stress in many plant species [1]. Na^+ and Cl^- accumulation can however contribute to the osmotic potential and increase the protection against osmotic stress [30]. There was a report that [31] increase in N content under NaCl application was due to production of compatible solutes, proline and betaine, which would require N. The compatible solutes also contribute to osmotic adjustment. High Na: K ratio indicates metabolic disorders such as reduction in protein synthesis and enzyme activities and an increase in membrane permeability [33]. Reduced growth could be due to low K^+ uptake in the presence of a high NaCl concentration.

Some salt tolerant plants reduce stomata density on leaf surface to limit the entry points to salt spray and minimize water loss through transpiration [26]. Previous studies have also confirmed stomata density decrease in salt-tolerant strandline plants like *Kandelia candel* [26], *Kyllinga peruviana* [19] and *Alternanthera maritima* [20]. Increase in percentage necrotic leaf area with increasing level of salt spray confirms the results on *Solidago puberula*, *Solidago rugosa*, *Gaylussacia baccata* and *Quercus ilicifolia* [12], *Pinus rigida* [28] and

Diodia maritima [15]. The reduction in visual ratings was recorded in *Miscanthus sinensis* and *Pennisetum alopecuroides* [11] thereby reducing its aesthetic value. However, the visual ratings decreased in *C. maritma* but not at a significant level. High visual ratings recorded in *Kyllinga peruviana* [19] and *Alternanthera maritima* [20] under salt spray informed their recommendation for beach landscaping. Shiny waxy leaf surface of the plant makes it not completely wettable, resulting in the beading of droplets on the leaf surface, thus reducing entrance of harmful chlorides [3-4].

Conclusively, *Canavalia maritima* is a salt spray tolerant plant that has developed some adaptations to cope with salt spray related stress in the strandline. It decreased leaf size and stomata density/stomata number per leaf to minimize entry points for salt and to minimize water loss. Decreased leaf size also reduced surface area available for salt deposition to limit ion toxicity. It accumulated salt in its tissues and probably produced nitrogen based quaternary amino compounds for osmotic adjustment to salt stress. Plants reduced xylem water potential to cope with salt-related water stress. There was an increase in leaf and stem succulence for ion dilution. Besides, *Canavalia maritima* is recommended for use as a landscaping plant in coastal beaches where salt spray is known to pose a problem because of its high aesthetic value.

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