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Suaeda vermiculata Forssk. ex J.F. Gmel.: Structural Characteristics and Adaptations to Salinity and Drought: A Review

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Abstract: The aim of the present study is to review the structural characteristics possessed and the adaptations implemented by *Suaeda vermiculata*; a partially succulent habitat-indifferent desert halophyte, to cope with salinity and drought stresses and gaining insight into its tolerance mechanisms. These characteristics include succulence, leaf burns, leaf shedding, stunted growth habit, change in colour of the leaves, thick cuticular layers and sunken stomata. Deep rooting system and high root/shoot ratio are two more drought adaptations that may also be incorporated as tolerance mechanisms, but no previous studies were encountered for *S. vermiculata*. These adaptations allowed *S. vermiculata* to tolerate broad distribution in arid and semi-arid regions and variable habitats including salinity. The presence of small glossy seeds devoid of structures enhancing dispersal, limit its range of spatial dispersal and may be regarded as an inherent limit to tolerance mechanisms.

Keywords: Succulence, Leaf Burns, Leaf Shedding, Stunted Growth, Sunken Stomata

Introduction:

The genus *Suaeda* Forssk. ex J.F. Gmel. is of about 110 species worldwide and belongs to family Chenopodiaceae (Welsh *et al.* 2003). Molecular and morphological studies by Judd and Ferguson (1999) supported the inclusion of this family with the family Amaranthaceae.

Suaeda vermiculata Forssk. ex J.F. Gmel. (seablite) is a polymorphic leaf succulent perennial shrub, with variable growth forms, shape and size of leaves, length of internodes, orientation and number of flowers in the inflorescence (Freitag *et al.* 2001). *S. vermiculata* is a valuable palatable forage for animals especially camels and is used also for fuel (Al-Farrajii and Al-Hilli, 1994). In addition, it has been used to treat asthma and other respiratory disorders (Phondani *et al.* 2016), hepatitis and viral diseases (Sefidanzadeh *et al.* 2015), and showed antimicrobial activity (Al-Tohamy *et al.* 2018).

S. vermiculata is widely distributed in the arid lands of North Africa, East Tropical Africa, South west Asia, Cape Verde and Canary Islands, Arabian Peninsula and South Europe (Guma *et al.* 2010, Freitag *et al.* 2001). It inhabits coastal bushlands, inland saline, stony and sand plains, and desert wadis (African Plant Database 2019), and was classified as habitat-indifferent desert halophyte (Jongbloed *et al.* 2003). Habitat-indifferent halophytes can cope with both salty and salt free soils (Cushman, 2001) and thus, offer an opportunity to study drought (Al-Shamsi *et al.* 2018) and salt tolerances (El-Keblawy *et al.* 2018) in soils of different salinity. In addition, *S. vermiculata* was considered as bioindicator of sewage pollution in saline environments (El Ghazali *et al.* 2017).

Salinity and drought are considered as the main environmental challenges that affect distribution and plant growth of many plants in arid and semi-arid regions (Ashraf and Harris, 2004). In response to salinity and drought, plants implement a series of morphological and physiological adaptations for acclimatization (Acosta-Motos *et al.* 2017). In the present study, the peculiar structural characteristics in response to salinity and drought adapted by *S. vermiculata* were reviewed in an attempt to gain insight into its tolerance mechanisms.

Taxonomic Description of *S. vermiculata*:

Perennial succulent shrubs up to 50 cm high, mostly glabrous, much branched from base with stunted growth. Stems pale green at first, becoming grey and fissured. The branches and young leaves drying black. Leaves alternate, subsessile or sessile, older

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leaves obovate to oblong to elliptical, flat on upper side, the upper or all leaves obovate to globular, spreading or downwards directed, upper leaves gradually reduced in size, dark green, 25 mm x 5mm, inflorescences of 2-5 flowered axillary clusters in lax or rather dense, leafy, terminal or branched spikes, or the spikes laxly paniculated. Flowers bisexual, bracteated, bracts scarious. Perianth segments persistent, 5, succulent, connate at base, 1-2 mm long, almost hooded at tip. Stamens inserted on the perianth segments. Stigmas 3, 0.6-1.5 mm long, shortly papillose. Seeds vertical with spiral embryos, c. 1.5 mm in diameter, glossy back, globular and slightly flattened. Fruits utricle, thin walled.

Adaptations to salinity and drought:

Plants have developed several tolerance mechanisms that improve their ability to reach suitable habitats and have adapted several features that allow them to function in a changing local environment (Bazzaz, 1991). *S. vermiculata* adapts various structural characteristics and modifications to cope with salinity and drought stresses. These adaptive features include succulence, leaf burns, shedding of leaves, stunted growth habit and change in the colour of the leaves (Fig. 1), thick cuticular layers and sunken stomata.

1. Succulence:

S. vermiculata is a partially succulent halophyte, which requires salinity for their optimal growth (Alhejoj *et al.* 2015).

Succulence is due to an increase in the length of palisade and diameter of spongy mesophyll cells (Atwell *et al.* 1999), and it assumes various functions, ranging from water storage, salt accumulation to thermal insulation (Males, 2017), and Crassulacean acid metabolism (CAM) (Smith *et al.* 1997).

Water storage is accompanied by reduced leaf area, thick leaves, high cell wall plasticity, large vacuolated cells alow number of stomata per unit area (Grigore and Toma, 2017).

Salt accumulation in leaves decrease the supply of carbohydrates and or growth hormones (Munns, 1992), affecting the photosynthetic process (Munns and Tester, 2008), decreasing chlorophyll and carotenoid concentrations (Stepiens and Johnson,

2009, Parida *et al.* 2002, Duarte *et al.* 2013), and lowering water potential (osmotic effect) (Slama *et al.* 2008).

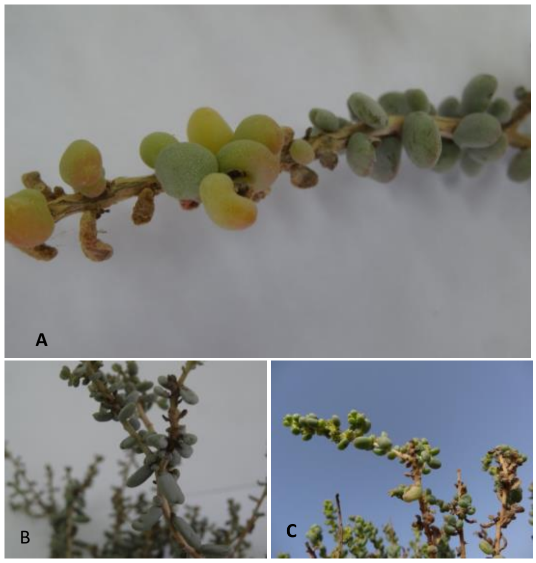

Figure 1*: Suaeda vermiculata* A: vegetative branch showing succulent and dried leaves with various leaf colorations and teret stems. B: greenish succulent leaves and leaf burns. C: flowering branch with succulent and dried leaves.

2. Leaf burns:

Leaves of *S. vermiculata* turn black in responds to large amount of salt elements (Batanouny, 2001). Leaf burn or blackening of the plant tissues, is a visual symptom of salt damage which leads to wilting and defoliation (Sharma *et al.* 2011). Leaf burns is probably not only due to high element accumulation in the leaves due to toxic levels in the leaves, but may also be attributed to element deficiencies. Chlorides, sodium and boron are the most common elements usually associated with leaf burn, resulting in salt accumulation in toxic levels (Abrol *et al.* 1988).

In *Vitis vinifera* (grapevine), leaf burn was associated with (Cl^-) content (Baneh *et al.* 2014), in *Lactuca sativa* (lettuce), it was associated with sodium accumulation (Bartha *et al.* 2015), whereas, in *Solanum lycopersicum* (tomato) and *Eucalyptus* it was linked to high boron content (Cervilla *et al.* 2012, Poss *et al.* 1999). Leaf burn may also be attributed to (Ca^+) (Carassay *et al.* 2012) or to (K^+) deficiencies (Slabu *et al.* 2009).

3. Shedding of leaves:

Shedding of plant organs (leaves, flowers, fruits, seeds, bark, *etc.*) from the main body is an important stage in the life cycle of higher plants (Patterson and Bleecher, 2004). These organs are shed actively via the development of abscission zones which are triggered by growth regulator signals (Mishra *et al.* 2008, Bisht *et al.* 2018). Leaves may be shed in response to environmental stress (Rio-Garcia *et al.* 2015), as an antifungal (Kim and Kim, 2007) or antibacterial defense (Patharkar *et al.* 2017), due to leave senescence (Woo *et al.* 2018), or in response to salt stress (Krauss *et al.* 2008). Leaves of *S. vermiculata* are shed after being loaded with a high salt content (Batanouny, 1990, Alhejoj *et al.* 2015). Shedding of salt saturated leaves is one of the elimination mechanism used by plants to avoid excessive salt accumulation (Krauss *et al.* 2008, Garcia-Caparros *et al.* 2016, Zeng *et al.* 2009).

4. Stunted growth habit:
***S.** vermiculata* exhibits a unique stunted (dwarf) growth habit (Schutze *et al.* 2003). Stunted growth habit refers to the reduction in size of the whole plant or a specific part of it and may be controlled by growth rate and duration of cell division (Beemster and Baskin, 2000), or by spatial patterns of expansion (Baskin *et al.* 1995). The causes of these stunted growth habit may be due to biotic (Hammond-Kosack *et al.* 2000) or abiotic factors (Wang *et al.* 2003). The biotic factors include infection with fungi, nematodes (Wicks *et al.* 2010), viruses (Vincent *et al.* 2014), bacteria and herbivorous insects (Hammond-Kosack *et al.* 2000). Abiotic factors affecting the stunted growth habit include lead accumulation (Chandrasekher and Ray, 2018), hydrogen sulphide toxicity (Wamishe *et al.* 2018), nutrient deficiency (Shiwachi *et al.* 2006), too-deep planting, excess light, dehydration, heat, cold, drought (Atkinson and Urwin, 2012), or salinity stress (Rasmuson and Anderson, 2002, Khan *et al.* 2006).

5. Change in colour of the leaves:
S. vermiculata was noticed to exhibit a wide range of pigment coloration within the growth period ranging from dark green, pale green, yellow, brown and red. Such changes in colour pigment of leaves are symptoms of chlorophyll degradation (chlorosis) or carotenoid accumulation (Borghesi *et al.* 2011), which are directly related to salinity stress (Taibi *et al.* 2016). Chlorophyll degradation may be attributed to oxidative (Smirnoff, 1996) or enzymatic degradations (Santos, 2004).

6. Thick cuticular layers:
The adaxial and abaxial leaf and stem surfaces of *S. vermiculata* possess high longitudinal cuticular folds or striate crusts (El Ghazali *et al.* 2018, El Ghazali *et al.* 2016). These cuticular layer beside its function in protection against mechanical damage, pests and pathogens attack (Riederer, 2006), it increases the wettability of their surfaces (Koch and Barthlott, 2009), provides an effective barrier to water transpiration (Riederer and Muller, 2006), and affects light reflection or absorption of UV radiation (Pfundel *et al.* 2006).

7. Sunken stomata:
Sunken stomata were encountered in the adaxial and abaxial leaf surfaces of *S. vermiculata* (El Ghazali *et al.* 2018). These stomata are completely sunken between the longitudinal cuticular folds on their surfaces. These sunken stomata keep cuticular transpiration low (Jimenez *et al.* 2000), regarded as a drought evading and xeromorphic feature (Lyshede, 1979), increasing adaptation to aridity (Jordon *et al.* 2008) and facilitate CO_2 diffusion from the abaxial surface to adaxial palisade cells in thick leaves (Hassiotou *et al.* 2009).

Sunken stomata may not be linked to xerophytic plants. They occur in a range of habitats, from arid to wet or occasionally flooded environments (Jordan *et al.* 2008), and are relatively common in scleromorphic leaves of plants on nutrient poor soils in (semi) arid climates (Sobrado and Medina, 1980).

Conclusion and perspectives:
S. vermiculata is a dwarf partially succulent, habitat-indifferent desert halophyte. It possesses a number of morphological features allowing it to cope with both drought and variable habitats including salinity. In the present review, seven morphological features exhibited by *S. vermiculata* to overcome salinity and drought stresses were studied to gain insight into tolerance mechanisms. Deep root system and high root/shoot ratio are two more morphological adaptations critical to respond to drought stress to avoid desiccation (Hund *et al.* 2009), but no previous studied were encountered. Salinity and drought are abiotic, and plants respond to these multiple stresses differently from their reaction to individual stresses (Atkinson and Urwin, 2012).

The adaptations exhibited by *S. vermiculata* resulted in its wide spatial distribution in arid environments (Guma *et al.* 2010, Boulos 1991), and its presence in variable habitats (African Plant Database, 2019). *S. vermiculata* produces small seeds and have limited dispersal due to the lack of dispersal structures (Gairola *et al.* 2019), unlike other members of the family Chenopodiaceae possessing winged accrescent sepals inyact to the seeds, enhancing wind dispersal (Zhu *et al.* 2003). This limited dispersal of *S. vermiculata* describes the threshold when adaptation fail (Polechova and Barton, 2015).

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