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Structural-Adaptation Features of Assimilation Organs of the Species *Salsola incanescens* Cam. in Conditions of Kyzylkum

Guli A. Ibrokhimova[1], Guljan M. Duschanova[2*]

[1]Department of Botany and Plant Physiology, National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan
[2]Department of Botany and Ecology, Tashkent State Pedagogical University named after Nizami, Tashkent, Uzbekistan
Email: *gugushana@mail.ru, guljon.duschanova@mail.ru

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Abstract

The article presents the results of the morpho-anatomical structure of the assimilation organs of the species Salsola leptoclada Gand, which is widespread in the Kyzylkum desert region of Uzbekistan, and reveals the structural, diagnostic and adaptive features. In the assimilation organs, Kranz type of mesophyll was found: in the cotyledons of the Kranz-spherical (Atriplicoid) type, and in the leaf—mesophylls of the Kranz-centric (Salsoloid) and Kranz-ventrodorsal type. These revealed diagnostic features of the assimilating organs of this species in arid conditions noted C4-type photosynthesis. Based on the comparative biometric analysis of quantitative indices of the anatomical features of the assimilating organs, xero-halomorphic features predominate. Halomorphic features are in the cotyledons—thin outer walls of the epidermal cells; few stomata of the anomocytic and paracytic type; few rows of spongy cells (3 - 4 rows); few vascular bundles of the collateral type and xylem, in the leaf—large and thin outer walls of the epidermal cells; succulence of the leaf mesophyll, the presence of aquiferous cells; large palisade, keratin and aquiferous cells. Xeromorphic features in the cotyledons—small and numerous epidermal cells and hemiparacytic type stomata also deep immersion; small palisade cells and a high palisade index, small spongy, hypodermal and keratin cells; small diameter of the xylem in vascular bundles; in the leaf numerous epidermal cells and stomata also deeply immersed; presence and numerous multicellular nodular, dentate trichomes; multi-row water-bearing cells; high palisade index; small and numerous xylem; numerous peripheral vascular bundles of the collateral type. These identified specific diagnostic features showing adaptation to arid conditions can also serve in the identification of plant materials.

Keywords

Morphology, Anatomy, Cotyledon, Leaf, *Salsola incanescens*, South-West Kyzylkum

1. Introduction

The family Chenopodiaceae contains the largest number of halophyte species. Chenopodiaceae includes about 110 genera and 1700 species, distributed throughout the world mainly in temperate and subtropical ecosystems, arid, semi-arid, saline and hypersaline areas [1]-[3].

The anatomical structure of cotyledons, shoots and the primary conducting system of species of the family Chenopodiaceae is diverse; based on the development of the sprout of the species, 2 structural and evolutionary lines of leaves and cotyledons have been identified [4].

V. Kh. Tutayuk [5] on the general diagram of the anatomical structure of Salsola dendroides Pall shows that the outside of the leaf is covered with epidermis, its cells are elongated along the length of the leaf, the hypodermis is everywhere under the epidermis, they are interrupted under the stomata, and the stomata are on the surface, lie in the same plane and represented by the fact that they are located shallowly.

Based on the study of the anatomical structure of the cotyledons of the species *S. paulsenii*, *S. aperta and S. sclerantha*, it was determined that the species *S. aperta* and S. sclerantha have a weak dorsiventral type of mesophyll and C_3 type of photosynthesis, and *S. paulsenii* has a kranz-centric type of mesophyll and type of photosynthesis C_4 [1] [6] [7].

V.I. Pyankov, A.N. Kuzmin, E.D. Demidov *et al.* studied the leaf structure of 22 Chenopodiaceae species of Central Asia in connection with C_4 and C_3 types of CO2 fixation [8].

Butnik A. A., Dushanova G. M., Yusupova D. M. *et al.* [9] based on a study of the anatomical structure of the mesophyll of leaves of species belonging to the family Chenopodiaceae Vent. widespread in Central Asia determine their role in monitoring desertification. They described that species of the genus *Salsola* have three types of leaf mesophyll: *Salsoloid* type (*S. dzhungarica* Iliin, *S. orientalis* S. G. Gmell., *S. incanescens* C.A.Mey., *S. micranthera* Botsch., *S. roshevitzii* Iliin, *S. gemmascens* Pall., *S. implicata* Botsch., *S. titovii* Botsch., *S. gossipina* Bunge, *S. vvedenskyi* Iljin et M. Pop, *S. chiwensis* M. Pop., *S. drobovii* Botsch., *S. foliosa* (L.) Schrad, *S. aperta* Pauls., *S. praecox* Litv., *S. rosaceae* L., *S. sclerantha* C. A. Mey), flatleaf-salsoid type (*S. euruphylla*) and sympegmoid type (*S. arbusculiformis*, *S. montana*, *S. pachyphylla*).

An analysis of the literature showed that the anatomical structure of many species of the genus *Salsola* has been studied. Including, *Salsola iberica* (Sennen et Pau) Botsch., *S. oreophila* Botsch., *S. arbusculiformis* Drob., *S. australis* L. (=

S. tragus), *S. kali* subsp. ruthenica, *S. dendroides* Pall., *S. soda* L., *S. laricifolia* Turcz. et Litv., *S. richteri* (Moq.) Kar. et Litv., *S. paletzkiana* Litv., *S. euryphylla* Botsch., *S. dzhungarica* Iljin, *S. orientalis* S. G. Gmell., *S. incanescens* C.A. Mey., *S. micranthera* Botsch., *S. roshevitzii* Iljin, *S. gemmascens* Pall., *S. implicate* Botsch., *S. titovii* Botsch., *S. gossipina* Bunge, *S. vvedenskyi* Iljin et M. Pop, *S. chiwensis* M. Pop., *S. drobovii* Botsch., *S. montana* Litv., *S. pachyphylla* Botsch., *S. foliosa* (L.) Schrad, *S. aperta* Pauls., *S. praecox* Litv., *S. rosaceae* L., *S. sclerantha* C. A. Mey [2] [9]-[21].

Based on our study of the anatomical structure of the assimilative organs of the species *S. paulsenii*, *S. aperta*, *S. leptoclada* and *S. sclerantha*, the mesophyll of the cotyledons of the species *S. leptoclada* has a dorsiventral (*Aksiroid*) type [20], in the species *S. paulsenii* the kranz-centric type [22], the species *S. sclerantha* has a dorsiventral (*Aksiroid*) type, the species *S. paulsenii*, *S. aperta*, *S. leptoclada* and *S. sclerantha* have kranz-centric (Salsoloid) and kranz-ventrodorsal types of leaf mesophyll [22]-[26].

We studied the anatomical structure of the vegetative and generative organs of some plant species and determined the diagnostic adaptive features of the studied species [27] [28].

Anatomical structure of the assimilative organs *S. incanescens* was partially studied based on the information from the literature sources listed above. Identification of structural, diagnostic and adaptive features based on a comparative analysis of cotyledons and leaf mesophyll shows the relevance and scientific novelty of our research.

The aim of the study is to study the structural-adaptation features of assimilation organs in the species *Salsola incanescens* Cam. in the conditions of KyzylKum

2. Materials and Methods

The object of study is the species *S. incanescens* CAM, an annual herbaceous plant belonging to the genus *Salsola* L. of the family Amaranthaceae.

H. Ahani, G. Edwards, E.H. Roalson [29] listed the annual species *S. incanescens* of the genus *Salsola* as species *Caroxylon incanescens* (CA Mey.) Akhani & EH Roalson of the genus *Caroxylon* Thunb. MM. Ilyin [26] in the flora of the USSR, the species *Salsola incanescens*, growing in the conditions of the South-western Kyzylkum, was assigned to the section *Caroxylon* (Thunb.) Iljin, later according to V.P. Bochantsev [30] is included in the section *Caroxylon* (Thunb.) Ulbrich subsection *Vermiculatae* Botsch. The species *S. incanescens* was identified by N. Beshko (1.05.2023).

S. incanescens is an annual forage grass, branched from the base, 15 - 45 sm tall. The outside of the stem is covered with thick, nodular and jagged trichomes that are gray in color due to the almost non-shedding hairs. The leaves are linear, short, widened at the base, and arranged in a row on the stem. The leaves of the plant fall off when they dry out. The species *S. incanescens* is a halophytic plant, common on saline, clayey, clayey-sandy and sandy-gravel soils, distribut-

ed in the southwestern part of Kyzylykum. Distributed in Central Asia, Iran, the Caucasus [26] [31], Iraq, Iran, Pakistan, Turkmenistan, southern Tajikistan, southern Uzbekistan [30] and in our homeland in Bukhara, Kashkadarya and Surkhandarya regions (**Figure 1**) [31].

Studies of the species *S. incanescens*, widespread in natural conditions, were carried out in 2022-2024 in the Southwestern Kyzylkum region of the Bukhara region, herbarium specimens and fixation material were collected from saline, clay-sandy and sandy-gravel soils. One of the largest deserts in Uzbekistan is the Kyzylkum Desert. Its area is 300,000 km^2 [32]. It consists mainly of sandy plains and rocky mountains. I.P. Gerasimov and P.N. Chikhachev [2]. divided the territory of Kyzylkum according to its geological structure into four regions: 1) Northern Kyzylkum; 2) Central Kyzylkum; 3) South-Eastern Kyzylkum; 4) South-Western Kyzyl Kum [33]. Todjibaev K.Sh., Beshko N.Yu., Popov V.A. [34] argued in the botanical-geographical zoning scheme of Uzbekistan that South-western Kyzylkum is included in the Turan Province and consists of the Kyzylkum district (Kyzylkum and Kyzylkum regions of the remnants of the mountains) and the Bukhara district (Lower Zarafshan and Karshi-Karnabchol regions). South-Western Kyzylkum consists of sandy, gypsum, salt, gravel, rocky, clayey deserts, wastelands and anthropogenically developed areas. There are also lakes, basins, and remains of mountains and hills. This region borders the Karshi-Karnab and Sundukli deserts in the east, the Amu Darya in the west, the Bukhara and Karakol oases in the south, and the Kulyuktag ridge in the north. There is not a single surface watercourse throughout the entire territory (with the exception of the drying up Jonadarya), but there are rich reserves of pressurized underground fresh water. The soil is grey-brown, saline, gypsum, sand and gravel [35]-[38].

(a) virginil (immature period) period; (b) generative period.

Figure 1. General view of *Salsola incanescens* species in natural conditions.

The study of the morphological and anatomical structure of the assimilative organs of the species *S. incanescens* was carried out based on generally accepted methods. The plant was fixed in 70% ethanol alcohol to study the anatomical structure of the vegetative organs of the plant, as well as the morphological description of the leaf and cotyledons.

The epidermis of leaves and cotyledons was studied on the basis of paradermal and transverse sections. Transverse serial cuts were made from the leaves on the main stem (from tip to base). Preparations prepared manually were stained with methylene blue and then sealed in glycerin-gelatin [39]. Tissues and cells of assimilative organs of plants K. Esau [40], N.S. Kiseleva [41], A.A. Butnik *et al.* [42], epidermis—S.F. Zakharevich [43], descriptions of the main tissues and cells are given according to R.F. Evert [44]. The measurements were carried out in 30-fold repetition with an eyepiece micrometer and converted to micrometers. Photomicrographs were made using a *Bioblue S/N-EC* 2209876 trinocular microscope. Statistical processing of the obtained data was performed in the OriginPro 7.5 program.

3. Results and Discussion

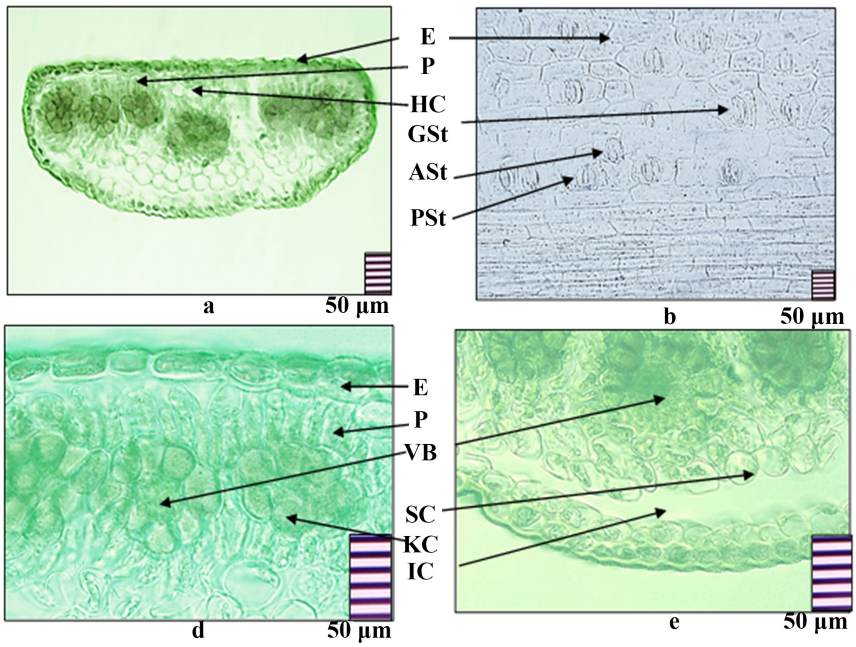
When studying the assimilative organs of *S. incanescens* by morphological state, the cotyledon is up to 6 - 8 mm long, up to 0.6 mm wide, and has a semicircular shape. In the paradermal section of the cotyledons, the epidermal cells are straight, the projection is multifaceted, the number of epidermal cells in 1 mm2 is 923.15 ± 3.45. The cotyledons have an amphistomatic structure. The number of stomata in the cotyledons is 107.8 ± 1.31 per mm2, the length of the oval stomata is 21.63 ± 0.22 μm, the width is 15 ± 0.18 μm, the stomata in the epidermal cell are located deeply (4.06 ± 0.05 μm). Also, in the epidermis of the seed coat, 3 types of stomata were identified—anomocytic, hemiparacytic and parasitic type, of which hemiparacytic (44%) and anomocytic (37%) orifices predominated and were numerous, stomata of the parasitic type (19%) were few in number (**Figure 2(b)**).

The type of mesophyll of the cotyledon in the cross section of the species *S. incanescens* is kranz-rosette (*Atriplicoid*), in the central part of the mesophyll, the main and lateral ligaments of the cotyledons are completely or partially surrounded by fringe and palisade cells, and it was found that the process of C_4-type photosynthesis occurs in the mesophyll (**Figure 2(a)**).

The epidermal cells are rows of round-oval shape with a height of 11.95 ± 0.23 μm and consist of a thin-walled cuticle (3.95 ± 0.06 μm) compared to the leaf. Below the epidermal cells there is 1 row of hypodermal cells, the diameter of the oval cells is 21.18 ± 0.23 μm. On both sides of the main vascular ligament in the central part of the mesophyll of the cotyledons, i.e., under the hypodermal cells, there are 2 - 3 rows of spongy cells. Spongy cells are thin-walled, round, oval in shape with a diameter of 22.41 ± 0.21 microns. In the mesophyll of cotyledons, the thickness of porous cells is 66.3 ± 0.33 μm and accounts for 27.6%.

The main and lateral vascular bundles are of a closed collateral type, consisting of phloem and xylem, the number of xylems in the main vascular bundle is 3 - 4, and its diameter is 4.6 ± 0.04 μm. The vascular bundles are relatively lignified, the mechanical tissue—sclerenchyma—is well developed. It was established that these vascular bundles are located between the kranz and spongy mesophyll cells of the cotyledons (Figure 2(a), Figure 2(d), Figure 2(e)).

Kranz cells with a diameter of 15.39 ± 0.14 μm completely or partially surround the main and lateral vascular bundles. Under it there were two rows of elongated shapes—palisade cages, 23.01 ± 0.17 μm long, 6.6 ± 0.1 μm wide, index palisade—3.49 μm (Figure 2(d), Figure 2(e)).

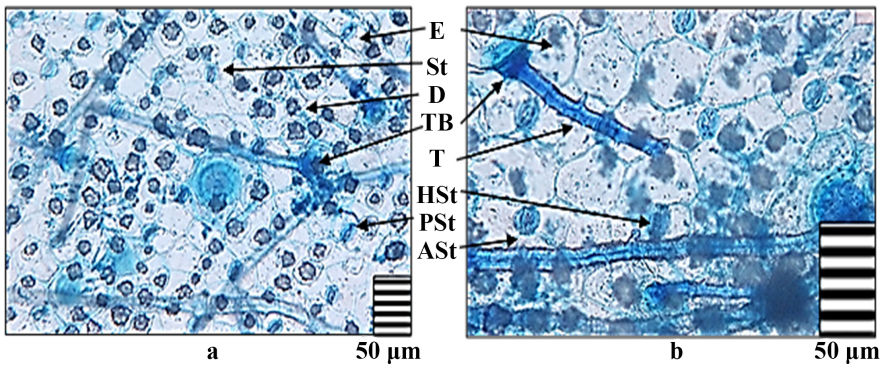


a—general view, b—epidermis, stomata: stomata of anomocytic, hemiparacytic and paracytic type; d—epidermis, cotyledon stomata, columnar, kranz cells and vascular bundle; e—subcutaneous cells and intercellular spaces. Legenda: ASt—stomata of the anomatocyte type, HSt—stomata of the hemiparasitic type, KC—kranz cells, HC—hypodermal cells, IC—intercellular cavity, PSt—stomata of paracytic type, PP—palisade cells, VB—vascular bundle, E—epidermis

Figure 2. Anatomical structure of the cotyledon of *Salsola incanescens*.

Leaves of the *S. incanescens* type are non-striped, linear, ring-shaped, semicircular, 1.6 - 1.8 cm long, 1 - 1.5 mm wide, 0.5 - 1 mm thick, expanded from the base to 2/3 of the leaf length, covered with long multicellular nodular jagged hairs and arranged alternately on the stem. At the beginning of the generative period, it was discovered that the leaves on the main stem dry out and fall off. In paradermal section of leaves of *S. incanescens* epidermal cells are straight, the projection is multifaceted, its height is 15.045 ± 0.17 μm. The epidermal cells contain numerous crystalline oxalate drusen and long multicellular nodular and jagged trichomes, the length of the trichomes is 1779.62 ± 4.005 μm, these tri-

chomes retain little water vapor in the leaves of plants and in arid conditions perform a retaining and protective function (Figure 3).



a—epidermis, leaf apertures, drusen, trichome bases, paracyte of leaf stomata and tangled trichomes; b—stomata of leaves of anomocytic and hemiparacytic type in the epidermis. Legenda: ASt—anomocytic type stomata, D—drusen, E—epidermis, JT—jagged trichomes, HSt—hemiparacytic type stomata, PSt—paracytic type stomata, St—stomata, TB—trichome bases.

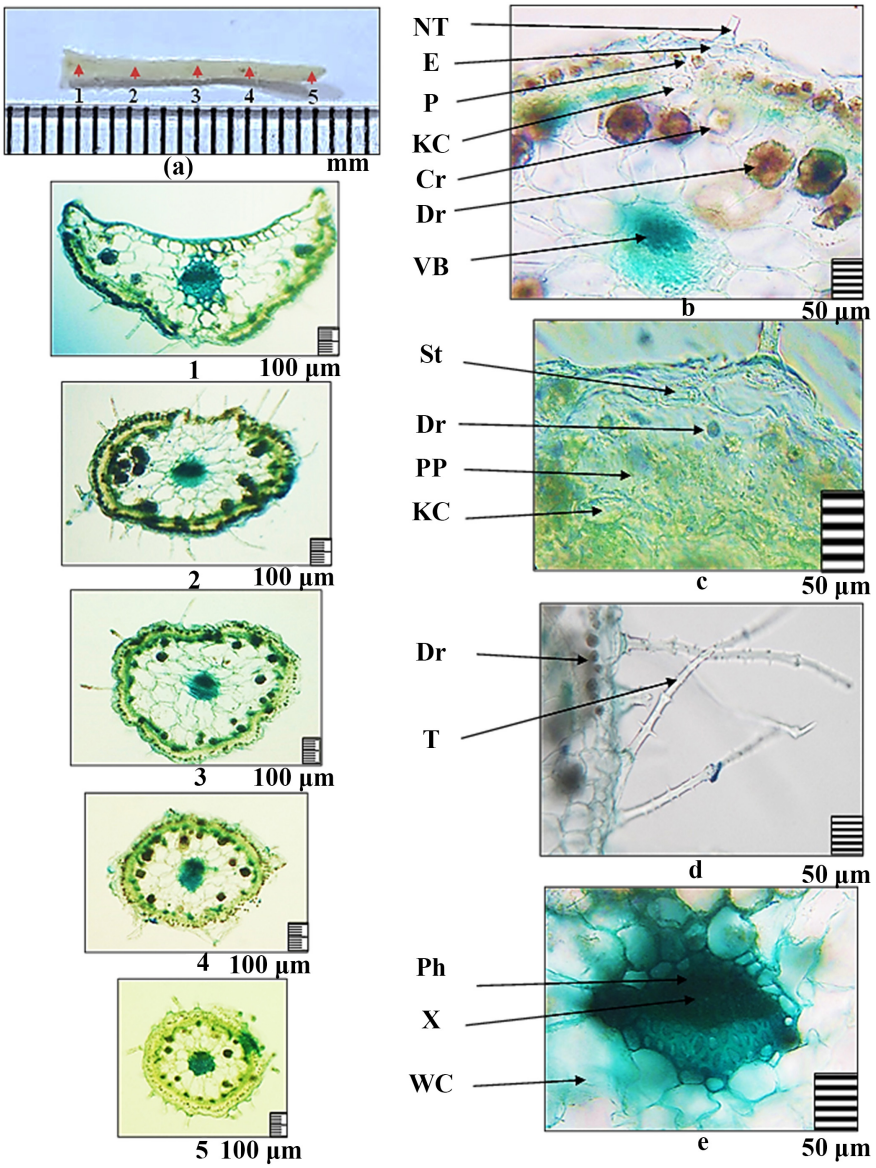
Figure 3. Anatomical structure of the epidermis of Salsola incanescens leaves in a paradermal section.

The leaves of *S. incanescens* have an amphistomatic structure, length of stomata of oval leaves—21.38 ± 0.24 µm, width 9.08 ± 0.10 µm, connecting cells of the stomata are almost the same length and are located deep (6.03 ± 0.068 µm) in the epidermal cell. In the epidermis of leaves, 3 types of anomocytic, hemiparacytic and paracytic types of leaf stomata were identified, the predominance and large number of stomata of the anomocytic type (67.5%), a small number of hemiparacytic type—20% and paracytic type—12.5% of stomata (Figure 4, Table 1).

A study of the anatomical structure of the leaf mesophyll of the species *S. incanescens* was carried out by making transverse serial sections of the leaf and 2 different types of leaf mesophyll were identified. Mesophylls of leaves of the kranz-ventro-dorsal type are found in the basal part of the leaf mesophyll, and mesophylls of leaves of the kranz-centric type are found from the tip to 2/3 of the leaf. It was established that in the identified leaf mesophylls, C_4-type photosynthesis is carried out in palisade and kranz cells. In the kranz-ventro-dorsal mesophyll of the leaf in the lower (abaxial) part there are a number of palisade, kranz cells and peripheral vascular bundles, and in the upper (adaxial) part of the leaf there are aquifer cells and 3 main vascular bundles (Figure 4(a), 1-3).

In the mesophyll of a leaf of the kranz-centric (*Salsoloid*) type, the leaf has a ring-shaped structure, in the central part of the leaf there is 1 main conducting bundle and water-bearing parenchyma cells (Figure 4(a), 4-6). Also, in the kranz-centric (salsoloid) type of leaf mesophyll, lateral (peripheral) vascular bundles are located along the perimeter of the aquifer cells, in contact with the kranz cell, followed by a row of palisade cells (Figure 4(a), 1-3). The height of the epidermal cell is 15.045 ± 0.17 µm, the thin-walled cuticle is 3.07 ± 0.05 µm. Epi-

dermal cells contain numerous crystalline oxalate drusen (Figure 4). The mesophyll of the leaf contains palisade, edge, water-bearing cells and vascular bundles. The cells of the palisade parenchyma contain relatively many chlorophyll granules; the palisade cells located in a row have a length of 48.8 ± 0.38 μm, a width of 4.61 ± 0.07 μm, and a palisade index of 10.59 μm. The cells of the palisade parenchyma are located between the epidermis and the kranz cells (Figure 4, Table 1).



a—general view of a ring-shaped leaf; b—detail of leaf mesophyll; c—leaf stomata, palisade parenchyma and kranz cells in the rib-like part of the leaf; d—druses and trichomes in leaf epidermis; e—water storage cell and vascular bundles. Legenda: Cr—crustals, Dr—drusen, E—epidermis, KH—kranz cells, NT—nodular trichomes, Ph—phloem, P—palisade parenchyma, St—stomata, X—xylem, WC—water-bearing cell.

Figure 4. Anatomical structure of the mesophyll leaf of *Salsola incanescens* in cross section.

Table 1. Quantitative parameters of the assimilative organ of species *Salsola incanescens* (n = 30).

Indicator		Assimilating organ	
		cotyledon	leaf
Mesophyll thickness, μm		**239.52 ± 2.26**	762.8 ± 2.81
Epidermis, μm:			
height		**11.95 ± 0.23**	15.045 ± 0.17
thick. outside walls		3.95 ± 0.06	3.07 ± 0.05
Number of epidermis 1 mm^2		**923.15 ± 3.45**	**960 ± 4.01**
Stomata, μm:			
Length		21.63 ± 0.22	21.38 ± 0.24
Width		15 ± 0.18	9.08 ± 0.10
Number of stomata 1 mm^2		**107.8 ± 1.31**	**146.9 ± 1.84**
Stomatal density		**4.06 ± 0.05**	**6.03 ± 0.068**
Anomocytic types		37%	**67.5%**
Hemiparacytic types		**44%**	20%
Paracytic types		19%	12.5%
Trichome length, μm		-	**1779.62 ± 4.005**
Palisade parenchyma, μm:	Height	**23.01 ± 0.17**	48.8 ± 0.38
	Width	**6.6 ± 0.1**	**4.61 ± 0.07**
	Palisade index	**3.49**	**10.59**
Water-bearing cell, μm:	thickness of layer	-	587.25 ± 3.80
	diameter	**-**	**97.97 ± 0.48**
	row number	-	**6 - 7**
	% of d-list	-	**76.99**
Spongy cell, μm:	thickness of layer	**66.3 ± 0.33**	-
	diameter	**22.41 ± 0.21**	-
	row number	3 - 4	-
Hypodermal cells, μm:	Diameter	**21.18 ± 0.22**	
	row number	1	
	% of d-cotyledon	8.84%	
Diameter of the Kranz cell, μm		**15.39 ± 0.14**	23.88 ± 0.30
Number of peripheral vascular bundles (in longitudinal section)		5 - 6	**19 - 20**
Number of xylem in the main vascular bundles		3 - 4	**5 - 6**
Xylem diameter		**4.6 ± 0.04**	**6.09 ± 0.09**

Kranz-cells have a cubic shape, their diameter is 23.88 ± 0.30 μm. Kranz cells contain more chlorophyll grains than columnar cells. The main vascular bundles

of the leaf are of the closed collateral type and consist of phloem and xylem. The main vascular bundle has 5 - 6 xylem tubes, its diameter is 6.09 ± 0.09 μm. The vascular bundle is relatively lignified, the mechanical tissue—sclerenchyma—is well developed. It has been established that these vascular bundles are located between the water-bearing cells of the leaf mesophyll.

Also, 19 - 20 lateral (peripheral) vascular bundles in the leaf mesophyll are adjacent to the kranz cell and are located between the kranz and water-storing cells. Water-storing cells are thin-walled, round, oval, isodermal cells with a diameter of 97.97 ± 0.48 μm. In the leaf mesophyll there are 5 - 7 rows of water-storing cells, their thickness is 587.25 ± 3.80 microns, which is 76.99% and occupy the main part of the leaf mesophyll and have large, numerous crystalline oxalate drusen (Figure 4, Table 1).

Based on a comparative biometric analysis of quantitative indicators of the anatomical features of the assimilative organs of the species *Salsola incanescens*, the following halomorphic and xeromorphic characteristics were established.

It has been established that halomorphic characters predominate, such as the thinness of the outer wall of the epidermal cells of the cotyledon mesophyll; a small number of stomata of the anomocytic and paracytic type; a small number of spongy cells (3 - 4 rows); a small number of collateral-type vascular bundles and a small number of xylem cells.

It was found that xeromorphic characters predominated, such as small and large numbers of epidermal cells in the mesophyll of cotyledons, a large number of hemiparacytic type stomata; deep immersion of stomata; small (length) palisade cells and high palisade index, small spongy, hypodermal and kranz cells; small xylem cells (Figure 5).

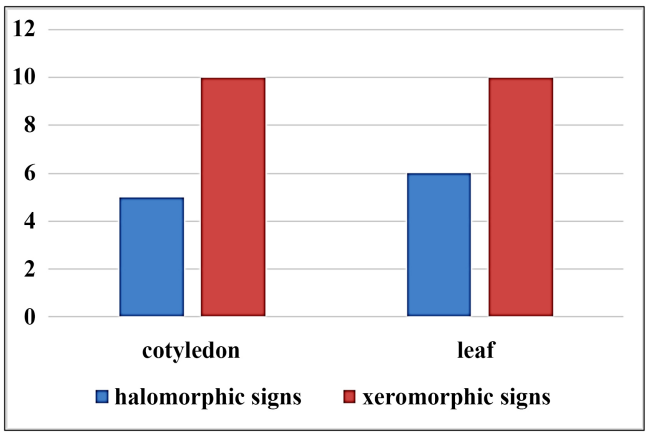


Figure 5. Comparative analysis of the anatomical features of the assimilative organs of the species *Salsola incanescens*.

It has been established that xeromorphic features predominate, such as a large number of epidermal cells in the leaf mesophyll; a large number of stomata; deep immersion of stomata; the presence and large number of multicellular nodular, jagged trichomes; a large number of water-retaining cells; high index of palisade

index of palisade cells; small and large amount of xylem; a large number of peripheral vascular bundles of the collateral type.

It has been established that halomorphic characters such as the large size of epidermal cells and the thinness of the outer wall of the leaf mesophyll predominate; succulent leaf mesophyll; large palisade, kranz and water-retaining cells.

Based on the results obtained above, it explains the predominance of xero-halomorphic characters in the assimilative organs of the species *S. incanescens*.

4. Conclusions

In brief, as a result of our studies growing in the conditions of South-western Kyzylkum, based on the study of the anatomical structure of the assimilating organs of some species of the genus *Salsola*, kranz cell types of mesophyll—*S. incanescens*—kranz-rosette (*Atriplicoid*) type of cotyledon mesophyll, kranz-centric *(Salsoloid*) and kranz-ventro-dorsal type in the leaf mesophyll, *S. paulsenii*—kranz-centric (*Salsoloid*) in the cotyledon mesophyll and kranz-centric (*Salsoloid*) and kranz-ventro-dorsal type in the leaf mesophyll [22], in the leaf mesophyll *S. leptoclada* has kranz-centric (*Salsoloid*) and kranz-ventro-dorsal type [45], and in *S. aperta*—leaf mesophyll, kranz-centric (*Salsoloid*) and kranz-ventro-dorsal type [23]. The type of kranz mesophyll of cotyledons and leaves in these studied species is explained by the fact that they carry out C_4-type photosynthesis [2] [9] [15] [16] [19] [21] [44].

Based on the results obtained above, based on the study of the anatomical structure, diagnostic structural and adaptive features of the assimilative organs of the species *Salsola incanescens* were determined. Based on a comparative analysis of the anatomical features of the mesophyll of the cotyledon and leaves of the species *Salsola incanescens*, the predominance of xero-halomorphic characters indicates the good adaptation of this species to the sand and gravel conditions of the South-western Kyzylkum, and diagnostic characters can be used for taxonomic identification of the studied species.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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