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# ANATOMICAL FEATURES OF THE VEGETATIVE ORGANS OF *ARTEMISIA* L. (ASTERACEAE) SPECIES DOMINATING IN THE ALTYN-EMEL STATE NATIONAL NATURAL PARK (KAZAKHSTAN)

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**Abstract**

The genus *Artemisia* comprises around 500 plant species widely distributed across Asia, Europe, and North America and known for their medicinal and aromatic properties. The highest species diversity is observed in Asia with the following breakdown across countries - around 150 species in China, 170 in Russia, around 50 in Japan, 35 in Iran, and 81 in Kazakhstan. Notably, 19 species have been identified within the territory of the Altyn-Emel State National Natural Park in Kazakhstan, indicating a high plant species richness of the region. According to recent observations, previous species descriptions have been supplemented with new data. Representatives of the genus *Artemisia* have a wide range of biologically active substances, making them a subject of considerable scientific interest. The present study provides an anatomical analysis and comparative assessment of the vegetative organs of three dominant species - *Artemisia serotina*, *Artemisia heptapotamica*, and *Artemisia terra-albae* - collected from the Altyn-Emel State National Natural Park. In the study sites, the soils were light chestnut formed under sagebrush-grass vegetation. These soils are shallow, stony, and characterized by a well-developed turf layer. The humus horizon reaches a depth of 25–35 cm, with a humus content ranging from 2.5% to 3.2%. Carbonates ($CaCO_3$) are present from the surface layer (2–3%)) downwards, reaching 14–15% in the lower horizons. For anatomical studies, cross-sections of the vegetative organs (root, stem, and leaf) were prepared using the paraffin embedding method. Sectioning was performed with a microtome, followed by double staining with safranin and fast green. The findings of the study emphasize the ecological importance and resilience of *Artemisia* species, highlighting the need for continuous conservation efforts. The data provide critical insights for biodiversity management and the sustainable development of natural resources of Kazakhstan.

**Key words:** *Artemisia serotina*; *Artemisia heptapotamica; Artemisia terra-albae*; correlation; Altyn-Emel State National Natural Park

## Introduction

The Altyn-Emel State National Natural Park (the Altyn-Emel SNNP) was established in 1996 in the Kerbulak and Panfilov districts of the Zhetysu region, the Ili Basin, in the southeastern part of Kazakhstan (Bayadilov *et al.,* 2016). The area of the park is 307,653 hectares, and the total area of the protected zone is more than 500 thousand hectares (Fig. 1). The territory of the park includes mountainous, sandy-desert, and gravelly-clay-desert landscape complexes. There are remnant xerophytic mountains (https://www.altyn-emel.kz/en/). According to Danilov *et al*., (2016), the Altyn-Emel SNNP has 864 species of vascular plants from 88 families and 403 genera, of which 30 species are listed in the Red Book of Kazakhstan.

The family Asteraceae comprises over 32,000 currently accepted species in more than 1,900 genera and 13 subfamilies (The Plant List, 2013; Gostel *et al.,* 2020; Govaerts *et al.,* 2021; Qaiser *et al*., 2025). With about 500 species distributed globally, the genus *Artemisia* is one of the largest in the family Asteraceae (Hussain *et al.,* 2019a; Judžentiene *et al.,* 2016). There are 81 *Artemisia* species in Kazakhstan, 19 of which are endemic (Pavlov, 1966). *Artemisia* species occupy a variety of natural habitats in Europe, Asia, North Africa, North and South America, and Australia (Podbielkowski & Sudnik-Wójcikowska, 2003; Aglarova *et al.,* 2008).

According to Bremer (1994) and Ghafoor (2002), all studies concerning the taxonomy and classification of *Artemisia* were based on the capitulum morphology. They recognized four sections, or subgenera, within the genus *Artemisia*: *Artemisia*, *Absinthium*, *Dracunculus*, and *Seriphidium*. For a long time, the status of *Seriphidium,* either a separate genus or a subgenus of *Artemisia,* remained a subject of debate among taxonomists (Hussain *et al.,* 2019b).

A number of researchers have studied the anatomical characteristics of *Artemisia* species. Osmanlıoğlu Dağ *et al*., (2023) conducted anatomical analyses of several *Artemisia* L. species (*A. absinthium* L., *A. annua* L., *A. abrotanum* L., *A. incana* (L.) Druce, and *A. tournefortiana* Rchb.) from Turkey, contributing to the morphological characterization of the genus. Tojić & Rančić (2023) examined the general anatomical features of the vegetative organs of two *Artemisia* species (*A. vulgaris* and *A. absinthium*) in Belgrade, Serbia. Minarchenko *et al*., (2022) described the anatomical characteristics of two *Artemisia* L. species (*A. absinthium* and *A. argyi*) in Ukraine.

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Noorbakhsh *et al*., (2008) conducted the anatomical study of the leaves of 28 *Artemisia* species from Iran. The leaves of *Artemisia serotina* were additionally analyzed as part of their research. Six *Artemisia* species occurring in Iran were investigated by Karbalaei *et al*., (2021). Mirzaliyeva *et al*., (2020) conducted the first anatomical study of the vegetative organs of *Artemisia heptapotamica*.

Uteulin *et al*., (2021) performed the microscopic analysis of the leaf anatomical structure of *Artemisia terrae-albae* Krash. growing in the wild on sandy loam soils in Kazakhstan.

*Artemisia* species are economically valuable and can be used in medicine, food industry , horticulture, and ecological restoration (Tu, 2011). In this regard, the study of the anatomical structure of the vegetative parts of dominant *Artemisia* species growing under the conditions of the Altyn-Emel SNNP is of significant scientific interest.

Understanding the internal structure of plants is of great importance. Plant anatomy focuses on identifying the structural characteristics of major systematic groups. Plant taxonomy is based not only on external morphological traits but also on internal anatomical characteristics. The important role of anatomy in plant taxonomy has long been recognized, and many taxonomic controversies have been resolved using anatomical evidence (Sinyak, 2010; Hussain, 2020).

Many studies examined the morphological, palynological, cytogenetic, molecular, and evolutionary features of the genus *Artemisia*, but there are limited data on the anatomical aspects and their value for the classification of *Artemisia* species, especially those occurring in Kazakhstan.

The purpose of this article is to present the results of the study of the anatomical features of the vegetative organs and to perform a comparative analysis of the dominant representatives of the genus *Artemisia* – *A. serotina* Bunge, *A. heptapotamica* Poljakov, and *A. terrae-albae* Krasch. – from the Altyn-Emel SNPP.

## Materials and Methods

**Study species:** In this study, three species of *Artemisia* were used for anatomical analysis focusing on identifying and describing the most important structural features (Pavlov, 1966).

*Artemisia serotina* Bunge is a perennial herbaceous plant. Stems few, erect or slightly ascending at the base (Figs. 2-3). Lower stem leaves long-stalked, oblong or broadly ovate, middle and upper stem leaves sessile. Inflorescence is a panicle with long (up to 15 cm) lateral branches, capitula arranged in a spike-like manner ovoid, up to 33 mm long, sessile or on short stalks. Involucral leaves (phyllaries) grayish and densely, spider-web-like pubescent . The florets bisexual and few in number (Pavlov, 1966; Kapustina, 2001).

*Artemisia heptapotamica* Poljakov is grayish in colour due to dense felted pubescence, which partially wears off with age. The plant has a woody, thick root system which produces numerous dense, deciduous, infertile shoots. Together with a few fertile stems, these form a small, loose turf. Fertile stems are ascending or erect at the base, 20 to 35 cm tall, occasionally up to 45 cm tall. Plants were moderately robust and branched from the middle. Leaves of the infertile shoots and petiolate leaves of the lower stem oblong, up to 2.5 cm long and 1.5 cm wide, grayish-green on both sides, covered with a spider-web-like felted pubescence, twice pinnately dissected. Terminal leaf lobes are narrowly linear, 2–5 mm long, and shortly pointed. Middle stem leaves are sessile, bases are pinnately dissected. Upper bracts simple, linear, not extending beyond the panicles (Figs. 2-3). *A. heptapotamica* was mainly distributed in the northern part of the Tian Shan Mountains, including the Dzungarian Alatau, Ili, Kungei Alatau, and Ketmen ranges (Pavlov, 1966; Ling & Ling, 1988).

*Artemisia terra-albae* Krasch. is grayish in colour, covered with dense spider-web-like pubescence, which later partially wears off or reduces to slight pubescence, leaving the surface almost glabrous and brownish. Root thick, woody, and multi-headed, with slightly ascending shoots. Flowering stems were ascending or erect at the base, from 8-15 cm to 15-30 cm tall, occasionally up to 45 cm tall, thin, sinuous or somewhat thick and woody at the base, with branching occurring near the top. Leaves of the lower stem and of non-reproductive shoots are short-petiolate, ovate, 1-2 cm long and up to 1 cm wide, grayish-green on either side due to dense spider-web-like pubescence, simply or twice pinnately dissected, with terminal lobes filiform-linear or linear, short, up to 2(3) mm long. Middle stem leaves sessile, with pinnately dissected basal lobes. Bracts simple, linear, not extending beyond the panicle (Figs. 2-3). The plant grows in desert areas and is found throughout all desert regions of Kazakhstan.

**Anatomical studies:** Plant samples of *Artemisia serotina* Bunge, *A. heptapotamica* Poljakov, and *A.terra-albae* Krasch. (Figs. 2-3) were collected from Altyn-Emel SNNP (http://www.plantsoftheworldonline.org/), Kazakhstan, on June 02, 2021 (44°05’580” N and 073°26’237” E, 1473 m above sea level).

Anatomical studies were conducted using plant material fixed in a mixture of 70% alcohol, glycerin, and water in a 1:1:1 ratio. Root, stem, and leaf sections were prepared using the paraffin embedding method. Each section was cut out with a microtome and stained with safranin and fast green (Johansen, 1944). Further anatomical observations were carried out under a light microscope, and photographs were taken using a *Leica DM750* research microscope. Standard methods accepted in plant anatomy were employed for slide preparation and description (Barykina *et al.,* 2004; Vekhov *et al.,* 1980; Khanina *et al.,* 1999; Prozina, 1960). The description of external morphological features was carried out in accordance with the requirements of the XI edition of State Pharmacopoeia (GF XI), (State Pharmacopoeia of the USSR, 1987; State Pharmacopoeia of the USSR 1990). Species identification was according to the *Flora of Kazakhstan* (Pavlov, 1966). Plant nomenclature is according to Anon., (2025). The voucher specimens have been deposited in the Department of Botany and Agroecology, Faculty of Biology and Biotechnology, Al-Farabi Kazakh National University. Correlation analysis was conducted using RStudio (2015) software.


Fig. 1. Map of the Altyn-Emel SNNP in Kazakhstan.

Fig. 2. *Artemisia* species: (a) *A.serotina* (Bunge) Poljakov; (b) *A. heptapotamica* Poljakov; (c) *A.terrae-albae* Krasch.

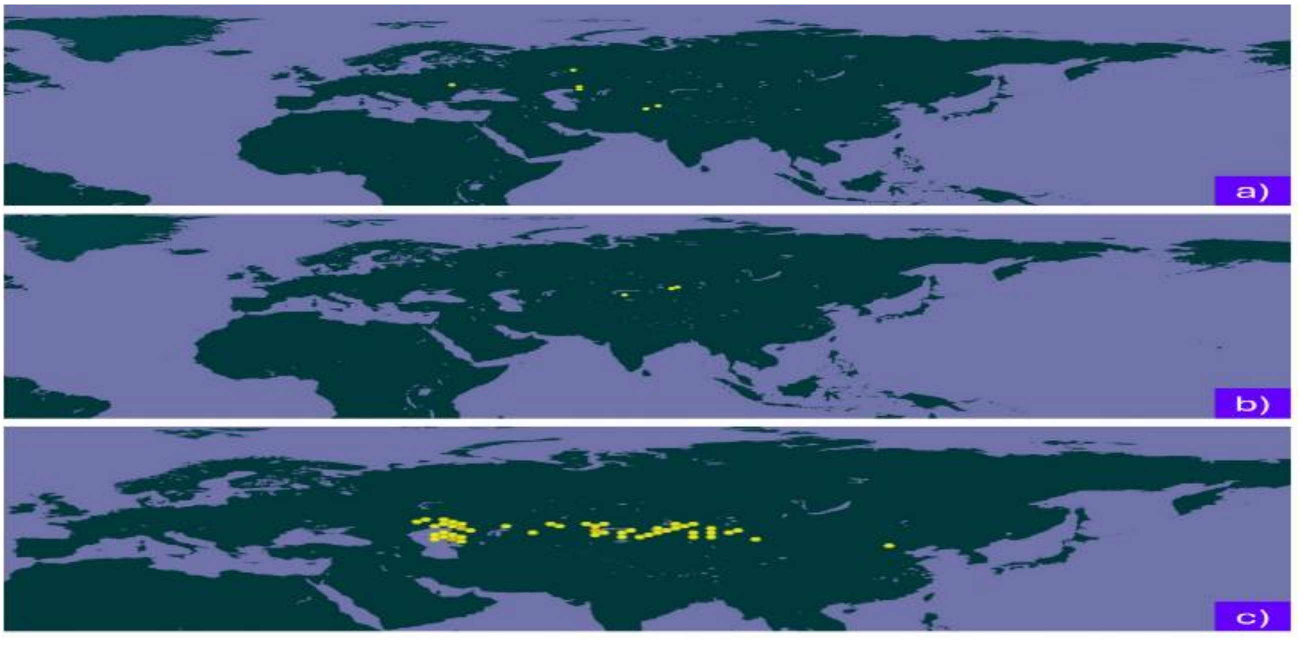


Fig. 3. Global distribution of *Artemisia* species: (a) *A.serotina* (Bunge) Poljakov; (b) *A. heptapotamica* Poljakov; (c) *A.terrae-albae* Krasch.

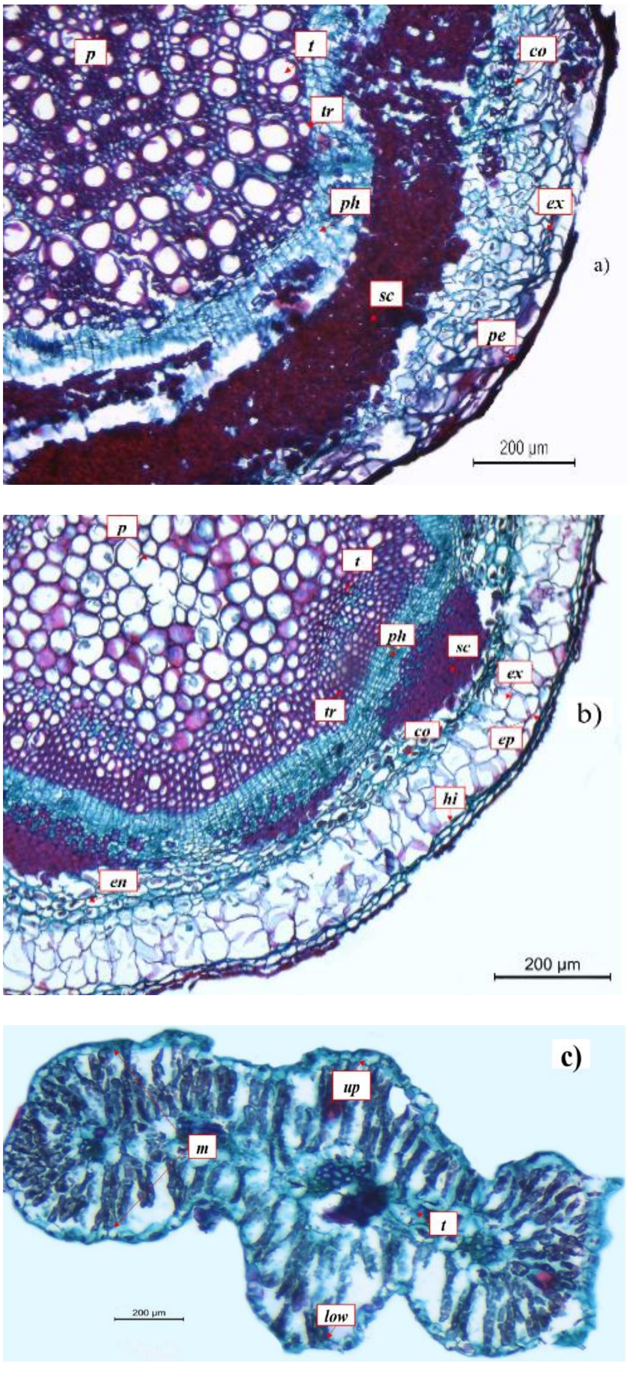


Fig. 4. Anatomical structure of *Artemisia serotina* (Bunge) Poljakov. (a) Root sections; (b) Stem sections; (c) Leaf sections
(p: pith, co: cortex, sc: sclerenchyma, ph: phloem, ex: exodermis, en: endodermis, t: trachea, tr: tracheaid, pe: periderm, hi: hipodermis, m: mesophyll, up: upper epidermis, low: lower epidermis)

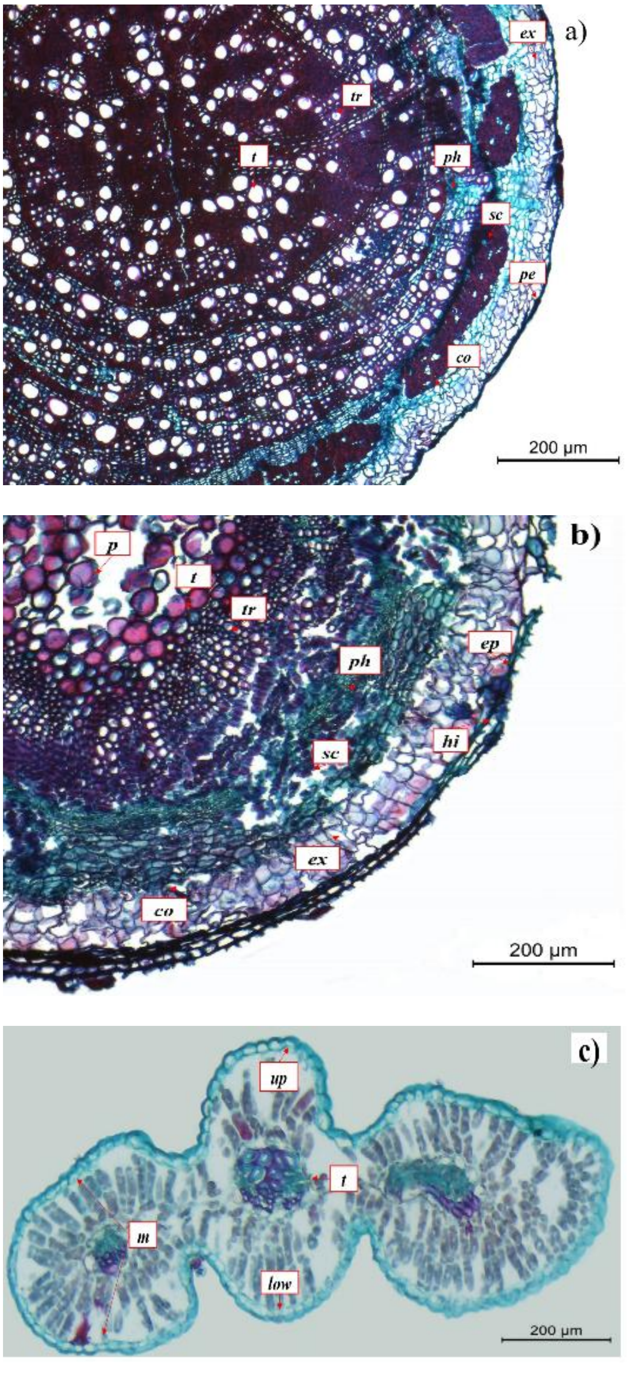


Fig. 5. Anatomical structure of *Artemisia heptapotamica* Poljakov (a) Root sections; (b) Stem sections; (c) Leaf sections
(p: pith, co: cortex, sc: sclerenchyma, ph: phloem, ex: exodermis, en: endodermis, t: trachea, tr: tracheaid, pe: periderm, hi: hipodermis, m: mesophyll, up: upper epidermis, low: lower epidermis)

## Results

### Anatomical characteristics of *Artemisia serotina* Bunge

Following anatomical structure of vegetative structure of *Artemisia serotina* were observed (Figs. 4-6).

**Root:** Secondary growth was observed. The outer contour was uneven and slightly notched, covered with the periderm, a secondary protective tissue composed of three cell layers: phellem (cork), phellogen (cork cambium), and phelloderm. Beneath the periderm were flattened, irregularly shaped, rectangular exodermal cells. Below the exoderm, parenchyma cells formed the primary cortex, within which small crystalline inclusions were observed. Endodermal cells were absent The mechanical tissue (sclerenchyma) represented by a continuous five- to six-layered band of cells is well developed. Sclerenchymatous cells thick-walled formed a continuous layer surrounding the central cylinder. In some cases, fragmentation of these cell layers resulted in a loose structure. This was followed by a continuous layer of the secondary phloem, while the cambial cell layer was poorly developed and not clearly distinguishable in the anatomical structure of the root.

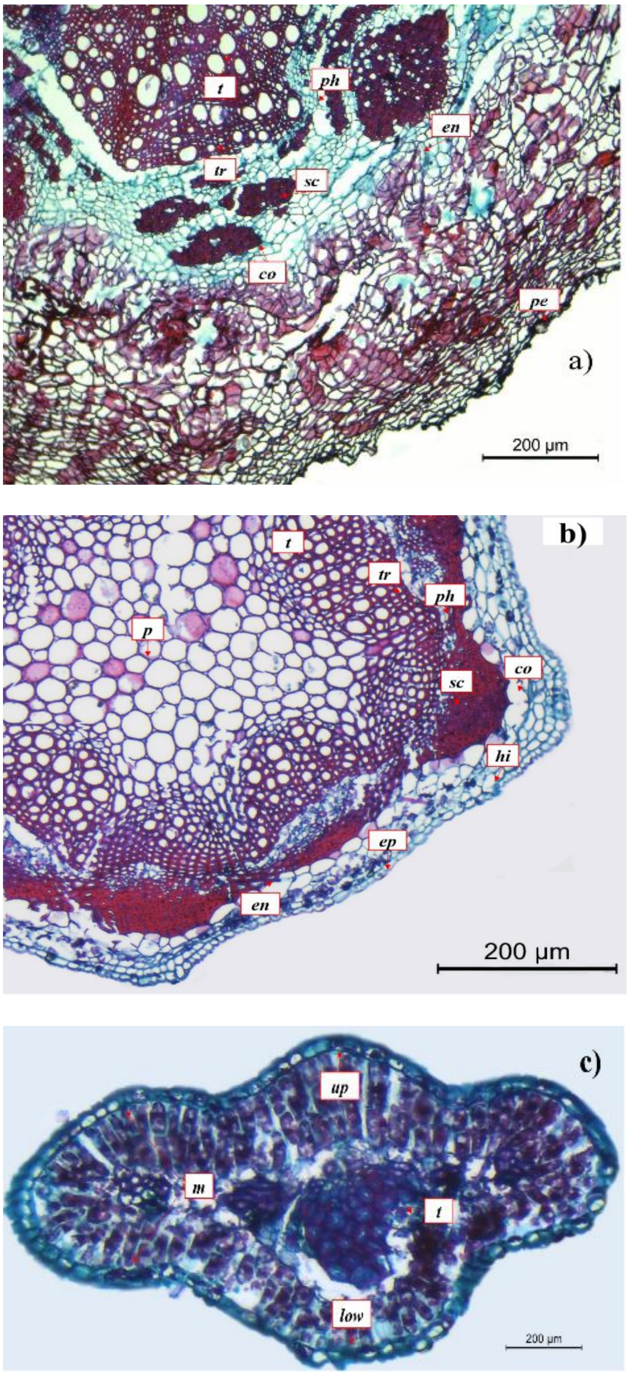


Fig. 6. Anatomical structure of *Artemisia terrae-albae* Krasch. (a) Root sections; (b) Stem sections; (c) Leaf sections
(p: pith, co: cortex, sc: sclerenchyma, ph: phloem, ex: exodermis, en: endodermis, t: trachea, tr: tracheaid, pe: periderm, hi: hipodermis, m: mesophyll, up: upper epidermis, low: lower epidermis)

The central cylinder is characterized by the presence of numerous mechanical tissue cells surrounding the xylem tracheids. The central part of the root cylinder consisted of xylem vessels and tracheids, along with the elements of the secondary phloem. The xylem vessels were relatively large. Isolated granular inclusions, both singly and in groups were also observed (Fig. 4a).

**Stem:** The stem was ribbed and covered with the single- or double-layered epidermis. Beneath the epidermis, in some areas of the stem single layer of hypodermal cells functioning as a storage tissue were present. Next were large, irregularly shaped, rounded-oblong cells of the exoderm, forming the outer layer of the primary cortex. The cells of the primary cortex were located deeply closer to the central cylinder. A layer of rectangular to oval endodermal cells with inclusions was found between the primary cortex and the central cylinder. The mechanical tissue within the central cylinder consisted of numerous groups of small sclerenchyma cells with thickened walls positioned at the level of the vascular bundles. The vascular bundles were open collateral type. A continuous cambial layer was present between the phloem (consisting of living sieve tubes) and the xylem (consisting of dead tracheids). The numerous xylem vessels varied in diameter. In most cases, the phloem was bordered by a sclerenchymatous cap formed by bast fibers. The central part of the stem was composed of the medullary (pith) parenchyma, consisting of numerous densely packed, rounded cells with inclusions. The anatomical structure of the stem was well-defined, and both liquid and rounded inclusions were observed throughout the stem, particularly within the central cylinder (Fig. 4b).

**Leaf:** The leaf blade of *A. serotina* was covered by the epidermis overlaid with a thin cuticle. Scattered simple trichomes (hairs) were present on the leaf surface. The cells of the upper and lower epidermis were continuous, forming a smooth transition from the adaxial (upper) to the abaxial (lower) side. The margins of the leaf blade were rounded. The leaf was equifacial, as it contained a homogeneous mesophyll. Columnar mesophyll cells occupied the entire space between the upper and lower epidermis. The mesophyll consisted of two rows of cells on both the upper and lower sides of the leaf, with the cells loosely arranged and elongated perpendicular to the leaf surface. The central vascular bundle was located in the middle of the leaf, with smaller bundles positioned along the margins. The vascular bundles were closed collateral, consisting of the phloem and xylem elements represented by vessels. The central vascular bundle was surrounded by individual sclerenchyma cells, whereas the smaller bundles lacked a sclerenchyma sheath (Fig. 4c).

**Anatomical characteristics of *Artemisia heptapotamica* Poljakov**

**Root:** In the root of *A. Heptapotamica,* the secondary structure was present. In cross-section, along the outer surface, the integumentary tissue (periderm) was visible, consisting of rectangular cells with thickened cell walls. Beneath it lies the exoderm formed by 3–4 layers of rounded-rectangular cells with thin, curved cell walls. The primary cortex cells were arranged in two layers adjacent to the mechanical tissue – sclerenchyma. The cortex cells were elongated, rectangular in shape, and rounded at the ends. The sclerenchyma consisted of different groups of cells: some are larger and elongated, while others are smaller and oval. Among the sclerenchyma cells, there were intercellular spaces filled with air. The cambial cell layer located next to the elements of the central cylinder consisted of living cells with thin walls.

Beneath the cambium was the secondary phloem formed by sieve tubes; theparenchyma cells of the phloem form both soft and hard bast fibers. The secondary xylem was formed by dead, elongated tracheal cells and vessels. The cellular structures of the secondary phloem and secondary xylem alternate, forming a layered structure. The secondary xylem contained both vertical and horizontal systems, the latter formed rays. The central part of the root consisted of more densely packed elements of the primary phloem and xylem (Fig. 5a).

**Stem:** Incross-section, the stem of *A. heptapotamica* (×70) was covered by the single- or double-layered epidermis with a layer of hypodermal tightly tile-like packed cells beneath. The surface of the epidermis was covered by a thin layer of the cuticle. Beneath the hypoderm was the exoderm - the outer layer of the primary cortex - composed of 3-4 layers of irregularly shaped, loosely arranged cells followed by a dense layer of the mechanical tissue, sclerenchyma having intercellular spaces between the sclerenchyma cells. The secondary phloem consists of bast fibers located toward the periphery of the stem. The xylem consisted of tracheae and tracheids. The phloem and xylem elements formed a continuous layer surrounding the stem core. Inclusions were found among the cells of the primary cortex and the central cylinder. The xylem contained numerous narrow- and medium-sized, lightly coloured elements. Toward the center of the conductive tissues was a loose, large-celled core formed by the non-specialized parenchyma. The core cells were rounded and contained liquid inclusions (essential oils). These cells were densely packed near the periphery but more loosely arranged closer to the center of the stem (Fig. 5b).

**Leaf:** On the outside, the leaves of *A. heptapotamica* were covered by the small cells of the upper and lower epidermis. The epidermal cells were rounded and closely packed. The cuticle was poorly developed on both sides with occasional simple hairs. The mesophyll cells were arranged in two rows on both the upper and lower sides, occupying the entire space between the upper and lower epidermis. The leaf was equifacial. Notably, there were relatively large intercellular spaces filled with air between the mesophyll cells. The mesophyll tissue was loosely arranged. The main vascular bundle was located at the center of the leaf, with smaller vascular bundles distributed along its edges. All bundles were closed collateral type. The vascular bundles had a typical structure and consisted of the phloem and xylem, with the xylem represented by vessels. Single layer of sclerenchyma cells were present around the vascular bundles. Inclusions were rare and appeared as droplet-like structures (Fig. 5c).

**Anatomical characteristics of *Artemisia terrae-albae* Krasch**.

**Root:** The anatomical structure of the root was characterized by the secondary growth. The outer surface of the root was covered with the periderm. The periderm was a secondary protective tissue consisting of three layers: the phellogen (cork cambium, middle layer), the phellem (cork, outer layer), and the phelloderm (inner layer). The large, irregularly shaped parenchyma cells of the primary cortex were located beneath the phellogen. Within the primary cortex, there were islands of the mechanical tissue composed of the thick-walled sclerenchyma cells. Endodermis, the innermost layer of the primary cortex formed a continuous layer surrounding the central cylinder. The central part of the root was occupied by elements of the primary xylem and phloem. The xylem consisted of tracheae and tracheids (Fig. 6a).

**Stem:** The stem of *A. Terrae-albae* was covered with the single-layered epidermis. The epidermal cells were rounded and tightly packed followed by 2–3 layers of the hypodermis. Both the hypodermal layers and the underlying primary cortex cells contained inclusions of essential oils. The inner single-layered endoderm formed the innermost layer of the primary cortex. The endodermal cells were large and oval in shape. Vascular bundles were located beneath the endoderm, each surrounded on the phloem side by the mechanical tissue – the sclerenchyma. The vascular bundles were open collateral, arranged in a circle around the central cylinder. A continuous layer of the cambial cells was present between the phloem and xylem. The phloem consisted of bast fibers, while the xylem is composed of tracheids and vessels (tracheae). The central part of the stem cylinder was filled with the core parenchyma, having large cell and containing essential oil inclusions (Fig. 6c).

**Leaf:** The leaf blade was covered with the single-layered upper and lower epidermis. The cells of the upper epidermis were tightly packed, closely arranged, and covered by a thin layer of the cuticle. The cells of the lower epidermis were slightly looser, containing stomata, and also cutinized. Simple, single-celled trichomes were present on the epidermal surface. There was no differentiation of the main tissue; therefore, the cells of the palisade mesophyll occupied the entire space between the upper and lower epidermis. The leaf was equifacial and had a homogeneous mesophyll. The palisade mesophyll cells were arranged perpendicular to the leaf surface in two layers. A large vascular bundle was located in the central part of the leaf, with smaller vascular bundles positioned along its sides. The vascular bundles were closed collateral, consisting of the phloem and xylem. The mechanical tissue cells (sclerenchyma) surrounded the large vascular bundle. The small peripheral bundles were embedded within the palisade mesophyll (Fig. 6b).

**Statistical analysis**

To compare the data obtained, biometric measurements of the anatomical structure of the leaf blades, stems and roots of the studied species were carried out. The results are presented in tables 1-3.

A statistical analysis of the anatomical parameters of leaves, stems, and roots of all three species revealed significant correlations (Figs. 7-9).

According to the results presented in Table 1, *A. serotina* had the largest width and length of the leaf epidermis, mesophyll thickness, and vessel diameter. *A. heptapotamica* was similar to *A. terrae-albae* in terms of morphometric indicators, with the only difference being the leaf length which was greater in *A. terrae-albae* (7 ±1 µm) than in *A. heptapotamica* (6 ±1 µm).

**Table 1. Morphometric indicators of the leaves of *A.serotina, A. heptapotamica, A. terrae-albae* (average ± standard deviation).**

| Species | The epidermis,of the leaf (μm) Avr. ± Sd | | The thickness of the mesophyll, (μm) Avr. ± Sd | Diameter of trachea, (μm) Avr. ± Sd |
|---|---|---|---|---|
| | Width | Length | | |
| *Artemisia serotina* | 14.28 ± 4.22 | 9.02 ± 2.21 | 177.96 ± 30.72 | 6,78 ± 1.69 |
| *Artemisia heptapotamica* | 12.13 ± 2.79 | 6.23 ± 1.4 | 153.12 ± 36.31 | 5,60 ± 2.22 |
| *Artemisia terrae-albae* | 11.03 ± 2.94 | 6.87 ± 1.5 | 150.81 ± 45.65 | 5,40 ± 2.16 |

**Table 2. Morphometric parameters of the stems of *A. serotina, A. heptapotamica, A. terrae-albae* (average± standard deviation).**

| Species | | *Artemisia serotina* Avr. ± Sd | *Artemisia heptapotamica* Avr. ± Sd | *Artemisia terrae-albae* Avr. ± Sd |
|---|---|---|---|---|
| The epidermis of the stem, (μm) | Width | 8.80 ± 2.38 | 9.03 ± 2.05 | 8.25 ± 2.47 |
| | Length | 19.35 ± 7.17 | 16.16 ± 4.61 | 14.20 ± 3.74 |
| The diameter of the trachea, (μm) | | 17.10 ± 5.46 | 11.14 ± 2.44 | 13.67 ± 3.33 |
| The cortex, (μm) | Width | 18.27 ± 6.02 | 10.67 ± 2.98 | 8.74 ± 2.41 |
| | Length | 32.56 ± 9.39 | 18.69 ± 6.75 | 15.88 ± 4.5 |
| Core diameter, (μm) | | 36.13 ± 12.78 | 20.57 ± 6.38 | 25.58 ± 9.25 |
| Phloem, (μm) | Width | 7.19 ± 2.33 | 4.60 ± 1.78 | 6.24 ± 2.41 |
| | Length | 13.00 ± 3.08 | 9.00 ± 1.88 | 8.36 ± 2.32 |
| Diameter of the tracheids, (μm) | | 4.74 ± 1.12 | 3.99 ± 0.6 | 5.68 ± 1.44 |
| Endoderm, (μm) | Width | 10.84 ± 2.99 | - | 13.81 ± 3.48 |
| | Length | 23.36 ± 8.91 | - | 28.30 ± 5.13 |
| Exoderm, (μm) | Width | 35.43 ± 8.31 | 22.40 ± 5.64 | - |
| | Length | 39.61 ± 10.89 | 23.90 ± 8.08 | - |
| Diameter of the sclerenchyma, (μm) | | 11.81 ± 2.24 | 10.11 ± 1.64 | 8.73 ± 2.15 |

**Table 3. Morphometric parameters of the roots of *A. serotina, A. heptapotamica, A. terrae-albae* (average ± standard deviation).**

| Species | | *Artemisia serotina* Avr. ± Sd | *Artemisia heptapotamica* Avr. ± Sd | *Artemisia terrae-albae* Avr. ± Sd |
|---|---|---|---|---|
| Diameter of the trachea, (μm) | | 24.43 ± 9.09 | 17.4 ± 6.72 | 19.54 ± 6.79 |
| Diameter of the tracheids, (μm) | | 5.93 ± 1.85 | 4.89 ± 1.14 | 5.87 ± 1.93 |
| Diameter of the sclerenchyma, (μm) | | 13.79 ± 3.78 | 10.75 ± 2.01 | 10.54 ± 2.82 |
| Phloem, (μm) | Width | 6.38 ± 1.81 | 4.79 ± 1.4 | 7.03 ± 1.91 |
| | Length | 11.84 ± 3.01 | 8.77 ± 2.23 | 11.28 ± 3.51 |
| The cortex, (μm) | Width | 10.39 ± 3.3 | 7.05 ± 1.87 | 13.62 ± 3.41 |
| | Length | 18.00 ± 4.33 | 12.40 ± 3.27 | 20.56 ± 6.92 |
| Exoderm, (μm) | Width | 24.91 ± 5.93 | 16.75 ± 3.6 | 19.25 ± 7.18 |
| | Length | 38.80 ± 15.93 | 17.91 ± 6.39 | 27.91 ± 11.35 |

In the present study, the morphological parameters of the three Artemisia species (*A. serotina* Bunge, *A. heptapotamica* Poljakov and *A. terrae-albae* Krasch.) were analyzedusing R Studio software (Rstudio, 2015).

The analysis of the leaf morphological traits in *A. serotina* revealed that leaf mass and thickness were the most closely correlated parameters, reflecting an adaptive environmental strategy of the species (Fig. 7). The presence of both positive and negative correlations indicated a high degree of morphological variation within the species, suggesting substantial intraspecific plasticity.

In *A. heptapotamica*, a tendency toward coordinated development of leaf structures was observed. The predominance of positive correlations among morphological traits indicates an integrated biomorphological strategy aimed at maintaining the functional efficiency of leaves under varying environmental conditions.

In *A. terra-alba*, leaf morphological traits generally exhibited weak interdependence, which may reflect a greater flexibility in the species' adaptive mechanisms. A moderately strong positive correlation between leaf length and mass highlighted the importance of this parameter in the overall leaf biomass, while other traits tend to vary more independently. These findings emphasized the complexity of morphological regulation and the potential influence of abiotic factors on leaf structure formation.

According to the results presented in Table 2, the largest stem width was observed in *A. heptapotamica* (9±2), while the longest stem was found in *A. serotina* (19±7 μm). *A. serotina* also had the most pronounced primary cortex layer with a width of 18±6 μm and a length of 32±9 μm. The diameter of the core was the largest in *A. serotina* (36±13 μm), as were the phloem parameters. However, the diameter of the trachea was the largest in *A. heptapotamica* (11±2 μm). The diameter of the sclerenchyma was the greatest in *A. serotina* (12±2 μm), while the diameter of the tracheids was the largest in *A. terrae-albae* (6±1 μm).

*A. serotina* demonstrated a high degree of coordination in tissue development, particularly in the epidermis, sclerenchyma, and endodermis. This correlation structure indicateed ecological plasticity and adaptive features of the stem anatomy of this species within specific habitats (e.g., mountainous climates or arid regions).

The stem of *A. heptapotamica* exhibited structural adaptability due to variation in the size of vascular bundles, epidermis, and sclerenchyma, which may reflect the plant's capacity for morphological adjustments in response to environmental factors.

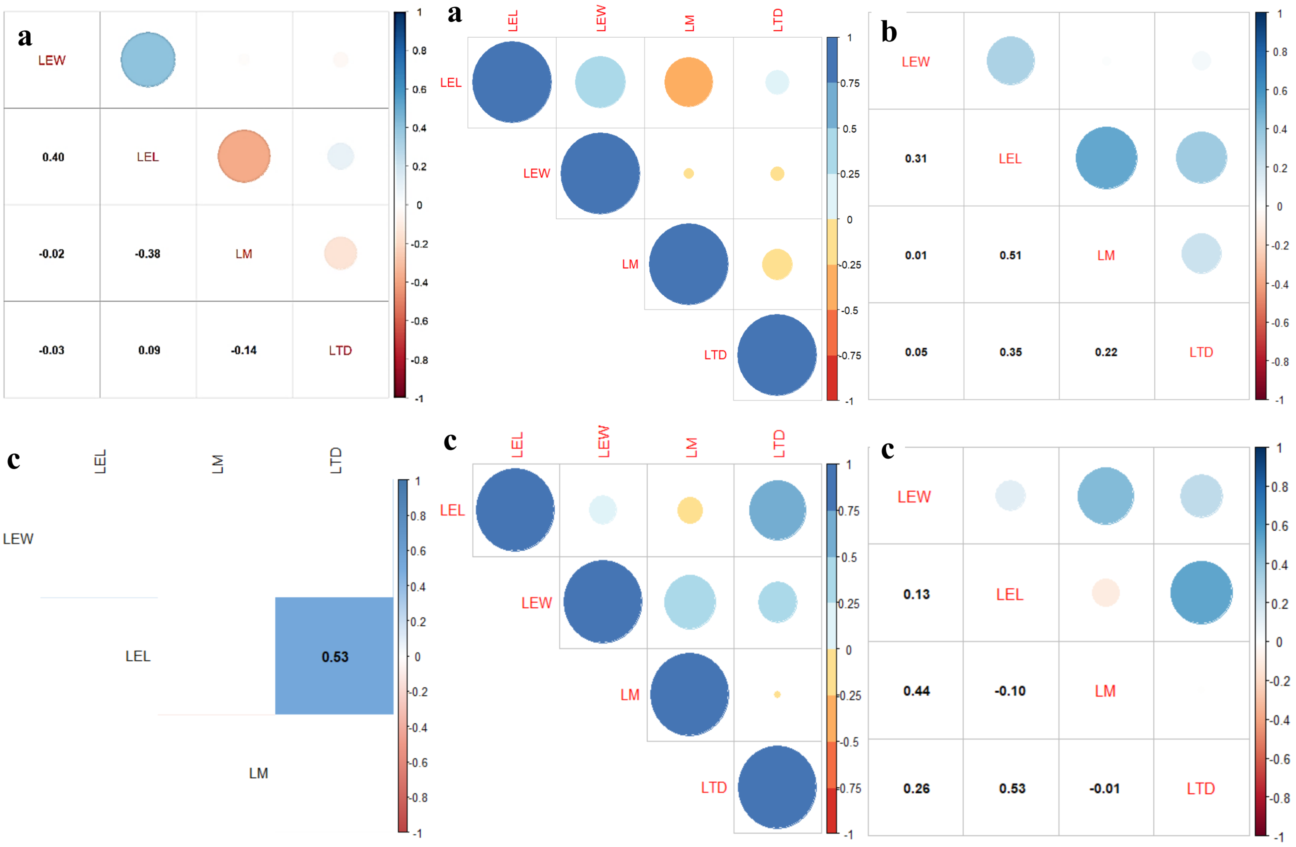


Fig. 7. Correlation analysis of anatomical measurements of leaves. The correlations significant at p<0.05 are highlighted blue (positive) or orange (negative). LEW - the width of the epidermis (µm); LEL - the length of the epidermis (µm); LM - mesophyll thickness (µm); LTD - diameter of the trachea (µm). (a) *A.serotina* (Bunge) Poljakov; (b) *A. heptapotamica* Poljakov; (c) *A.terrae-albae* Krasch.

The positive correlation observed in *A. terrae-albae* suggested that the reinforcement of mechanical tissue (sclerenchyma) occured proportionally with stem thickening. This relationship represented an important adaptation that enhanced the plant's strength and resilience to mechanical stress under arid or extreme environmental conditions (Fig. 8).

The morphometric analysis of the roots of *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* revealed that *A. serotina* had the largest vessel diameter (24±9 µm), tracheid diameter (6±2 µm), and the diameter of sclerenchyma cell groups (14±4 µm) compared to the other two species (Table 3)-. Conversely, *A. terrae-albae* had the greatest width of bast fibers in the phloem (7±2 µm), as well as the width (14±3 µm) and length (20±7 µm) of the primary cortex. The exodermal layer width (25±6 µm) and length (39±16 µm) were also the greatest in *A. serotina*.

Correlation analysis of the root morphological traits in *A. serotina* revealed a strong significant positive relationship between root elongation (REL) and estimated root biomass (REW), with a correlation coefficient of $r$ = 0.67. This statistically significant association suggests that increased root length is accompanied by a proportional increase in biomass. Such a relationship likely reflects the species' strategy of active resource allocation to the development of a deeper or more extensively branched root system, which may enhance drought tolerance and competitiveness for soil resources.

In *A. heptapotamica*, correlation analysis revealed several statistically significant associations among root system traits. The results are visualized in a correlation matrix, where the size and color of the circles represent the magnitude and direction of the correlations. Positive correlations are shown in blue and negative, in red, with the size of each circle corresponding to the absolute value of the correlation coefficient.

The strongest positive correlation was observed between root crown width and length (RCW and RCL, $r$ = 0.53), suggesting a coordinated development of the root system in both horizontal and vertical dimensions. This pattern may indicate an adaptive strategy aimed at establishing a stable and functionally efficient root architecture capable of supporting plant performance under varying environmental conditions.

A strong negative correlation ($r$ = – 0.48) was found between root system width (RPW) and the length of primary roots (RPL), potentially reflecting divergent growth strategies. Some individuals may favor the formation of a more compact and branched root system, while others allocate growth toward deeper soil penetration enabling access to water and nutrients from lower soil layers.

In *A. terra-alba*, the analysis also revealed several statistically and biologically meaningful correlations between root morphological traits. The strongest positive correlation was found between root crown width and length (RCW–RCL, $r$ = 0.57), indicating synchronous development of these dimensions. This relationship may be associated with spatial optimization of soil exploitation and enhanced resilience to environmental stressors.

Additionally, a positive correlation ($r$ = 0.49) between estimated root biomass (REW) and root elongation (REL) suggests that increased root length is accompanied by greater biomass accumulation. This may highlight the functional importance of vertical root growth as a strategy for accessing deeper soil resources (Fig. 9).

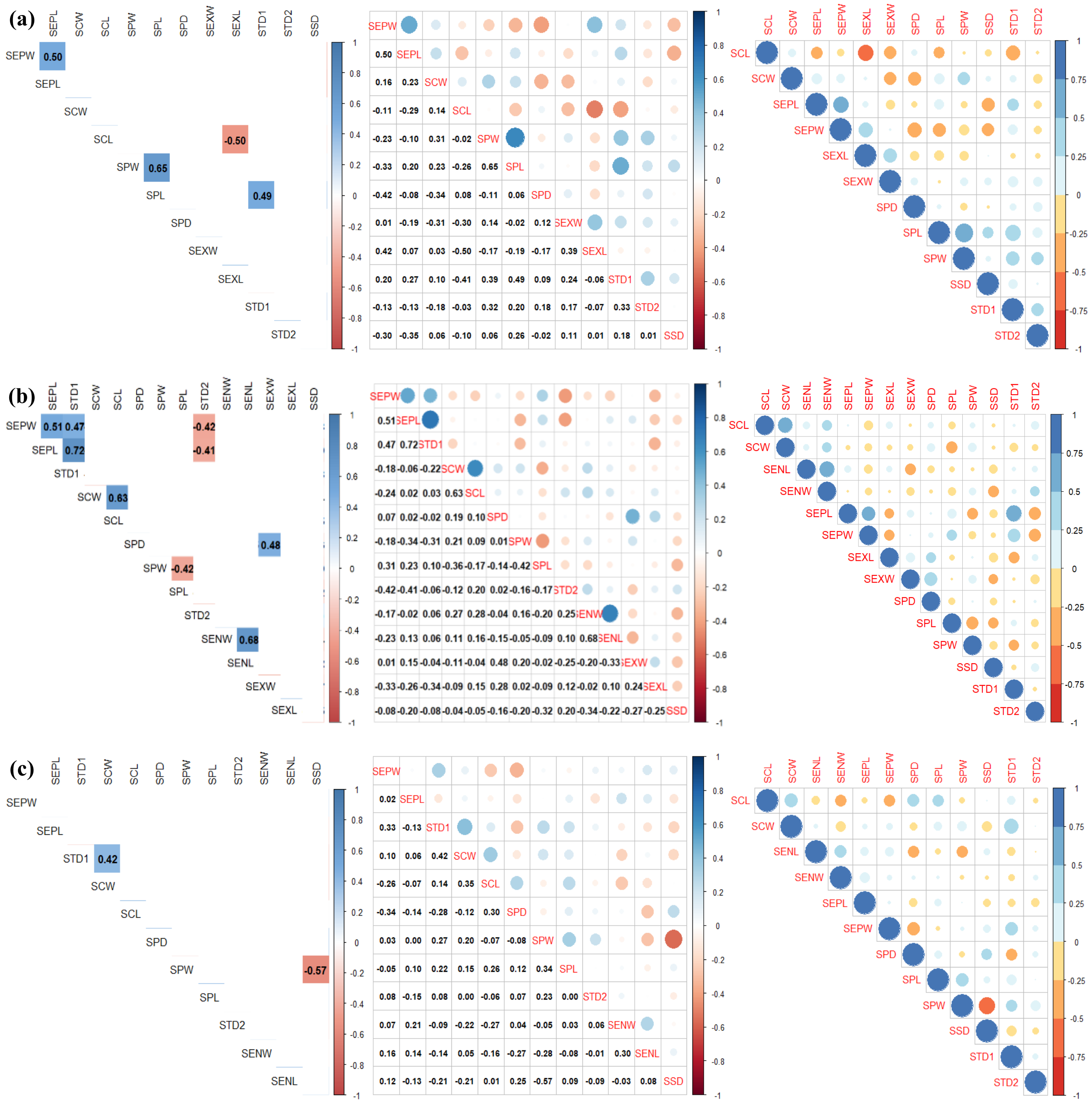


Fig. 8. Correlation analysis of the anatomical measurements of stems. The correlations significant at p<0.05 are highlighted blue (positive) or orange (negative). LEW - the width of the epidermis (µm); LEL - the length of the epidermis (µm); LM - mesophyll thickness (µm); LTD - diameter of the trachea (µm). SEPW - the width of the epidermis (µm); SEPL - the length of the epidermis (µm); STD1 - diameter of the trachea (µm); SCW - the width of the cortex (µm); SCL - the length of the cortex (µm); SPD - diameter of the pith (µm); SPW - the width of the phloem (µm); SPL - the length of the phloem (µm); STD2 - diameter of the tracheaid (µm); SENW - the width of the endodermis (µm); SENL - the length of the endodermis (µm); SEXW - the width of the exodermis (µm); SEXL - the length of the exodermis (µm); SSD - diameter of the sclerenchyme (µm).
(a) *A.serotina* (Bunge) Poljakov; (b) *A. heptapotamica* Poljakov; (c) *A.terrae-albae* Krasch.

## Discussion

Osmanlıoğlu Dağ *et al*., (2023) studied the the cross-sections of stems of *Artemisia* species (*A. absinthium* L., *A. annua* L., *A. abrotanum* L., *A. incana* (L.) Druce, *A. tournefortiana* Rchb.) and found that they had more or less irregular rounded shapes with ribs. Our study showed that the stems of *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* had small simple trichomes on the surface, which was also ribbed (Figs. 3-4).

Tojić *et al*., (2023) identified significant differences in the anatomical structure of *A. vulgaris* and *A. absinthium* leaves. Specifically, the mesophyll of *A. vulgaris* leaves comprised both the spongy and palisade parenchyma, whereas *A. absinthium* had the palisade tissue beneath both the upper and lower epidermal layers. A key diagnostic anatomical feature in these species is the presence and distribution of trichomes. Our findings corroborate this observation, reinforcing the significance of trichome presence in anatomical differentiation of these species (Figs. 3-5).

Minarchenko *et al*., (2022) investigated the anatomical features of two *Artemisia* species *(A. absinthium* and *A. argyi)* from Ukraine and reported that the epidermal cells were irregular in shape with wavy walls and were covered with the predominantly smooth cuticle. In contrast, our study revealed that the epidermis of the vegetative organs consisted mainly of columnar mesophyll cells, which filled the entire space between the upper and lower epidermal layers (Figs. 3-5).

Noorbakhsh *et al*., (2008) studied 28 species of *Artemisia* from Iran and found that in *A. serotina*, the central vascular bundle was ovoid in shape and completely surrounded by fibrous sclerenchyma. In our study, in *A. serotina* the central vascular bundle was surrounded only by individual sclerenchyma cells, while the smaller vascular bundles lacked sclerenchymatous sheaths.

According to Karbalaei *et al*., (2021), the adaxial leaf surface of *Artemisia serotina* from Iranian populations exhibited the greatest variability in epidermal cell length. In contrast, our findings demonstrated that in the studied specimens, the epidermal layers on both leaf surfaces were uniformly structured and exhibited a continuous, smooth transition from the adaxial to the abaxial side.

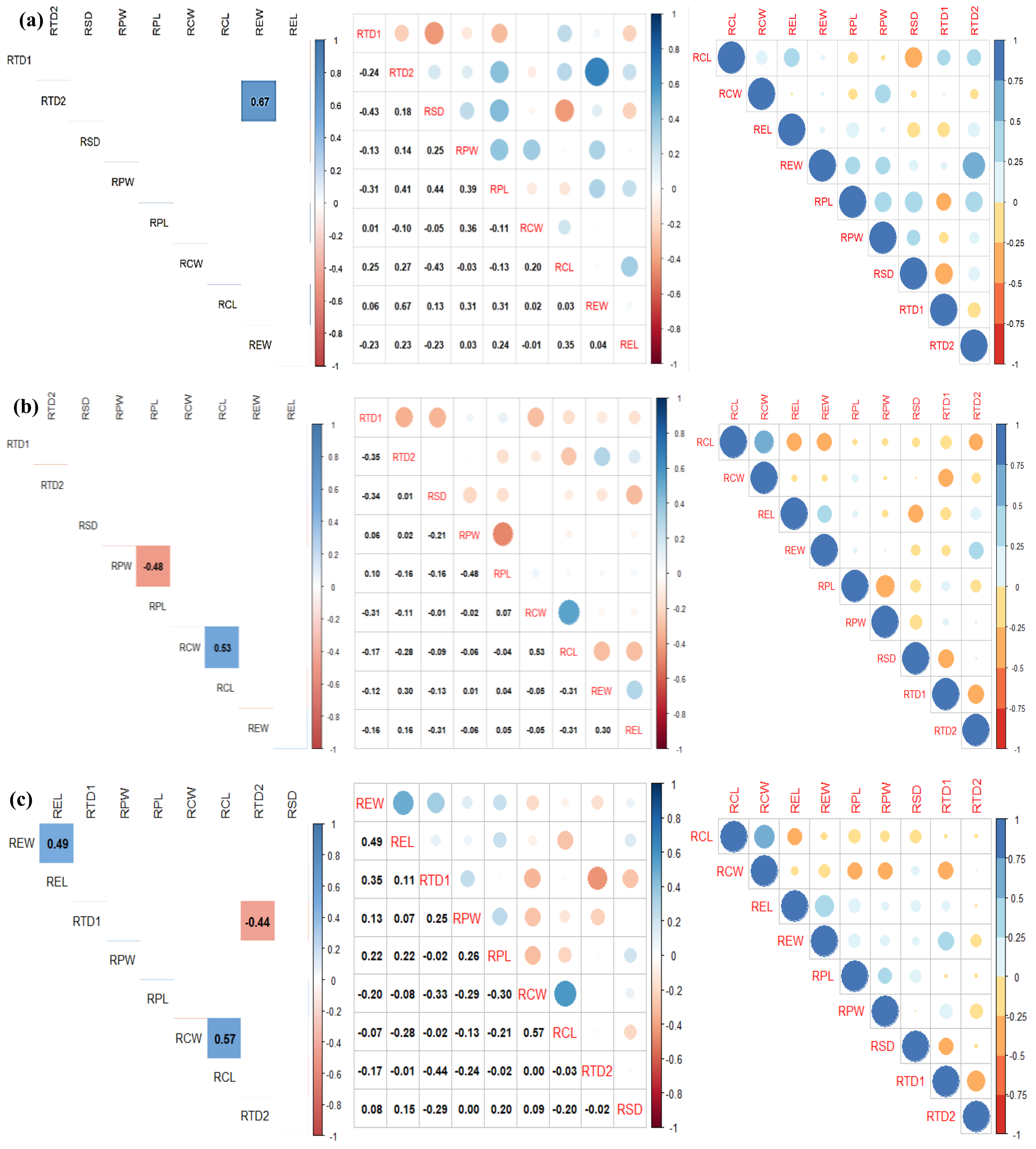

Fig. 9. Correlation analysis of anatomical measurements of roots. The correlations significant at $P < 0.05$ are highlighted blue (positive) or orange (negative). RTD1 - diameter of the trachea (μm); RTD2 - diameter of the tracheaid (μm); RSD - diameter of the sclerenchyme (μm); RPW - the width of the phloem (μm); RPL - the length of the phloem (μm); RCW - the width of the cortex (μm); RCL - the length of the cortex (μm); REW - the width of the exodermis (μm); REL - the length of the exodermis (μm). (a) *A.serotina* (Bunge) Poljakov; (b) *A. heptapotamica* Poljakov; (c) *A.terrae-albae* Krasch.

In the study conducted by Mirzaliyeva *et al*., (2020), it was found that the stem epidermis of *Artemisia heptapotamica* was composed of a single layer of rectangular cells located at the outermost surface. In the root, the cambium consisted of living cells with thin cell walls. Below the cambium layer the secondary phloem consisted of sieve tubes, while the parenchyma cells of the phloem formed both soft and hard bast. The secondary xylem was represented by elongated dead cells, including tracheids and vessels. No significant differences were observed between the cells of the upper and lower epidermis. In the leaf, beneath both the upper and lower epidermis, there was the palisade parenchyma consisting of two layers containing a high number of chloroplasts.

Uteulin *et al*., (2021) reported that the mechanical tissue in the leaves of *A. terrae-albae* consisted of the sclerenchyma adjacent to the abaxial epidermis and extending along the major veins, reaching the adaxial epidermis where it formed a noticeable thickening. The mesophyll was composed of homogeneous parenchyma cells, which allowed us to classify the leaves as isolateral. In our study, sclerenchyma cells were found surrounding the large vascular bundles, whereas the smaller peripheral bundles were embedded within the palisade mesophyll tissue.

## Conclusions

The three study species - *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* - grew in the same conditions at 44°05’58” N, 73°26’23.7” E, at an altitude of 1473 m, at the same level of atmospheric moisture, in the territory of the Altyn-Emel SNPP. To study the anatomical and morphological features of the roots, stems, and leaves, all species selected for the study were taken from the same population.

Based on the anatomical and morphological studies of the leaves, stems and roots of *A. serotina, A. heptapotamica, A. terrae-albae*, the following conclusions were made:

1. The leaves of *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* had the equifacial type of structure, i.e. they consisted of the homogeneous palisade mesophyll. Columnar mesophyll cells occupied the entire space between the upper and lower epidermis. The conducting bundles were closed collateral. The central bundle was surrounded by individual sclerenchyma cells, while the smaller conducting bundles lack a sclerenchyma lining and were embedded within the mesophyll tissue.

2. The stems of *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* were ribbed, there were small simple trichomes on the surface. The stems were covered with the single- or double-layer epidermis, beneath which lied the hypodermis with inclusions. The exodermis consisted of rounded-oblong cells. The primary cortex was developed to varying degrees depending on the species. Between the primary cortex and the central cylinder, there was a layer of rectangular-oval endodermal cells. The mechanical tissue of the central cylinder was represented by numerous groups of sclerenchyma cells located at the level of the vascular bundles. The conducting bundles were open collateral. Xylem vessels were numerous and vary in diameter. In most cases, the phloem was covered by a sclerenchyma layer consisting of bast fibers. The central part of the stems of the studied species consisted of the core parenchyma containing essential oil inclusions.

3. The roots of *A. serotina*, *A. heptapotamica*, and *A. terrae-albae* shared several similarities, but also had distinctive structural features. The similarities include the presence of the secondary growth and periderm, which was a secondary protective tissue consisting of three layers: phellogen, phelloderm, and phellema. When differences were considered, in *A. serotina*, endodermal cells were not found in the anatomical structure of the root. The mechanical tissue was well developed, which consisted of a continuous, 5-6 layers of thick cellular structure. In *A. heptapotamica*, the sclerenchyma consisted of different groups of cells: some were larger and elongated, while others were smaller and oval. Among the sclerenchyma cells, there were intercellular spaces filled with air. Beneath the cambium lied the secondary phloem, composed of sieve tubes; the parenchyma cells of the phloem form both soft and hard bast fibers. The secondary xylem consisted of dead, elongated tracheal cells and vessels. The cellular structures of the secondary phloem and secondary xylem alternated, forming a layered structure. The secondary xylem had both vertical and horizontal systems, with the latter forming rays. The central part of the root consisted of the elements of the primary phloem and xylem, which were more densely organized. In *A. terrae-alba,* large, irregularly shaped parenchyma cells of the primary cortex were located beneath the phellogen. Among the primary cortex cells, there were clusters of mechanical tissue cells with thickened cell walls, sclerenchyma cells. The innermost layer of the primary cortex was the endodermis, the cells of which formed a continuous layer surrounding the central cylinder. The central part of the root was occupied by the elements of the primary xylem and phloem.

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