Comparative ecological anatomical characteristics of generative and vegetative organs of the medicinally important plant *Fragaria vesca* L. (*Rosacea*e Juss.) under *in situ* and *ex situ* conditions

Aygun Sardarova

Department of Biology, Azerbaijan State Agrarian University, 450 Ataturk Ave., AZ2000, Ganja, Azerbaijan

For correspondence: *aygun.sardarova4442@gmail.com*

Received: April 16, 2025; Reviewed: May 22, 2025; Accepted: June 03, 2025

In this research, the anatomical structure of different parts of plants belonging to the species *Fragaria vesca* grown in two different regions of the Republic of Azerbaijan was studied, and the comparative study of the internal structure of these ecotypes was set as the objective. The plant samples collected from the regions were processed with reagents under laboratory conditions and subjected to anatomical investigations. Transverse sections from *in situ* and *ex situ* specimens of Fragaria vesca were examined through microscopic analyses. During the microscopic analyses, photomicrographs of the complete view of the specimens and at the level of individual tissues were taken using all magnification levels of the objective lens. The analyses carried out on vegetative and generative organs made it possible to determine the types of tissues constituting them, the relationship between their localization within the organ and their function, as well as the similar and different anatomical structures formed in the samples from the two different regions. As examples of such different characteristics, one can mention ecological anatomical adaptations such as the presence of capitate trichomes on the petiole in the *in situ* sample, the formation of aerenchyma in the flower stalk, the more intensive development of polyderm tissue in the root and rhizome, etc. Another difference can be exemplified by the presence of druse crystals and other biologically active substances accumulated in the parenchyma tissue of other vegetative organs (leaf, rosette, root) in different concentrations in samples from different regions. The comparative analysis performed allows determining how the anatomical structure of individuals of the same species will be expressed in various ecotopes. This, in turn, plays an important role in identifying potential anatomical structures that will form under the influence of ecological factors in plants growing in different ecological conditions.

Keywords: *Collenchyma, druses, aerenchyma, abaxial epidermis, polyderm*

INTRODUCTION

Fragaria vesca, also known as woodland strawberry, is a plant species in the genus *Fragaria* of the *Rosaceae* family. Representatives of this species are distributed throughout almost all regions of the Republic of Azerbaijan, including plains, mid-altitude mountainous zones, and high mountainous belts (Qurbanov, 2024). The leaf of the plant is its main above-ground vegetative organ. The leaf is trifoliate, with three broad green leaflets attached to the main petiole via short petiolules. Each leaflet has a single central vein, from which lateral veins branch outward in a parallel arrangement. These leaflets serve as the main organs for photosynthesis and respiration, and they have serrated edges (Tutayuq, 1967). The petiole is long, attaching the leaf to the rosette from below. The rosette, where all leaves converge, can be understood as a form of reduced stem. This area, displaying primary structural characteristics, is where both vegetative and generative above-ground organs originate, including the stem that supports the plant's flowers. The flowers are connected to the stem via flower stalks, comprising five petals and numerous sepals. The developed fruits of the plant are smaller in size compared to those of cultivated strawberry varieties but stand out due to their strong aromatic content. The rosette gradually connects downward to the rhizome and root system. The rhizome functions both in the plant's vegetative propagation and as an organ for storing reserve nutrients. The roots consist of primary roots and branching secondary roots, which play a role in water absorption (Koc, 2018). *F.vesca* is known as a plant with a rich composition. It contains antioxidants such as flavonoids and polyphenols in its leaves and fruits (Ibadullayeva, 2024). These compounds help protect the body from damage caused by free radicals by trapping them, thus playing a role in preventing cellular damage and

the aging process. The fruit, rich in fiber, can contribute to improving gut flora and, consequently, the gastrointestinal system (Baytop, 2017; Yeşilada, 2012).

MATERIALS AND METHODS

Collection of material. In May 2021, the *Fragaria vesca* plant was brought from the city of Shusha and initially cultivated under *ex situ* conditions in container culture in the Bala Bagman area of Ganja city. One year later, it was transplanted into open soil conditions and subjected to artificial cultivation. For the purpose of analysis, in 2024, a comparative ecological anatomical study of the plant was conducted based on material collected both from the cultivated *ex situ* sample and from the natural population of Shusha city as the *in situ* sample.

Processing of material in the laboratory. Before applying anatomical, microscopic, and biometric methods, both *in situ* and *ex situ* samples were subjected to fixation by histochemical methods. This stage is extremely important for the ideal preservation and observability of the structural elements of plant tissues. After the plant materials were fixed using the appropriate fixation method (Chamberlain, 2020; Criswell et al., 2025), they were processed under laboratory conditions. During this process, paraffin (BW Blended Waxes, Inc. US) was used as an auxiliary medium both for infiltration of the materials and during the sectioning process. During the study, the thickness of the sections was controlled and calibrated using the special micrometric adjustment screw on the modern hand microtome (RADICAL, RMT-5, India), and micron measurements were taken. The thickness of the sections obtained by the microtome was determined within the range of 6, 7, and 8 μm through micrometric adjustment. After the microtome sections, histochemical methods were applied, and differential staining was performed using specific reagents. During this process, special dyes such as safranin O, fast green, sudan III, toluidine blue, phloroglucinol-HCl, methylene blue (KimyaLab, Turkey) were used. The staining process applied for selective staining of tissue components was carried out stepwise using the decolorization method (Peterson et al., 2008; Engin et al., 2024). The successive use of various histological staining techniques enabled a more precise identification of the comparative ecological anatomical structural components of the *F.vesca* plant in different ecological conditions.

For the preparation of permanent slides from the stained sections, Canada balsam (INNOVATING SCIENCE, US) was used. After adding one drop of balsam to the section placed on the slide, it was covered with a cover slip. The prepared slides were placed inside a special incubator device where the temperature was kept constant (20–25°C) to allow the complete drying of the Canada balsam, and they were kept there until fully dried. The permanent slides prepared from the transverse sections of the plant were then subjected to microscopic analyses.

Microscopic analysis. During the microscopic studies, modern digital and more versatile microscopes available at the Department of Biology of Azerbaijan State Agricultural University were used. Primarily, "Carl Zeiss, Axio Imager A2" (ZEISS, Germany) microscopes, equipped with an LED light source and special objectives minimizing aberration, were employed. This model possesses very high optical performance, and in this regard, Zeiss's AxioCam microscope cameras were integrated into the interface. By utilizing all these versatile capabilities of the microscope, it was possible to analyze the structural elements more precisely, provide micrometric measurements, conduct video observations, and obtain digital microphotographs from the preparations taken from the vegetative organs of *F.vesca* studied *in situ* and *ex situ*.

Additionally, the LCD Digital Microscope NLCD-307B (Wincom Company Ltd., China) model was used during the microscopic analyses. This model is equipped with modern digital equipment and an LCD screen monitor, which allows the images to be transmitted directly to the screen and viewed from there. Using the specific capabilities of the microscope, ecological anatomical analyses of the *in situ* and *ex situ* samples of *F.vesca* were carried out with high precision. During the study, all magnification levels of the objective lens (4x, 10x, 40x, 60x, 100x) were used to perform a precise identification of the anatomical structure of the organs. At the same time, observations were made using immersion oil (RMY, US) with the 100x objective. The use of the immersion medium enhanced the optical resolution, thereby increasing the accuracy and contrast of the microscopic images of the studied samples. The LCD Digital Microscope NLCD-307B model was used to monitor the quality of the sections and the effectiveness of histological staining at the stage before transferring the transverse sections of plant samples to permanent slides, while the final analyses, micrograph acquisition, and obtaining statistical measurements on the prepared slides were carried out using the Carl Zeiss, Axio Imager A2 model. Stereoscopic microscopes (Stereoscope Zeiss Stemi508 (ZEISS, Germany), Stereo YK-

SM067B2 (Wincom Company Ltd., China)) were also used to conduct macroscopic analysis of the samples during the study.

To verify the accuracy of the micrometric measurements automatically obtained through the microscope during the analyses, eyepiece and stage micrometers (MUHVA, China) were used. For this purpose, first, the eyepiece micrometer was calibrated using the stage micrometer, and then, based on the scales on the micrometer, the measurements of the observed objects were calculated (Moyo et al., 2015). In addition, a digital micrometer (Jiavarry, China) was used to record the macroscopic measurements of the organs from which the sections were taken.

Preparation of herbarium specimens. The herbarium specimens prepared from *F.vesca* plants collected from *in situ* and *ex situ* conditions not only provide a systematic basis for the in-depth analysis of the ecology and anatomy of the species but also serve as essential reference material for determining the potential of this species in the fields of pharmacognosy and phytotherapy. The extensive herbarium specimens prepared from the medicinally important species *F.vesca* have been included in the herbarium collection of the Department of Biology named after Academician Valida Tutayuq at Azerbaijan State Agricultural University, where they are preserved as a systematized botanical collection and are available for scientific research, educational, and reference purposes.

Statistical methods. In the conducted study, the samples of the species *F.vesca* collected from two regions of the Republic of Azerbaijan with different ecological conditions - Shusha City (*in situ* condition - natural distribution) and Ganja City (*ex situ* condition - introduced environment) - were statistically analyzed in terms of various parameters. From the populations of the same species in both regions, 8-12 different plants were selected, and samples were taken from both the generative and vegetative organs of each plant for the study. From each organ, 10-15 transverse sections were prepared and anatomical analyses were carried out. During the microscopic analyses, various parameters were measured. All measurements were statistically analyzed using the RStudio software (version 2023.09.1, R Foundation for Statistical Computing, Austria). First, normal distribution was tested using the Shapiro-Wilk test, and then, for parameters with confirmed normal distribution, a two-sample ANOVA (analysis of variance) test was applied, and for those without normal distribution, the Mann–Whitney U test was used. All results were presented as mean±standard deviation, and statistical differences were considered significant at the $P < 0.05$ level.

RESULTS

Sepal and Petal. In the transverse section of the sepal taken from Shusha city, trichomes are found on the lower epidermis, which are somewhat elongated. In the specimens of the species growing in the Ganja city area, trichomes are found on both the upper and lower epidermis of the sepal, and they are smaller in size and shorter compared to those in the *in situ* sample (Fig. 1). Small-sized guard cells are found in the stomata on the lower epidermis. The internal part is filled with chlorenchyma tissue, which, in the *ex situ* sample, is clearly distinguished by the slightly larger size of the cells and their more sparse arrangement. This arrangement of the cells creates conditions for the presence of numerous intercellular spaces with large volumes. Within this tissue, it is observed that a druse crystal forms in each cell arranged in a single layer along the upper subepidermal zone in the *in situ* sample. In the *ex situ* sample, this component is less frequent and may be found around vascular bundles. Within the chlorenchyma, central and lateral vascular bundles are located in a scattered manner, and bundle sheath cells are present around them. The size of these cells is larger in the *in situ* sample, indicating that the metabolic processes in the sample growing under ecological pressure are more intense (Huseinović et al., 2021). The vascular bundle located inside the sepal is single in the center, while in the lateral parts, there are numerous bundles of both large and small sizes. In both samples, the vascular bundles have poorly developed xylem and phloem. The underdevelopment of the vascular elements in the sepal is associated with its status as a non-primary photosynthetic organ and its limited size. Near the central bundle, in the lower subepidermal area, a mechanical tissue type known as collenchyma is weakly developed. Unlike the *ex situ* sample, the other sample shows distinct characteristics between the lower and upper epidermis. In this case, the cells forming the upper epidermis are positioned more closely together, resulting in their somewhat columnar or oval shape. It is observed that the tissues in the sample have absorbed substances, which is a distinguishing feature related to the rich composition the plant has adapted to, in response to high environmental factors.

The structure of the petal is similar in both *in situ* and *ex situ* samples. The amount of parenchyma tissue is relatively greater in the *ex situ* sample. As in the sepal, the collateral-type vascular bundles here have a simple structure, consisting of poorly developed phloem and xylem elements, and are surrounded by bundle sheath cells (Dinç et al., 2013).

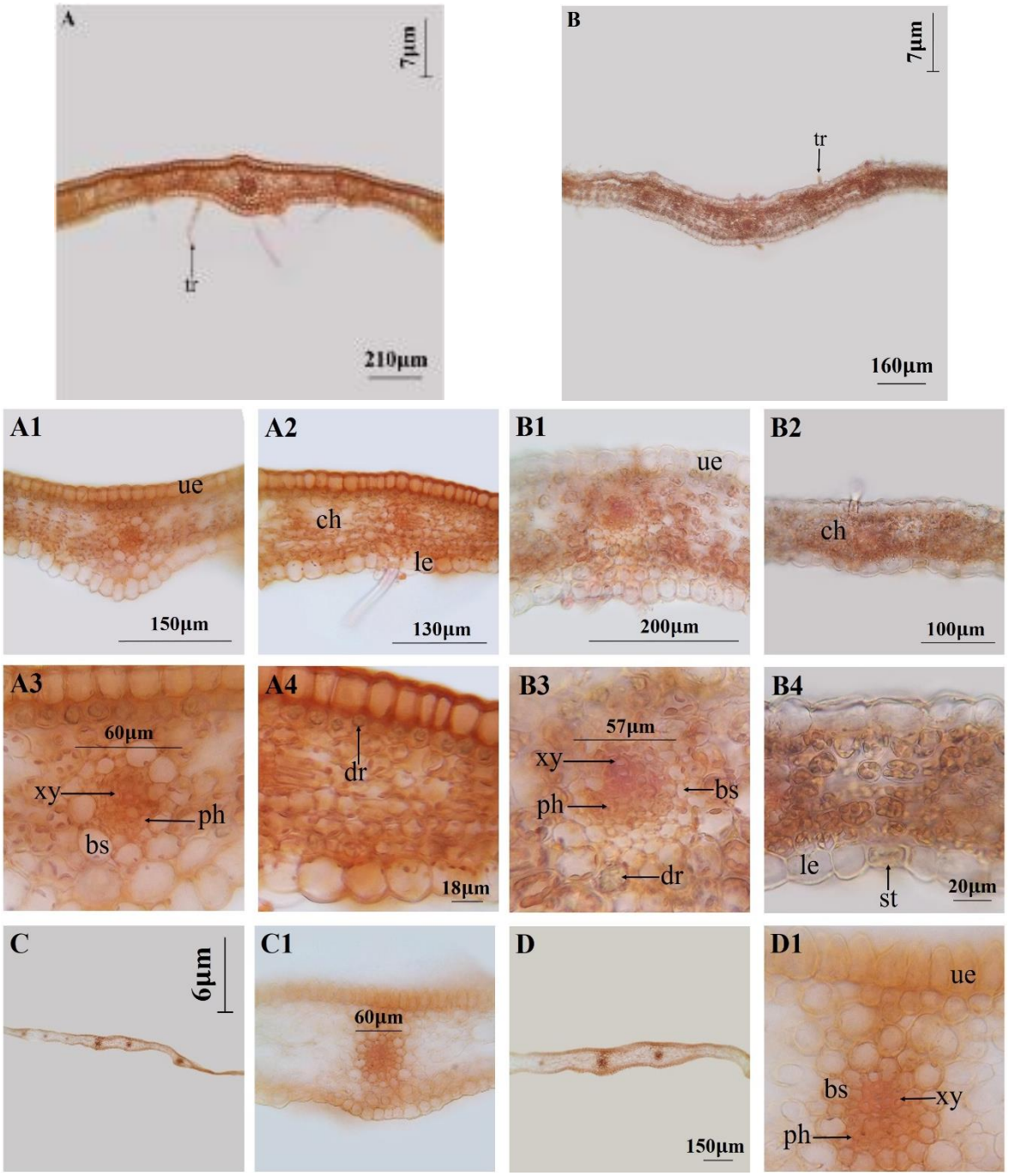

Fig. 1. *Fragaria vesca*. Sepal and petal. **A -** General structure of the transverse section of the sepal (Shusha; *in situ*) (**tr**-tectorial trichome) (10x), **A1 -** Central part (**ue**-upper epidermis) (40x)**, A2 -** Lateral part (**ch**-chlorenchyma; **le**-lower epidermis) (40x), **A3 -** Central bundle (**ph**-phloem; **xy**-xylem;**bs**-bundle sheat) (100x), **A4 -** Chlorenchyma containing druse (**dr**-druse) (100x), **B -** General structure of the transverse section of the sepal (Ganja; ex situ) (**tr**-tectorial trichome) (10x), **B1 -** Central part (**ue**-upper epidermis) (40x), **B2 -** Lateral part (**ch**-chlorenchyma) (40x), **B3 -** Central bundle (**ph**-phloem; **xy**-xylem; **bs**-bundle sheat; **dr**-druse) (100x), **B4 -** Mesophyll of the sepal (**le**-lower epidermis; **st**-stoma) (100x), **C -** General view of the transverse section of the petal (Shusha; *in situ*) (4x), **C1 -** Central part of the petal (40x), **D -** General view of the transverse section of the petal (Ganja; ex situ) (10x), **D1 -** Central vascular bundle (**ph**-phloem; **xy**-xylem; **bs**-bundle sheat; **ue**-upper epidermis) (100x).

Noticeable structural differences are present in the lower and upper epidermis layers that cover the petal from the outside, existing in plant specimens from both regions. However, the cell volume is larger in the *ex situ* sample. This difference is manifested in the petal by the generally square shape of the lower epidermis cells and the conical structure of the upper epidermis cells. The specific structure of the upper epidermis results in the roughness of the petal surface.

Flower Stalk. When examining the transverse section of the flower stalk, it is seen that the vascular system is densely arranged around the pith. In addition, sclerenchyma elements have formed in the outer part of the phloem, creating a mechanical ring surrounding the vascular system (Fig. 2).

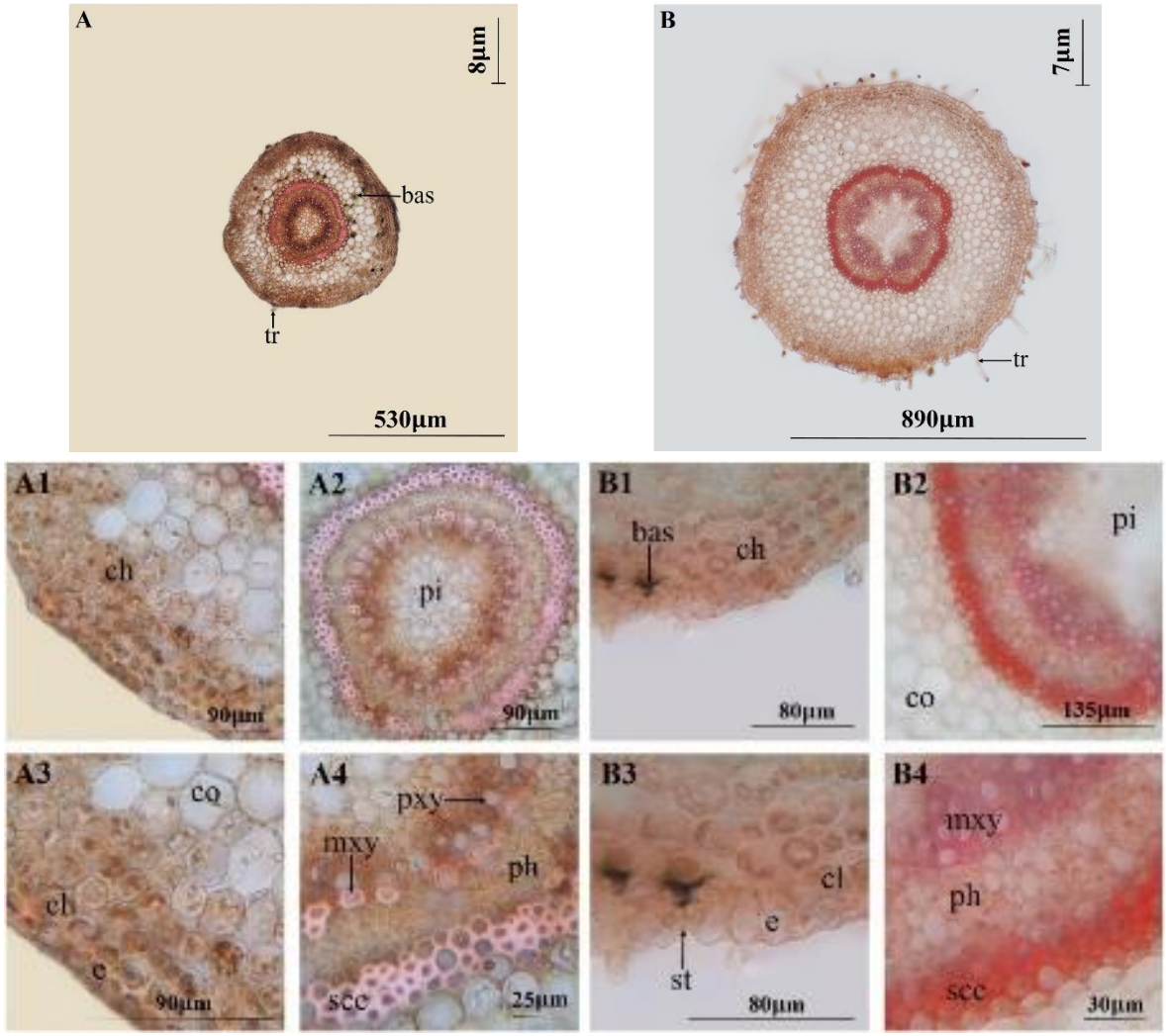

Fig. 2. *Fragaria vesca*. Flower stalk. **A -** General structure of the transverse section of the flower stalk (Shusha; *in situ*) (**bas**-biological active substances) (10x), **A1 -** Cortex (**ch**-chlorenchyma) (40x), **A2 -** Central part (**pi**-pith) (40x), **A3 -** Subepidermal zone of the cortex containing chlorenchyma (**co**-cortex; **cl**-collenchyma; **e**-epidermis) (100x), **A4 -** Structure of the vascular tissue of the flower stalk (**mxy**-metaxylem; **pxy**-protoxylem; **ph**-phloem; **scc**-sclerenchyma) (100x), **B -** General view of the transverse section of the flower stalk (Ganja; ex situ) (**tr**-trichome) (10x), **B1** - Peripheral part of the cortex (**bas**-biological active substances; **ch**-chlorenchyma) (60x), **B2 –** Vascular tissue (**co**-cortex; **pi**-pith; **er**-ergastic substances) (40x), **B3** - Subepidermal zone with chlorenchyma (**st**-stoma; **cl**-collenchyma; **e**-epidermis) (100x), **B4 -** Structure of the vascular tissue and the surrounding sclerenchyma (**mxy**-metaxylem; **ph**-phloem; **scc**-sclerenchyma) (100x).

The sclerenchyma tissue is more actively developed in the *in situ* sample. In this sample, the mechanical ring is surrounded by a weakly darkened layer consisting of small-sized cells arranged in a single row. It is observed that a small amount of ergastic substances has accumulated both within these cells and in some cells of the cortical parenchyma surrounding the central part. In the *in situ* sample, the accumulation of biologically active substances of different compositions along with ergastic substances is also observed (Lata et al., 2021). These substances are dark green in color. Trichomes and stomata are noticeable on the epidermis layer covering the cortical parenchyma from the outside, and their density is higher in the *ex situ* sample. The subepidermal area, which contains weakly developed collenchyma tissue, is internally bordered by chlorenchyma tissue, where in the *in situ* sample, more chloroplast-containing cells are observed in this region. In general, it can be stated that the flower stalk in the *in situ* sample has a more compact structure, and the lignification process has progressed intensively both in the xylem and in the sclerenchyma. The very center of the flower stalk consists of pith cells, which are light brown in color due to the accumulation of biologically active substances. In the *ex situ* sample, however, there is a greater number of parenchyma cells in this part, while the number of these colored cells is lower. As a result of microscopic analysis, it can be concluded that the cortical parenchyma of the flower stalk in the *ex situ* sample is larger. In the subepidermal part of this sample, there are light brown cells with fewer biologically active

substances accumulated compared to the *in situ* sample.

Stem. In the *ex situ* sample, the pith parenchyma located in the center of the stem is larger compared to the *in situ* sample, and ergastic substances can be observed in both samples. Unlike the *ex situ* sample, a small aerenchyma cavity has formed in the pith of the *in situ* sample. On the inner sides of the vascular system surrounding the pith, protoxylem vessels, which are the primary structural elements, are visible. Towards the cortex, secondary metaxylem has begun to form (Fig. 3).

The vascular system is surrounded in a ring by mechanical tissue composed of thick-walled cells. This ring, formed by sclerenchyma cells, is somewhat thicker in the *in situ* sample, and endodermis cells are located on its surface facing the cortex. The walls of these cells are slightly thickened, they are small in size, and arranged in a single row. In both samples, ergastic substances are found in the cortical parenchyma, and in the *in situ* sample, dark localized idioblasts are also observed. The cortical parenchyma is replaced outwardly by chlorenchyma, and it has been observed that this tissue, formed by small-sized cells, is more strongly developed in the *in situ* specimen. In both samples, collenchyma is present outside the chlorenchyma in the subepidermal zone. The cells forming the epidermis are more densely arranged in the *ex situ* sample, and in both samples, trichomes and stomata are formed on this tissue (Orsini et al., 2012).

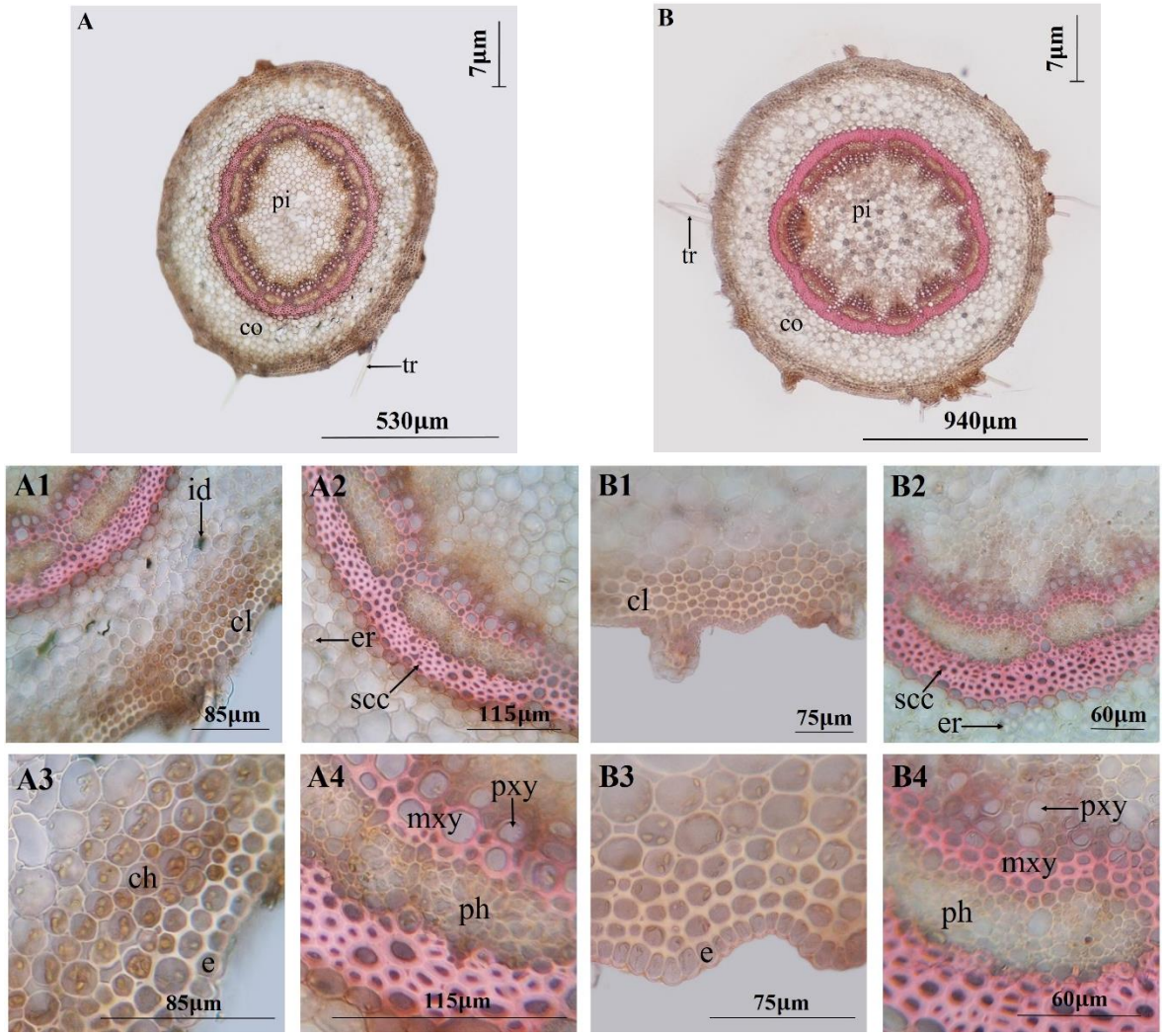

Fig. 3. *Fragaria vesca*. Stem. **A -** General view of the transverse section of the stem (Shusha; *in situ*) (**co**-cortex; **pi**-pith; **tr**-tectorial trichome), **A1** - Cortex (**id**-idioblast; **cl**-collenchyma) (40x), **A2 –** vascular system (**er**-ergastic substances; **scc**-sclerenchyma) (40x), **A3 -** Subepidermal zone containing chlorenchyma (**ch**-chlorenchyma; **e**-epidermis) (100x), **A4 -** Structure of the vascular tissue (**ph**-phloem; **mxy**-metaxylem; **pxy**-protoxylem) (100x), **B -** General structure of the transverse section of the stem (Ganja; ex situ) (**co**-cortex; **pi**-pith; **tr**-tectorial trichome), **B1 -** Cortex (**cl**-collenchyma) (40x), **B2 -** vascular system (**er**-ergastic substances; **scc**-sclerenchyma) (40x), **B3 -** Collenchyma filling the subepidermal zone (**e**-epidermis) (100x), **B4 -** Structure of the vascular tissue (**ph**-phloem; **mxy**-metaxylem; **pxy**-protoxylem) (100x).

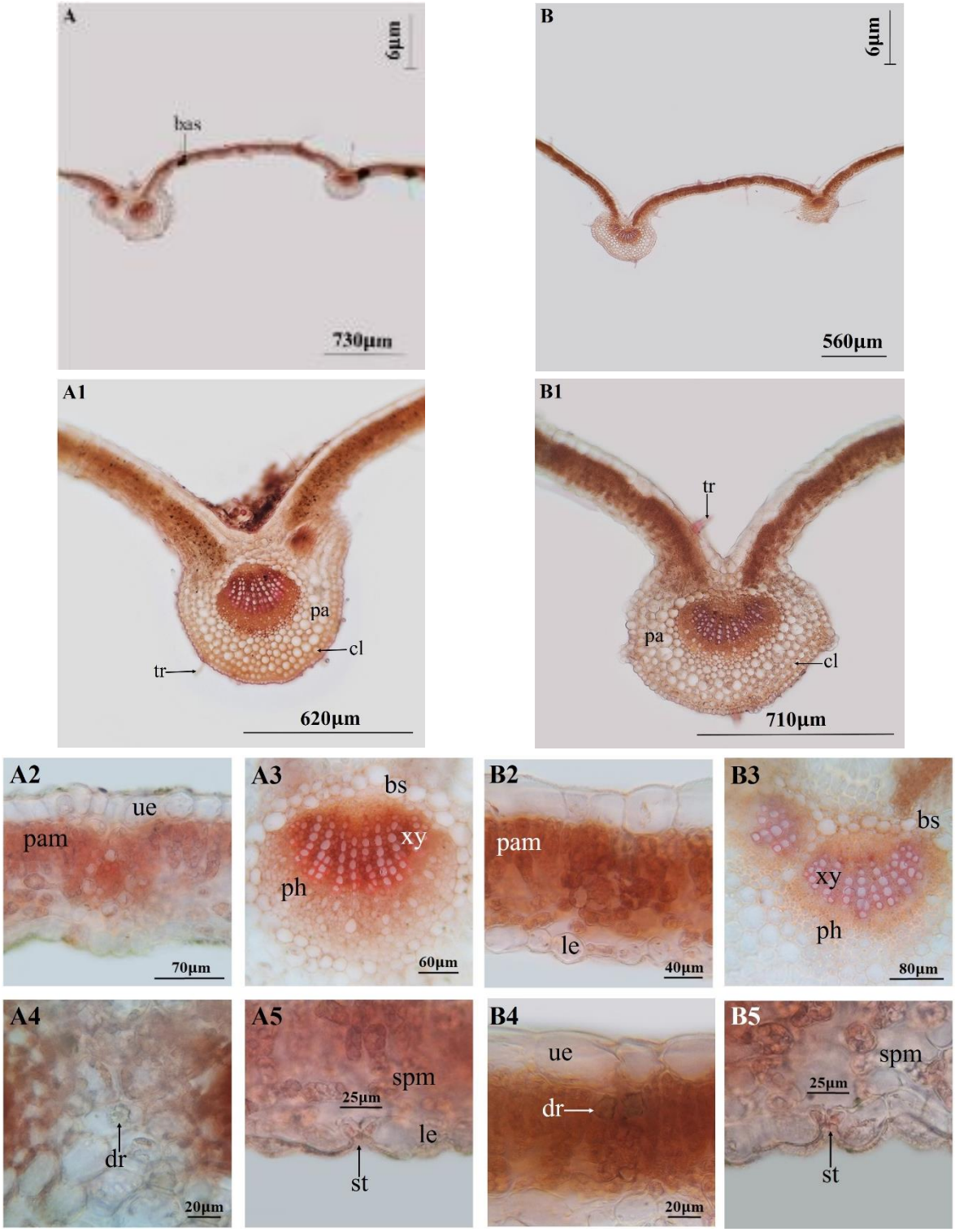

Fig. 4. *Fragaria vesca*. Leaflet. **A** - General structure of the transverse section of the leaflet (Shusha; *in situ*) (**bas**-biological active substances) (4x), **A1** - Large-sized lateral bundle (**pa**-parenchyma; **cl**-collenchyma; **tr**-tectorial trichome) (10x), **A2** - Mesophyll area where the small-sized lateral bundle is located (**ue**-upper epidermis; **pam**-palisade mesophyll) (60x), **A3** - Elements of the central bundle (**ph**-phloem; **xy**-xylem; **bs**-bundle sheat) (40x), **A4** - Parenchyma containing druse crystal (**dr**-druse) (60x), **A5** - Abaxial stoma (**st**-stoma; **le**-lower epidermis; **spm**-spongy mesophyll) (100x), **B** - General structure of the transverse section of the leaflet (Ganja; ex situ) (4x), **B1** - Large-sized lateral bundle (**pa**-parenchyma; **cl**-collenchyma; **tr**-tectorial trichome) (10x), **B2** - Mesophyll area where the small-sized lateral bundle is located (**le**-lower epidermis; **pam**-palisade mesophyll) (60x), **B3** - Elements of the central bundle (**ph**-phloem; **xy**-xylem; **bs**-bundle sheat) (40x), **B4** - Palisade parenchyma containing druse crystal (**ue**-upper epidermis; **dr**-druse) (100x), **B5** - Lower epidermis containing the stoma (**st**-stoma; **spm**-spongy

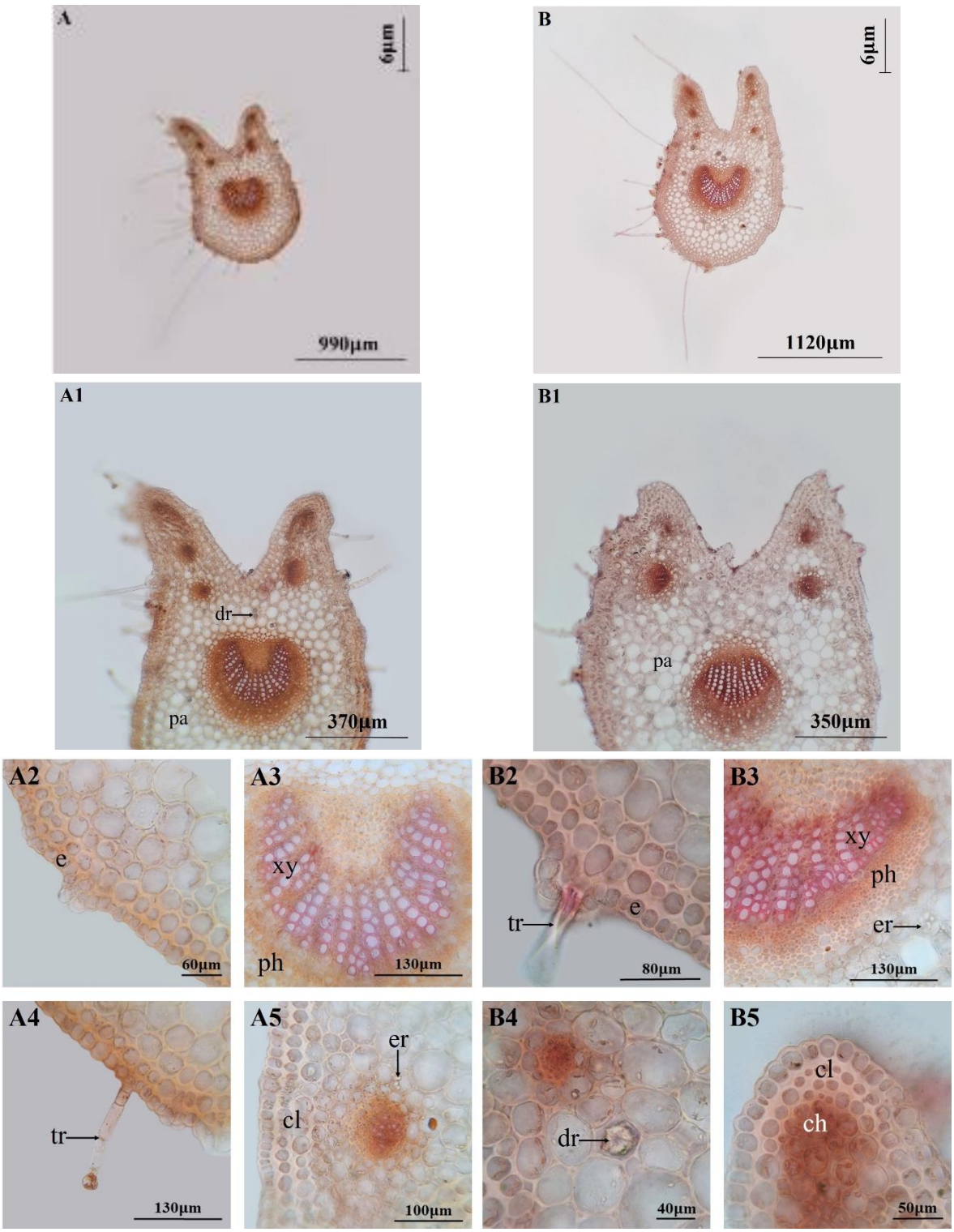

Fig. 5. *Fragaria vesca*. Petiolule. **A -** General view of the transverse section of the petiolule (Shusha; *in situ*) (4x)**, A1 -** Location of the vascular bundles of the petiolule (**pa**-parenchyma; **dr**-druse) (10x), **A2** - Subepidermal zone (**cl**-collenchyma; **e**-epidermis) (40x), **A3** - Structure of the large central bundle (**ph**-phloem; **mxy**-xylem) (40x), **A4** - Epidermal area containing trichomes (**cl**-collenchyma; **tr**-capitate trichome) (40x), **A5** - Parenchymal area containing the small-sized vascular bundle (**cl**-collenchyma; **er**-ergastic substances) (40x), **B -** General view of the transverse section of the petiolule (Ganja; ex situ) (4x)**, B1 -** Location of the vascular bundles of the petiolule (**pa**-parenchyma) (10x)**, B2 -** Epidermal area containing trichomes (**e**-epidermis; **cl**-collenchyma; **tr**-tectorial trichome) (60x), **B3 -** Structure of the large central bundle (**ph**-phloem; **xy**-xylem; **er**-ergastic substances) (40x), **B4 -** Parenchymal area containing the druse (**dr**-druse) (60x), **B5 -** Structure of the wing of the petiolule (**cl**-collenchyma; **ch**-chlorenchyma) (60x).

Leaflet. In the transverse section of the leaflets forming the trifoliate leaf, bulges appear in the abaxial direction in the areas where large vascular bundles pass, and the lateral mesophyll regions connect to these areas from above. Within the central vein, next to the large bundle, there is a

lateral bundle branch that has just separated from it. The subsequent branching of the vascular tissue forms vascular bundles located in the mesophyll between the large vessels, containing a small number of xylem and phloem elements. The bundles are separated from the surrounding tissues by bundle sheath cells. The mesophyll of the leaflet has a bifacial structure, with palisade parenchyma composed of densely arranged cells on its adaxial side. On the abaxial side, spongy parenchyma with large intercellular spaces is located. When the chloroplast-containing tissue enters the large veins, it is bordered by the cells surrounding the vascular bundle and the isodiametric ground parenchyma cells located in the vascular region. Within the mesophyll, complex-structured calcium oxalate druse crystals and other types of metabolites, which form dark-colored regions observed only in the *in situ* sample, are encountered (Jan et al., 2022). On the abaxial side of the veins, collenchyma tissue is formed internally from the epidermis, and it is observed to be better developed in the *in situ* sample, consisting of thick-walled cells arranged in one or two layers. The cells forming the upper or adaxial epidermis are larger than those of the lower epidermis. Additionally, the epidermal cells of the *ex situ* sample are observed to be larger in size (Fig. 4). Tectorial trichomes are present in both epidermal layers, which are somewhat longer and more numerous in the *in situ* sample. Stomata are located in the abaxial epidermis, and their guard cells are oriented slightly inward.

Petiolule. In the transverse section of the petiolules connecting the leaflets of the trifoliate leaf to the petiole, a two-layered collenchyma tissue formed along the subepidermal zone of the organ is noticeable in both samples (Fig. 5). A large collateral bundle is located at the center of the petiolule, and in addition, one or two small lateral bundles are situated within the wings that originate from the upper part of the organ (Papp et al., 2005). The collenchyma tissue formed at the ends of the wings is better developed than the collenchyma regions formed in other parts of the petiolule. In the *in situ* sample, chlorenchyma cells are localized within the wings, especially near their ends. In this sample, the amount of ground parenchyma located in the internal cavity of the petiolule is smaller. In the parenchyma cells of both samples, a small amount of druse crystals and ergastic-type small granular components are observed. In the *in situ* sample, capitate trichomes have formed on the epidermis surrounding the organ externally. In addition, tectorial trichomes are present in both samples.

Petiole. In the transverse section of the *in situ* sample, the upper part of the petiole is convex, whereas in the *ex situ* sample it is concave inward. In the transverse section of both petioles, a large central collateral bundle and two small lateral bundles located at the corners towards the upper sides are observed. The central bundle is larger in the *in situ* sample, while the lateral bundles are larger in the *ex situ* sample. Slightly above the central bundle of the petiole, aerenchyma cavities begin to form within the parenchyma. In the *in situ* sample, these cavities are mainly localized in the middle part. In the *ex situ* sample, however, these aerenchyma cavities appear more on the lateral sides, in two separate regions (Fig. 6). Ergastic substances are found in the parenchyma of both samples, with a greater amount in the *in situ* sample. In the *in situ* sample, a greater number of tectorial and capitate trichomes have been observed to form on the epidermis surrounding the petiole externally. Small protrusions have formed outward in areas where some trichomes originate along the surface of the petiole. The epidermal cells in the *in situ* sample appear larger compared to the *ex situ* sample, and these cells are slightly darkened. In both samples, collenchyma tissue composed of small cells has formed in the subepidermal region. The cells forming this tissue are larger in the *in situ* sample and smaller in the *ex situ* sample. The vascular bundles located within the parenchyma of the petiole have bundle sheath cells, and in the *in situ* sample, around the central bundle - especially towards the upper side of the petiole - these cells appear to be filled with a slightly dark-colored substance in the cytoplasm. Well-structured sclerenchyma is formed on the outer side of the phloem tissues of the vascular bundles (Åström et al., 2015). The sclerenchyma tissue is better developed in the *in situ* sample and surrounds the phloem in an arc shape. The phloem is bordered internally by the xylem. Stomata formed in the epidermal tissue, which is the covering tissue, can be observed (Davis et al., 1988).

Rosette. It is seen from the transverse section of the rosette that the pith is surrounded by vascular elements, and the medullary rays extending from it towards the cortex separate the areas of the vascular system's xylem tissue from each other. In the *ex situ* specimen, leaf traces appearing as spots on the xylem areas are not yet fully formed in the *in situ* specimen. The leaf traces are the vascular elements branching from the vascular system of the rosette and passing into the leaves formed around this rosette, constituting their vascular tissue. In both specimens, there are also other leaf traces located at various depths of the cortex area. In the *ex situ* specimen, the darkened storage parenchyma is clearly visible in the part of the xylem closer to the pith (Fig. 7).

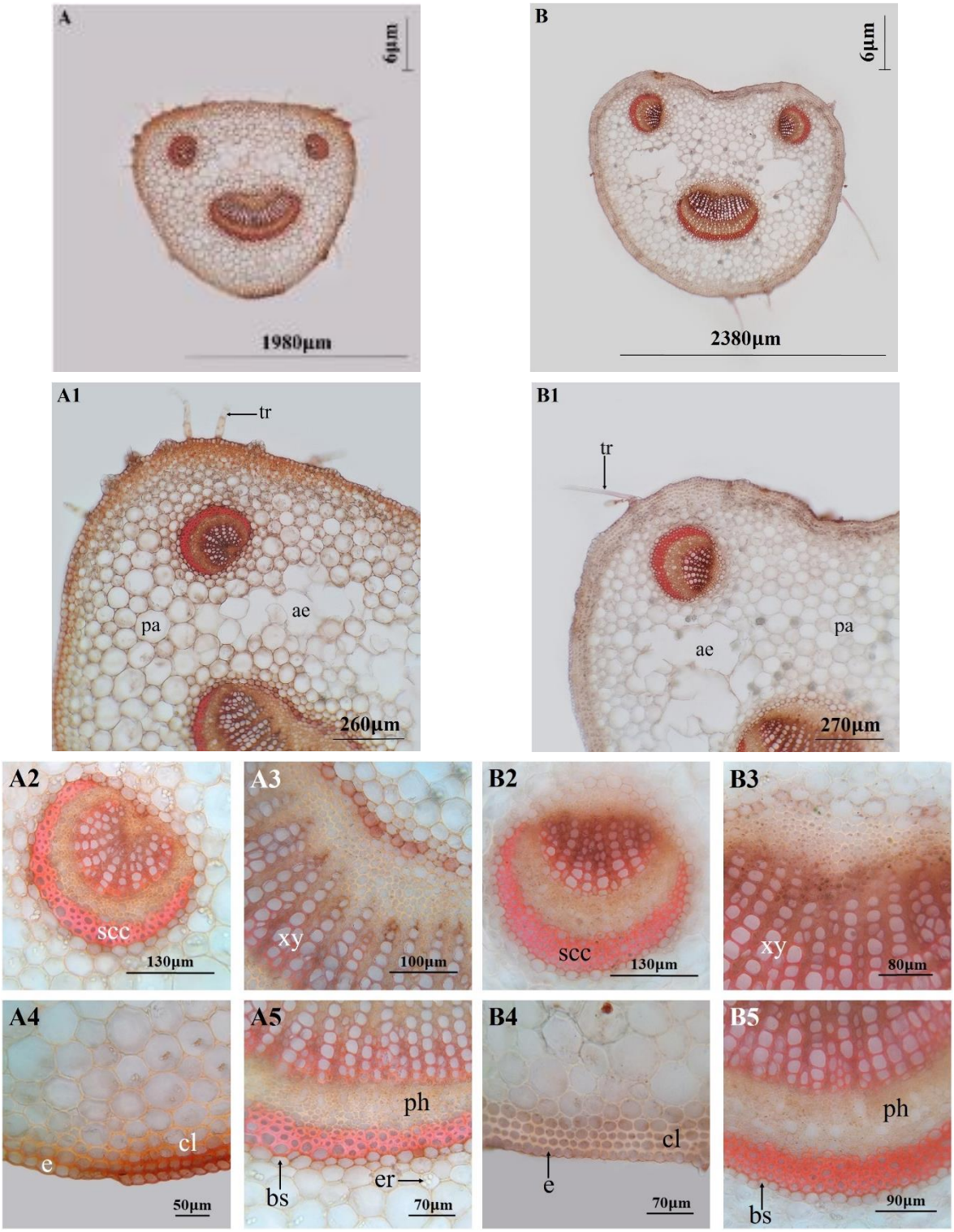

Fig. 6. *Fragaria vesca*. Petiole. **A -** General structure of the transverse section of the petiole (Shusha; *in situ*) (4x), **A1** - Upper edge region (**pa**-parenchyma; **ae**-aerenchyma **tr**-capitate trichome) (10x), **A2 -** Structure of the small-sized vascular bundle (**scc**-sclerenchyma) (40x), **A3** - Upper part of the large central bundle (**xy**-xylem) (40x), **A4** - Supepidermal zone (**e**-epidermis; **cl**-collenchyma) (40x), **A5 -** Lower part of the large central bundle (**ph**-phloem; **bs**-bundle sheath; **er**-ergastic substances) (40x), **B -** General structure of the transverse section of the petiole (Ganja; ex situ) (4x), **B1** - Upper edge region (**pa**-parenchyma; **ae**-aerenchyma **tr**-tectorial trichome; **dr**-druse) (10x), **B2** - Structure of the small-sized vascular bundle (**scc**-sclerenchyma) (40x), **B3 -** Upper part of the large central bundle (**xy**-xylem;) (40x), **B4 -** Supepidermal zone (**e**-epidermis; **cl**-collenchyma) (40x), **B5 -** Lower part of the large central bundle (**ph**-phloem; **bs**-bundle sheat) (40x).

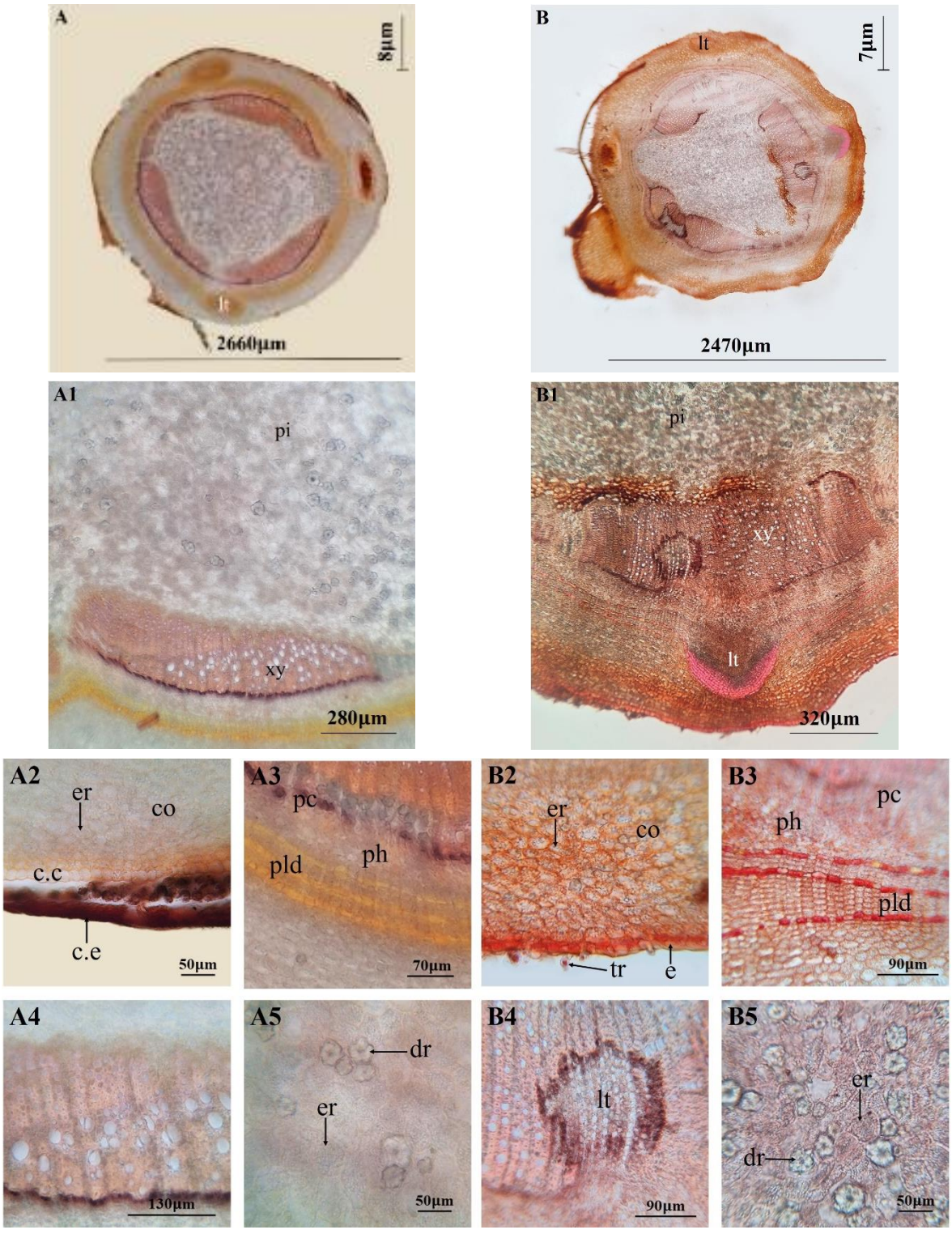

Fig. 7. *Fragaria vesca*. Rosette. **A -** General structure of the transverse section of the rosette (Shusha; *in situ*) (**lt**-leaf trace) (4x), **A1 -** A part of the rosette (**pi**-pith; **xy**-xylem) (10x), **A2 -** Peripheral zone of the cortex (**c.e**-pigmented cuticular-epidermal complex; **c.c**-collenchymatous covering cells; **er**-ergastic substances; **co**-cortex) (40x), **A3 -** Polyderm located near the central cylinder (**pld**-polyderm; **ph**-phloem; **pc**-procambium) (40x), **A4 -** Vascular bundle (40x), **A5 -** Pith parenchyma containing druse crystals (**er**-ergastic substances; **dr**-druse) (40x), **B -** General structure of the transverse section of the rosette (Ganja; ex situ) (**lt**-leaf trace) (4x), **B1 –** A part of the rosette (**pi**-pith; **xy**-xylem; **lt**-leaf trace) (10x), **B2 -** Peripheral zone of the cortex (**e**-epidermis; **tr**-trichome; **co**-cortex; **er**-ergastic substances) (40x), **B3 -** Polyderm located near the central cylinder (**pld**-polyderm; **ph**-phloem; **pc**-procambium) (40x), **B4 -** Vascular bundle (**lt**-leaf trace) (40x), **B5 -** Pith parenchyma containing druse crystals (**er**-ergastic substances; **dr**-druse) (40x).

The pith parenchyma cells, like many other cell types of the rosette, are rich in ergastic substances (Nazari et al., 2023). There are also druse crystals within this tissue. The xylem of the rosette consists of vessel elements and libriform fibers, and in the *in situ* specimen, the diameter of these vessel elements

is large and their walls are thickened. In the *ex situ* specimen, the total volume of the vascular system is larger. The phloem tissue lies from the xylem towards the cortex, and active procambium tissue is observed between them. In both specimens, it is clearly seen that between the phloem and cortex, there are consecutively arranged rings of suberized and unsuberized cells characteristic of polyderm. The rings formed by unsuberized cells are multilayered, while the rings formed by suberized cells consist of a single cell layer. Among the suberized cells, there are also isolated, unsuberized passage cells, which optimize the exchange of substances and ensure that metabolic processes between the pith and cortex proceed in a coordinated manner. In the *in situ* specimen, the suberized layers of this tissue are located closer to each other, whereas in the *ex situ* specimen, the number of layers of unsuberized cells between them is higher. In addition, in the *in situ* specimen, the cells undergoing suberization are observed in yellow-orange color, while in the *ex situ* specimens they appear orange-red. Ergastic substances as well as druses are present in the parenchyma that forms the main part of the cortex area. In both specimens, there is an epidermis on the surface of the rosette. Due to the high concentration of biologically active substances in the *in situ* conditions of the medicinally significant *Fragria vesca* species, stronger pigmentation has occurred in the epidermis and cuticle. As a result of this pigmentation and the stress factors of the mountainous area, the covering tissue has started to disintegrate and deteriorate, and instead, renewal has taken place for this function. The mentioned pigmentation process is also observed relatively weakly in the cuticle, epidermis, and subepidermal cells of the *ex situ* specimen. Since it is characteristic for the plant to possess a phytochemical composition based on phytotherapy, the formation of this pigmentation is very likely due to the anthocyanins present in the plant. It is simply more active as an ecotypic feature in the *in situ* specimen. The pigmentation process due to the impregnation of anthocyanins into the epidermis, the disintegration of the tissue by mechanical damages, and the formation of a new epidermal layer are clearly visible in the *in situ* specimen. However, such an event is not observed in the *ex situ* specimen. It is covered with epidermal cells and trichomes have formed on it.

Rhizome. The rhizome is in a secondary structure, and the pith parenchyma cells located in its central part contain a large amount of ergastic substances. In addition, in the *ex situ* specimen, the occurrence of intracellular and intercellular pigmentation processes in the pith was observed. This is probably related to the localization of biologically active substances containing anthocyanins. The protoxylem vessels, which were formed at the primary structure stage at the boundary with the pith, can be clearly observed. Outward from this, towards the cortex along the stele, there are broad areas of xylem tissue alternating with wide medullary rays. The vessel elements of the xylem have a somewhat larger diameter in the *in situ* specimen. In both specimens, the main part of the xylem is occupied by libriform fibers formed both between the vessel elements and in the parts of the medullary rays towards the pith (Fig. 8). These are rich in ergastic substances (Pant et al., 2021). From the xylem tissue towards the cortex, the cambium is located, followed by the phloem. The phloem tissue cells are numerous in the *ex situ* specimen. In both the *in situ* and *ex situ* specimens, the development of both periderm and polyderm in the outermost part of the rhizome was observed. This is evaluated as a specific anatomical characteristic of the *F.vesca* plant. Through microscopic analyses, phellem, phellogen, and phelloderm cells were identified in the periderm, and inward from it, polyderm was formed. Suberization and relatively pigmentation processes occurred in the polyderm part.

Primary Root. In the sections taken from samples collected from two different areas, the secondary structure is noticeable. In both roots, polyderm has formed, and the suberization of its individual cell layers has resulted in the disruption of metabolic connections between the primary cortex and the central cylinder, leading to the gradual degeneration of this primary tissue. As the root grows in thickness, the pressure that arises causes this tissue to break up and fall off. In all cell layers forming the polyderm tissue, a relatively evident pigmentation process is clearly observed, similar to the polyderm cells of the rhizome. In the *in situ* specimen, the polyderm has formed smaller cells, and they are concentrated within a greater number of layers. In the *ex situ* specimen, however, these cells are concentrated in 7–8 layers and are larger in size (Fig. 9). In both specimens, ergastic compounds are seen to have accumulated in the parenchyma cells located internally in the polyderm. The central part of the root is occupied by xylem tissue, whose vessel elements responsible for water transfer are scattered within this tissue and are relatively evenly distributed. The libriform fibers filling the area between these elements are slightly larger in the *in situ* specimen, and the thickening of their walls has occurred uniformly. In the *ex situ* specimen, however, in some of the libriform fibers, the thickening of the walls is observed to be weaker.

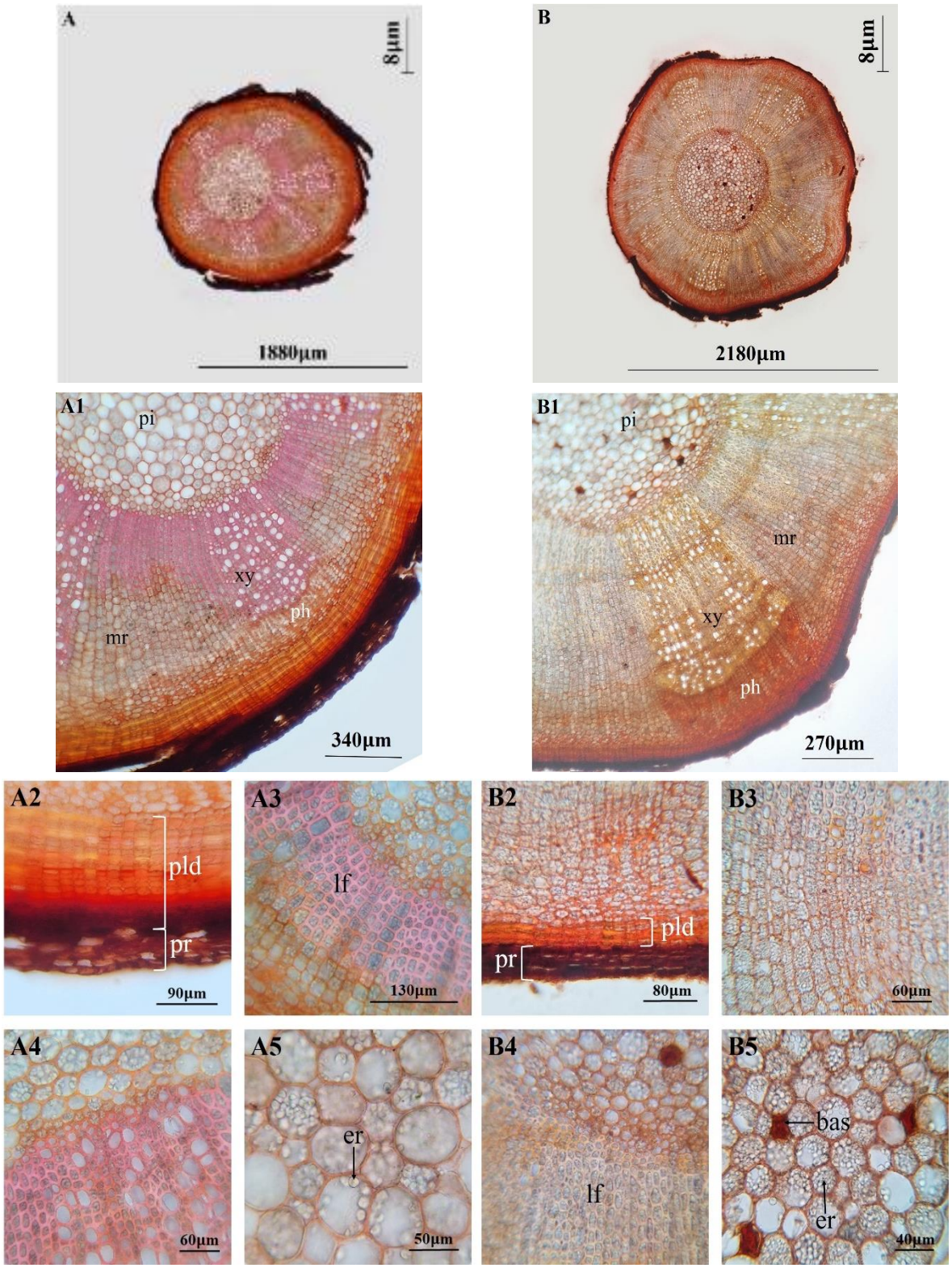

Fig. 8. *Fragaria vesca*. Rhizome. **A** - General structure of the transverse section of the rhizome (Shusha; *in situ*) (4x), **A1** - Peripheral zone of the rhizome (**pi**-pith; **xy**-xylem; **ph**-phloema; **mr**-medullary ray) (10x), **A2** - Structure of the protective tissue (**pld**-polyderm; **pr**-periderm) (40x), **A3** – Medullary ray where libriform fibers are formed (**lf**-libriform fibres) (40x), **A4** - Xylem area adjacent to the pith (40x), **A5** – Pith (**er**-ergastic substances) (40x), **B** - General structure of the transverse section of the rhizome (Ganja; ex situ) (4x), **B1** - Peripheral zone of the rhizome (**pi**-pith; **xy**-xylem; **ph**-phloema; **mr**-medullary ray) (10x), **B2** - Structure of the protective tissue (**pld**-polyderm; **pr**-periderm) (40x), **B3** - Medullary ray where libriform fibers are formed (40x), **B4** - Xylem area adjacent to the pith (**lf**-libriform fibres) (40x), **B5** - Pith (**bas**-biological active substances; **er**-ergastic substances) (40x).

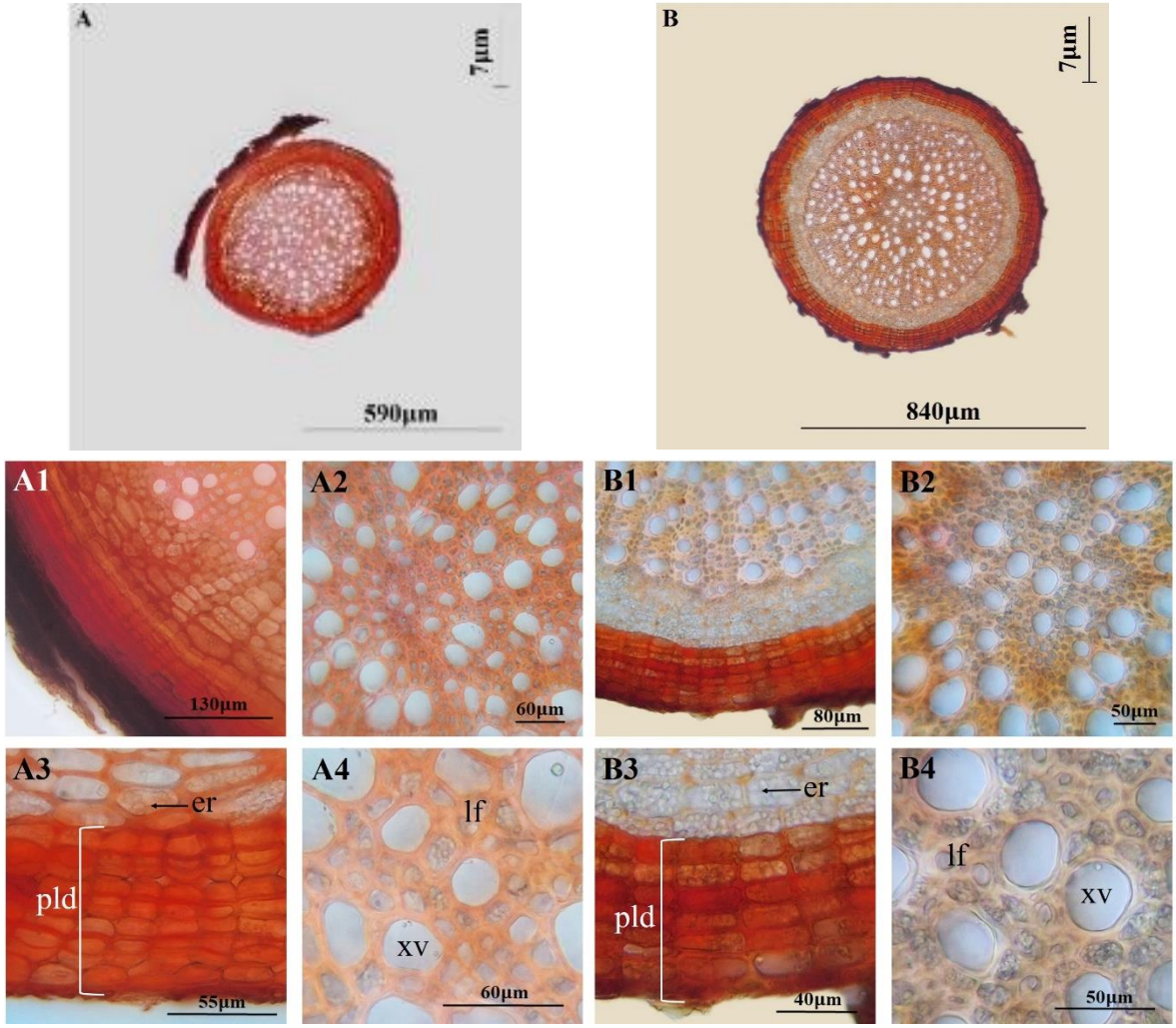

Fig. 9. *Fragaria vesca*. Primary root. **A -** General structure of the transverse section of the primary root (Shusha; *in situ*) (10x), **A1 -** Edge region of the root (40x), **A2 –** Xylem tissue (40x), **A3 -** Structure of the protective tissue (**pld**-polyderm; **er**-ergastic substances) (100x), **A4 –** Structure of the xylem (**xv**-xylem vessel; **lf**-libriform fibres) (100x), **B -** General structure of the transverse section of the primary root (Ganja; ex situ) (10x), **B1 -** Edge region of the root (40x), **B2** - Xylem tissue (40x), **B3 -** Structure of the protective tissue (**pld**-polyderm; **er**-ergastic substances) (100x), **B4 -** Structure of the xylem (**xv**-xylem vessel; **lf**-libriform fibres) (100x).

In both specimens, ergastic substances have accumulated in the internal cavity of these fibers (Lia et al., 2020). In the outer part of the xylem is the phloem, and between these lies the cambium, which is the secondary meristematic element that forms both tissues.

Tertiary Root. In the transverse section of the primary-structured root, in the *in situ* specimen, a hexarch structure of the central cylinder has formed. In the *ex situ* specimen, however, a five-rayed radial structure, or in other words, a pentarch structure is evident in the central cylinder. Along the xylem rays formed in the central cylinder, as a result of the activity of the procambium, protoxylem is initially formed, followed by the formation of metaxylem vessel elements in the exoarch direction (Fabbri et al., 1986). The metaphloem elements of the cylinder are located in the areas between these xylem rays (Fig. 10). The single-layered endodermis surrounding the central cylinder consists of small-sized cells in both specimens, with some cells in the *ex situ* specimen having accumulated constitutional substances. A thick mesodermal layer composed of large cells surrounds the endodermis. Inside its isodiametric cells, numerous ergastic substances accumulate. Such ergastic substances are also found in the endodermal cells and in the tissues within the cylinder. The mesodermal tissue gradually transitions into the exodermis towards the surface, which has thicker walls and contains fewer ergastic substances. In the *ex situ* specimen, the cells forming this layer are larger. The exodermis is surrounded externally by the epiblema, which is the primary covering tissue, and the cells forming this layer have begun to undergo deformation in both specimens (Aybazova and Erkenova, 2024).

Statistical measurements of several structural elements in the organs of plant specimens studied under *in situ* and *ex situ* conditions are presented in "Table 1".

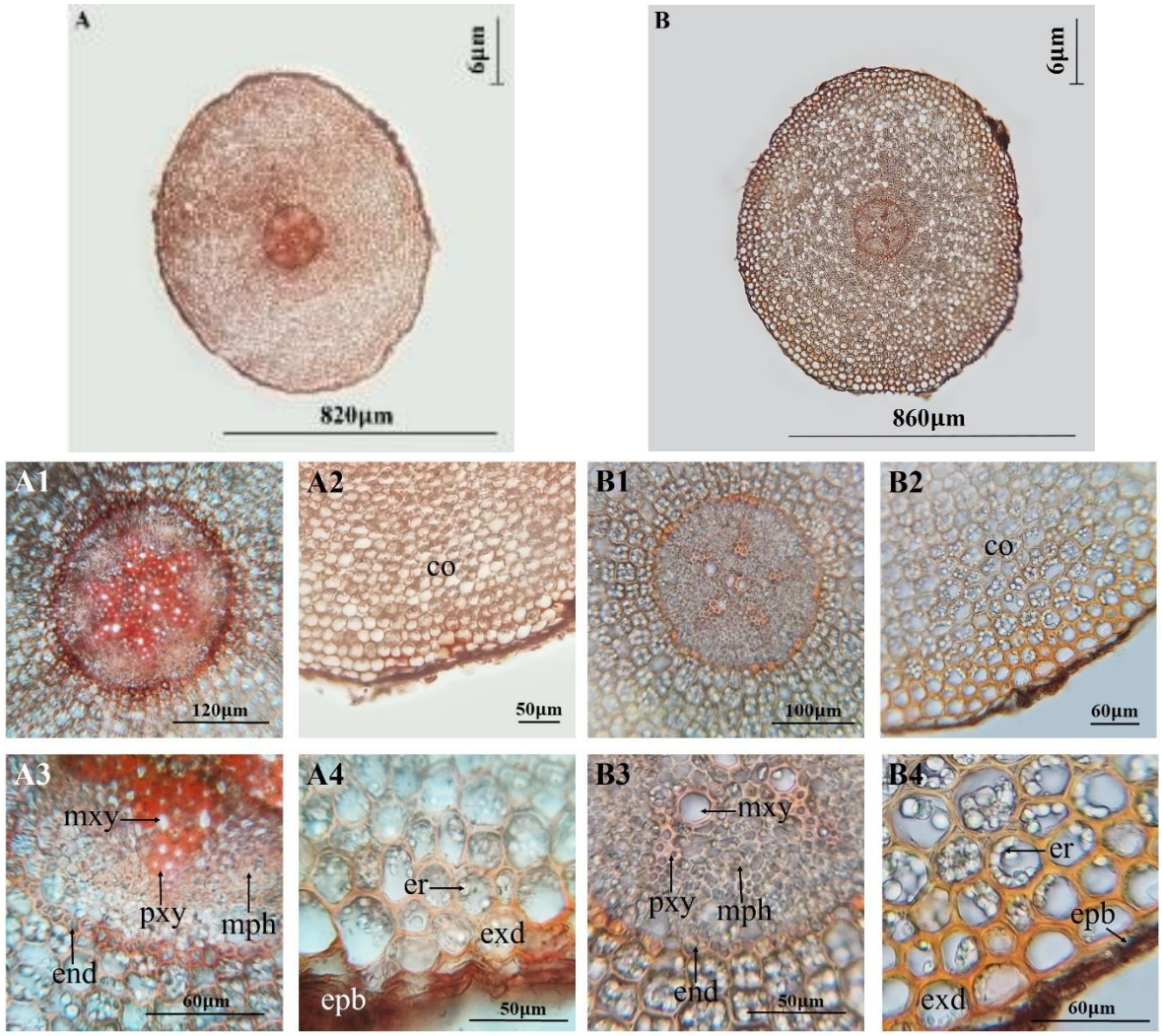

Fig. 10. *Fragaria vesca*. Tertiary root. **A -** General structure of the transverse section of the tertiary root (Shusha; *in situ*) (10x), **A1 -** Central cylinder (40x), **A2 -** Cortex (**co**-cortex) (40x), **A3 -** Edge region of the central cylinder (**mph**-metaphloem; **mxy**-metaxylem; **pxy**-protoxylem; **end**-endodermis) (100x), **A4 -** Edge boundary of the root (**exd**-exodermis; **epb**-epiblem; **er**-ergastic substances) (100x), **B -** General structure of the transverse section of the tertiary root (Ganja; ex situ) (10x), **B1 -** Central cylinder (40x), **B2 -** Cortex (**co**-cortex) (40x), **B3 -** Edge region of the central cylinder (**mph**-metaphloem; **mxy**-metaxylem; **pxy**-protoxylem; **end**-endodermis) (100x), **B4 -** Edge boundary of the root (**exd**-exodermis; **epb**-epiblem; **er**-ergastic substances) (100x).

Table 1. Quantitative characteristic of *Fragaria vesca*, µm

Sepal			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean±SD)*
Upper epidermis cells	height	28,24±1.86	19.41±1.61
	width	20.33±3.42	27.59±2.54
Thickness of the outer wall of the upper epidermis cells		4.51±0.97	1.95±0.37
Lower epidermis cells	height	29.37±2.07	18.52±2.21
	width	28.47±2.67	21.12±2.45
Thickness of the outer wall of the lower epidermis cells		1.69±0.54	1.26±0.26
Flower stalk			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean±SD)*
Epidermis cells	height	25.81±1.55	34.41±1.37
	width	26.17±1.68	25.86±1.42
Diameter of the cortex parenchyma cell		48.24±4.13	51.32±3.21
Thickness of the sclerenchyma tissue		29.87±3.47	23.43±2.98
Diameter of the xylem vessel		9.12±0.61	12.03±1.16
Stem			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean + SD)*
Epidermis cells	height	11.47±1.13	15.63±1.28
	width	11.39±1.06	8.37±1.32
Tangential thickness of the sclerenchyma tissue		47.46±1.74	42.51±1.85
Diameter of the xylem vessel		15.73±2.11	10.79±1.89

Table 1. Quantitative characteristic of *Fragaria vesca*, μm

Leaflet			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean + SD)*
Adaxial epidermis cells	height	32.18±2.87	37.31±2.79
	width	40.03±3.17	53.91±4.29
Thickness of the outer wall of the adaxial epidermis cells		3.57±0.44	1.77±0.15
Abaxial epidermis cells	height	25.03±2.96	20.54±1.67
	width	24.31±3.14	21.32±2.42
Thickness of the outer wall of the abaxial epidermis cells		1.96±0.45	1.53±0.12
Diameter of the xylem vessel		13.32±1.94	12.69±1.73
Petiolule			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean + SD)*
Epidermis cells	height	28.78±2.25	26.57±2.41
	width	20.25±2.14	18.83±2.29
Diameter of the parenchyma cells		47.91±3.98	63.49±4.19
Diameter of the xylem vessel		17.19±2.49	15.14±1.42
Petiole			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean + SD)*
Epidermis cells	height	18.32±1.73	18.83±1.21
	width	19.94±1.24	18.81±1.56
Diameter of the parenchyma cells		62.82±2.75	61.68±5.48
Thickness of the sclerenchyma tissue in the large vascular bundle		56.27±3.54	51.87±2.84
Diameter of the xylem vessel		18.77±2.36	21.51±3.46
Rosette			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean±SD)*
Diameter of the cortex parenchyma cell		36.59±3.43	32.36±3.84
Diameter of the pith parenchyma cell		43.12±3.22	39.25±2.92
Diameter of the xylem vessel		17.79±3.51	12.81±2.47
Rhizome			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean±SD)*
Diameter of the pith parenchyma cell		57.13±5.83	39.76±4.24
Diameter of the xylem vessel		29.31±3.15	25.19±2.69
Primary root			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean±SD)*
Polyderm cells	height	9.64±2.48	11.85±2.27
	width	21.44±2.14	34.51±2.89
Cortex cells	height	15.14±1.91	17.25±2.15
	width	34.37±3.69	31.34±3.45
Diameter of the xylem vessel		32.57±6.18	33.03±6.31
Tertiary root			
Indicators		*In situ (Mean±SD)*	*Ex situ (Mean + SD)*
Diameter of mesodermal cells		21.69±3.17	32.66±3.35
Diameter of endodermal cells		7.62±1.03	6.52±0.95
Diameter of the xylem vessel		10.29±1.31	17.35±1.27

Note: ANOVA and Mann-Whitney U tests were applied for statistical analysis ($P<0.05$).

DISCUSSION

Anatomical analyses conducted on *Fragaria vesca* have revealed the presence of various anatomical structures and highlighted the differences in samples collected from two different regions. The weak development of the vascular elements in the sepal is related to its limited size and its role as a non-primary photosynthetic organ. Additionally, the compact arrangement of the upper epidermis and the presence of druse crystals below it in the *in situ* sample may be an adaptation to the extreme conditions of the mountainous habitat. The sclerenchyma tissue formed in the flower stalk and the supporting stem ensures that heavy organs such as flowers and fruits are held above the surface, indirectly increasing the probability of reproduction through pollination. Ergastic substances accumulated in the cortical parenchyma of these vegetative organs serve as reserve nutrients for the plant. The lower accumulation of ergastic and constitutional substances in the *ex situ* sample was observed through microscopic analyses, which can be considered a result of the unique influence mechanisms of different ecosystems. It was observed that trichomes formed on the leaf were better developed and more abundant on the abaxial surface in the *in situ* sample, indicating a protective role. Collenchyma tissues, which develop along the upper and lower parts of the major veins of the leaflet, as well as in the subepidermal zones of the petiolule and petiole, provide structural support, ensuring the stability of these organs. As can be seen, in petioles, which bear the main weight of the

leaf, both collenchyma and sclerenchyma are well-developed, increasing their resistance to mechanical pressure. The rosette and rhizome are organs that connect the aerial and underground parts of the plant, preserving characteristics of both the root and stem. Stronger lignification in the vascular system and larger xylem elements were observed through anatomical analysis of the *in situ* sample. The accumulation of biologically active substances in the rosette and rhizome as reserves is clearly distinguishable. Microscopic studies indicate the presence of polyderm, which is characteristic of the species, in some vegetative organs (i.e., rosette, rhizome, and root).

In the *in situ* specimen of the *F.vesca* species, microscopic analysis of the rosette section revealed that the outermost layer consists of epidermal cells. Due to the accumulation of high amounts of anthocyanin pigments in these cells, the epidermis has turned dark. Particularly, in the *in situ* conditions, this darkening was prominently observed in the plant subjected to environmental stress (Fig. 11). Beneath the epidermis, several layers of parenchymatous, living cells were observed, and these cells may perform functions related to photosynthetic activity or mechanical stability. It was determined that these structures are not of peridermal origin, as the rosette part has not yet entered the secondary thickening stage. The dark-colored cells observed in the rosette section are of epidermal origin, and their coloration is associated with the high concentration of anthocyanin pigments accumulated in the vacuoles. Tissue histology showed that these cells are alive and not impregnated with suberin, meaning they are not of peridermal origin. Therefore, the formation of the dark layer in the rosette section is anatomically explained by the accumulation of anthocyanins in the epidermis, rather than the accumulation of suberin. In general, the rosette is a primary-structured, young vegetative organ, in which fellogen does not form. The rosette is a structure in plants like *F.vesca*, where the above-ground part of the stem is highly shortened, and the leaf petioles are densely arranged. Here, young photosynthetically active tissues are located near the apical meristem. No periderm develops in the rosette region, as it is not part of the older, secondary-structured stem. Its main functions are photosynthesis and vegetative growth, and defensive tissues do not develop. The layer covering the rosette, along with the cuticle of the epidermis, can thicken under environmental stress and then undergo necrosis, peeling off and falling off. Anatomical analyses show that epidermal cells, which are starting to degrade and accumulate anthocyanins and phenols, also exhibit this structure. The high concentration of anthocyanins, especially under cold, UV, and water deficiency conditions, causes the epidermis to form a dark color. This can be interpreted as the more intense synthesis of biologically active substances in *F vesca* in the ecological pressing conditions of mountainous areas. Subsequently, these cells can undergo necrosis and fall off, which aligns with the observed results. Additionally, mechanical damage to the epidermis occurs due to micro-injuries. For example, leaf detachments, rubbing with the soil, and drought cause the epidermis to dry out, and it begins to peel off in fragments.

In conclusion, it should be noted that the dark layer observed in the rosette section of the *F.vesca* species, which peels off and becomes dysfunctional, is not of peridermal origin histologically. The dried and pigment-enriched epidermal cells of this layer are hypothesized to be remnants of the cuticle. Microscopic analysis has shown that this process occurred in the *in situ* specimen, which can be explained by the degenerative changes in the epidermis resulting from the extreme environmental factors of the mountainous area (e.g., low temperature, ultraviolet rays, drought, etc.). The darkening, drying, abrasion, and detachment of the epidermal layer observed in the rosette section of the *in situ* specimens of *F.vesca* is likely caused by the accumulation of anthocyanins in epidermal cells, thickening of the cuticle, as well as structural degeneration, due to the impact of natural abiotic stress factors. In contrast, in the *ex situ* specimens, the epidermis remained intact, with unicellular and multicellular trichomes developing on the upper layer, and the cells retained their vitality and functional status. This difference shows the potential of *F.vesca*'s epidermal tissue to respond morphologically and plastically to environmental changes, as well as epidermal structural modification as a defense mechanism against *in situ* stresses. Therefore, this observed differential adaptive response in epidermal behavior can be considered one of the ecological plasticity indicators of the species and is presented as a rare feature in the scientific literature.

Another interesting morphological change observed in the rosette section of the *F.vesca* species *in situ* is the formation of a new layer of living cells beneath the epidermis after the darkening, drying, abrasion, and detachment of the epidermis. This layer structurally resembles the classical epidermis and is most likely formed as a result of the differentiation of subepidermal parenchyma cells.

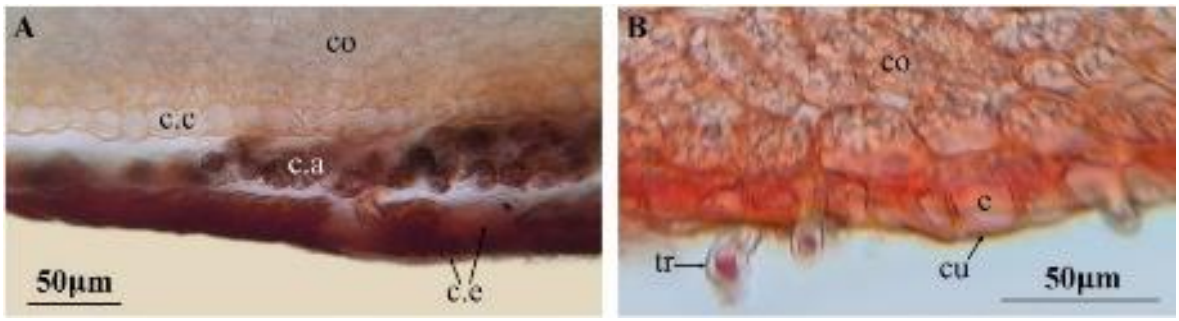

Fig. 11. Histology of the rosette under *in situ* (**A**)and ex situ (**B**) conditions. **c.e**-pigmented cuticular-epidermal complex; **c.a** - cells accumulating anthocyanins; **c.c** - collenchymatous covering cells; **co** - cortex; **cu** - cuticle; **e** - epidermis; **tr** - trichome.

The results obtained show that this regenerative cell layer forms to partially continue the protective function of the epidermis. This process demonstrates the plant's compensatory morphological adaptation ability to stress and its potential for functional tissue renewal. Such occurrences are rare in anatomical studies and represent significant scientific novelty. The formation of a temporary tissue element isolating the loss of epidermis in the *in situ* conditions of the *F.vesca* species is a unique structure.

As a result of the conducted research, it was found that in the specimens distributed under *in situ* conditions, the number of polyderm layers in the rhizome was 13-14, whereas in the specimens grown under *ex situ* conditions, the number of these layers decreased to 4-5. This difference can be explained by the plant's adaptive response to soil structure, moisture level, and ecological stress factors. Since the polyderm layer usually carries mechanical and ecological protection functions, the presence of more layers under *in situ* conditions may be related to the plant being exposed to harsher ecological influences in the mountainous ecosystem of the city of Shusha. In addition, the observation of capitate-type trichomes in the petiole under *in situ* conditions also reflects the characteristic ecosystem of the environment. Capitate trichomes, being secretory structures, perform defense and communication functions by synthesizing and secreting phytochemical substances. The fact that these structures were detected only in the *in situ* specimens indicates that this type of trichome has formed as a response to environmental factors, particularly to biotic and abiotic stress.

A significant difference was also observed in the flower petiole: in the *in situ* specimens, well-developed aerenchyma tissue was noted in the pith region, which plays an important role in regulating oxygen diffusion and metabolic adaptation. The observation of aerenchyma only under *in situ* conditions can be explained by high humidity, poor aeration, or microstructural differences in the soil. The anatomical differences obtained as a result of this direction of research, which was conducted by us for the first time and has scientific and practical significance, not only demonstrate the plant's ecological plasticity and adaptive potential but can also be evaluated as a manifestation of ecophysiological tension between *in situ* and *ex situ* environments.

Albornoz et al. conducted anatomical analyses on the roots of *F.vesca* distributed in the Tucumán region of Argentina to examine the anatomical effects of light and temperature. For this, they collected samples from plants growing in different ecological conditions at various altitudes and also used samples grown under greenhouse conditions. In the anatomical analysis of plant roots collected from natural habitats in different months (February, May, August, and November), they recorded the formation of diarch, triarch, tetrarch, and pentarch conductive strand types, whereas a polyarch structure was observed in the roots of plants grown under greenhouse conditions (Albornoz et al., 2007). In our study, the central cylinder of the root in the *in situ* sample had a hexarch structure, while the *ex situ* sample exhibited a pentarch structure. In the secondarily thickened roots of *F.vesca* growing in the Tucumán region of Argentina, polyderm formation was observed in all samples, which the authors considered a species-specific characteristic. Correspondingly, in our examined samples, this tissue was also recorded. It was determined that in samples from the Shusha region, this tissue consisted of 10-11 cell layers, while in samples collected from the Ganja region, it consisted of 7-8 layers. Thus, compared to the roots of the same species in the Tucumán region, which have 3-4 layers of polyderm, differences are evident. This variation is attributed to the unique geographical location, complex orographic structure, and diverse ecological conditions of the Republic of Azerbaijan. According to the Köppen climate classification, Azerbaijan encompasses nine main climate types, covering approximately 70% of the world's existing climate types. Based on the obtained results, it can be stated that these factors positively influence the

structural characteristics of flora elements. In the foreign study, elements of the primary cortex were still visible on the outer side of the polyderm in the analyzed plant roots, whereas in our studied samples, this tissue had degenerated, leaving the polyderm enclosing the root externally.

B.F.Chabot and J.F.Chabot conducted a study on the leaf anatomy and physiological processes of *F.vesca* to investigate potential changes by adjusting light intensity and temperature in controlled conditions. They cultivated plant samples using different combinations of these factors and conducted physio-anatomical analyses. It was determined that increased light intensity led to an increase in leaf thickness, mesophyll cell surface area, and volume. Additionally, it was recorded that high temperatures also increased leaf thickness but simultaneously caused cell deformations (Chabot and Chabot, 1977). The study, which analyzed *F.vesca* cultivated near Cornell University in Ithaca, USA, reported thickening of the mesophyll and an increase in the volume of palisade and spongy parenchyma cells. Our study also observed similar results. Specifically, the leaf mesophyll of the *ex situ F.vesca* sample was larger, and its parenchyma cells were better developed compared to the *in situ* sample.

Åström et al. analyzed leaves of *F.vesca* that were shed in summer and those that formed in autumn and persisted through winter to investigate the plant's adaptation to cold climates. For this purpose, they collected leaf samples from naturally growing plants in a mixed-forest area of Viikki, Helsinki, Finland, during different seasons and conducted morpho-anatomical and physiological studies. Analyses revealed that winter leaves had a higher density of trichomes and stomata, a more compact mesophyll structure, and a palisade parenchyma layer containing more cells (Åström et al., 2015). These adaptive traits ensure prolonged photosynthetic activity and contribute to the plant's survival in low temperatures. Our study also yielded similar findings. Anatomical studies conducted *on F.vesca* growing in the forested areas of Dashalti village in the Shusha region of the Lesser Caucasus showed a higher density of trichomes in the *in situ* sample compared to the *ex situ* sample. Additionally, the superiority of palisade parenchyma cell numbers in the *in situ* sample was observed, which aligns with the hypothesis that plants in cold environments develop structural adaptations to enhance survival.

CONCLUSION

In the *in situ* specimen of *Fragaria vesca*, the dark-colored and exfoliating cover layer observed in the rosette region is, from a histological perspective, not of periderm origin but is likely composed of epidermal cells and/or cuticle remnants that have dried, necrotized, and become enriched with pigments as a result of environmental stresses (cold, drought, UV). Such changes can be associated with functional disruption of the epidermis and defense responses. It was determined that the dark-colored and degenerating cover layer observed only under *in situ* conditions in the rosette region of *F.vesca* is not periderm but a structure of epidermal origin that has dried and become enriched with pigments in response to abiotic stresses. This layer is not observed under *ex situ* conditions; the epidermis remains intact and trichomes develop on its surface, which demonstrates the potential of the species' epidermal tissue for morphological adaptive response to environmental conditions. This important result, which reflects scientific novelty, is considered an advancement in the field of ecological anatomy. After the exfoliation of the epidermis under *in situ* conditions, a living cell layer observed in the rosette of *F.vesca* has formed as a regenerative protective tissue. This proves that the species possesses a morphological adaptation mechanism aimed at partially restoring the function of the epidermis under extreme environmental conditions.

As a result of this eco-anatomical research conducted by us for the first time, it was determined that there are significant differences in ecological-anatomical indicators between the plant species under *in situ* and *ex situ* conditions. In the *in situ* specimens, the number of polyderm layers in the rhizome was 13-14, whereas in the *ex situ* specimens, this indicator was limited to 4-5 layers. Capitate trichomes were observed only in the petiole under *in situ* conditions. In the flower petiole, aerenchyma tissue was formed in the pith under *in situ* conditions, while this structure was not recorded under *ex situ* conditions. Through these results, it was determined that the mountainous, harsher, and more complex ecological conditions of the Shusha region cause a more active manifestation of defense and adaptive mechanisms (increase of polyderm, development of secretory trichomes, formation of aerenchyma) in the plant. Comparative ecological-anatomical analysis shows that plants have the ability to differentiate their structures according to the environment in which they live.

REFERENCES

Albornoz P., Arias M., Castagnaro A., Díaz Ricci J.C. (2007) Comparative root anatomy of Duchesnea indica, *Fragaria vesca* and *Potentilla*

tucumanensis (Rosaceae) in Tucumán province, Argentina. *Adansonia*, **29:** 255-267.

Åström H., Metsovuori E., Saarinen T., Lundell R., Hänninen H. (2015) Morphological characteristics and photosynthetic capacity of *Fragaria vesca* L. winter and summer leaves. *Flora*, **215:**33–39.

Aybazova F.U., Erkenova M.M. (2024) Anatomy and morphology of plants: laboratory practical training in botany. Part 1. Cherkessk: BIC SKGA, 180 p.

Chabot B.F., Chabot J.F. (1977) Effects of light and temperature on leaf anatomy and photosynthesis in *Fragaria vesca*. *Environmental and Experimental Botany*, **26:**363–377.

Davis P.H., Mill R.R., Tan K. (1988) Flora of Turkey and the East Aegean islands (Suppl. 1), Edinburgh, UK: Edinburgh University Press, **Vol. 10:**169-170.

Dinç M., Aytaç Z., Doğu S. (2013) A new species of *Astragalus (Fabaceae)* from Turkey. *Turkish Journal of Botany*, **37(5):**841-846.

Fabbri A., Sutter E., Dunston S.K. (1986) Anatomical changes in persistent leaves of tissue-cultured strawberry plants after removal from culture. *Scientia Horticulturae*, **28(4):**331–337.

Huseinović S., Bektić S., Kovačević M., Salkić B. (2021) Analysis of vegetative and generative characters of *Fragaria vesca* L. (*Rosaceae*) populations. *Journal of Applied Life Sciences International*, **24(10):**9–19.

Ibadullayeva S.J. (2024). Traditional folk medicine of Azerbaijanis. Baku: Savad, 264 p.

Jan M. Mir T.A. Khare R.K. (2022) Adaptation Strategies of Medicinal Plants in Response to Environmental Stresses. In: T.Aftab (ed.) *Environmental challenges and medicinal plants, environmental challenges and solutions*, pp. 133–151.

Kadereit G., Borsch T., Weising K., Freitag H. (2003) Phylogeny of *Amaranthaceae* and *Chenopodiaceae* and the evolution of C4 photosynthesis. *International Journal of Plant Sciences*, **164:**959–986.

Qurbanov E.M. (2024) Vegetation of Azerbaijan. Monograph. Baku: Elm, 536 p.

Lata S., Lata R., Ram R.B., Verma R.S. (2021) Morphological and anatomical adaptations of plants to cope up with environmental stress. *Journal of Pharmacognosy and Phytochemistry*, **10(6):**142–147.

Lia Y., Kong D., Fu Y., Sussman M.R., Wu H. (2020) The effect of developmental and environmental factors on secondary metabolites in medicinal plants. *Plant Physiology and Biochemistry*, **148:**80–89.

Nazari M., Ghasemi-Soloklui A.A., Kordrostami M., Abdel Latef A.A.H. (2023) Deciphering the response of medicinal plants to abiotic stressors: A focus on drought and salinity. *Plant Str*ess, **10:**100255.

Orsini F., Alnayef M., Bona S., Maggio A., Gianquinto G. (2012) Low stomatal density and reduced transpiration facilitate strawberry adaptation to salinity. *Environmental and Experimental Botany*, **81:**1–10.

Pant P., Pandey S., Dall'Acqua S. (2021) The influence of environmental conditions on secondary metabolites in medicinal plants: A literature review. *Chem. Biodiversity*, **18:**e2100345.

Papp J., Gracza P., Szenthe A., Sárdi E., Simon G. (2005) Anatomical relations of the leaves in strawberry. *International Journal of Horticultural Science*, **1(111):** 81–84.

Sardarova A.S. (2022). Anatomy of medicinal plants. Baku: Apostroff, 678 p.

Tutayuq V.X. (1967) Plant anatomy and morphology. Baku: Maarif, 193 p.

Chamberlain C.J. (2020) Methods in plant histology. London: Forgotten Books, 364 p.

Criswell S., Gaylord B., Pitzer C.R. (2025). Histological methods for plant tissues. *J. Histotechnol*., **48(1):** 58–67.

Peterson R.L., Peterson C.A., Melville L.H. (2008) Teaching plant anatomy through creative laboratory exercises. Ottawa: NRC Press, 154 p.

Engin H., Kuzucu F.C., Gökbayrak Z. (2024) Studies on the use of different staining techniques in the microscopic examination and imaging of hardwood cuttings. *ÇOMÜ J. Agric. Fac*., **12(1):** 108–120; doi: 10.33202/comuagri.1387460

Moyo M., Aremu A.O., Van Staden J. (2015) Insights into the multifaceted application of microscopic techniques in plant tissue culture systems. *Planta*, **242:** 773–790; doi: 10.1007/s00425-015-2359-4

In situ və *ex situ* şəraitlərdə dərman əhəmiyyətli *Fragaria vesca* L. (*Rosaceae* Juss.) bitkisinin generativ və vegetativ orqanlarının müqayisəli ekoloji anatomik xarakteristikası

Aygün Sərdarova

Azərbaycan Dövlət Aqrar Universitetinin Biologiya kafedrası, Gəncə, Azərbaycan

Tətqiqat işində Azərbaycan Respublikasının iki fərqli ərazisində yetişən *Fragaria vesca* növünə aid bitkilərin ayrı-ayrı hissələri anatomik olaraq tətqiq edilmiş və bu ekotiplərin daxili strukturunun müqayisəli öyrənilməsi məqsəd kimi götürülmüşdür. Ərazilərdən götürülmüş bitki nümunələri laboratoriya şəraitində reagentlərlə işlənilərək anatomik tədqiqatlara cəlb olunmuşdur. *Fragaria vesca* növünün *in situ* və *ex situ* nümunələrindən en kəsimləri alındıqdan sonra mikroskopik analizlərlə tədqiq olunmuşdur. Mikroskopik təhlillər zamanı nümunələrin tam görüntüsü və ayrı-ayrı toxumalar səviyyəsində obyektivin bütün böyütmə dərəcələrindən istifadə olunaraq fotomikroqraflar götürülmüşdür. Vegetativ və generativ orqanlar üzərində aparılan analizlər onların təşkil olunduğu toxuma növlərini, bunların orqan daxilində yerləşmə xüsusiyyəti ilə funksiyası arasındakı bağlılığı, o cümlədən iki fərqli əraziyə aid nümunələrdə formalaşan oxşar və fərqli anatomik strukturları müəyyən etməyə imkan vermişdir. Belə fərqli xüsusiyyətlərə misal olaraq *in situ* nümunədə saplaqda kapitat trixomaların mövcudluğu, çiçək saplağında aerenximanın formalaşması, kök və kökümsovda poliderm toxumasının daha intensiv inkişafı və s. kimi ekoloji anatomik adaptasiyaları göstərmək olar. Başqa bir fəqli məqam kimi isə digər vegetativ orqanların (yarpaq, rozet, kök) parenxima toxumasında toplanan druz kristallarının və digər bioloji aktiv maddələrin fərqli ərazilərə aid nümunələrdə müxtəlif konsentrasiyalarda olmasını misal çəkə bilərik. Aparılmış müqayisəli analiz eyni növün fərdlərinin anatomik strukturunun müxtəlif ekotoplarda hansı şəkildə biruzə verəcəyini müəyyən etməyə imkan verir. Bu da öz növbəsində müxtəlif ekoloji şəraitlərdə yetişən bitkilərdə ekoloji amillərin təsiri altında formalaşacaq potensial anatomik strukturların müəyyən olunmasında önəmli bir rol oynayır.

Açar sözlər: *Kollenxima, druz, aerenxima, abaksal epidermis, poliderm*

ORCID:
Aygun Sardarova: https://orcid.org/0009-0006-0075-7478