Plant & Fungal Research (2025) 8(1): 23-35
https://doi.org/10.30546/2664-5297.2025.8.1.09

June 2025

Ecological anatomical study of structural-plastic response reactions of the medicinally important species *Laurus nobilis* (Lauraceae) in various ecological conditions

Aygun S. Sardarova[1]
Azerbaijan State Agricultural University, Ozan Street, Ganja, AZ2007, Azerbaijan
Sayyara J. Ibadullayeva
Institute of Botany, Ministry of Science and Education of the Republic of Azerbaijan, A. Abbaszade str., entr. 99, AZ1004, Baku, Azerbaijan

Abstract: The aim of the research is to carry out comparative ecological anatomical analyses to study the structural anatomical differences that may arise under the influence of environmental factors in representatives of the plant species *Laurus nobilis* collected from various ecosystems of the Republic of Azerbaijan. During the scientific investigation, in order to determine the internal anatomical structures and to obtain the necessary descriptive materials, samples were taken from specific organs of the plant, preserved in fixative, and prepared for sectioning under laboratory conditions. Cross-sections obtained from leaves, petioles, and stems were processed with histochemical reagents, and permanent preparations were made from them. These preparations were analyzed using a light microscope, and the necessary photomicrographs were taken. Based on microscopic observations and references to bibliographic databases, the structural-functional dependencies in the different organs of the plant were explained. During the research, microscopic analysis revealed the formation of trichomes in the leaf of the *L. nobilis* species collected from Toghanali. Additionally, it was determined that all vegetative organs of the three ecotype samples studied in comparison contained schizogenous secretion cavities, which is an endogenous secretion tissue structure that confirms the species' phytotherapeutic value. In addition, lysigenous cavities and various ergastic and constitutional substances accumulated in the cells were identified in the cortex region of each analyzed vegetative organ. In the leaf of the sample collected from Ganja area, parenchymatic excretion was observed as an adaptation characteristic to the ecosystem of the region. Based on histo-anatomical studies, differences were noted both in the structural characteristics of the species and in the local concentrations, which can be considered as an ecotopic characteristic of the *L. nobilis* species.

Keywords: *ergastic substances, idioblasts, parenchymatic excretion, schizogenous cavities, subepidermal cells, trichomes*

INTRODUCTION

Laurus nobilis is an evergreen tree or shrub belonging to the Lauraceae family. In Azerbaijan, it is distributed in mid-mountain and foothill subtropical zones. It is introduced for ornamental purposes in relatively humid microclimates and mild areas [Qurbanov, 2024]. Naturally, it grows easily and demonstrates ecological plasticity in mountainous terrains with a mild climate [Akyol et al., 2023]. The glossy leaves are attached to the stem via short petioles and exhibit alternate phyllotaxy. The stem of *L. nobilis* possesses a hard, woody structure and the main root is rich in well-developed lateral roots. The rigid structure of its leaves and the covering of the aerial vegetative organs with cuticle ensure the plant's resistance to seasonal changes. The plant's yellowish, unisexual flowers are located in the leaf axils [Judd et al., 2015; Simpson, 2019; Khodja et al., 2023]. The *L. nobilis* species is used both as an ornamental, medicinal, and spice plant. The plant is pharmacologically rich in composition [Ibadullayeva, 2024; Kızılyıldırım et al., 2024]. The essential oils contained in the plant provide it with a distinctive aroma [Joshi, 2018; Jason, 2023]. *L. nobilis* possesses high phytotherapeutic significance both in folk medicine and in modern medicine [Anzano et al., 2022; Mansour et al., 2023]. At the same time, it is a plant with adaptation potential in various ecological conditions.

In the modern era, the investigation of adaptation mechanisms of medicinal plants under various ecological conditions is of great importance both for studying their resilience potential and for scientifically substantiating the rational use of bioresources. The comparative study of the ecological-anatomical structures of the same plant species growing in different ecological conditions is of significant scientific importance for clarifying the mechanisms of the influence of abiotic factors (climate, soil, anthropogenic impact, etc.) on the morpho-anatomical adaptations of plants. *L. nobilis* is a plant that is valuable both pharmacologically and has an

[1]E-mail: aygun.sardarova4442@gmail.com
Received: 10.02.2025; Received in revised form: 23.04.2025; Accepted: 31.05.2025

adaptation potential in various ecological conditions. In the modern era, the study of the adaptation mechanisms of medicinal plants in different ecological conditions is of great importance for both understanding their resilience potential and scientifically justifying the rational use of bioresources. The comparative study of the ecological-anatomical structure of *L. nobilis* species in different ecosystems allows determining the level of morphostructural adaptation of this species to environmental stress factors. Changes in anatomical structure (epidermal cells, cuticle thickness, secretion structures, etc.) influence the synthesis and accumulation of biologically active compounds in medicinal plants, making this research relevant from both pharmacological-ecological and bioindication perspectives. Furthermore, the conservation of *L. nobilis* in the context of biodiversity is closely related to assessing its cultivation potential and resilience levels in various ecological conditions.

As mentioned above, *L. nobilis* was a subject of the various studies in Azerbaijan. Thus, this research aims at revealing ecological anatomical pecularities of *L. nobilis* L. growing in various ecological conditions.

MATERIAL AND METHODS

Collection of material and laboratory processing: Samples for the study were collected from Toghanali village (Goygol district), characterized by a mountain-forest landscape (Fig. 1 A, B), Ganja city, which has a continental climate and an urban park and green space area (Fig. 1 C, D); and Nakhchivan city, located in a dry continental climate zone (Fig. 1 E, F). After the plant materials were stabilized 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 both in the infiltration and sectioning stages as an auxiliary medium. During the study, the thickness of the sections was precisely calibrated and measured in microns using the special micrometric adjustment knob of the modern hand microtome (RADICAL, RMT-5, India). The thickness of the sections obtained via the microtome was determined within a range of 6, 7, and 8 µm through micrometric adjustment. After microtome sectioning, histochemical methods were applied, and differential staining was performed using specific reagents. Special stains such as safranin O, fast green, Sudan III, toluidine blue, phloroglucinol-HCl, and methylene blue (KimyaLab, Turkey) were used in this process. The staining procedure, applied to selectively stain tissue components, was carried out stepwise through a decolorization method [Peterson et al., 2008; Engin et al., 2024]. The successive application of various histological staining techniques allowed for a more precise comparison of the eco-anatomical structural components of *L. nobilis* under different ecological conditions. For the preparation of permanent stained specimens, Canada balsam (INOVATING SCIENCE, US) was used. A drop of balsam was placed on the section positioned on the slide, and a cover glass was placed over it. The prepared specimens were then kept in a specialized incubator, where the temperature was maintained at a constant 20–25°C to ensure complete drying of the Canada balsam. After this stage, the permanent cross-section specimens of the plant were subjected to microscopic analysis.

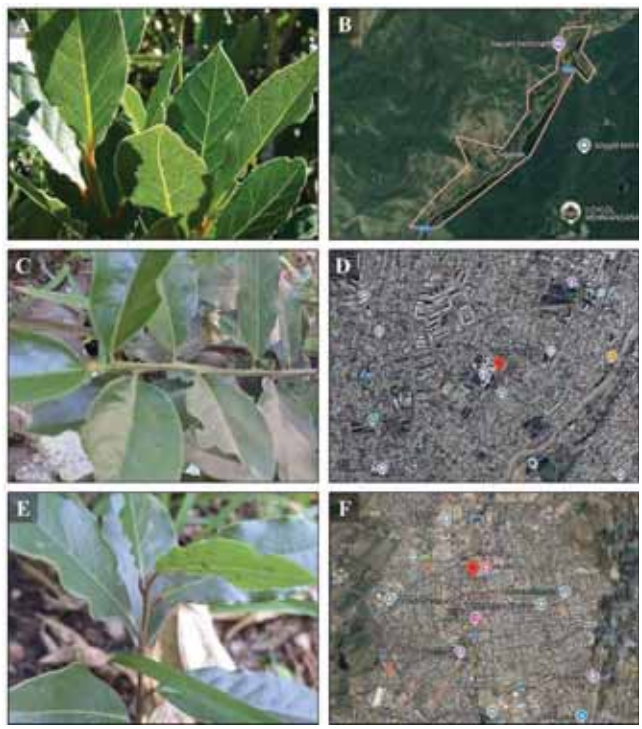

Figure 1. General view and map of collected area of *Laurus nobilis*: Toghanali village, Goygol (A, B); Ganja (C, D); Nakhchivan (E.F).

Microscopic analysis: During microscopic investigations, "Carl Zeiss, Axio Imager A2" (ZEISS, Germany) microscope was used. The structural elements of the vegetative organs of *L. nobilis* were analyzed and digital microphotographs were obtained. Additionally, during microscopic analyses, the LCD Digital Microscope NLCD-307B model (Wincom Company Ltd., China) was used for utilizing the

advanced features, high-precision eco-anatomical analyses of *L. nobilis*. To ensure precise identification of anatomical structures, all objective magnification levels (4×, 10×, 40×, 60×, and 100×) were employed during the study. At the same time, observations were carried out using a 100× objective lens with the application of immersion oil (RMY, US). The use of the immersion medium enhanced optical resolution, thereby increasing the accuracy and contrast of the microscopic images of the examined samples. The LCD Digital Microscope model NLCD-307B was used to monitor the quality of the sections and the effectiveness of histological staining at the stage prior to transferring the plant sample cross-sections to permanent slides. Final analyses on the prepared slides, acquisition of micrographs, and collection of statistical measurements were carried out using the Carl Zeiss Axio Imager A2 model. During the research, stereomicroscopes (Stereo microscope Zeiss Stemi508 (ZEISS, Germany), Stereo YK-SM067B2 (Wincom Company Ltd., China)) were also used for macroscopic analysis of the samples. A digital micrometer (Jiavarry, China) was used to record the macroscopic measurements of the organs where the sections were made [Moyo et al., 2015].

Preparation of herbarium samples: Herbarium samples of *L. nobilis* are stored in the herbarium collection of the Department of Biology at Azerbaijan State Agricultural University.

Statistical methods: From the populations of the same species in each region, 8-12 different plants were selected and samples were taken from the leaves, petioles, and stems of each plant for study. About 10-15 cross-sections were prepared from each organ, and anatomical analyses were carried out. During the microscopic analyses, various parameters were measured. Statistical analyses were performed using Microsoft Excel. A t-test was applied for comparison between the two groups. The results are presented as mean ± standard deviation, and statistical differences were considered significant at $P < 0.05$.

Abbreviations used in article: ab.ep-abaxial epidermis; ad.ep-adaxial epidermis; c.s-constitutional substances; ca-cambium; cl-collenchyma; cu-cuticle; ep-epidermis; er-ergastic substances; id-idioblast; l.ca-lysigenous cavities; lf-libriform fibres; mr-medullary ray; pa-parenchyma; pa.ex-parenchymatous excretion; pam-palisade mesophyll; ph-phloem; pi-pith; s.ca-schizogenous secretion cavity; scc-sclerenchyma; spm-spongy mesophyll; tr-trichome; xy-xylem.

RESULTS AND DISCUSSION

Leaf: The leaf has a bifacial structure, with areas extending dorsally and somewhat ventrally along its central vein. In the ventral region, within this expanded area, angular collenchyma tissue has formed along the subepidermal zone. This tissue has also developed in the dorsally expanded area, and at the lateral sides, it is bordered by chloroplast-containing parenchyma cells of the leaf mesophyll. The mechanical tissue, a different type of structure, forms sclerenchyma around the central vascular bundle with a collateral arrangement, surrounding both the phloem on the lower side of the leaf and the xylem on the upper side. In the plant sample taken from Ganja, the sclerenchyma surrounding the xylem directly connects with the collenchyma, which fills the ventral part. Here, the collenchyma cells are smaller and fewer in number compared to the collenchyma cells in other samples. In the transverse sections of the leaf samples collected from the village of Toghanali, there are parenchyma cells with slightly thickened walls between the sclerenchyma surrounding the xylem on the upper side and the collenchyma on the ventral side. These cells have an isodiametric structure and are larger in size compared to the mechanical cells. In the sample taken from Toghanali village (Goygol), it was observed during microscopic examination that the sclerenchyma tissue, alongside the collenchyma tissue, was more actively formed (Fig. 2).

The sclerenchyma fibers surrounding the phloem are arranged in large groups, and the area between these groups is occupied by parenchyma cells. In this area, the parenchyma cells are more numerous and larger in size in the sample taken from Ganja. Towards the adaxial epidermis, these parenchyma cells are supported by the collenchyma on the dorsal side. Both tissue types contain accumulated ergastic and constitutional substances within their cells. In the sample taken from Ganja, a greater accumulation of these substances, as well as the presence of idioblast-type cells in the parenchyma and the concentration of these substances in lysigenous cavities within the collenchyma tissue, was observed during microscopic analysis (Fig. 2).

The central vascular bundle of the leaf is large in size and, in the sample taken from Toghanali, it is composed of a greater number of xylem and phloem elements. The xylem vessels are mainly arranged along radial rays and have a circular-angular structure. In the areas between them, libriform fibers are formed. Within the xylem tissue, there are also medullary rays extending radially. In the sample taken from Ganja, some of these

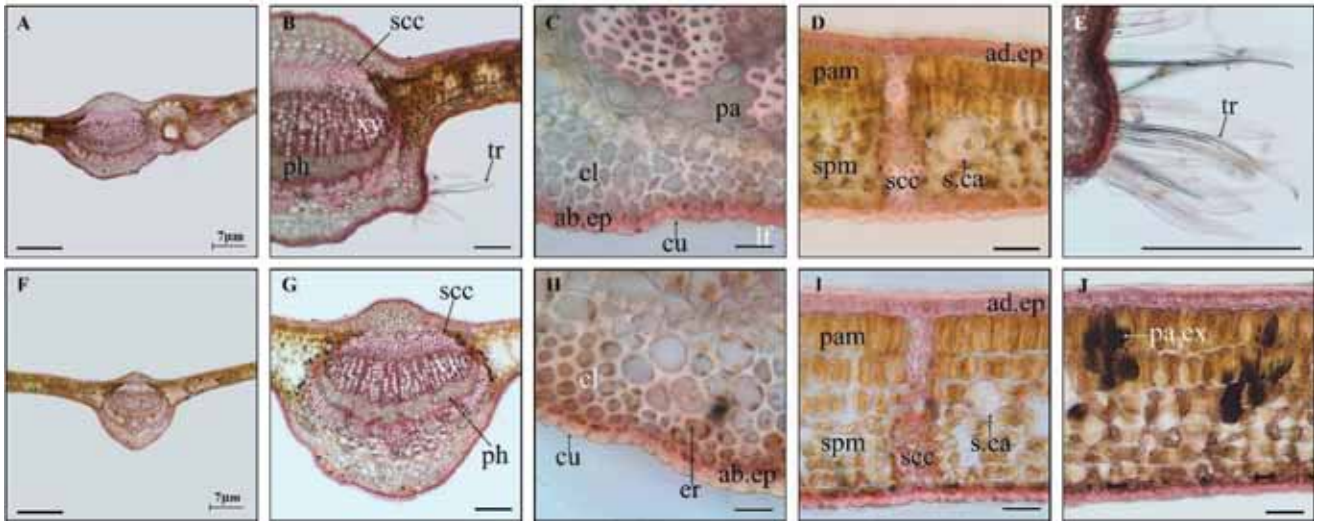

Figure 2. Leaf of *Laurus nobilis* (upper row from Toghanali, lower row from Ganja): A, F. the general appearance of the cross-section of the leaf; B. midrib and trichomes on the abaxial epidermis; C, H. periferal part of the midrib; D, I. the leaf blade area with the lateral bundle; E. a cluster of trichomes present on the abaxial epidermis; G. midrib; J. parenchymatous excretion in the mesophyll; Scale bar: A - 700 μm; B - 200 μm; C, H, I, J - 50 μm; D - 60 μm; E - 350 μm; F - 600 μm; G - 200 μm.

medullary rays extend into the phloem and divide it into sections. In the other sample, such a condition is almost not observed, and the phloem tissue is continuous. The cells forming the upper or adaxial epidermis of the leaf are larger in size compared to the cells of the lower or abaxial epidermis, and both surfaces possess a cuticle layer. Additionally, in the specimen collected from, the cells forming both epidermises are larger in size than the cells constituting the corresponding dermal tissue layers of the other specimen. In the lateral mesophyll regions, palisade parenchyma cells arranged in two rows are located internally to the adaxial epidermis. Internally to the abaxial epidermis, spongy parenchyma cells of various shapes are present [Chmit et al., 2018; Gonçalves, 2018]. The height of both the palisade and spongy parenchyma is greater in the specimen collected from Ganja (Tab. 1).

In this specimen, parenchymatic excretions, appearing as dark-colored spots, are accumulated between the palisade parenchyma cells and, to a lesser extent, within the spongy parenchyma. These were not observed in the other specimen. The small-sized vascular bundles branching along the lateral mesophyll regions are supported by a small amount of sclerenchyma tissue against both the adaxial and abaxial epidermis [Serebrynaya et al., 2017]. This type of structure leads to the division of the chloroplast-containing parenchyma into sections. Schizogenous secretion cavities are formed among the chloroplast-containing parenchyma cells and also within the collenchyma tissue formed in the central vein region. These cavities are larger in the specimens collected from the village Toghanali. In the specimens collected from this area, it can also be observed that the mesophyll tissue, especially near the central vein, is composed of more compactly arranged cells.

Comparative ecological-anatomical studies have shown that certain structural-functional features were observed in the specimen of *Laurus nobilis* collected from Ganja. The formation of lysis zones in the collenchyma of the central vein region, the accumulation of constitutional substances in the parenchyma tissue, and the presence of idioblast-type cells were observed through microscopic analysis. The mesophyll region in the leaf is thick, and the spongy and palisade cells are large. It was also observed that the epidermis cells are larger in size. In the specimens collected from Toghanali, differential characteristics were recorded. The schizogenous secretion cavities are larger in size compared to the schizogenous cavities formed in the leaves of the specimen growing in Ganja. Adaptation structures such as the development of trichomes on the epidermis, better organization of xylem and phloem elements in terms of number and development, etc., were clarified. These anatomical differences demonstrate the variability of the adaptive mechanisms of the *L.*

Table 1. Quantitative characteristic of the leaf of *Laurus nobilis* (μm).

Indicators	Ganja (Mean ± SD)	Toghanali (Mean + SD)
Adaxial epidermis cell size	24.34 ± 2.15	20.78 ± 1.95
Abaxial epidermis cell size	18.53 ± 2.42	15.71 ± 1.98
Height of palisade parenchyma	95.08 ± 3.84	82.28 ± 2.85
Height of spongy parenchyma	135.86 ± 7.14	102.8 ± 5.62
Xylem vessel diameter	20.13 ± 3.55	20.32 ± 4.26
Cell group size in the width of the sclerenchyma	125.54 ± 7.03	146.88 ± 7.65
Diameter of the schizogenous secretion cavities	47.14 ± 2.85	67.34 ± 2.04

Note: Statistical analysis was performed using the t-test ($P < 0.05$). SD - standard deviation.

nobilis species in accordance with different ecological conditions [Fasseas, Akoumianaki-Ioannidou 2010; Kharchenko, 2008].

It should be noted as an important scientific novelty that, as a result of the research, the observation of trichomes on the leaf epidermis of *L. nobilis* specimens collected from Toghanali was recorded for the first time in the flora of Azerbaijan. However, several fundamental botanical sources state that trichomes are generally absent on the leaves of this species [Fahn, 1990; Metcalfe, Chalk, 1950; Werker, 2000]. This finding can be evaluated as an indicator of the morpho-anatomical plasticity of *L. nobilis* in the context of ecological adaptation and represents an anatomical diagnostic adaptation structure directly related to the influence of specific ecological factors (humidity, radiation, wind, etc.) of the regional environment (Toghanali area). This observation can be considered preliminary evidence that the presence of trichomes on *L. nobilis* leaves may be induced by environmental conditions, and it necessitates the implementation of large-scale integrated studies on the morpho-anatomical variability of this species in the future.

In the specimen of *L. nobilis* growing in Toghanali, the actively developed trichomes can be interpreted as an adaptive response induced by high radiation, humidity, wind, or other stress factors. By fulfilling a role in reducing transpiration or providing protection under these conditions, the trichomes demonstrate a broader level of ecological plasticity of the species.

Petiole: The petiole has a collateral structure with a single central vascular bundle, and this bundle is structurally similar to that in the leaf. However, due to the weak lignification of the libriform fibers located between the xylem vessels, thin-walled, small-sized parenchymatous cells are observed in this area. In the petiole of the plant specimens collected from Toghanali village, a small number of lignified fibers were observed between the xylem vessels. Here, the overall diameter of the xylem vessels is also smaller (Tab. 2). In both samples, the xylem vessels have a circular-angular structure.

One of the main differences in the sample collected from Toghanali is the well-developed sclerenchyma surrounding the vascular tissue. This tissue completely encircles the vascular bundle, and the mechanical fibers that make up the sclerenchyma are located in groups on the underside of the vascular bundle, at the boundary with the phloem tissue [Serebrynaya et al., 2018; Sardarova, 2024b]. These mechanical cell groups are partially separated by parenchymatous rays, and a small number of cells with large size and lignified walls were observed between them during microscopic analysis. In the petiole from Ganja, sclerenchyma was not formed. The diameter of the parenchyma cells surrounding the vascular tissue is smaller in this sample compared to the other, and their walls are much thinner. The mentioned parenchyma transitions into collenchyma, which is concentrated in 12-16 layers towards the epidermis, and in the sample collected from Toghanali village, the cell walls of this tissue are thicker (Fig. 3). In this sample, the collenchyma tissue has a more compact structure, and its cells are almost completely filled with ergastic and constitutional substances.

As a result of the comparative ecological anatomical analysis, significant structural differences were identified between the petiole samples of *L. nobilis* collected from Ganja and Toghanali areas. In the samples grown in the mild continental climate of Ganja city, sclerenchyma tissue was not observed, the secretion cavities were slightly larger, and they were mainly localized in the zone near the epidermis, where they had darkened (Fig. 3). Sclerefication did not occur, and cutinization was weak. These structural changes indicate weak development of defensive and supporting tissues, formed under relatively stress-free conditions [Sardarova, 2024a].

Table 2. Quantitative characteristic of the petiole of *Laurus nobilis* (μm).

Indicators	Ganja (Mean ± SD)	Toghanali (Mean + SD)
Epidermis cell size	32.1 ± 2.76	43.22 ± 2.26
Thickness of the outer wall of epidermis cells	12.39 ± 0.45	35.47 ± 1.64
Thickness of the collenchyma cell wall	5.45 ± 0.24	8.31 ± 0.48
Diameter of the schizogenous secretion cavities	54.58 ± 4.65	51.7 ± 3.79
Xylem vessel diameter	32.54 ± 4.77	24.73 ± 4.62
Cell group size in the width of the sclerenchyma	——	122.82 ± 6.63
Diameter of parenchyma cells near the vascular bundle	44.82± 3.78	55.17 ± 6.89
Thickness of the parenchyma cell wall near the vascular bundle	1.84 ± 0.31	8.96 ± 1.27

Note: Statistical analysis was performed using the t-test ($P < 0.05$). SD - standard deviation.

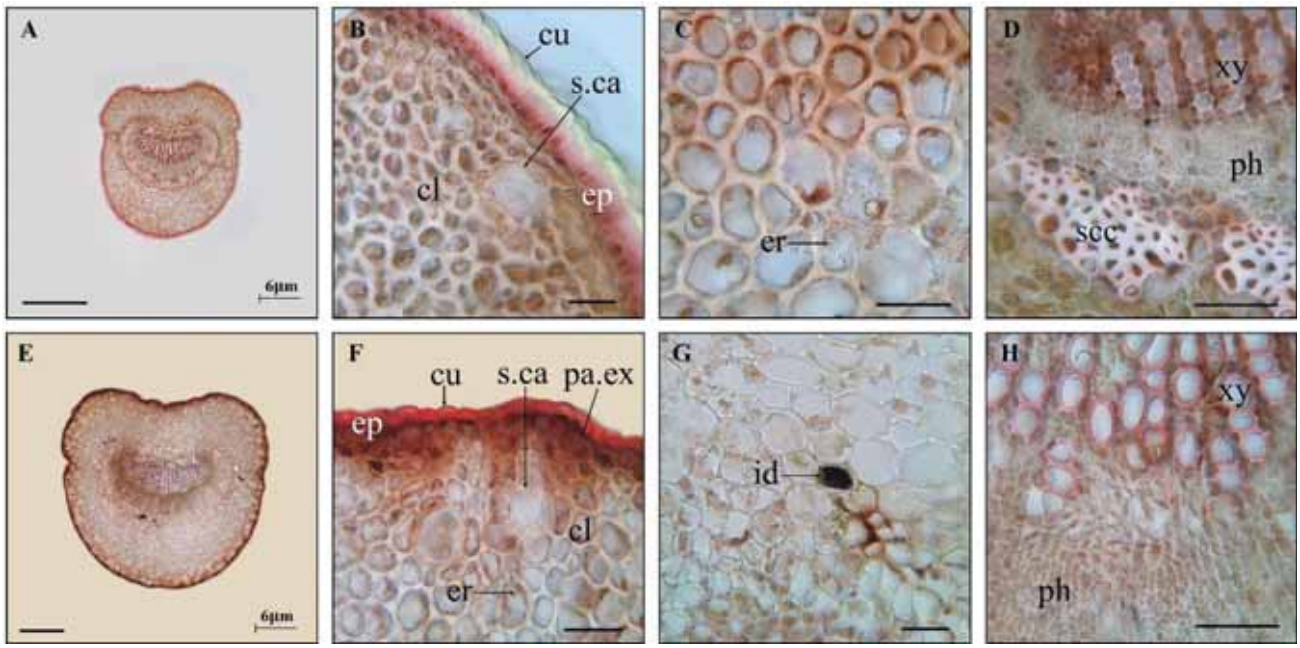

Figure 3. Petiole of *Laurus nobilis* (upper row from Toghanali, lower row from Goygol): A, E. the general appearance of the cross-section of the petiole; B, F. periferal part of the petiole; C, G. the area above the bundle; D, H. a part of the vascular bundle; Scale bar: A - 700 μm; B, G - 50 μm; C - 80 μm; D, H - 100 μm; E - 500 μm; F - 60 μm.

Stem: The stem has a eustele type stele, with the xylem tissue forming a continuous ring that surrounds the pith. The pith in the sample collected from Ganja city is larger in size and composed of more cells. The cells of this tissue are tightly packed, which causes them to appear polygonal in cross-section during microscopic observations. In the stem of *L. nobilis*, the pith parenchyma contains cells filled with ergastic substances, and such cells are primarily concentrated in the perimedullary areas, although they are also occasionally found in various parts of the pith parenchyma. The xylem ring surrounding the pith is primarily filled with libriform fibers, and the xylem vessels are arranged mainly along the radial rays between these elements. The number of xylem vessels is higher in the sample collected from Toghanali village area. However, in the sample from Ganja city, their overall diameter is slightly larger. Within the xylem tissue, there are numerous medullary rays consisting of a single cell row arranged radially [Kasapligil, 1962]. The xylem ring is surrounded by a clearly distinguishable cambium layer from the cortex side, and the meristematic cells forming this cambium are observed to be somewhat darker in the sample from

Ganja, distinguishing it from the other sample. From this tissue, phloem is formed by meristematic cells, which produce the exarch phloem towards the cortex. The phloem tissue is better developed in the sample collected from Toghanali village, with a thicker and more voluminous layer (Fig. 4).

This tissue is divided into sections in both samples through parenchyma rays. Corresponding to the number of these sections, sclerenchyma fibers are grouped and located towards the cortex side from the phloem. In the sclerenchyma tissue surrounding the pith along the stem, the number of cells in the transverse thickening is 5-6 cells in the sample from Ganja (Fig. 4). In the stem of the *L. nobilis* plant growing in Toghanali, the number of these cells increases in some areas of the circular sclerenchyma tissue, reaching 8-9 cells.

Peripheral to the mechanical tissue, the tissues that form the cortex are located. On the inner side of the cortex, a dense formation of larger parenchyma cells with relatively thin cell walls has developed. In the peripheral parts of the cortex, collenchyma consisting of smaller, thick-walled cells is present. In both samples, schizogenetic secretion cavity have formed within these tissues, and their overall diameter is larger in the sample collected from Toghanali. In areas where these cavities are located near the epidermis, the surface appears slightly raised outward. The majority of the parenchyma and collenchyma cells forming the cortex are filled with a high amount of ergastic and constitutional substances, which can be observed through microscopic analyses. The epidermal layer covering the stem from the outside is thicker in the sample collected from Toghanali, and its surface has a more intensively developed cuticle layer (Tab. 3). In this sample, the darkening process is clearly observed due to the accumulation of constitutional substances within the epidermal cells, with some of these substances even penetrating the cell walls.

Thus, significant differences were identified between the stem anatomical structures of samples of *L. nobilis* grown in Ganja and Toghanali. In Ganja sample, the development of sclerenchyma cells is relatively weak, and the size of the medullary parenchyma in the stem of the plant from Toghanali is observed to be approximately twice as large. This is an anatomical feature of adaptation to a relatively stable environment with few stress factors [Tutayuq, 1972].

In the samples taken from Toghanali, a higher number of phloem cells was observed. Additionally, the accumulation of dark, sometimes black-colored constitutional substances in the cell walls of the epidermis and subepidermal layers, and the darkening of the cell walls due to impregnation with these substances, was noted. This process can be interpreted as the accumulation of phenolic compounds, tannins, or resin-type metabolites in the cell walls for defensive purposes [Sardarova, 2022], and it is recommended that

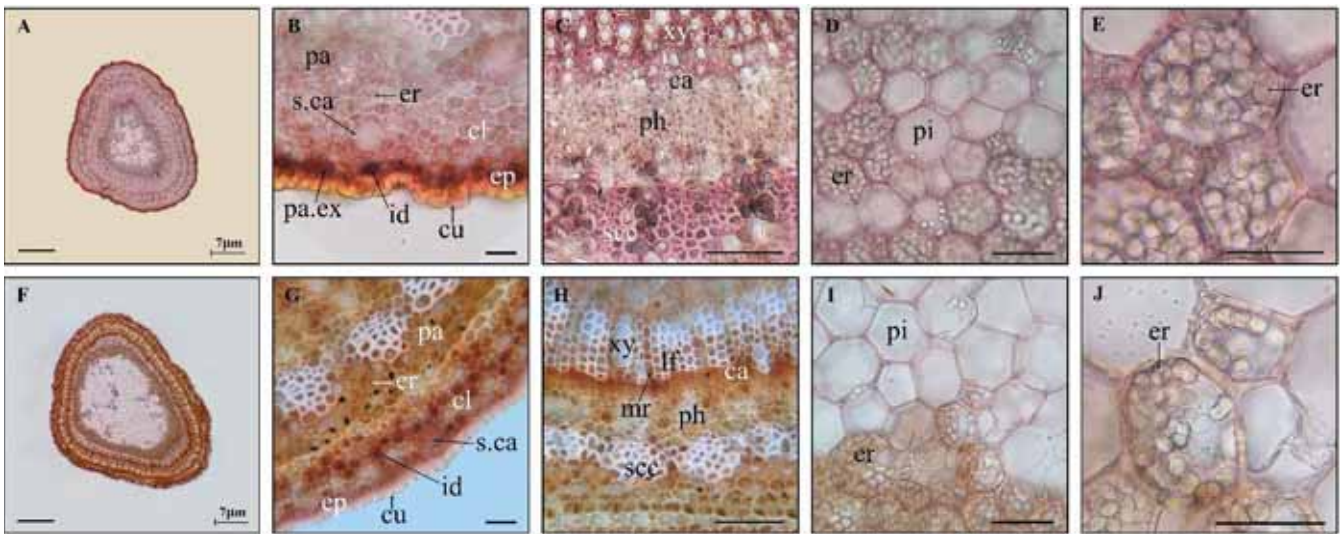

Figure 4. Stem of *Laurus nobilis* (upper row from Toghanali, lower row from Ganja): A, F. the general appearance of the cross-section of the stem; B, G. cortex of the stem; C, H. elements forming the vascular andmechanical tissuses; D, I. pith; E. ergastic substrances in the pith parenchyma cells; F. the general appearance of the cross-section of the stem; Scale bar: A, F - 500 μm; B, E, G, J - 40 μm; C - 100 μm; D, I - 80 μm; H - 90 μm.

Table 3. Quantitative characteristic of the stem of *Laurus nobilis*, μm.

Indicators	Ganja (Mean ± SD)	Toghanali (Mean + SD)
Epidermis cell size	27.28 ± 2.05	29.39 ± 2.15
Thickness of the outer wall of epidermis cells	16.72 ± 1.25	17.04 ± 1.57
Diameter of the schizogenous secretion cavities	36.04 ± 1.34	49.9 ± 1.27
Diameter of the idioblasts	16.64 ± 1.42	17.35 ± 1.5
Cell group size in the width of the sclerenchyma	71.83 ± 3.54	87.58 ± 3.23
Xylem vessel diameter	21.74 ± 1.15	20.92 ± 1.04

Note: Statistical analysis was performed using the t-test ($P < 0.05$). SD - standard deviation.

these be further investigated in phytochemical research for pharmaceutical purposes. This opens the way for transdisciplinary methodological studies, making it possible to achieve more modern results in line with international standards.

At the same time, the thickening of the cuticle and the formation of larger secretion sites in Toghanali samples indicate the active physiological and morpho-anatomical defense strategies of the plant against stress. These changes reflect the plant's adaptation to the harsher abiotic factors of Toghanali (strong solar radiation, wind, water scarcity, etc.).

A different ecosystem sample: In the leaf of the plant sample taken from the Nakhchivan AR, the central vascular bundle is observed to be slightly narrower and elongated in the dorsoventral direction compared to the samples taken from other regions. The thickness of the phloem here is lower. Areas composed of parenchyma cells have formed on both the upper and lower sides of the vascular bundle. As in the samples taken from other regions, in this sample, the mesophyll in the area where the central vein is located has expanded in both dorsal and ventral directions (Fig. 5).

In the expanded areas, collenchyma tissue has formed in the subepidermal zone. Unlike the other samples, very small amounts of ergastic and constitutional-type substances have accumulated in the parenchyma and collenchyma, but nevertheless, idioblast-type cells were observed within the collenchyma. In the leaf sample taken from this area, sclerenchyma fibers, arranged in groups around the vascular bundle, have formed and surround the xylem and phloem. In the lateral parts of the leaf, it was observed that the chloroplast-containing parenchyma had fewer chloroplasts and a weaker structure. Microscopic observations showed that in this sample taken from the Nakhchivan region, the mesophyll's upper subepidermal area mainly consists of two rows of palisade parenchyma, but the cells forming it are relatively more rounded and slightly shorter in the vertical direction compared to the samples taken from other regions. Additionally, in this leaf sample, it was observed that the spongy parenchyma cells were sparser and irregularly arranged. The schizogenetic cavities formed within the mesophyll are similar in size to those in the samples taken from Ganja. As in the samples from other regions, the cuticle layer formed on the abaxial epidermis of the leaf is thicker than the cuticle formed on the adaxial epidermis.

Microscopic analysis and measurements of petiole samples taken from Nakhchivan (Fig. 5) revealed that the thickness of the cuticle layer formed on the epidermis is greater than that of the sample taken from Ganja, but thinner than that of the sample from Toghanali.

Starting from the subepidermal zone, the collenchyma tissue cells, which are arranged in 10-12 layers, are larger in this sample and have thicker cell walls compared to the other two samples. No sclerenchyma tissue was formed around the vascular bundle, and the walls of the parenchyma cells located between the bundle and the collenchyma are somewhat thinner compared to those in the sample from Toghanali. In this regard, it resembles the petiole from Ganja. However, in the sample taken from the Nakhchivan AR, it was observed that there were fewer ergastic and constitutional substances accumulated in the collenchyma and parenchyma cells, as determined by microscopic observations. Nevertheless, it was observed that in both tissues, especially near the vascular bundle, a large number of schizogenetic cavities had formed, and their diameter was larger than those formed in the petioles from the other two regions.

In the stem sample of *L. nobilis* taken from the Nakhchivan AR, a large number of lysigenous cavities filled with accumulants were observed to be scattered, particularly in the peripheral parts of the cortex. In

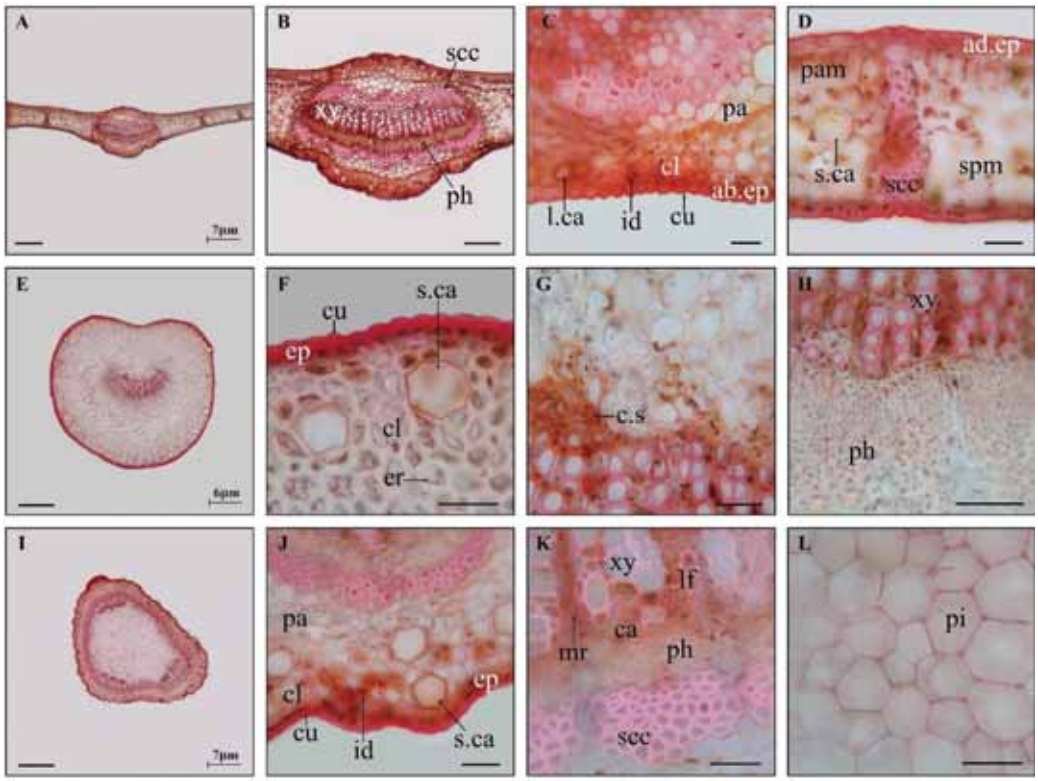

Figure 5. Leaf of *Laurus nobilis* from the Nakhchivan AR: A. the general appearance of the cross-section of the leaf; B. midrib; C. periferal part of the midrib; D. the leaf blade area with the lateral bundle; Petiole: E. the general appearance of the cross-section of the petiole; F. periferal part of the petiole; G. the area above the bundle; H. a part of the vascular bundle; Stem: I. the general appearance of the cross-section of the stem; J. cortex of the stem; K. elements forming the vascular andmechanical tissuses; L. pith; Scale bar: A - 400 μm; B - 40 μm; C, F, L - 80 μm; D, J, K - 50 μm; E, I - 500 μm; G - 60 μm; H - 100 μm

contrast, very small amounts of ergastic or constitutional substances were accumulated in other tissue cells of the cortex, such as collenchyma and cortical parenchyma. Here, the number of schizogenetic cavities is higher, and their sizes are quite large. The thickness of the cuticle layer formed on the epidermis surrounding the cortex is slightly thinner than in the samples taken from the other two regions. In the vascular tissues of the stem, the phloem is located in a thin layer, while xylem elements have formed more intensively in the corner areas of the stem. The thickness of the sclerenchyma tissue formed between the phloem and the cortex is of average size. No ergastic substances were observed in the medullary parenchyma of the stem (Fig. 5).

During the analysis of internet resources and scientific archives, foreign literature that carried out anatomical analysis of the same species was studied. Thus, in the research conducted by Serebrynaya et al. (2018), the comparative morphological and anatomical characteristics of the leaves and petioles of six different cultivars of the *L. nobilis* species grown in the Botanical Garden of the Pyatigorsk Medical and Pharmaceutical Institute and the Nikitsky Botanical Garden of the Republic of Crimea were studied. The authors noted that the cross-section of the petiole has a horseshoe-shaped form, that in some cultivars, long and thin unicellular covering trichomes were observed on the upper side of the petiole, and that secretion reservoirs were present and exhibited various localization characteristics. During our research, a similar structure of the cross section in the petiole and the presence of secretion cavities were recorded. However, trichomes were not observed on the petiole in any of the samples taken from three different areas. Nevertheless, in the leaf sample collected from Toghanali, trichomes were identified on the abaxial epidermis in the areas where the central vein branches, which is noted in only a few archived materials regarding the presence of such trichomes in the leaf. In another study conducted by Serebrynaya et al. [2017], the petiole and leaf anatomy

of the *L. nobilis* species cultivated in the Botanical Garden of the Pyatigorsk Medical and Pharmaceutical Institute was investigated. In that study, large and thin-walled idioblast cells containing essential oil were recorded in high numbers in the leaf mesophyll. In the samples of the *L. nobilis* species from three different regions investigated by us, secretion cavities of isodiametric structure, larger than the parenchyma cells and located among the chloroplast-containing cells of the leaf mesophyll, were observed. In another article, Kharchenko [2008], while analyzing the leaf structure, notes that in the *L. nobilis* species, the leaf has a dorsoventral structure and the palisade parenchyma is two-layered. The spongy parenchyma is three to four-layered and thicker. The upper and lower epidermal regions surrounding the leaf are composed of a single layer of cells. The cuticle formed on the upper epidermis has a wavy shape over the veins and along the leaf margins. The cuticle of the lower epidermis is very thin and also has a wavy structure. The author states that the cells forming the upper epidermis are larger, all of their walls are thickened, and the outer walls of the lower epidermis cells are also thickened and lignified. Additionally, Fasseas and Akoumianaki-Ioannidou [2010] state that the leaves of *L. nobilis* initially have a soft structure but gradually become harder. Studies conducted using light and electron microscopy show that this hardening is related to lignification occurring in the fibers formed around the vascular bundles and in the cells of the leaf epidermis. The authors note that while thickening and lignification occur in all cell walls of the upper epidermis, this process is weaker in the lower epidermis. The mentioned features generally correspond to the results we obtained. The structure of the mesophyll, the presence of a dorsoventral organization, the differences in the size of the epidermal cells, and the lignification process in their walls were also observed during our research. However, contrary to what foreign authors have stated, the thickening occurring mainly in the outer periclinal wall of the lower epidermis cells is greater than the thickening in the outer wall of the upper epidermis cells, especially in the sample collected from Toghanali. Nevertheless, as noted by the foreign authors, the thickening in the lower epidermis occurs only in the outer walls of the cells, while in the upper epidermis it extends throughout the entire cell wall. This process in the upper epidermis is more evident in the sample collected from Ganja, whereas in the samples from other regions, it is observed mainly in the outer periclinal and anticlinal walls of the epidermal cells.

The analysis of archival data revealed that the tissue structures in the plant samples we studied are more compact in structure and distinguished from the plant samples studied by foreign authors by their richness in accumulants. In our study, the leaves of all three ecosystem samples contained two rows of densely arranged palisade parenchyma cells, whereas in the *L. nobilis* species grown in the Botanical Garden of the Pyatigorsk Medical and Pharmaceutical Institute studied by Serebrynaya et al. [2017], palisade parenchyma is completely absent. From both anatomical and phytotherapeutic perspectives, the *L. nobilis* samples growing in the Republic of Azerbaijan possess a very rich structure. Strong lignification in the tissues and the more active formation of mechanical elements are clearly observed in the samples of *L. nobilis* we examined. In particular, sclerenchyma tissue intensively develops around the central vascular system. The appearance of such a feature is associated with the rich ecological and geographical characteristics of the Republic of Azerbaijan.

CONCLUSION

As a result of the research, the presence of trichomes on the leaf epidermis of *Laurus nobilis* specimens collected from Toghanali village was identified. The identification of these trichomes on the leaf of L. nobilis is considered the first scientific novelty for the flora of Azerbaijan and is regarded as a step in the evolution of ecological anatomy. However, in the scientific literature, a trichomeless leaf epidermis is typically considered characteristic for this species. The formation of trichomes under the influence of ecological factors can be regarded as initial evidence of the induction of this structure by specific environmental factors. In the *L. nobilis* samples grown in Toghanali, thickening of the cuticle and epidermal layers, active development of sclerenchyma tissue, large-sized parenchyma cells with thick walls, as well as a reduction in the diameter of xylem vessels and thickening of their walls, were observed. These changes represent structures not observed in the samples taken from Ganja and reflect the species' morpho-anatomical adaptation potential to ecological stress. In the *L. nobilis* samples taken from Toghanali, thickening of the phloem elements in the stem, accumulation of constitutional substances in the epidermal and subepidermal cell walls leading to darkening through impregnation, thickening of the cuticle, and the formation of actively structured secretion

cavities were observed. Ganja samples, relatively weak development of the sclerenchyma system and the presence of a larger-sized central region were identified. These differences demonstrate the morpho-anatomical adaptations in the species' defense and support systems in response to ecological conditions. During the study, structures formed through inductive processes in *L. nobilis* were identified as ecological indicators, representing an evolutionary marker discovered through ecological anatomical characterization. These findings reflect an evolutionary development in plant anatomy and represent a scientific and practical innovation brought to the field of plant anatomy for the first time. In the *L. nobilis* sample taken from the Nakhchivan AR, weak accumulation of ergastic and constitutional-type substances in the vegetative organs was observed during microscopic analysis. It was recorded that the tissues forming the mesophyll in the leaf from this region had a weak structure and contained fewer chloroplasts. The presence of numerous and large schizogenetic cavities in the petiole is an indicator of its adaptation to the environment. During microscopic analysis, it was observed that no ergastic substances had accumulated in the medullary parenchyma of the stem. During the research, it was observed through microscopic analysis in all three ecotypes of *L. nobilis* that in all vegetative organs, the xylem vessels differentiated into both the classical circular structure and angular structures. It was determined that, as a characteristic of different ecotopic structures, in the samples originating from Toghanali, the parenchyma, vascular, dermal, secretory (idioblasts, schizogenous and lysigenous) tissues, and the vascular tissue complex are actively developed. Trichomes were observed only in this sample. In Ganja samples, the accumulation of ergastic and constitutional substances predominated, whereas in Nakhchivan samples, the development of schizogenous structures was more prominently observed. In both Nakhchivan and Ganja samples, sclerenchyma was not formed in the petiole.

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Dərman əhəmiyyətli *Laurus nobilis* (Lauraceae) növünün müxtəlif ekoloji landşaftlarda struktural-plastik cavab reaksiyalarının ekoloji anatomik tədqiqi

Aygün S. Sərdarova
Azərbayca Dövlət Aqrar Universiteti, Ozan küç., Gəncə, AZ2007, Azerbaijan

Səyyarə C. İbadullayeva
Botanika İnstitutu, Azərbaycan Respublikası Elm və Təhsil Nazirliyi, A. Abbaszadə küç., giriş 99, Bakı, AZ1004, Azərbaycan

Aparılmış tədqiqatın məqsədi Azərbaycan Respublikasının müxtəlif ekosistemlərindən götürülmüş *Laurus nobilis* bitki növü nümayəndələrində mühit faktorlarının təsiri ilə yarana biləcək struktur anatomik fərqlərin öyrənilməsi üçün müqayisəli ekoloji anatomik analizər aparmaqdır. Elmi tədqiqat zamanı daxili anatomik strukturların müəyyənləşdirilməsi və lazımi təsviri materialların əldə edilə bilməsi məqsədilə bitkinin konkret orqanlarından nümunələr götürülmüş, bu nümunələr fiksator daxilində qorunmuş və laboratoriya şəraitində kəsim üçün hazırlanmışdır. Yarpaq, saplaq və gövdədən əldə edilmiş en kəsimləri histokimyəvi reagentlərlə işlənildikdən sonra onlardan daimi preparatlar hazırlanmışdır. Bu preparatlar işıq mikroskopu ilə analiz edilmiş və lazımi fotomikroqraflar götürülmüşdür. Mikroskopik müşahidələr və biblioqrafik bazalara istinad edilərək bitkinin ayrı-

ayrı orqanlarındakı struktur funksional asılılıqlar izah olunmuşdur. Tədqiqat zamanı mikroskopik analizlərlə Toğanalı ərazisindən götürülmüş *L. nobilis* növünün yarpağında trixomaların əmələ gəlməsi müşahidə olundu. Eyni zamanda müqayisəli şəkildə öyrənilən hər üç ekotip nümunənin bütün vegetativ orqanlarında sxizogen tipli ifrazat yerliyinin olması müəyyənləşdirildi ki, bu da növün fitoterapevtik dəyərini təsdiqləyən endogen ifrazat toxuma strukturudur. Bununla yanaşı analiz olunan hər bir vegetativ orqanın qabıq sahəsində lizigen tipli yerliklər və hüceyrələrdə toplanmış müxtəlif erqast və konstitusion maddələr müəyyən olundu. Gəncə ərazisindən götürülmüş nümunənin yarpağında bu ərazinin ekosisteminə adaptasiya əlaməti kimi parenximatik ekstreziya müşahidə edildi. Histoanatomik tədqiqatlar əsasında həm növün struktur göstəricilərində, eyni zamanda lokal konsentrasiyalarında fərqli məqamlar qeydə alınmışdır ki, bu da *L. nobilis* növündə ekotop xarakteristikası kimi qiymətləndirilə bilər.

Açar sözlər: *erqast maddələr, idioblast, parenximatik ekstreziya, şizogen boşluq, subepidermal hüceyrələr, trixoma*

Экологико-анатомическое исследование структурно-пластических реакций лекарственно важного вида *Laurus nobilis* (Lauraceae) в различных экологических ландшафтах

Айгюн С. Сардарова
Азербайджанский Государственный Аграрный Университет, улица Озан, Гянджа, AZ2007, Азербайджан

Сайяра Дж. Ибадуллаева
Институт ботаники, Министерство Науки и Образования Азербайджанской Республики, ул. А.Аббасзаде, подъезд 99, Баку, AZ1004, Азербайджан

Цель проведённого исследования – провести сравнительный эколого-анатомический анализ с целью изучения структурно-анатомических различий, которые могут возникать под воздействием факторов окружающей среды у представителей вида растения *Laurus nobilis*, собранных из различных экосистем Азербайджанской Республики. В ходе научного исследования для определения внутреннего анатомического строения и получения необходимых описательных материалов были взяты образцы из отдельных органов растения, зафиксированы в фиксирующем растворе и подготовлены к срезке в лабораторных условиях. Поперечные срезы, полученные из листьев, черешков и стеблей, были обработаны гистохимическими реагентами, после чего были подготовлены постоянные препараты. Эти препараты были проанализированы с использованием светового микроскопа, и были сделаны необходимые фотомикрографы. На основе микроскопических наблюдений и ссылок на библиографические базы данных была объяснена структурно-функциональная зависимость в различных органах растения. В ходе исследования микроскопический анализ выявил образование трихом на листьях вида *L. nobilis*, собранных в районе Тоганалы. Кроме того, было установлено, что все вегетативные органы трёх экотипов, исследованных для сравнения, содержат шизогенные секреторные полости, что является эндогенной секреторной тканевой структурой, подтверждающей фитотерапевтическую ценность вида. Кроме того, в корковом слое каждого анализируемого вегетативного органа были идентифицированы лизигенные полости и различные эргастические и конституционные вещества, накопившиеся в клетках. На листьях образца, собранного в районе Гянджа, было отмечено паренхиматическое выделение как адаптация, характерная для экосистемы региона. На основе гисто-анатомических исследований были отмечены различия как в структурных характеристиках вида, так и в местных концентрациях, что можно считать экотопической особенностью вида *L. nobilis.*

Ключевые слова: *эргастические вещества, идиобласты, паренхиматическое выделение, шизогенные полости, подэпидермальные клетки, трихомы*