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ANATOMICAL FEATURES OF LEAVES AND STEMS OF *TILIA CORDATA* MILL. UNDER INTRODUCTION CONDITIONS IN THE TASHKENT BOTANICAL GARDEN

Duschanova Guljan Madrimbaevna[1*],
Alieva Namuna Komilovna[2]
[1] Professor of the Department of Biology, at the National Pedagogical University of Uzbekistan named after Nizami, Tashkent,
E-mail - guljon.duschanova@mail.ru, https://orcid.org/0000-0001-7783-2049
[2]PhD, senior lecturer, Department of Biology, Faculty of Natural Sciences, Kokand State University 150700, Kokand, Uzbekistan E-mail – namunaxon.aliyeva.76@mail.ru, https://orcid.org/0009-0000-2909-4993

Abstract

This article presents the results of a study on the morphological and anatomical characteristics of the leaves and stems of *Tilia cordata* Mill. introduced in the Tashkent Botanical Garden. The leaves of this species were found to be simple, petiolate, with a cordate leaf blade and pinnate-reticulate venation. Anatomically, the leaf exhibits a dorsiventral structure characterized by well-developed palisade and spongy parenchyma. The stem possesses a typical secondary structure of woody dicotyledonous plants, with clearly differentiated protective, mechanical, ground, and vascular tissues. Distinct annual growth rings, vessels of various diameters, and medullary rays were observed in the secondary xylem. Calcium oxalate druses and storage cells were detected within the parenchymatous tissues. The identified anatomical traits indicate the preservation of species-specific characteristics of *Tilia cordata* under introduction conditions and demonstrate its high adaptive potential to the soil and climatic conditions of the Tashkent Botanical Garden.

Keywords: *Tilia cordata* Mill.; introduction; leaf; stem; morpho-anatomical characteristics; plant adaptation; Tashkent Botanical Garden.

Introduction

Under current conditions of global climate change, increasing anthropogenic pressure, and the expansion of urban greening programs, studies aimed at evaluating the adaptive potential of introduced woody plants have become increasingly important. One of the promising species widely used in ornamental horticulture and urban landscaping is *Tilia cordata* Mill. (small-leaved lime), which is characterized by high ornamental value, longevity, ecological plasticity, and tolerance to adverse environmental conditions [1, 2].

The anatomical structure of vegetative organs reflects the adaptive responses of plants to environmental conditions and serves as an important indicator of species resilience. Investigation of leaf and stem anatomy provides valuable information on the structural mechanisms that enable plants to adapt to new habitats. Therefore, the study of the anatomical characteristics of *Tilia cordata* Mill. introduced into the Tashkent Botanical Garden is of considerable scientific and practical significance.

Species of the genus *Tilia* L. have been the subject of numerous studies focusing on taxonomy, ecology, biology, and introduction of woody plants. A comprehensive overview of the origin, distribution, morphology, and ecology of the genus *Tilia* was provided by Pigott [1], while issues related to genetic resource conservation and practical utilization of *Tilia* species were discussed by Jensen [2].

The theoretical foundations of plant anatomy and tissue development were thoroughly described by Esau [3]. Significant contributions to the comparative anatomy of angiosperms were made by Metcalfe and Chalk [4, 5], who provided detailed descriptions of leaf, stem, and wood structures in dicotyledonous plants. Morphological and anatomical characteristics of vegetative organs of flowering plants have also been extensively discussed by Takhtajan [6] and Vasiliev et al. [7].

Methodological approaches to anatomical investigations of plants are comprehensively presented in the handbook by Barykina et al. [8], whereas the structure of leaf epidermis and methods for its examination were described by Zakharevich [9].

Despite the substantial body of research devoted to representatives of the genus *Tilia*, information on the anatomical structure of *Tilia cordata* under the introduction conditions of Central Asia remains limited. In particular, the anatomical characteristics of the leaves and stems of this species under the sharply continental climate of Uzbekistan have not been sufficiently investigated. Therefore, the present study aims to expand current knowledge of the anatomical characteristics of *Tilia cordata* and to assess its adaptive responses under the environmental conditions of the Tashkent Botanical Garden.

The aim of this study was to investigate the anatomical structure of the leaves and stems of *Tilia cordata* Mill. introduced in the Tashkent Botanical Garden and to identify anatomical characteristics associated with the adaptation of this species to the local soil and climatic conditions.

Materials and Methods

The study was conducted on *Tilia cordata* Mill. plants growing in the collections of the Tashkent Botanical Garden of the Academy of Sciences of the Republic of Uzbekistan. Morphological observations and phenological monitoring were carried out on five model plants throughout the growing season.

Leaves and annual shoots collected during the period of active vegetation were used for anatomical analysis. Leaf samples were taken from the middle part of the shoots. The collected material was fixed in 70% ethanol. Anatomical preparations were prepared manually following standard botanical microtechnique procedures. Transverse sections of the leaf blade were made through the central portion of the leaf, whereas stem sections were obtained from the middle part of the annual shoot. The sections were stained with safranin and methylene blue and subsequently mounted in glycerin-gelatin. Epidermal characteristics were examined using both paradermal and transverse sections. Descriptions of tissues and cellular structures were carried out according to generally accepted methods of plant anatomical research [3–5, 7]. Preparation of microscopic slides followed the procedures described by Barykina et al. [8], while epidermal features were studied according to the methodology proposed by Zakharevich [9].

Microphotographs of anatomical structures were obtained using a Canon A123 digital camera mounted on a Motic B1-220A-3 light microscope. The resulting images were used for comparative anatomical analysis of the investigated vegetative organs.

Results and Discussion

The leaves of *Tilia cordata* Mill. are simple, alternate, and long-petiolate. The leaf blade is cordate in shape, 5–9 cm long, with an acute apex and a finely serrated margin. The adaxial surface is dark green, whereas the abaxial surface is lighter and bears tufts of hairs in the axils of the veins. Venation is pinnate-reticulate. The petiole is slender and 2–5 cm long. Leaves of coppice shoots are generally larger and more elongated in shape.

Leaf Anatomy. The leaf of *Tilia cordata* exhibits a dorsiventral mesophyll structure. In transverse section, the mesophyll is clearly differentiated into palisade and spongy tissues. The palisade mesophyll is located beneath the adaxial epidermis, while the spongy mesophyll is situated above the abaxial epidermis (Figure 1).

The epidermis consists of a single layer of cells covered by a well-developed cuticle. Cells of the adaxial epidermis are larger than those of the abaxial epidermis.

Between the two epidermal layers lies the assimilatory tissue, composed of palisade and spongy parenchyma.

The palisade parenchyma is chlorenchymatous and formed by two layers of elongated cells arranged perpendicular to the leaf surface. It is located directly beneath the adaxial epidermis and plays a major role in photosynthesis. The spongy parenchyma consists of three to four layers of loosely arranged oval to rounded chlorenchyma cells with well-developed intercellular spaces. This tissue occupies the region between the palisade parenchyma and the abaxial epidermis (Figure 1).

The observed anatomical characteristics indicate a well-developed assimilatory apparatus, which contributes to the efficient photosynthetic activity of *Tilia cordata* under the introduction conditions of the Tashkent Botanical Garden.

The mesophyll is loosely arranged, and the spongy parenchyma contains large intercellular spaces that facilitate gas exchange within the leaf tissue. Numerous lateral vascular bundles are distributed between the palisade and spongy mesophyll layers, each containing three to four small xylem vessels (Figure 1).

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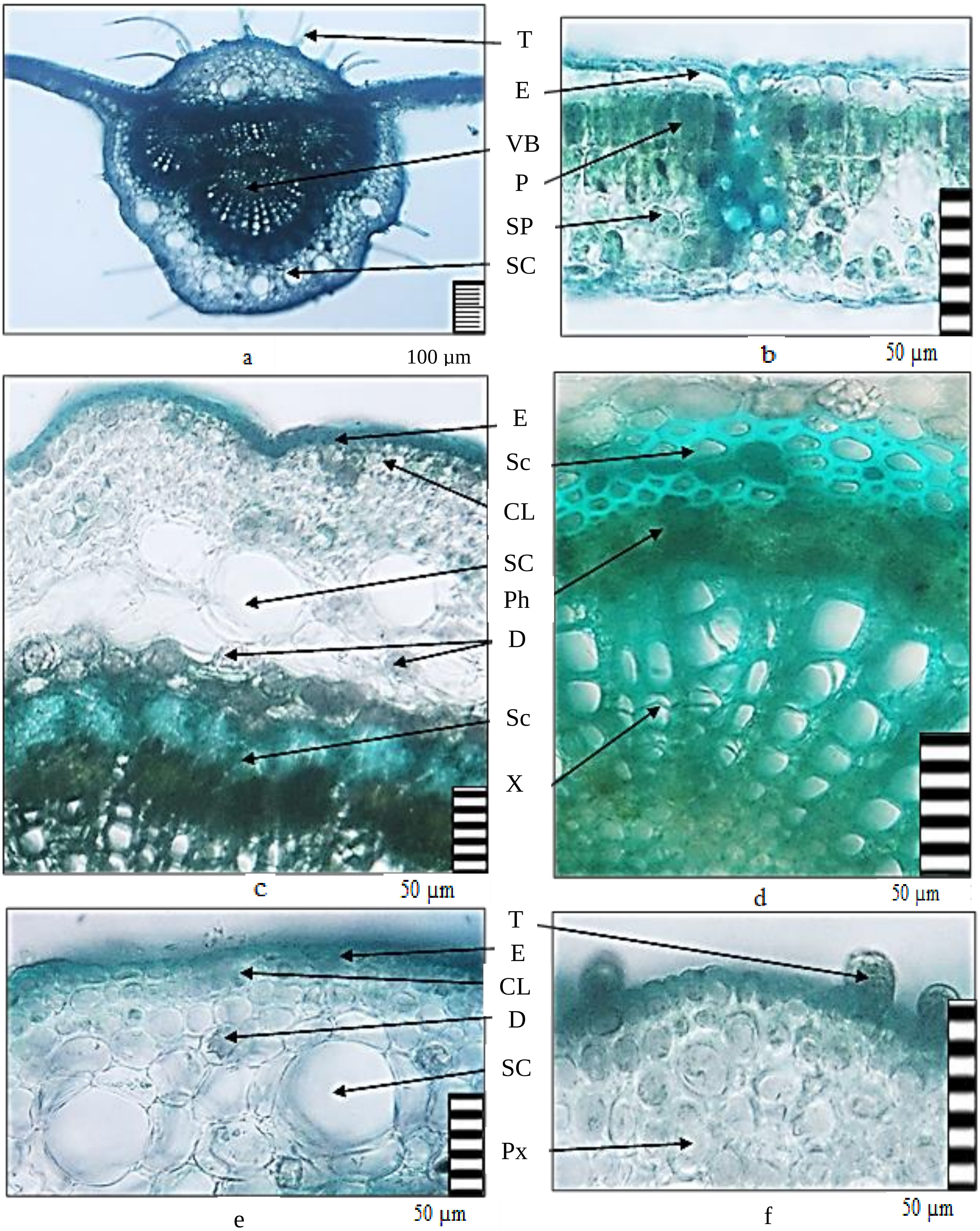

Figure 1. Anatomical structure of the leaf of *Tilia cordata* Mill.:
(a) general view of the leaf midrib in transverse section; (b) mesophyll differentiated into palisade and spongy parenchyma; (c) epidermis, collenchyma, parenchyma and secretory cavities of the midrib region; (d) vascular bundle; (e) secretory cavities within the midrib tissues; (f) glandular trichomes. **Abbreviations:** SP – spongy parenchyma; D – calcium oxalate druses; GT – glandular trichomes; CL – collenchyma; Xy – xylem; PP – palisade parenchyma; VB – vascular bundle; XP – xylem parenchyma; Sc – sclerenchyma; SC – secretory cavities; Tr – non-glandular trichome; Ph – phloem; Ep – epidermis.

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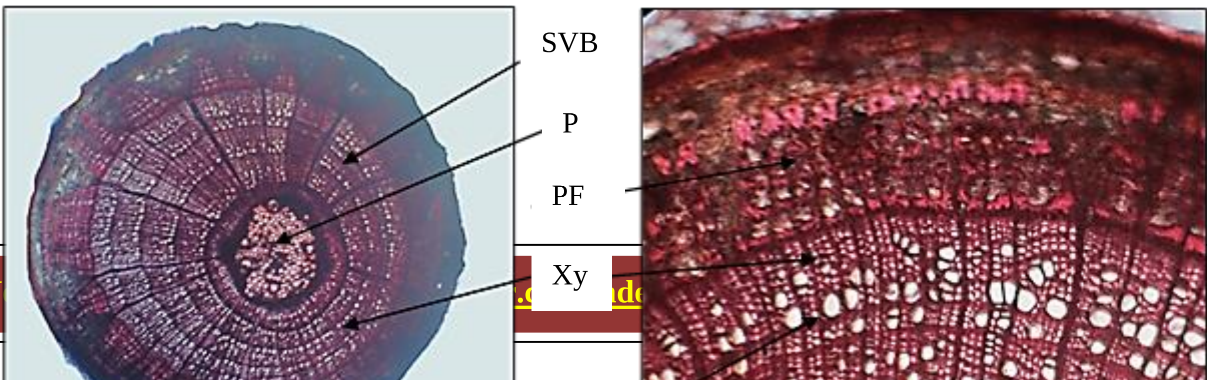
The midrib is prominent on the abaxial side and occupies the central region of the leaf blade. Both adaxial and abaxial epidermal surfaces are covered with simple unicellular and multicellular trichomes, as well as glandular trichomes. The ground tissue of the midrib is composed of thin-walled, rounded to oval parenchyma cells. The vascular system of the midrib consists of three large and one small closed collateral vascular bundles. Beneath the epidermis, a three-layered angular collenchyma provides mechanical support. Schizogenous secretory cavities are present among the parenchyma cells, together with numerous calcium oxalate druses and hydrocytic cells (Figure 1).

Stem Anatomy. The stem of *Tilia cordata* Mill. exhibits a typical secondary structure characteristic of woody dicotyledonous plants. In transverse section, the protective, ground, mechanical, and vascular tissues are clearly differentiated. The central region is occupied by the pith, which consists of parenchymatous cells varying in size and shape. Surrounding the pith is the secondary xylem, which forms distinct annual growth rings, indicating the seasonal activity of the vascular cambium.

The secondary xylem is composed of vessels of different diameters, wood parenchyma, libriform fibers, and medullary rays. Large vessels are mainly concentrated in the early wood, whereas the late wood contains predominantly smaller conductive and supporting elements. The clear boundary between earlywood and latewood makes the annual growth rings readily distinguishable.

A continuous cambial zone is located between the xylem and phloem and consists of several layers of meristematic cells with thin cell walls and dense cytoplasmic contents (Figure 2). This cambial layer is responsible for the formation of secondary vascular tissues and contributes to the radial growth of the stem. The vascular cambium, situated between the secondary xylem and secondary phloem, is composed of several layers of actively dividing meristematic cells characterized by thin primary cell walls and dense cytoplasmic contents. Continuous cambial activity is responsible for the formation of secondary vascular tissues and contributes directly to the radial growth and structural development of the stem.

100 µm



The secondary phloem consists of sieve tube elements, companion cells, phloem parenchyma, and groups of sclerenchymatous phloem fibers. In transverse section, the phloem occurs as wedge-shaped sectors separated by broad medullary rays extending radially through the vascular cylinder. The abundance of phloem fibers provides additional mechanical support and enhances stem rigidity.

External to the phloem lies the pericyclic region, represented by alternating zones of parenchymatous and sclerenchymatous tissues. The primary cortex is composed predominantly of large parenchyma cells containing reserve compounds and numerous calcium oxalate druses. The outer cortical layers are differentiated into collenchyma, which performs a supporting function and contributes to the mechanical stability of developing tissues (Figure 2).

The protective tissue system is represented by a well-developed periderm composed of suberized cork cells with thickened cell walls. This tissue functions as an effective protective barrier, reducing water loss and protecting internal tissues from environmental stress factors.

The stem anatomy of *Tilia cordata* is therefore characterized by a highly differentiated arrangement of protective, mechanical, storage, and conducting tissues. The presence of extensive secondary xylem, a well-developed secondary phloem, conspicuous medullary rays, and clearly defined annual growth rings reflects the advanced structural organization of the stem and ensures efficient transport, storage, and mechanical support under the introduction conditions of the Tashkent Botanical Garden.

Conclusions

The anatomical investigation of the leaves and stems of *Tilia cordata* Mill. introduced in the Tashkent Botanical Garden revealed the preservation of species-specific diagnostic traits together with the development of structural adaptations associated with growth under the arid climatic conditions of Uzbekistan.

The leaf blade is characterized by a dorsiventral mesophyll organization with a distinct differentiation into palisade and spongy tissues. The well-developed assimilatory apparatus, together with the presence of a protective cuticle, trichomes, and an efficiently organized vascular system, promotes optimal photosynthetic performance and contributes to the regulation of transpiration and maintenance of water balance under conditions of elevated temperature and reduced atmospheric humidity.

The stem exhibits a typical secondary structure characteristic of woody dicotyledonous species and is distinguished by a well-developed periderm, secondary phloem, vascular cambium, and secondary xylem. The extensive development of wood tissue containing vessels of different diameters, prominent medullary rays, and numerous mechanical elements indicates high hydraulic conductivity and mechanical stability. The occurrence of calcium oxalate druses, storage parenchyma, and other specialized cellular inclusions reflects the active involvement of these tissues in storage and metabolic processes.

The obtained results demonstrate that *Tilia cordata* maintains a stable anatomical organization under introduction conditions and possesses a considerable adaptive potential. These findings support the suitability of this species for urban landscaping, afforestation, and ecological restoration programs in Uzbekistan and provide valuable information for further studies on the adaptive mechanisms of introduced woody plants in arid environments.

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