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Anatomical structure and saponin content in roots of *Acanthophyllum albidum* in Uzbekistan

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Abstract

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Plant root anatomy and saponin accumulation may vary with plant age and environmental conditions. This study investigated age-related and population-level variation in the root anatomy and saponin content of *Acanthophyllum albidum* Schischk. (Caryophyllaceae), a Central Asian endemic species. We collected root samples from six localities in Uzbekistan, representing contrasting foothill and mountain habitats. Anatomical characteristics were examined using light microscopy, while saponin content was assessed gravimetrically in two- and four-year-old plants. We used thin-layer chromatography to compare the chromatographic profiles of root extracts. Anatomical observations revealed age-related differentiation of secondary vascular tissues, development of internal vascular bundles and differences in the relative proportions of conducting and mechanical elements among populations. Mean saponin content across the six localities increased from 54.17 ± 6.52 mg/g in two-year-old plants to 113.87 ± 15.70 mg/g in four-year-old plants. A paired comparison of locality-level values indicated a significant difference between the age groups (Wilcoxon signed-rank test, $W = 0$, $p = 0.031$). The lowest saponin content was recorded in Khurjun and the highest in Mindon. Thin-layer chromatography revealed a common Rf value of 0.44 across the investigated samples. However, the available data did not establish a statistically supported quantitative relationship between individual anatomical traits and saponin content. The findings highlight the importance of developmental stage and population origin in evaluating root anatomical variation and estimated saponin content in *Acanthophyllum albidum*, while indicating the need for further compound-specific phytochemical analyses.

Keywords: Caryophyllaceae, Fergana Valley, population variability, root anatomy, saponin content, secondary xylem.

INTRODUCTION

The genus *Acanthophyllum* C.A. Mey. (Caryophyllaceae) comprises 82 currently accepted species distributed predominantly across the Irano–Turanian floristic region (POWO, 2026). Central Asia represents an important region of species diversity for the genus, with 31 species reported from the region

(Li & Tojibaev, 2024). The geographical distribution of individual Central Asian species, including *Acanthophyllum gypsophiloides* Regel, has also been investigated (Jorayev et al., 2025). The major centres of diversity include northeastern Iran, southern Turkmenistan and western Afghanistan, where considerable species richness and endemism have been documented (Mahmoudi Shamsabad et al., 2012, 2019). Molecular phylogenetic investigations have revealed complex evolutionary relationships within *Acanthophyllum* and contributed to revisions of its generic boundaries and infrageneric classification (Pirani et al., 2014, 2020). Pirani & Rabeler (2017) have addressed additional nomenclatural aspects of the genus.

Beyond their taxonomic and ecological significance, *Acanthophyllum* species are important sources of bioactive secondary metabolites, particularly triterpenoid saponins (Ruzimatov et al., 2026), which have surface-active properties and potential medicinal and industrial applications (Mamadalieva et al., 2024; Rezazadeh et al., 2026). Recent studies have revealed considerable phytochemical variation among species and ecotypes. Balali et al. (2026), investigating ten *Acanthophyllum* species and 68 ecotypes, have demonstrated substantial differences in root saponin content, indicating that phytochemical characteristics vary both among species and within species. Furthermore, Mursaliyeva et al. (2026) have investigated relationships between root growth characteristics, developmental stages and saponin accumulation in wild populations of *Acanthophyllum pungens* (Bunge) Boiss., showing that saponin accumulation patterns vary during plant development. Together, these studies highlight the importance of considering both biological variation and developmental processes when evaluating saponin-producing plants.

Among the Central Asian representatives of the genus, *Acanthophyllum albidum* is of particular interest because of its restricted geographical distribution and conservation significance. The species is native to Uzbekistan and Tajikistan and is therefore endemic to Central Asia (POWO, 2026). In Uzbekistan, *Acanthophyllum albidum* is included in the national Red Data Book (Khassanov, 2019). The species occurs in foothill and mountainous habitats of the Fergana Valley and adjoining mountain areas of Uzbekistan, where populations experience contrasting environmental conditions. Habitat loss and fragmentation are identified as conservation concerns in the region. These characteristics make *Acanthophyllum albidum* an important subject for investigating population-level anatomical and phytochemical variation and for better understanding its ecological differentiation.

Although previous studies have advanced our understanding of *Acanthophyllum* taxonomy, root morphology and phytochemical diversity, important questions remain concerning the relationships between internal root anatomy and saponin accumulation. For example, Balali et al. (2026) have demonstrated phytochemical variation among species and ecotypes, whereas Mursaliyeva et al. (2026) have examined changes in root morphometry and saponin content across different developmental stages. However, these investigations did not specifically address how the differentiation of secondary vascular tissues, including xylem, mechanical tissues and parenchyma, relates to variation in root saponin content among geographically separated populations of *Acanthophyllum albidum*. Comparative anatomical observations combined with phytochemical extraction data may therefore provide additional insight into the relationships between root development, population differentiation and saponin accumulation.

To address this research gap, the present study aimed to investigate the anatomical characteristics of *Acanthophyllum albidum* roots from different populations in Uzbekistan and to evaluate their variation in relation to plant age, ecological conditions and saponin content. We hypothesised that differences in root anatomical structure, particularly in the development of conducting, mechanical and parenchymatous tissues, may be associated with variation in saponin content among populations. The study addressed three research questions: (a) How does the anatomical structure of *Acanthophyllum albidum* roots change with plant age, and what differences occur among populations inhabiting contrasting ecological environments? (b) How does root saponin content vary between two- and four-year-old plants and among the investigated populations? (c) What comparative patterns can be identified between root anatomical differentiation and saponin content across the investigated populations?