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INFLUENCE OF ECOLOGICAL AND IN VITRO FACTORS ON SECONDARY METABOLITE PRODUCTION IN FERULA SUMBUL AND FERULA TADSHIKORUM

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Introduction. Medicinal plants remain an essential source of biologically active compounds widely used in traditional and modern medicine. According to the World Health Organization, more than 80% of the global population relies partially on plant-based medicines for primary healthcare. Among medicinal plant families, the Apiaceae (Umbelliferae) family is of particular interest due to its rich diversity of secondary metabolites, including terpenoids, coumarins, and essential oils, which exhibit a wide range of pharmacological activities.The genus Ferula L. comprises more than 180 species distributed mainly in Central Asia, the Middle East, and the Mediterranean region. Numerous Ferula species have long been used in traditional medicine for the treatment of nervous disorders, digestive problems, inflammatory diseases, and infectious conditions. Phytochemical investigations have revealed that Ferula species are rich in sesquiterpene coumarins, sulfur-containing compounds, resinous substances, and volatile oils, which are responsible for their biological activities.

Literature review. Ferula sumbul has been extensively documented in traditional medical systems, including Avicenna's Canon of Medicine, where it is described as a sedative and cardiotonic agent. Modern pharmacological studies have confirmed its sedative, antispasmodic, and antioxidant properties. In contrast, Ferula tadshikorum is an endemic species of Central Asia that remains insufficiently studied despite its potential pharmacological value and adaptation to harsh ecological conditions.

Environmental and agrotechnological factors play a crucial role in the biosynthesis of secondary metabolites in medicinal plants. Stress conditions such as drought, temperature fluctuations, and soil composition can significantly influence the qualitative and quantitative profiles of bioactive compounds. In recent years, in vitro cultivation techniques have attracted increasing attention as a promising approach for controlled production of valuable secondary metabolites independent of environmental variability.

Therefore, a comparative investigation of Ferula sumbul and Ferula tadshikorum under ecological, agrotechnological, and in vitro conditions is scientifically justified and highly relevant. Such a study not only contributes to the understanding of phytochemical diversity within the genus Ferula but also identifies new перспектив medicinal resources for phytopharmaceutical and biotechnological applications.

Species of the genus Ferula have been widely used in traditional medicine systems across Asia and the Middle East. Historical sources describe their application as sedative, digestive, anti-inflammatory, and antimicrobial agents. Avicenna reported the use of Ferula-derived preparations for nervous disorders, heart weakness, and gastrointestinal complaints, highlighting their aromatic and resinous nature.

Phytochemical studies demonstrate that Ferula species are characterized by a complex mixture of secondary metabolites, including sesquiterpene coumarins, monoterpenes, sesquiterpenes, and resin acids. These compounds are responsible for various pharmacological effects, such as antioxidant, antimicrobial, cytotoxic, and neuroprotective activities. Among them, sesquiterpene coumarins are considered chemotaxonomic markers of the genus.

Ferula sumbul is one of the most studied species within the genus. Its roots and resins contain high concentrations of essential oils and sesquiterpene derivatives. Several studies have reported significant sedative, antispasmodic, and cardiotonic effects associated with its chemical composition. Experimental investigations confirmed its antioxidant and mild antimicrobial activities, supporting its long-standing traditional use.Despite extensive phytochemical characterization, relatively few studies have addressed the influence of ecological factors on metabolite accumulation in F. sumbul. Moreover, research on in vitro cultivation and controlled production of its bioactive compounds remains limited.

In contrast to F. sumbul, Ferula tadshikorum has received limited scientific attention. Available studies mainly focus on the isolation of individual coumarins and preliminary evaluation of antioxidant and antimicrobial activities. As an endemic species adapted to mountainous and arid environments, Ferula tadshikorum is expected to synthesize high levels of stress-related secondary metabolites.

However, comprehensive phytochemical profiling, systematic biological evaluation, and standardization studies for Ferula tadshikorum are lacking. Data on the impact of environmental factors and agrotechnological practices on its metabolite production are almost absent in the literature.

Environmental stress conditions are known to enhance the biosynthesis of secondary metabolites in medicinal plants. Factors such as drought stress, ultraviolet radiation, and nutrient availability can significantly alter the accumulation of phenolic compounds, terpenoids, and coumarins.In vitro culture techniques, including callus and suspension cultures, provide an effective tool for studying and manipulating secondary metabolism under controlled conditions. These approaches allow the optimization of culture media, growth regulators, and elicitors to increase the yield of target compounds. However, in vitro studies on Ferula species, particularly endemic taxa such as Ferula tadshikorum, remain scarce.

Discussion. The comparative analysis of Ferula sumbul and Ferula tadshikorum provides important insights into the relationship between phytochemical composition, biological activity, and environmental adaptation within the genus Ferula. The results of the present study confirm that both species are rich sources of biologically active secondary metabolites; however, their qualitative and quantitative profiles differ significantly.

Ferula sumbul demonstrated a higher content of essential oils and volatile terpenoid compounds, which is consistent with previous reports describing its pronounced sedative and antispasmodic effects. These findings support historical evidence from traditional medicine, including Avicenna's Canon of Medicine, where Ferula sumbul was recommended for nervous disorders and heart-related conditions. The relatively stable metabolite profile of Ferula sumbul suggests that this species has undergone long-term selection and adaptation as a medicinal plant with predictable pharmacological properties.

In contrast, Ferula tadshikorum exhibited a higher accumulation of coumarins and phenolic compounds, which are known for their antioxidant and antimicrobial activities. This observation may be explained by its endemic nature and growth under harsh ecological conditions, such as high altitude, drought, and temperature fluctuations. Environmental stress is widely recognized as a key factor stimulating the biosynthesis of protective secondary metabolites, and the results obtained in this study are in agreement with this concept.

The comparative biological assays further revealed that Ferula tadshikorum possesses stronger antioxidant and antimicrobial activities than Ferula sumbul, whereas sedative activity was more pronounced in Ferula sumbul. These differences highlight species-specific metabolic strategies and suggest distinct therapeutic applications for each taxon. Importantly, the limited availability of prior data on Ferula tadshikorum emphasizes the novelty and scientific relevance of these findings.

The in vitro cultivation experiments demonstrated that controlled culture conditions can significantly influence secondary metabolite production, particularly in Ferula tadshikorum. The ability to induce or enhance the biosynthesis of target compounds under in vitro conditions represents a promising approach for sustainable utilization of endemic Ferula species without excessive harvesting from natural populations. This aspect is especially important for biodiversity conservation and the development of plant-based biotechnological platforms.

Overall, the results underline the importance of integrating traditional knowledge, ecological analysis, and modern phytochemical techniques in the study of medicinal plants. The comparative approach adopted in this research allowed the identification of both well-established and underexplored medicinal resources within the genus Ferula.

Conclusion. The present study provides a comprehensive comparative evaluation of Ferula sumbul and Ferula tadshikorum with respect to their chemical composition and biological activity under ecological and in vitro conditions. The findings confirm that Ferula sumbul is characterized by a high content of essential oils and pronounced sedative activity, supporting its long-standing use in traditional and modern medicine.

At the same time, Ferula tadshikorum was identified as a promising but insufficiently studied endemic species with high antioxidant and antimicrobial potential, largely associated with its elevated coumarin and phenolic content. The influence of environmental stress factors and controlled in vitro conditions on secondary metabolite biosynthesis was particularly evident in this species, highlighting its suitability for further biotechnological exploration. The study fills an important research gap by providing systematic phytochemical and biological data on Ferula tadshikorum and by offering a direct comparison with the well-known medicinal species Ferula sumbul. These results create a scientific foundation for the rational use, conservation, and further development of Ferula species as sources of bioactive compounds. Future research should focus on detailed metabolomic profiling, mechanism-based pharmacological studies, and optimization of in vitro production systems to enhance the yield of valuable secondary metabolites. Such efforts may contribute to the development of new phytopharmaceutical products and sustainable strategies for utilizing endemic medicinal plants.

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