

**HIGH-MOUNTAIN DISTRIBUTION OF *SCROPHULARIA CHLORANTHA* KY ET BOISS. –
'M'TSVANEKVAVILA SHAVTSAMALA' BIOECOLOGY AND STUDY OF BIOLOGICALLY ACTIVE
COMPOUNDS**

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Abstract: The high-mountain flora of Adjara represents a significant center of biodiversity in the Caucasus, rich in endemic plant species that are particularly vulnerable under global climate change and increasing anthropogenic pressures. This region is characterized by unique habitats, where high-mountain subalpine and alpine belts create special ecological conditions, providing a favorable environment for the development of endemic species. Endemic plants are distinguished by a limited distribution range, high sensitivity to environmental factors, and unique biochemical properties, which increase their risk of extinction.

One such endemic species is *Scrophularia chlorantha* Ky et Boiss. – “Mtsvanekvavila Shavtsamala”, the study of which represents significant scientific and practical interest. The aim of this research was to determine the precise distribution range of this endemic plant in the high mountains of Adjara, study its biological characteristics, collect herbarium and analytical material, and perform a phytochemical analysis of biologically active substances using the GC-MS (Gas Chromatography–Mass Spectrometry) method.

The study was conducted using an expedition approach. The plant was recorded in the subalpine belt at an altitude of 2181 m above sea level, on the rocky slopes of the border zone of Beshumi, within subalpine thickets. Exact coordinates were recorded: N 41°35.523', E 42°35.172', H 2181 m. TLC+. GC-MS analysis of the methanolic extract identified 41 chemical components, including phenolic acids (protocatechuic and quinic acids), fatty acids (hexadecanoic and oleic acids), terpenoids, steroids, phytol, organic acids, and sugars. These compounds are known for their strong antioxidant, antimicrobial, and anti-inflammatory properties, enhancing the plant's medicinal and pharmacological significance.

The obtained data significantly complement the biochemical profile of endemic plants of Adjara-Lazeti and provide a foundation for further pharmacological, biological, and toxicological studies. The research highlights the necessity of protecting this endemic species to preserve regional biodiversity and ecosystem stability. *S. chlorantha* represents an important natural source for the development of bioactive compounds in medical practice, supports the creation of therapeutic preparations, and opens new perspectives for pharmacognostic research. Moreover, the study demonstrates that the conservation of endemic plants not only safeguards their survival but also ensures the sustainability of the regional ecosystem, which is particularly crucial under global climate challenges.

Keywords: *Scrophularia chlorantha*; endemic plants; Adjara-Lazeti.

The inventory of plant species belonging to major taxonomic groups within the floristic region of Adjara, including endemics, has always been a priority for both Georgian and foreign researchers and practitioners. This focus is reflected in numerous fundamental studies (Ketskhoveli, 1984; Nakhutsrishvili, 2012; Tutin et al., 1968–1980).

The Adjara (South Colchic) floristic region is rich in endemic species of the Caucasus, Georgia, and Colchis (Manvelidze, 2010; Varshanidze, 2005). A significant portion of these species has been studied and used in official medicine for therapeutic purposes (Dewick, 2009; Bruneton, 1999).

However, data on the local distribution, as well as the bioecological characteristics and biologically active compound content of some Adjara and Adjara-Lazeti endemics, remain scarce in the scientific literature. The systematic and botanical characteristics of certain species have been clarified by Georgian researchers (Memiadze, 1998; Kharazishvili, 2013).

Anthropogenic pressures have posed a threat to endemic plant species, placing some of them at risk of extinction (Nakhutsrishvili, 2012). Therefore, studying their biologically active compounds, identifying potential therapeutic substances, and planning conservation measures represent an urgent scientific challenge (Harborne, 1998; Dewick, 2009).

The phytochemical profile of *Scrophularia* species contains diverse biologically active compounds, including iridoids, phenolic glycosides, flavonoids, and triterpenoids, which are responsible for anti-inflammatory, neuroprotective, and antioxidant properties (Zhang et al., 2021). Studies have also shown that species of the family Scrophulariaceae, particularly *Scrophularia*, are rich sources of iridoid glycosides and phenolic acids, which exhibit strong antibacterial and anti-inflammatory activities and may have applications in modern medicine (Phytomedicine Plus, 2022).

Further research confirmed that flavonoids and glycosides in *Scrophularia peyronii* possess high antioxidant activity, highlighting the medicinal potential of this plant, especially in alternative therapeutic preparations (Yousef Al-Dalameh et al., 2023). Glycosidic phenolics in *Scrophularia striata* and other species, such as quercetin and acteoside (phenolic glycoside), are known for their antibacterial and antioxidant activities, further supporting the medicinal potential of these plants (Herbmed & Pharmacology, 2019).

These studies emphasize that the genus *Scrophularia* is rich in iridoids and triterpenoids, which are associated with strong biological activity and high toxicological safety (PubMed Reviews, 2022). In Scrophulariaceae species distributed in the Caucasus, high concentrations of flavonoids and triterpenoids have been recorded, confirming their antimicrobial and anti-inflammatory activity, which serves as a basis for the development of more complex therapeutic formulations (Fik Jaskółka et al., 2024).

The study of the high-mountain flora of Adjara, particularly endemic species, is crucial in the context of contemporary global climate change. Biodiversity loss and the high risk of species extinction affect endemics—species with restricted ranges and specific ecological requirements. In this context, the assessment of their biologically active compounds is important both pharmacognostically and conservationally.

The aim of our study was to determine the precise distribution range of the endemic plant *Scrophularia chlorantha* Ky et Boiss. (green-flowered figwort) in the high mountains of Adjara, collect herbarium and experimental material, and investigate its biologically active compound content using tandem chromatography, specifically GC-MS (gas chromatography–mass spectrometry). Analysis of the plant extract identified 41 chemical components, including phenolic acids (protocatechuic acid, quinic acid), fatty acids (hexadecanoic acid, oleic acid), organic acids, terpenoids, steroids, phytol, and sugars, all known for strong antioxidant, antimicrobial, and anti-inflammatory properties.

The results complement data on the biochemical profile of Adjara-Lazeti endemic plants and provide a foundation for further pharmacological, biological, and toxicological studies. The study also highlights the conservation importance of endemic species, particularly under increasing anthropogenic pressure, which is vital for maintaining regional biodiversity and ecosystem resilience.

The study employed traditional expedition-survey methodology, during which precise distribution ranges were recorded, and herbarium and experimental material were collected. Methanolic extracts were prepared from plant raw material. Identification of biologically active compounds was performed using GC-MS at the Chemical-Toxicological Laboratory of the Levan Samkharauli National Forensic Bureau (Georgia).

The equipment used was Agilent Technologies 7000 GC/MS Triple Quad; column – Elite 5-MS (30 m × 250 μm × 0.25 μm). Oven temperature program: 60°C–310°C; injector temperature – 250°C; transfer line temperature – 310°C; carrier gas – helium (1 mL/min); ionization source – EI, 70 eV; scanning mode – TIC (Total Ion Monitoring). Compounds were identified by comparing chromatographic peak mass spectra with the NIST spectral library (Stein, 2014). The methodological principles conform to contemporary phytochemical analysis standards (Harborne, 1998; Adams, 2007).

GC-MS analysis of the Adjara-Lazeti endemic *Scrophularia chlorantha* revealed 41 compounds, including carbon, organic, fatty, and phenolic acids (alpha-linolenic, erucic, lactic, gallic, quinic, malic, succinic, protocatechuic), and sugars such as furanose, arabinofuranose, deoxypentofuranose, turanose, naphthofuranose, and pyrrole derivatives (Figs. 1–2; Tables 1–2). The detected compounds belong to phenolic acids, fatty acids, organic acids, terpenoids, and other classes of biologically active substances, known for antioxidant, antimicrobial, and anti-inflammatory activities (Bruneton, 1999; Dewick, 2009). Protocatechuic acid, quinic acid, and phytol are widely reported as biologically active secondary metabolites in plants (Harborne, 1998; Dewick, 2009).

Scrophularia chlorantha Ky et Boiss. (Fig. 1) is a perennial herbaceous plant reaching up to 1 meter in height. Its leaves measure 9–16 cm in length and 8–14 cm in width, with sharply serrated edges, heart-shaped bases, and elongated tips, either glabrous or slightly pubescent. The inflorescence is multi-flowered, narrow-spiked, up to 30 cm long, with greenish corolla petals. The fruit is a capsule of oblong-ovoid shape. The stem is robust and smooth-ridged.

Scrophularia chlorantha occurs in upper and subalpine forest zones, along forest clearings, in shrublands, often near livestock enclosures, and in secondary forest meadows. Its distribution covers the entire high-mountain region of Adjara, including the Beshumi border area on rocky slopes and subalpine clearings. Coordinates recorded in our study: N 41°35'523", E 42°35'172", H 2181 m.

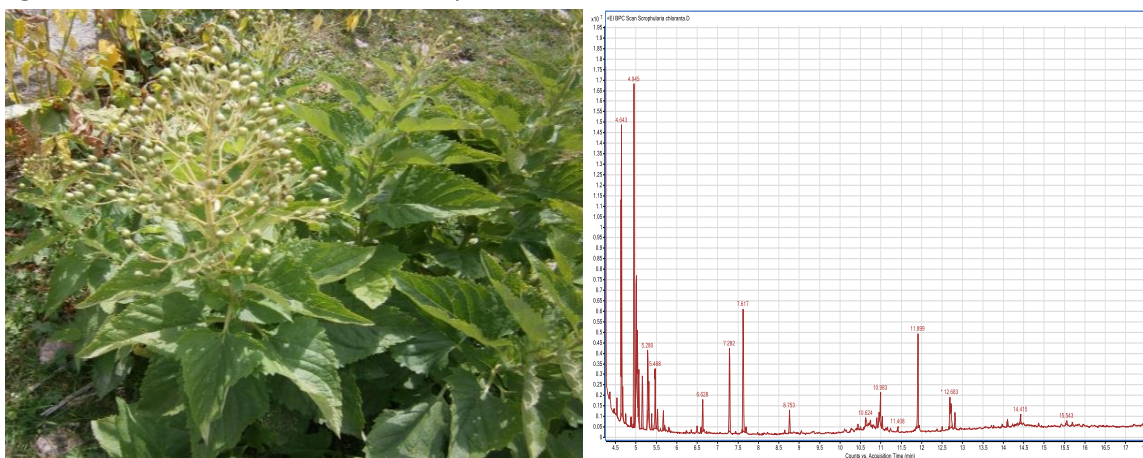


Fig. 1. *Scrophularia chlorantha* Ky et Boiss.

Fig. 2. GC-MS chromatogram of the methanolic extract of *Scrophularia chlorantha* Ky et Boiss.

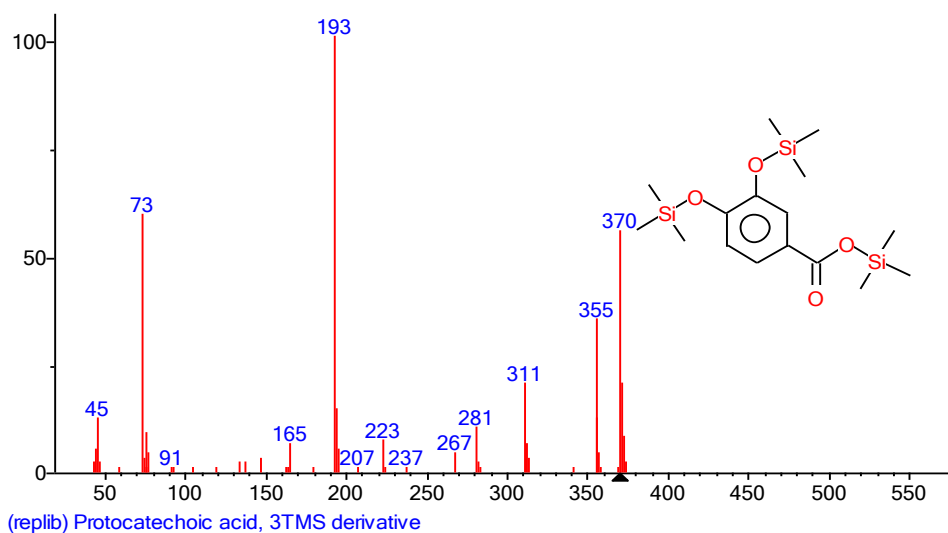


Fig. 3. Mass spectrum of protocathechuic acid, 3TMS derivative.

Table 1. Characterization of protocathechuic acid, 3TMS derivative.

Name	Formula	MW	Exact Mass	CAS	NIST	ID
Protocatechuic acid, 3TMS	C ₁₆ H ₃₀ O ₄ Si ₃	370	370.14519	2347-40-2	71847	28021

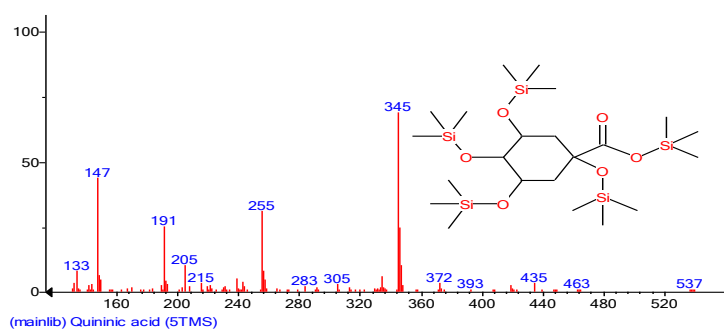


Fig. 4. Mass spectrum of quinic acid, 5TMS derivative.

Table 2. Characterization of quinic acid, 5TMS derivative.

Name	Formula	MW	Exact Mass	NIST	ID
Quinic acid (5TMS)	C ₂₂ H ₅₂ O ₆ Si ₅	552	552.26102	413965	44105

Table 3. GC-MS analysis results of the extract of *Scrophularia chlorantha* Ky et Boiss.

Name	Formula	Score	RT	m/z	Base	Mass
Methyl nonyl carbinol	C ₁₁ H ₂₄ O	72,15	7,729	69	69	172,2
4-Ethenylphenol acetate	C ₁₀ H ₁₀ O ₂	54,12	8,118	133	133	162,1
2-Hydroxyphenylethanol	C ₈ H ₁₀ O ₂	70,8	8,464	107	107	138,1
Benzoic acid	C ₁₁ H ₁₄ O ₄	65,74	8,859	179	179	210,1
Trimethylsilyl isobutyrate	C ₇ H ₁₆ O ₂ Si	68,83	8,899	73	73	160,1
Nonane, 2-methyl-	C ₁₀ H ₂₂	67,9	5,231	43,1	43,1	142,2

<i>Eugenic acid</i>	C ₁₀ H ₁₂ O ₂	62,87	8,958	103	103	164,1
<i>Silane, trimethyl(phenethylthio</i>	C ₁₁ H ₁₈ SSi	52,06	9,046	73	73	210,1
<i>2- Propenoic acid</i>	C ₁₂ H ₁₆ OSi	90,31	9,247	205	205	220,1
<i>N-Acetyltyramine</i>	C ₁₀ H ₁₃ NO ₂	58,93	9,329	120	120	179,1
<i>(E) Stilbene</i>	C ₁₄ H ₁₂	64,41	9,349	179	179	180,1
<i>Silan trmethyl</i>	C ₁₁ H ₁₈ OSi	59,85	9,612	73	73	194,1
<i>Butyrophenon</i>	C ₁₃ H ₂₀ O ₂ Si	51,98	9,688	221,1	221,1	236,1
<i>Cyclopentane, 1.</i>	C ₉ H ₁₈	66,94	5,92	69	69	126,1
<i>2-Oxavaleric acid</i>	C ₁₁ H ₂₂ O ₃ Si	63,4	10,145	73	73	230,1
<i>Anthracene, 9,1</i>	C ₁₈ H ₂₀	51,32	10,2	179	179	236,2
<i>Hydroquinone, acid</i>	C ₈ H ₈ O ₃	55,19	10,515	110	110	152
<i>Silan, trimethyl</i>	C ₇ H ₁₈ OSi	71,01	10,653	73	73	146,1
<i>Butane, 1,2,3-tris(trimethylsiloxy)-</i>	C ₁₃ H ₃₄ O ₃ Si ₃	70,13	10,813	73	73	322,2
<i>Furan, 2-hexa.</i>	C ₁₀ H ₁₆ O	51,41	10,874	95	95	152,1
<i>Angelicin</i>	C ₁₁ H ₆ O ₃	51,76	11,07	186	186	186
<i>1,3-Diphenylacetone</i>	C ₁₅ H ₁₄ O	58,03	11,724	210	210	210,1
<i>Hexadecanoic acid</i>	C ₁₉ H ₄₀ O ₂ Si	93,02	11,898	117	117	328
<i>2-Chloroethyl linoeleaTe</i>	C ₂₀ H ₃₅ ClO ₂	57,1	12,174	67	67	342,2
<i>Phytol</i>	C ₂₀ H ₄₀ O	82,81	12,249	71	71	296,3
<i>Cyclohexyldimethylsilyloxy-pentadecane</i>	C ₂₃ H ₄₈ OSi	79,35	12,491	143	143	368,3
<i>Oleic acid</i>	C ₂₁ H ₂ O ₂ Si	69,11	12,706	73	73	354,3
<i>Heptane, ethyl</i>	C ₉ H ₂₀	71,81	6,86	57,1	57,1	128,2
<i>Octadecanoic acid</i>	C ₂₁ H ₄₄ O ₂ Si	82,74	12,806	117	117	356,3
<i>Hexadecanoic acid</i>	C ₁₉ H ₃₈ O ₄	68,2	14,126	98	98	330,3
<i>2,2-diphenylacetoneitrile</i>	C ₁₄ H ₁₁ N	60,73	15,185	167	167	193,1
<i>2-hydroxy-iminostilbene</i>	C ₁₄ H ₁₁ NO	71,8	15,344	193	193	209,1
<i>Cholesterin</i>	C ₂₇ H ₄₆ O	67,66	18,943	81	81	386
<i>O-Trimethylsilylcholesterol</i>	C ₃₀ H ₅₄ OSi	87,3	19,035	129	129	458,4
<i>Hydrogen azide</i>	HN ₃	53,27	24	43,1	43,1	43
<i>Methyl nonyl carbinol</i>	C ₁₁ H ₂₄ O	77,57	7,67	69	69	172,2
<i>2H-Indol-2-one</i>	C ₉ H ₉ NO	71,19	7,975	147	147	147,1

The phytochemical study of the endemic Adjara-Lazeti species *Scrophularia chlorantha* using the GC-MS method confirmed that the plant contains a diverse range of biologically active compounds. A total of 41 chemical constituents were identified, including phenolic acids, fatty acids, organic acids, terpenoids, steroids, and sugars, which contribute to the plant's pharmacological activity.

Among the detected compounds, such as protocatechuic acid, quinic acid, phytol, hexadecanoic acid, and oleic acid, strong antioxidant, antimicrobial, and anti-inflammatory properties have been reported. These findings indicate that *S. chlorantha* represents a promising natural source for the development of bioactive compounds for medical and pharmacological applications.

The results of this study significantly complement the existing data on the biochemical profile of Adjara-Lazeti endemic species, which was previously limited in the scientific literature. This research provides a

foundation for further pharmacological, biological, and toxicological investigations, particularly for the identification and quantification of compounds with potential medical applications.

Moreover, under increasing anthropogenic pressure, the conservation and thorough study of this endemic plant represent a crucial step toward preserving biodiversity and ensuring the sustainability of the regional ecosystem.

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