



RESEARCH ARTICLE

An ethnobotanical investigation in the Serbian foothills of Mount Kopaonik: Regional uniqueness and comparison with other Balkan areas

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Abstract

This study was conducted in the foothills of Mount Kopaonik (Serbia), with a focus on medicinal and food applications. Ethnobotanical data were collected through interviews with local residents at 23 locations. Retrieval-augmented generation (RAG), a novel processing approach, was used to categorise and summarise the free-text ethnobotanical data. A total of 47 plant species and one mushroom species were recorded for medicinal use. These species were primarily used in the form of teas, fresh material, or oils to improve the health of the respiratory, digestive and immune systems. Eleven forest fruits were used to prepare foods such as stews, juices, jams and liqueurs. A comparative analysis of the studied and surrounding sites showed that five plant species- *Agropyron repens*, *Atropa belladonna*, *Cotinus coggygria*, *Lycopodium clavatum* and *Sorbus aucuparia* and one mushroom species (*Calvatia gigantea*) were used only at the foothills of Kopaonik. Two plant species, *Aronia arbutifolia* and *Polygonatum odoratum* were used in nearby sites. Plant species such as *Crataegus monogyna*, *Hypericum perforatum*, *Matricaria chamomilla*, *Primula vulgaris*, *Sambucus nigra* and *Urtica dioica* were reported across all compared localities. Our results provide novel information about the local specificity and regional continuity of traditional plant use. The use of several species in this area alone represents a resource for further detailed research on the recorded species.

Keywords: Balkan Peninsula; ethnobotany; Serbia; traditional knowledge; traditional medicine; wild edible plants

Introduction

Biodiversity encompasses every organism on Earth and the ecological interactions between them. Biodiversity is the diversity of living organisms from all places and the ecological systems of which they are a part. This includes diversity within species, between species and among ecosystems. If life were to exist on other planets or if living things were to be preserved as fossils from millions of years ago, the concept might also be applicable. The biodiversity of a country, a region, an ecosystem, a group of organisms, or a single species can be explored by analysing its components (1). The flora of the Balkan Peninsula consists of 6340 vascular plant species and according to some authors, as many as 8000 (2, 3). The number of endemic species and subspecies is estimated to be between 2600 and 2700 (3). Serbia is one of the 158 global biodiversity centres because of its exceptional floristic diversity and vegetation. About 700 species make up Serbia's medicinal flora, comprising 10.7 % of the nation's total plant diversity (3662 taxa) (4).

A plant is considered medicinal if one or more of its organs contain compounds that can be used therapeutically or as building blocks for the synthesis of drugs (5). Pharmacists and

pharmacologists frequently refer to a plant or one of its parts that has therapeutic qualities as "raw drugs of biological origin." The aforementioned definition indicates a distinction between plants whose therapeutic properties and constituents have been verified by science and those that are known to be therapeutic but have not yet been the subject of substantial scientific research. Despite the lack of scientific proof of their effectiveness, medicinal plants have been utilised in traditional medicine for many years. In practice, these plants have shown great efficacy (6).

The extent to which traditional medicine is practised varies depending on the climate and is impacted by the cultural, historical and philosophical aspects of the local population. More than 80 % of people worldwide use herbal remedies for their basic medical needs, according to statistics. These medications were previously used solely on the basis of their therapeutic potential, which was passed down from generation to generation without first examining their phytochemical composition. Due to customs that have grown over time and a lack of access to quality medical care, the belief in the therapeutic benefits of plants persists in many rural areas of Serbia (7).

Significant information from ethnobotany has served as the foundation for numerous investigations that successfully isolated numerous active compounds, including morphine, codeine, quinine and others, which are widely used in biological, biotechnological, pharmacological and medical research. Up to 40 % of all medications used in clinical practice today are said to have a natural origin, meaning they are derived from plants (8).

The main objective of this study was to document as many wild species as possible used in folk medicine in the foothills of the Kopaonik region, with the aim of guiding future research and evaluating the scientific justification for their traditional use. An additional objective was to compare local medicinal plant use with practices reported from other regions of Serbia and neighbouring countries.

Materials and Methods

The study was carried out in 23 different villages in the sub-Kopaonik region (Serbia). All studied villages are characterised by low population density. The Statistical Office of the Republic of Serbia provided the data used to determine the population of the sites under study (Table 1) (9). Since there were several respondents in some localities, data are shown for each respondent. Because of the unresolved status of the province and the lack of a population census, there is a lack of data for villages that are situated within the Autonomous Province of Kosovo. Regardless of how many respondents were available in each village, the aim was to cover as

many as possible. The locations under study are between 395 and 1610 m above sea level.

The climate of Serbia is moderately continental, but the foothill region of Kopaonik has strong mountain influences, with long, harsh winters and brief, cool summers (10).

Data collection

The ethnobotanical survey was conducted in 2024 from June to September. A total of 30 people, 11 women and 19 men, were interviewed from 23 villages during the survey. A higher number of male respondents were interviewed because men are predominantly involved in agriculture. The respondents' ages ranged from 34–75, with the majority falling into the 50–60 age range. The respondents were chosen without regard to any particular standards. The researchers aimed to include as many villages as possible located at the foot of Kopaonik. All those interviewed lived in rural areas and the main activity of the households was agriculture and orcharding, mostly for their own needs. All the respondents were of Serbian nationality, practised Orthodoxy and spoke Serbian, making the surveyed population ethnically homogeneous. Table 2 displays the demographic details of the residents who were interviewed.

The interviews were carried out face-to-face using a semi-structured interview form. The complete interview form is provided as supplementary material. Undetermined responses were not listed. The duration of the interviews ranged from 30 min to 1 hr. After being informed of the objective of the research, each participant agreed to be interviewed. The information

Table 1. The geographic position and number of inhabitants of the studied sites

Sl. No.	Study site (village)	Municipality	Elevation (m)	Global positioning system	No. of inhabitants
1.	Bistrica	Leposavić	619	43.224512 20.720129	
2.	Badanj	Raška	804	43.310034 20.706562	31
3.	Biljanovac	Raška	395	43.410506 20.666305	468
4.	Žiljci	Brus	473	43.374313 21.006686	368
5.	Semeteško jezero	Raška	874	43.175004 20.432188	23
6.	Donje Jarinje	Leposavić	526	43.211909 20.704458	
7.	Supnje	Raška	410	43.277639 20.610995	4053
8.	Draganići	Raška	409	43.267851 20.593995	310
9.	Donji Krnjin	Leposavić	524	43.141499 20.753936	
10.	Plešin	Raška	1610	43.311081 20.403326	88
11.	Plavkovo	Raška	418	43.1333 20.4133	56
12.	Žerovnica	Leposavić	549	42.931596 20.804218	
13.	Gradac	Raška	543	43.366872 20.554432	138
14.	Lešak	Leposavić	455	43.167472 20.744458	
15.	Beljak	Raška	756	43.1456 20.4459	327
16.	Pokrvenik	Raška	731	43.430005 20.691960	2
17.	Kovači	Raška	725	43.431117 20.745039	129
18.	Piskanja	Raška	401	43.391318 20.663094	363
19.	Jošanička Banja	Raška	579	43.384398 20.743212	914
20.	Kaznoviće	Raška	420	43.259357 20.674038	378
21.	Rakovac	Raška	732	43.394312 20.817460	128
22.	Žerađe	Raška	499	43.407779 20.709005	91
23.	Ploče	Aleksandrovac	1025	43.445772 20.857243	250

Table 2. The demographic characteristics of the interviewees

Sl. No.	Study site (village)	Household activity	Sex	Age	Level of education		
					Primary school	Secondary school	College
1.	Bistrica	Orcharding	F	60		X	
2.	Badanj	Orcharding	M	70	X		
3.	Biljanovac	Agriculture	M	71	X		
4.	Žiljci	Orcharding	M	65		X	
5.	Semeteško jezero	Agriculture	M	43			X
6.	Donje Jarinje	Orcharding	M	30		X	
7.	Supnje	Orcharding	M	34			X
8.	Draganići	Agriculture, livestock breeding	F	41			X
9.	Donji Krnjin	Orcharding	M	62		X	
10.	Pleštin	Agriculture	M	37		X	
11.	Plavkovo	Agriculture	M	68		X	
12.	Donji Krnjin	Orcharding	F	62		X	
13.	Žerovnica	Pensioners	F	67		X	
14.	Kovači	Agriculture, beekeeping	M	65		X	
15.	Gradac	Livestock breeding, povrtarstvo	M	38			X
16.	Lešak	Agriculture	M	36		X	
17.	Beljak	Agriculture	M	72	X		
18.	Žerađe	Agriculture	F	50		X	
19.	Biljanovac	Agriculture	F	57		X	
20.	Pokrvenik	Orcharding, agriculture	M	65	X		
21.	Kovači	Agriculture, beekeeping, livestock breeding	M	34			X
22.	Piskanja	Agriculture	M	70			X
23.	Jošanička Banja	Orcharding	F	71	X		
24.	Kaznoviće	Livestock breeding, agriculture	F	41		X	
25.	Kaznoviće	Livestock breeding	F	64		X	
26.	Draganiće	Agriculture	F	71	X		
27.	Draganiće	Agriculture	F	44		X	
28.	Rakovac	Pensioners	M	75	X		
29.	Žerađe	Orcharding	M	54	X		
30.	Ploče	Orcharding	M	68	X		

obtained in the interviews was recorded on printed interview forms. All respondents voluntarily participated in the interviews, stating that they were aware of the importance of documenting traditional knowledge about the use of wild plants.

During the interviews, the following information was collected: name and surname; gender; age; level of education; the main activity of the household and the number of household members. The second part of the interview included information about the use of medicinal plants and mushrooms. The questions during the interview were as follows: do they use medicinal plants, which types, what part of the plant do they use, for the treatment of which diseases, how they prepare them, do they collect mushrooms, do they use them for medicinal purposes or as food, do they collect forest fruits and how do they use them? Species cited by the respondents were verified using online resources and the Plants of the World Online (POWO) database of currently accepted plant species (11).

Retrieval-augmented generation as a resource for processing ethnobotanical data

Historically, the processing of botanical and ethnomedical data has been based on manual searching and hand-coding, which is slow, prone to errors and challenging to scale when working with semi-structured and heterogeneous sources such as tables in .doc format. These constraints necessitated the use of a technique that allows for more accurate, repeatable and automated information

extraction than manual methods. Retrieval-augmented generation (RAG), a contemporary generative artificial intelligence (AI) method that combines the retrieval of pertinent document segments with the creation of answers, was employed for this purpose. Retrieval-augmented generation captures the meanings and relationships between terms, in contrast to traditional techniques like regular expressions or keyword searches. For instance, even when the terminology used in the document is formulated differently, it is still able to determine which herbs are used for digestive problems. Retrieval-augmented generation depends on a language model that can comprehend and produce text. The system first extracts the most pertinent parts of the document and then gives them to the model as context because the model itself is unaware of the specific document's contents. This guarantees that the generated responses are based only on the real data. For botanical tables, where data regarding plant species, plant parts and traditional characteristics may be presented descriptively or fragmentarily, this method works especially well. By eliminating the need for manual data handling and lowering the possibility of errors, RAG makes it possible for the extraction process to be transparent, repeatable and much more effective.

The RAG pipeline was implemented through several clearly defined steps. First, all tabular data were extracted from the DOCX document and the tables, rows and cells were converted into a unified textual representation. The resulting text was then segmented using a recursive character-based splitter

(chunk size – 700 characters and overlap – 80 characters) to preserve semantic continuity across segments. Each text segment was then transformed into vector embeddings using the nomic-embed-text model within the Ollama environment. These embeddings were stored in a ChromaDB vector database, enabling efficient similarity-based retrieval. During querying, the system retrieves the top $k = 4$ most relevant segments based on semantic similarity to the user's question. The retrieved segments are then passed as contextual input to the generative language model (Mistral), together with a structured prompt that constrains the model to answer strictly based on the provided document context. If the required information is not present in the retrieved segments, the model is instructed to return a response “No data in the document”, reducing the likelihood of hallucinations. The system was evaluated through a set of predefined test queries targeting key information extraction tasks. The consistency of responses across repeated queries and their alignment with the original document content were used as indicators of reliability.

The Ollama environment was used to create a local chat system that responds to inquiries regarding the document using local embedding models. This configuration allows semantic analysis without requiring calls to an external API. While the generative model (Mistral) generates responses based only on the given context, the document was converted into a ChromaDB vector database, which facilitates quick retrieval of the most pertinent segments (Fig. 1). In situations where traditional methods are unable to provide the necessary scale, speed and reproducibility of analysis, this approach is especially useful for semi-structured biological and ethnobotanical data.

Despite its advantages, the RAG approach has several limitations. First, the chunking approach and embedding model have a significant impact on the quality of the results. Second, retrieval mistakes that occur when semantically relevant segments are not presented among the top results may result in responses that are either incomplete or only partially accurate. When a restricted prompt is employed, hallucinations are lessened but not completely eradicated, particularly when the returned context is unclear or inadequate. Additionally, the system's success is inextricably related to the arrangement and quality of the source content. Inconsistent formatting or terminology may inject noise into the extraction process because the data under examination are derived from semi-structured tables. Lastly, the underlying data

sources may be distorted. Subjective interpretations, geographical differences, or inadequate reporting may be present in ethnomedical knowledge, which is frequently acquired through interviews or customary methods. The collected data should therefore be carefully reviewed and, if feasible, cross-checked with other sources.

Results

The practice of medical ethnobotany

The results of the ethnobotanical study are presented in Table 3. The species are arranged in alphabetical order. For each species, the taxonomic affiliation, the plant parts used, the medicinal uses and the form in which it is used are given.

According to respondents, 47 plants and one mushroom are used in traditional medicine in all surveyed localities. A partial loss or unequal distribution of traditional knowledge within the study area is indicated by the respondents' declarations in four localities that they do not use wild herbs. Of all the 25 plant families represented by the recorded species, Rosaceae had the highest number of species (11), followed by Asteraceae (6 species) and Lamiaceae (6 species). All other families had only one species each. The dominance of these families is in line with their widespread availability in the area and their well-known therapeutic qualities, which have been reported in ethnobotanical research from comparable geographic regions.

Table 4 lists the primary therapeutic applications of wild medicinal plants. A contemporary generative AI-based RAG method was used to systematise and harmonise respondents' qualitative responses, which in turn helped to categorise use reports. Plant uses were classified into the following categories based on the data gathered: gynaecological diseases, respiratory tract, immunity, cardiovascular system, digestive tract, urinary tract, external use, anticancer use, antidiabetic use, nervous system and ritual use. Applying plant material directly to the affected area is referred to as external use. Examples of this include applying powdered fruiting bodies to stop bleeding (*Calvatia gigantea*), rubbing peeled rhizomes onto the skin for rheumatism (*Polygonatum odoratum*), or placing fresh leaves on wounds (*Plantago major*). Of all the documented categories, the greatest number of plant species were used to treat respiratory conditions (10 species), digestive disorders (8 species) and for immune system strengthening (8 species).

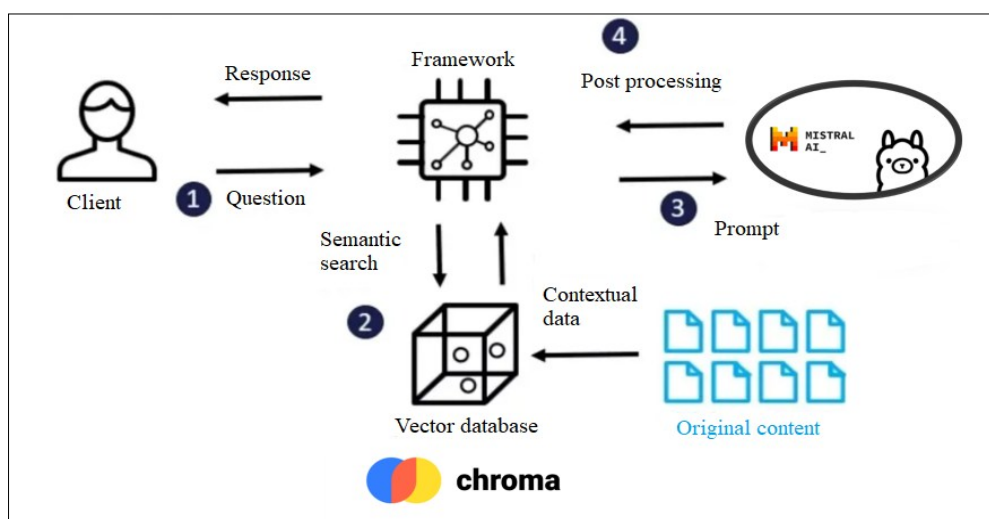


Fig. 1. Retrieval-augmented generation architecture for ethnobotanic chat system.

Table 3. The practice of medical ethnobotany in the foothills of the Kopaonik region

Sl. No.	Botanical taxa	Family	Local name	Parts used	Medicinal use	Preparation form
1.	<i>Achillea millefolium</i>	Asteraceae	Hjdučka trava	Aerial parts, flowers	Cleanses the blood and liver; used against colds and haemorrhoids	Infusion; flowers chewed and spat out
2.	<i>Agropyrum repens</i>	Poaceae	Pirevina	Rhizome	Against tumours	Infusion
3.	<i>Alchemilla vulgaris</i>	Rosaceae	Virak	Flowers	For female complaints (secretion, phlegm)	Infusion
4.	<i>Arctium lappa</i>	Asteraceae	Čičak	Leaves	Dressing at the scene of the murder	Fresh
5.	<i>Aronia arbutifolia</i>	Rosaceae	Aronija	Fruit	Improves blood count	Fresh
6.	<i>Asarum europeum</i>	Aristolochiaceae	Kopitnjak	Leaves	Protection from evil spirits (ritual value)	Grown in yard for protection
7.	<i>Atropa belladonna</i>	Solanaceae	Velebilje	Leaves	Pain relief	Infusion
8.	<i>Betula pendula</i>	Betulaceae	Breza	Cortex	Diuretic; for kidney disorders	Bark tea
9.	<i>Brassica oleracea</i>	Brassicaceae	Kupus	Leaves	Used against mastitis	Fresh
10.	<i>Calendula officinalis</i>	Asteraceae	Neven	Leaves and flowers	For colds and skin treatment	Infusion; flower oil
11.	<i>Calvatia gigantea</i>	Lycoperdaceae	Puhara	Powder	Stops bleeding	Directly to the site of injury
12.	<i>Cichorium intybus</i>	Asteraceae	Plava trava	Flowers	For coughs, better digestion and stomach problems	Infusion
13.	<i>Chelidonium majus</i>	Papaveraceae	Rusopas	Juice	Against warts	Directly on the wart
14.	<i>Cornus mas</i>	Cornaceae	Dren	Fruit	Boosts immunity	Dried
15.	<i>Cotinus coggygria</i>	Anacardiaceae	Ruj	Branches, leaves	Cancer prevention and colon cancer treatment, for the treatment of urinary infections and kidney diseases	Decoction of branches and infusion
16.	<i>Crataegus monogyna</i>	Rosaceae	Glog	Fruits, branches	For heart diseases, arrhythmia, blood pressure	Infusion
17.	<i>Cydonia oblonga</i>	Rosaceae	Dunja	Leaves	Against diarrhea	Infusion
18.	<i>Equisetum arvense</i>	Equisetaceae	Rastavić	Aerial parts	Against urinary infections	Infusion
19.	<i>Geranium robertianum</i>	Geraniaceae	Zdravac	Aerial parts	For female diseases	Infusion
20.	<i>Juniperus communis</i>	Cupressaceae	Kleka	Fruit	Improves digestion	Infusion
21.	<i>Lycopodium clavatum</i>	Lycopodiaceae	Prečica	Aerial parts	For gout and malignant diseases	Infusion
22.	<i>Hypericum perforatum</i>	Hypericaceae	Kantarion	Aerial parts, flowers	For wounds, headache, rheumatism, stomach issues, colds	Infusion; oil
23.	<i>Matricaria chamomilla</i>	Asteraceae	Kamilica	Flowers	For lowering the temperature, eye / genital washing, colds	Infusion
24.	<i>Mentha piperita</i>	Lamiaceae	Nana	Aerial parts, leaves	For stomach problems and colds; soothe the intestine	Infusion
25.	<i>Melissa officinalis</i>	Lamiaceae	Matičnjak	Leaves	Calming effect	Infusion
26.	<i>Plantago major</i>	Plantaginaceae	Bokvica	Leaves	Wound healing and dressing	Fresh
27.	<i>Polygonatum odoratum</i>	Liliaceae	Pokosnica	Rhizome	For rheumatism	Fresh
28.	<i>Primula vulgaris</i>	Primulaceae	Jagorčevina	Flowers	For cough and hoarseness	Infusion
29.	<i>Prunus avium</i>	Rosaceae	Divlja trešnja	Fruit stalks	For urinary infections	Infusion
30.	<i>Prunus domestica</i>	Rosaceae	Šljiva	Fruit	Improves digestion	Compote
31.	<i>Prunus spinosa</i>	Rosaceae	Trnjina	Fruit	Regulates diabetes	Fresh
32.	<i>Rumex acetosa</i>	Polygonaceae	Zelje	Leaves	For skin rashes, wounds, irritation	Fresh
33.	<i>Rubus idaeus</i>	Rosaceae	Malina	Leaves	For immunity and stomach problems	Infusion
34.	<i>Rubus fruticosus</i>	Rosaceae	Kupina	Leaves	Improves blood count	Infusion
35.	<i>Rosa canina</i>	Rosaceae	Šipurak	Fruit	For cough, cold, influenza	Infusion
36.	<i>Salvia officinalis</i>	Lamiaceae	Žalfija	Leaves	Mouth rinse	Infusion
37.	<i>Sambucus nigra</i>	Viburnaceae	Zova	Flowers	For diabetes and blood purification	Infusion
38.	<i>Symphytum officinale</i>	Boraginaceae	Gavez	Roots	Bone disorders	Fresh
39.	<i>Sempervivum tectorum</i>	Crassulaceae	Čuvarkuća	Leaves	The juice is squeezed against ear pain; the leaf is nibbled to regulate blood sugar	Fresh
40.	<i>Sorbus aucuparia</i>	Rosaceae	Jarebika	Fruit	Against haemorrhoids	Fresh
41.	<i>Taraxacum officinale</i>	Asteraceae	Maslačak	Root, flowers	Liver cleansing; for cough and lungs	Infusion
42.	<i>Teucrium chamaedrys</i>	Lamiaceae	Podubica	Flower	For stomach and cough	Infusion
43.	<i>Thymus serpyllum</i>	Lamiaceae	Majčina dušica	Aerial part, flowers	Calming effect; respiratory health; colds	Infusion
44.	<i>Teucrium montanum</i>	Lamiaceae	Trava iva	Flowers	For the whole organism, especially for stomach	Infusion
45.	<i>Tilia cordata</i>	Malvaceae	Lipa	Leaves, flowers	For colds and calming	Infusion
46.	<i>Urtica dioica</i>	Urticaceae	Kopriva	Aerial parts, young leaves	Fresh leaves for anemia combined with red fruit	Fresh; infusion
47.	<i>Vaccinium myrtillus</i>	Ericaceae	Borovnica	Leaves	For digestion and stomach	Fresh; infusion
48.	<i>Verbascum pholmoides</i>	Scrophulariaceae	Divizma	Flowers	For lung disorders	Infusion

Table 4. The practice of medical ethnobotany in the foothills of the Kopaonik region obtained by using modern generative artificial intelligence technique (RAG)

Sl. No.	Medicinal use	Species
1.	Respiratory tract disorders	<i>Mentha piperita</i> , <i>Thymus serpyllum</i> , <i>Matricaria chamomilla</i> , <i>Sambucus nigra</i> , <i>Tilia cordata</i> , <i>Rosa canina</i> , <i>Taraxacum officinale</i> , <i>Verbascum phlomoides</i> , <i>Hypericum perforatum</i> , <i>Achillea millefolium</i>
2.	Immunity enhancement	<i>Rosa canina</i> , <i>Taraxacum officinale</i> , <i>Achillea millefolium</i> , <i>Vaccinium myrtillus</i> , <i>Rubus fruticosus</i> , <i>Aronia arbutifolia</i> , <i>Sambucus nigra</i> , <i>Cornus mas</i>
3.	Cardiovascular system disorders	<i>Crataegus monogyna</i> , <i>Sorbus aucuparia</i> , <i>Sambucus nigra</i> , <i>Achillea millefolium</i>
4.	Digestive tract disorders	<i>Mentha piperita</i> , <i>Melissa officinalis</i> , <i>Cichorium intybus</i> , <i>Vaccinium myrtillus</i> , <i>Rubus idaeus</i> , <i>Teucrium chamaedrys</i> , <i>Teucrium montanum</i> , <i>Prunus domestica</i>
5.	Urinary tract disorders	<i>Betula pendula</i> , <i>Cotinus coggygria</i> , <i>Prunus avium</i> , <i>Equisetum arvense</i> , <i>Juniperus communis</i>
6.	Gynecological disorders	<i>Alchemilla vulgaris</i> , <i>Rubus idaeus</i> , <i>Rubus fruticosus</i> , <i>Geranium robertianum</i> , <i>Matricaria chamomilla</i>
7.	External applications (wounds, cuts, burns, rheumatism)	<i>Plantago major</i> , <i>Hypericum perforatum</i> (oil), <i>Symphytum officinale</i> , <i>Arctium lappa</i> , <i>Polygonatum odoratum</i> , <i>Calvatia gigantea</i>
8.	Anticancer use	<i>Cotinus coggygria</i> , <i>Agropyrum repens</i> , <i>Lycopodium clavatum</i> , <i>Teucrium montanum</i>
9.	Antidiabetic use	<i>Prunus spinosa</i> , <i>Sambucus nigra</i> , <i>Sempervivum tectorum</i>
10.	Nervous system disorders	<i>Tilia cordata</i> , <i>Melissa officinalis</i> , <i>Thymus serpyllum</i>
11.	Ritual / magical use	<i>Asarum europaeum</i>

Table 5. Practice food ethnobotany

English name	Usage
Boletus	Stew, soup, frying, pasteurisation
Golden chanterelle	Stew, soup, frying, pasteurisation
Dogwood	Juice
Wild strawberry, meadow strawberry	Sweet preserve
Juniper	Brandy
Rosehip	Jam
Wild raspberry	Sweet preserve
Wild blackberry	Juice, sweet preserve, pie, wine
Dandelion flower	Honey (sweet preserve)
Blueberry	Sweet preserve, juice
Wild apple	Vinegar

The practice of food ethnobotany

Eleven forest fruits, including wild edible plants and mushrooms, were reported as being used for non-medicinal purposes, primarily for nutrition (Table 5). Despite using different plant parts, the majority of the species used in cooking are also used in traditional medicine. Aerial parts and leaves are used for medicinal purposes, while fresh fruits are usually eaten as food.

Foothills of the Kopaonik region vs. surrounding regions (Balkan comparison)

Supplementary Table 1 provides comparative data between these regions and the current study area. Since there are differences in local flora, cultural customs and the transfer of traditional knowledge, these comparisons reveal both regional specificities and commonalities in the use of wild medicinal plants and plant foods.

Discussion

Analysis of ethnobotanical data has shown that the most popular uses of medicinal plants were as fresh plant material or as tea (infusion). Teas were predominantly prepared from dried plant parts, which suggests an adaptation of traditional practices to

year-round availability of medicinal resources. Respondents frequently described the effects of herbal teas in general terms (e.g., “the tea is excellent for...”), reflecting experiential rather than standardised medical knowledge. A somewhat specialised and moderate use of medicinal flora is indicated by most respondents, who reported using individual plant species for one to three medicinal indications. Plant combinations have also been documented, such as the inhalation of *Mentha piperita* and *Matricaria chamomilla* for sinus congestion or the relaxing effects of *M. piperita* and *Melissa officinalis*. Such combinations suggest an empirical understanding of synergistic effects among certain aromatic species. Several species were primarily used for external applications, particularly for wound treatment. *Plantago major* leaves were frequently applied directly to wounds and *Hypericum perforatum* oil was also frequently mentioned for the same purpose. The process of making *H. perforatum* oil, which involves macerating dried plant material in olive oil for about 40 days, then straining and storing it in a cool, dark environment, reflects long-standing traditional knowledge about the stability and extraction of phytochemicals. Occasionally, uncommon or highly individualised practices were documented, such as the use of *Achillea millefolium* flowers to treat haemorrhoids. Although these practices may seem unusual, it is crucial to document them because they might be traces of more ancient or regional healing customs. Another example of individualised practices is the report from one respondent that they chew one leaf of houseleek (*Sempervivum tectorum*) every day to control blood sugar levels.

A similar ethnobotanical study conducted in the Kopaonik area approximately 15 years prior to the present research reported results that differ considerably from those obtained in this study (12). Notably, the use of *Agropyron repens* and *Alchemilla vulgaris* was not recorded in their survey. In addition, differences were observed not only in the spectrum of utilised species but also in their reported medicinal applications. These discrepancies may be attributed to geographical and sociocultural differences between the investigated areas. The present study primarily covered the areas of the municipalities of Raška and Leposavić, while the earlier study was carried out on the northern slopes of Kopaonik, within

the municipality of Brus (12). Therefore, the selection of medicinal species and their applications may have been influenced by local ecological conditions, plant availability and the transmission of traditional knowledge. Differences in the purposes of use were also recorded for the same plant species. For instance, respondents in the present study reported the use of *Chelidonium majus* for the removal of warts, a practice that was not documented in the earlier study. Such variations highlight the spatial heterogeneity of traditional medicinal knowledge even within geographically proximate regions and emphasise the dynamic nature of ethnomedicinal practices. Large overlaps in recorded taxa used in traditional medicine may be a consequence of the sparseness of the terrain, as well as the great floristic diversity of Mount Kopaonik, which inevitably leads to local differences. Additionally, the investigated localities differ significantly in altitude, so these differences may also be due to variations in floristic composition.

Retrieval-augmented generation was used to categorise and summarise the free-text ethnobotanical data, which is a new processing approach. Respondents stated that they use the same species for different purposes. Numerous plant species were found to have a variety of medicinal uses. *Mentha piperita*, for instance, was used to treat digestive and respiratory issues, which is in line with earlier ethnomedical research (13). According to applications reported in a previous study, *Rosa canina* fruits were also frequently used to treat respiratory infections such as colds and coughs and to increase immunity (14).

By analysing nutritional and therapeutic uses, they are often distinct, but only a small number of plant species are consumed fresh for medicinal purposes. Previous studies have documented the region's well-known custom of collecting wild fruits and making a range of traditional products, such as juices, sweet preserves and various liqueurs (12, 15). Local ethnobotanical practices incorporate both medicinal and nutritional knowledge, as demonstrated by this dual use of wild plants.

Mushrooms are used to prepare various types of food; however, caution is required, as considerable prior knowledge is necessary to avoid confusing edible and poisonous species. Given the abundance of genetic resources for mushrooms on the Balkan Peninsula, this outcome is not surprising (16). According to customs ingrained in Serbian traditional culture, other wild edible fruits are used mostly for making alcoholic and non-alcoholic drinks, fruit preserves, or as ingredients in pies (7, 12).

Similar ethnobotanical studies have been carried out in Serbia's mountains Rtanj (17), Suva Planina (7), Zlatibor (18), Tara (19) and the Autonomous Province of Kosovo (20), as well as in neighbouring countries such as Montenegro (21) and Bosnia and Herzegovina (22), according to a review of the literature. According to a comparative study of ethnobotanical data from the locality under investigation and the surrounding areas, only the Kopaonik foothill region reported five plant species (*A. repens*, *Atropa belladonna*, *Cotinus coggygria*, *Lycopodium clavatum* and *Sorbus aucuparia*) and one mushroom (*C. gigantea*). Without naming specific varieties, respondents stated that *A. repens* was utilised in rhizome teas to treat tumours. *Agropyron repens* has historically been used as a tonic and demulcent, to alleviate urinary tract pain and spasm and as a calming diuretic, according to literature (23). Its phytochemical profile comprises minerals such as silica and iron, carbohydrates, mucilaginous materials, pectin,

triticin, cyanogenetic glycosides, phenolic compounds, flavonoids, saponins, volatile oils and vanillin glucoside. *Atropa belladonna* was reported for the treatment of pain, typically through leaf teas. Although the species' pharmacological effects on the nervous system are well known, its high toxicity necessitates careful use (24). Although not reported in nearby areas, *C. coggygria* is also utilised locally in traditional medicine. Research conducted in the Ibar Valley region shows that leaf extracts have high concentrations of phenols and flavonoids, which have strong antioxidant properties. These extracts show high, non-selective cytotoxicity against both normal cells and colorectal cancer cells, despite their evaluation for cancer prevention (25). *Lycopodium clavatum* is historically known worldwide for its medicinal applications. Literature reports the use of decoctions for liver and kidney conditions, muscle cramps, as well as analgesic, anti-rheumatic, carminative and urinary system treatments (26). The applications outlined in the present study partially align with these uses. The use of *S. aucuparia* to treat haemorrhoids was documented, but it was not reported in the surrounding areas. The species is widely used in Europe and Asia to treat a wide range of illnesses such as infections, rheumatism, cancer, gout, hypertension and respiratory and gastrointestinal disorders. It also has antidiabetic, diuretic, anti-inflammatory and vasorelaxant properties and is a good source of vitamin C (27–30). Furthermore, according to two respondents, the mushroom species *C. gigantea* can stop bleeding, which is in line with earlier ethnomycological reports (31, 32). These results demonstrate how some ethnomedicinal practices in the foothills of Kopaonik are specific to the area, possibly as a result of historical, cultural and ecological influences on the use of plants and mushrooms. According to reports, two plant species- *P. odoratum* (sub-Kopaonik region and Suva Planina) and *Aronia arbutifolia* (sub-Kopaonik region and Zlatibor) are utilised in both the locality under investigation and one other area (7, 18).

Additionally, a number of species that are utilised in all other surveyed localities as well as at the base of Kopaonik were noted. Among them are *Urtica dioica*, *Sambucus nigra*, *M. chamomilla*, *Primula vulgaris*, *H. perforatum* and *Crataegus monogyna*. The extensive use of these species indicates that they comprise a core group of medicinal plants frequently used across the Balkan Peninsula, reflecting both their ecological accessibility and the regional dissemination of traditional ethnobotanical knowledge.

Regarding the use of plants for medicinal purposes, the fewest overlaps of recorded taxa were found between the foothills of Kopaonik and Bosnia and Herzegovina, with only 19 taxa in common. In addition, the purpose of use of the overlapping taxa was very different. The reason for such large overlaps can be found in the different ethnic composition of the population, as well as the great distance between the compared localities, so there was no natural transfer of traditional knowledge. There is also surprisingly little overlap of recorded taxa between the examined area and the Rtanj locality, with only 21 taxa in common. This result is unexpected, given that traditional medicinal plants are mostly used in the area of southeastern Serbia.

Conclusion

The richness and uniqueness of regional ethnomedicinal knowledge are highlighted by this study, which details the traditional medicinal use of 47 wild plant species and one mushroom species in the

Kopaonik foothills. The findings support the preservation of biocultural heritage and offer a useful regional dataset to enhance the ethnobotanical research already conducted in Serbia and the Balkan Peninsula. Retrieval-augmented generation proved to be an effective tool in ethnobotanical research because it helped with the efficient processing and classification of free-text ethnobotanical data. Importantly, five plant species and one mushroom species were identified that have not been used medicinally in nearby areas before, suggesting the existence of regionally specific customs. These taxa are excellent candidates for upcoming studies in phytochemistry, pharmacology and toxicology that will evaluate the traditional uses of these species for scientific validity, as well as their potential to aid in drug discovery. Future research should focus on the targeted study of those specific taxa in order to confirm or refute the purpose of their use. Also, a comparison of ethnobotanical data between other Balkan regions would provide significant insight into whether traditional knowledge is slowly being lost or whether the differences are the result of local specificities.

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Authors' contributions

BPV contributed to conceptualisation, investigation and methodology (data collection, plant identification and data processing), as well as writing the original draft. AA contributed to methodology and artificial intelligence (RAG). DP contributed to writing, review and editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used retrieval-augmented generation (RAG) to systematise and harmonise respondents' qualitative answers. After using this tool / service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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