PLANT SCIENCE TODAY
Vol 13(2): 1-12
https://doi.org/10.14719/pst.10353

eISSN 2348-1900

RESEARCH ARTICLE

Medicinal mosses of Uzbekistan: Biochemical profiling and review of their ethnopharmacological uses

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Received: 29 June 2025; Accepted: 23 January 2026; Available online: Version 1.0: 19 March 2026; Version 2.0: 01 April 2026

Cite this article: Farrux A, Mushtaq A, Aqsa A, Kholmurod Z, Sakhib P, Mekhrubon K, Shazia S, Nagmetullayev M, Suyunkulova S, Mamadiyarov M. Medicinal mosses of Uzbekistan: Biochemical profiling and review of their ethnopharmacological uses. Plant Science Today. 2026; 13(2): 1-12. https://doi.org/10.14719/pst.10353

Abstract

Mosses, a diverse group within the bryophyte division, have been historically used for their medicinal properties. Despite their global distribution and resilience to extreme environmental conditions, their medicinal potential remains underexplored, particularly in regions like Uzbekistan. This study provides the first comprehensive investigation into the medicinal mosses of Uzbekistan, focusing on *Brachythecium rutabulum* (Hedw.) Schimp. , *Funaria hygrometrica* Hedw., *Marchantia polymorpha* L. and *Pellia epiphylla* (L.) Corda . Using advanced analytical techniques, including high-performance liquid chromatography (HPLC) and inductively coupled plasma mass spectrometry (ICP-MS), the study determines the biochemical composition, amino acid profiles, carbohydrate content, water-soluble vitamins and elemental concentrations of these species. Results revealed that *F. hygrometrica* had the highest total amino acid content, particularly rich in arginine, aspartic acid and tyrosine, while *B. rutabulum* exhibited the highest carbohydrate concentration (19.53 mg/g). *Marchantia polymorpha* contained the highest levels of water-soluble vitamins, including B and C complexes. Mineral analysis confirmed the presence of 41 essential elements, such as copper, iron, zinc, manganese and selenium, with cadmium and lead concentrations remaining below Uzbekistan's safety thresholds. In addition, the study reviews traditional medicinal applications of mosses globally, with particular emphasis on those within Uzbekistan's bryoflora. These results emphasise the bioactive potential of bryophytes and enhance the knowledge of their biochemical characteristics, therapeutic value and uses in natural medicine.

Keywords: amino acids; *Brachythecium rutabulum*; heavy metal salts; mosses; therapeutic applications; ultra-micro elements

Introduction

Nature provides rich resources for disease treatment and management, with natural products obtained from plants serving as the foundation for numerous promising medicinal drugs used in both ancient and modern times (1). Among these natural resources, mosses are an unexplored group that contains bioactive molecules with antioxidant activity and therapeutic potential.

Mosses, which belong to the division Bryophyta, form the largest group among bryophytes, alongside liverworts (Marchantiophyta) and hornworts (Anthocerotophyta) (2). Mosses are the most diverse lineage of land plants after angiosperms and possess a worldwide species estimate of 11000–13000 species (3). They are cosmopolitan, occurring in diverse habitats such as woodlands, deserts, tundra and alpine regions. This ecological range is possible due to physiological adaptations including desiccation tolerance, high UV resistance and the capacity to rapidly rehydrate after drought (4–6).

Secondary metabolites such as phenolics, flavonoids, terpenoids, alkaloids and fatty acids in mosses are the main active compounds that are associated with their wide spectrum of pharmacological activities (7). Extracts of several moss species have shown antioxidant, antimicrobial, antifungal, anti-inflammatory and anticancer activities indicating the industrial relevance in medicine (8, 9).

Medicinal use of mosses dates back hundreds of years across all traditional medicine systems of the world. In traditional Chinese medicine (TCM), approximately 22 types of mosses can heal wounds and support both the respiratory and nervous systems (10). For instance, *Polytrichum commune* Hedw. has been used for alopecia and inflammatory diseases (11). *Marchantia polymorpha* L. is used in European folk medicine as a liver tonic and diuretic under the "Doctrine of Signatures." This is based on the theory that if a part of a plant looks like an organ or part of the body, use of that plant will cure the organ or body part; as *Marchantia* looks like liver tissue, it was believed to be a cure for liver ailments (12). In North America, species such as *Mnium*, *Bryum* and *Philonotis,* were employed topically in poultices for wounds and skin infections (13). Comparable uses have been reported for wound healing, antipyretic and cough problems in the traditional Indian and Southeast Asian systems (14).

There is beginning to be some scientific evidence that these practices work. Recent scientific studies have begun to validate some of these traditional medicinal practices. For example, *Funaria hygrometrica* Hedw. and *Bryum capillare* Hedw. have exhibited antibacterial activity against *Escherichia coli*, *Staphylococcus aureus* and *Bacillus subtilis* (8). The physicochemical analysis of mosses also supports their potential as a source of novel natural remedies. Furthermore, moss-based antioxidants may be used to treat diseases associated with oxidative stress (e.g. diabetes, neurodegeneration, atherosclerosis and cancer) (15).

Uzbekistan, as a Central Asian country, is abundant with vegetation (approximately 4380 species of vascular plants) and over 1200 species are reported in TM (16). Bryophytes (especially mosses) are common in the mountains, steppes and deserts of Uzbekistan, but their biodiversity and phytochemistry are poorly understood. In Uzbekistan, no complex pharmacological or biochemical studies on bryophytes have been conducted (17). Prior to the present study, publications providing information on the bryophytes of Uzbekistan (18–20) were mainly devoted to bryophyte taxonomy and ecological characteristics and no scientific publications on medicinal bryophytes have been reported. Moreover, the ecological properties of mosses extended their therapeutic value. Other than vascular plants, bryophytes can recover quickly and grow with little input of agriculture, even in harsh environments. Such characteristics make them good candidates for sustainable conservation-led drug development, particularly in regions such as Central Asia, where climate change and unsustainable exploitation are placing growing threats on native biota (14).

The aim of the present study is to address this gap in research by examining chemical profiling and ethno-pharmacological value of 4 moss species growing in Uzbekistan: *Brachythecium rutabulum* (Hedw.) Schimp., *F. hygrometrica*, *M. polymorpha* and *Pellia epiphylla* (L.) Corda. These species were chosen due to their record in world ethnomedicinal literature, commonness in the locality and suitability for laboratory investigation due to their simple morphological characteristics. Their amino acid profiles, water-soluble vitamins, elemental contents and carbohydrate composition were determined by advanced analytical techniques such as spectrophotometry, chromatography and atomic absorption spectroscopy.

Materials and Methods

Collection and identification of medicinal mosses

Bryophyte samples were collected from various regions of Uzbekistan across ecological vertical zones in different habitats during 2021–2022, mainly from February to June. The samples (*M. polymorpha* – 39°37'43.3"N 68°29'34.1"E, *P. epiphylla* – 39° 37'42.5"N 68°29'33.3"E, *B. rutabulum* – 39°37'53.2"N 68°30'06.0"E, *F. hygrometrica* – 39°43'02.3"N 67°47'04.6"E) were collected on 02–03 March 2022 in polyethylene bags from the Northern Turkestan botanical–geographical region. Approximately 300 field samples were collected and detailed identification work was conducted with Levenhuk MED D30T LCD digital trinocular microscope and professional AmScope digital stereomicroscopes. The exact geographical location of the sampling points was recorded using a Garmin Dakota 20 global positioning system (GPS) at 39° 37 min North latitude, 68° 29 min East longitude. Voucher specimens were deposited at Herbarium SamSU. Based on the documented ethno medical significance of these collected samples in traditional medicine systems in Europe, Asia and North America, thallose liverworts and leafy stem bryophyte samples were selected for biochemical analysis (10, 13, 14). The chosen species included *B. rutabulum*, *F. hygrometrica*, *M. polymorpha* and *P. epiphylla*.

Sample cleaning and preparation

Prior to biochemical examination, the obtained bryophyte samples were meticulously cleansed to eliminate any dirt or dust adhering to them. Washed the samples delicately with distilled water to eliminate surface contamination. The purified material was dried by blotting with absorbent paper and allowing it to air dry in the shade. Subsequently, the samples were subjected to drying in an oven at a low temperature until completely dry. The dried material was crushed into a fine powder using a clean mortar and pestle and stored in sealed containers at room temperature until further chemical analyses.

Amino acid determination via high-performance liquid chromatography (HPLC)

The total amino acid content was determined using the method described by Cohen and Strydom (21), involving derivatisation with phenylisothiocyanate (PITC) to produce phenylthiocarbamyl (PTC) derivatives. Proteins and peptides were precipitated from aqueous extracts using 20 % trichloroacetic acid (TCA), followed by centrifugation at 8000 rpm for 15 min. The resulting supernatants were lyophilised and neutralised with a solution of triethylamine, acetonitrile and water. Analysis was performed on an Agilent 1200 HPLC system (Agilent Technologies, USA) equipped with a diode array detector (DAD) and a Discovery HS C18 column (75 × 4.6 mm, Sigma-Aldrich). The mobile phase consisted of 0.14 M sodium acetate containing 0.05 % triethylamine (pH 6.4) as solvent A and acetonitrile as solvent B. Detection was carried out at 269 nm using a predefined gradient program.

Carbohydrate quantification by high-performance liquid chromatography (HPLC)

The monosaccharide content (glucose, fructose, sucrose and maltose) was quantified according to standard HPLC-based sugar analysis protocols. High-performance liquid chromatography analysis was carried out using an Agilent 1200 Series HPLC system equipped with a Supelcosil LC-NH_2 column (4.6 × 250 mm, 5 µm; Supelco, USA) and a refractive index de.

Sample pre-treatment involved dilution with deionised water followed by filtration through 0.45 µm nylon filters. The equipment used included an ultrasonic bath (Elmasonic S30H, Elma, Germany), an analytical balance (GR-202, A&D, Japan) and

VWR/Biohit micropipettes. Acetonitrile (HPLC grade, Sigma-Aldrich, USA) was used as the organic mobile phase.

Liquid chromatography was performed under isocratic conditions using a mobile phase consisting of acetonitrile (Buffer A) and water (Buffer B) in a volume ratio of 82:18 (v/v). The flow rate was set at 1.0 mL/min and a 10 µL sample volume was injected. The column temperature was maintained at 35 °C. The refractive index detector settings were optimized to improve peak resolution, allowing effective separation.

Water-soluble vitamin analysis

This study investigates the content of water-soluble vitamins using a high-efficiency liquid chromatography (HPLC) method. A sample (5-10 g) was accurately weighed with an analytical balance and placed in a 300 mL flat-bottom flask. Fifty mL of a 40 % ethanol solution was added. The mixture was stirred magnetically and heated under reflux for 1 hr, followed by 2 hr at room temperature. The solution was allowed to settle and filtered. The residual material underwent two re-extractions with 25 mL of 40 % ethanol. The combined filtrates were transferred to a 100 mL volumetric flask and diluted with 40 % ethanol to the mark.

The resulting solution was centrifuged at 7000 rpm for 10 min and the supernatant was collected for analysis. Working solutions of each water-soluble vitamin were prepared at a concentration of 1 mg/mL by accurately weighing 50.0 mg of each vitamin standard, dissolving it in a 40 % ethanol solution in a 50 mL volumetric flask and filling to the mark.

Previous literature indicates that phosphate and acetate buffer systems, along with acetonitrile, are common eluents for HPLC analysis of water-soluble vitamins. In this study, we utilised an acetate buffer system in conjunction with acetonitrile.

Chromatography conditions:

Instrumentation: Agilent 1200 HPLC system equipped with an auto-sampler.

Column: Eclipse XDB C18, 5 µm, 4.6 x 150 mm (reversed-phase).

Detector: Diode array detector (DAD) for identification at 204 nm, 254 nm and 290 nm. Flow Rate: 1 mL/min.

Eluent Composition:

0-5 min: 96 % acetate buffer/4 % acetonitrile

6-8 min: 90 % acetate buffer/10 % acetonitrile

9-15 min: 80 % acetate buffer/20 % acetonitrile

15-17 min: 96 % acetate buffer/4 % acetonitrile

Thermostat Temperature: 25 °C.

Injection Volume: 5 µL.

Working standard solutions were introduced into the chromatograph initially, followed by the prepared samples.

Elemental analysis via inductively coupled plasma mass spectrometry (ICP-MS)

Contents of macro- and microelements were analysed by the ICP-MS, employing a NEXION-2000 system (PerkinElmer, USA). Samples were digested by closed-vessel microwave digestion system (Germany), nitric acid and hydrogen peroxide. The analyses were performed using certified multi-element standards (Merck, Germany) and high-purity argon gas (99.995 %). This method is in accordance with the general procedures applied in trace metal analysis of plant material (22).

Results and Discussion

Mosses have been largely overlooked in the search for novel bioactive compounds compared to higher plants. However, recent research has highlighted the importance of natural products derived from these plants, including mosses, have been vital in drug discovery and development, particularly in the fight against various diseases such as cancer and infectious diseases (23–25).

Based on literature review, a list of medicinal mosses used in traditional medicine by various nations and found in bryoflora of Uzbekistan has been compiled. This list includes 4 species from the Marchantiophyta section and 16 species from the Bryophyta section, as shown in Table 1.

These medicinal mosses have been used for thousands of years in various regions to treat serious diseases, for example, *M. polymorpha, P. commune, F. hygrometrica* are known for their effectiveness in treating pulmonary tuberculosis.

Bryum argenteum Hedw., *F. antipyretica, L. riparium* are known for their fever-reducing properties. Among the medicinal bryophytes found in the Republic of Uzbekistan, specimens belonging to the Marchantiophyta and Bryophyta division are illustrated in Fig. 1.

These therapeutic properties of mosses are related to their bioactive compounds, which exhibit a range of pharmacological activities (31). Substances and extracts from several mosses have been tested *in vitro* to determine their effects on the viability and enzymatic activity of several types of fungi microorganisms, including *Escherichia coli, Staphylococcus aureus, Vibrio cholera* and *Streptococcus pyogenes*. Genera such as *Amblystegium, Bryum, Brachythecium, Philonotis, Mnium* and *Sphagnum* have demonstrated significant bactericidal properties, with *Sphagnum* being particularly prominent (32).

Phytochemical research on various bryophyte species has uncovered the presence of biologically active compounds including polyphenols, organic acids, terpenoids, lipids, proteins and fatty acids which exhibit several bioactivities such as antifungal, antitumor, antibacterial and insecticidal properties (33). The amino acids, carbohydrates, vitamins and micro-elements composition in *B. rutabulum, F. hygrometrica, M. polymorpha and P. epiphylla* species was analysed using advanced analytical techniques, providing a comprehensive understanding of their medicinal properties.

Amino acid profiling

Table 2 summarises the amino acid composition of 4 medicinal mosses (*B. rutabulum, F. hygrometrica, M. polymorpha* and *P. epiphylla*. Among the analysed data, *F hygrometrica* has the highest total amino acid content with notably elevated levels of arginine, aspartic acid, glutamic acid, glycine and tyrosine. In contrast, *M. polymorpha* had the lowest total amino acid content, but contained relatively higher proportions of aspartic acid and tyrosine.

Each type of moss contains a specific set of amino acids. In *B. rutabulum*, there is a higher concentration of tryptophan and tyrosine, whereas in *P. epiphylla*, it has a balanced variety of amino acids, both non-essential and essential amino acids such as histidine, lysine, valine, methionine and isoleucine. The variation among each type of moss could indicate their varied metabolic process that may account for their traditional healing

Table 1. Mosses used in traditional medicine among the peoples of the world, which are part of the bryoflora of Uzbekistan

No.	Taxa	Regions using mosses as traditional medicine	Ailments	Citation
1	*Marchantia polymorpha*	American Indian	Antidotes, pulmonary tuberculosis, kidney stone and liver ailments	(26)
2	*Pellia epiphylla*	Türkiye	Antimicrobial	(27)
3	*Riccia fluitans*	European	Skin disease	(28)
4	*Bryum argenteum*	Chinese American European	Against inflammation and fever, antidote, antipyretic and antifungal	(29,30)
5	*Bryum capillare*	American	Treatment of pain and fever, burns and fungal Infections	(28)
6	*Barbula unguiculate*	Indian	Treatment of pain and fever	(28)
7	*Brachythecium rutabulum*	Indian	Cuts, Burns, Wounds	(29)
8	*Brachythecium salebrosum*	European	Exhibit high antitumor activity	(30)
9	*Ceratodon purpureus*	European	Antibacterial and antioxidant	(30)
10	*Cratoneuron filicinum*	Chinese Indian	Heart diseases	(30)
11	*Conocephalum conicum*	Chinese European	Antidotes, Stones, Eczema, Cuts and Snake Bites	(30)
12	*Fontinalis antipyretica*	Chinese European	Against inflammation and fever and antipyretic	(29)
13	*Funaria hygrometrica*	Chinese European	Against bleeding, pulmonary tuberculosis hemostatic, sedative, diuretic, epilepsy and kidney stone reducer	(29)
14	*Fissidens osmundoides*	European	Disinfectant and infections	(28)
15	*Leptodictyum riparium*	Chinese	Against inflammation and fever, antipyretic and urinary tract infections	(11)
16	*Mnium stellare*	European	The genus Mnium is known to have highly unsaturated lipids	(28)
17	*Philonotis fontana*	Indian	Against inflammation and fever, antidotes and tonsillitis	(30)
18	*Polytrichum commune*	Chinese American Indian	Antidotes, pulmonary tuberculosis, stones hemostatic, uterine prolapse and hair care	(29)
19	*Polytrichum juniperinum*	Chinese American Indian European	Disinfectant and infections, in the treatment of prostate, diuretics and burns	(29)
20	*Hypnum cupressiforme*	European	Antifungal	(29,30)

Table 2. Amino acid composition of some medicinal mosses

No.	Amino acid name	Concentration mg/g			
		A	B	C	D
	Exchangeable amino acids				
1	*Arginine*	0.164053	0.472256	0.184158	0.18657
2	*Aspartic acid*	0.677436	0.696769	0.772775	0.402013
3	*Glutamic acid*	0.413836	0.633367	0.17982	0.300949
4	*Serine*	0.054035	0.015573	0.030911	0.110665
5	*Glycine*	0.167711	0.439351	0.148918	0.090831
6	*Asparagine*	0.153194	0.431317	0.14952	0.089033
7	*Glutamine*	0.245288	-	0.098574	0.016556
8	*Cysteine*	0.176292	-	0.203647	-
9	*Tyrosine*	1.241766	1.73241	0.608533	0.568862
	Essential amino acids				
10	*Threonine*	-	0.285009	-	-
11	*Valin*	-	-	-	0.186528
12	*Methionine*	-	-	-	0.128212
13	*Isoleucine*	0.086197	0.00874	0.017782	0.011151
14	*Leucine*	0.048838	0.013276	0.010906	0.00972
15	*Histidine*	-	-	-	0.321121
16	*Tryptophan*	0.828546	0.204668	0.112507	0.126272
17	*Phenylalanine*	0.48249	-	0.533804	0.791099
18	*Lysine*	0.025141	-	0.003684	0.267013
	Total	4.764823	4.932736	3.055538	3.606597

A: *B. rutabulum*; B: *F. hygrometrica*; C: *M. polymorpha*; D: *P. epiphylla.*

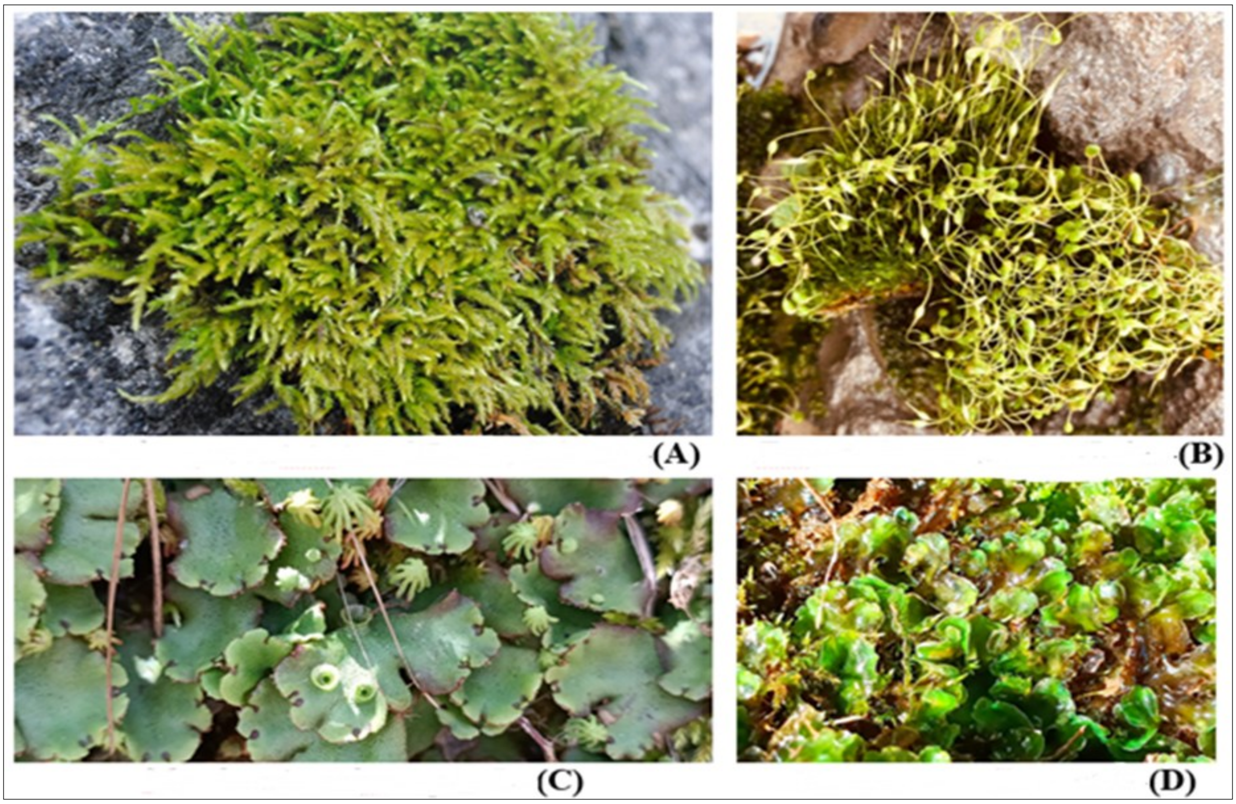

Fig. 1. (A): *Brachythecium rutabulum* (Hedw.) Schimp.; (B): *Funaria hygrometrica* Hedw.; (C): *Marchantia polymorpha* (L.); (D): *Pellia epiphylla* (L.).

properties. In Fig. 2A, the chart of the amino acid standards is displayed through HPLC with distinct peaks and corresponding retention times. In Fig. 2B-E are the moss samples (*B. rutabulum, F. hygrometrica, M. polymorpha* and *P. epiphylla*). The designated amino acids were determined based on their corresponding retention times under similar settings as that of the standards. Quantification was performed using external calibration curves of standard amino acids and the assigned peaks correspond to the amino acids quantified in Table 2.

Several amino acids identified at elevated concentrations in the examined mosses has established physiological significance. Glutamic and aspartic acids, prevalent in *F. hygrometrica* and *M. polymorpha*, have a role in hepatic metabolism and nitrogen equilibrium (34, 35). Glycine, notably abundant in *F. hygrometrica*, has been linked to antioxidant defence and reduced inflammatory responses in liver damage models (36). The presence of histidine, leucine and arginine, particularly in *P. epiphylla* and *F. hygrometrica*, underscores the nutritional and therapeutic significance of these species, given that these amino acids have roles in glucose control, lipid metabolism and cellular proliferation (34, 37).

Carbohydrate profiling

This study conducted carbohydrate profiling on various moss species through HPLC to evaluate their therapeutic potential. Fig. 3A shows the HPLC chromatogram of standard sugars, where peaks are well resolved and retention times clear. Fig. 3B–E display the chromatograms for *B. rutabulum*, *F. hygrometrica*, *M. polymorpha* and *P. epiphylla*, respectively. Based on the retention times of glucose, fructose, sucrose and maltose compared to the reference sugars tested under identical conditions of chromatography, the identification of the carbohydrates was determined. Quantification is based on external calibration curves created from standard sugars and the peaks assigned correspond to the carbohydrate levels listed in Table 3.

The result showed that among the species analysed, *B. rutabulum* had the highest carbohydrate content at 19.53 mg g^{-1}; it was followed by *F. hygrometrica*, with 17.05 mg. *Marchantia polymorpha* and *P. epiphylla* had comparable total carbohydrate values of 16.91 and 17.03 mg g^{-1}.

Carbohydrates are essential for constructing major macromolecules, regulating lipid metabolism, providing energy to the organism, storing energy for later use and maintaining protein reserves (38). These compounds can be metabolised through aerobic and anaerobic pathways to produce simple energy sources for the body (39). *Bryum reticulum, F. hygrometrica, M. polymorpha* and *P. epiphylla* each exhibit unique carbohydrate compositions that contribute to their significant strength and

Table 3. Disaccharide composition of some medicinal mosses

Carbohydrates names	Concentration mg/g			
	A	B	C	D
Monosaccharide				
Glucose	4.28	7.07	3.96	2.99
Disaccharides				
Fructose	1.65	3.64	2.16	0.20
Sucrose	4.44	1.46	0.63	5.22
Maltose	9.15	4.88	10.16	8.62
Total	19.53	17.05	16.91	17.03

A: *Bryum rutabulum*; B: *Funaria hygrometrica*; C: *Marchantia polymorpha*; D: *Pellia epiphylla.*

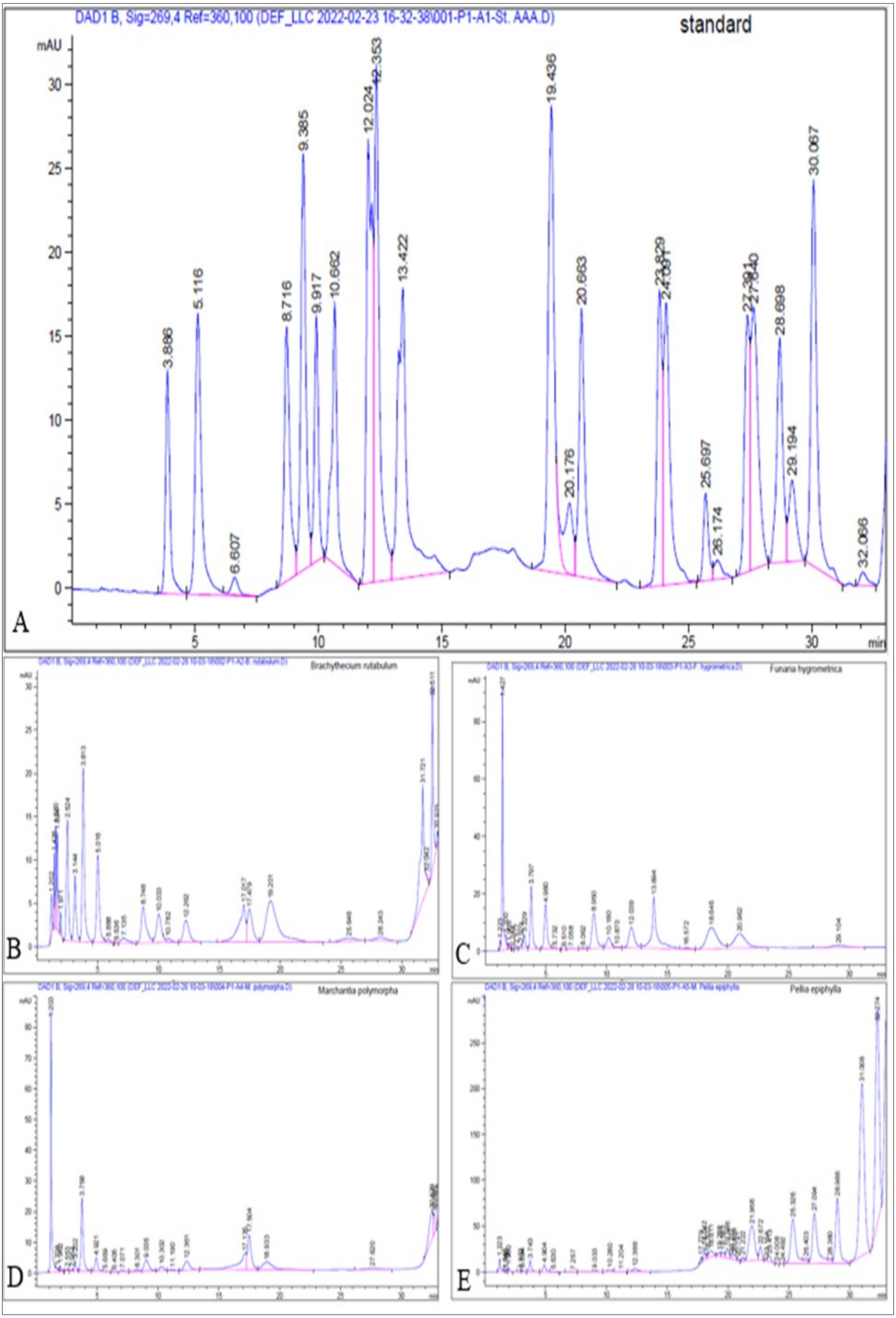

Fig. 2. High-performance liquid chromatography chromatogram of amino acids in investigated moss samples. A: standard amino acids; B: *Brachythecium rutabulum*; C: *Funaria hygrometrica*; D: *Marchantia polymorpha*; E: *Pellia epiphylla*.

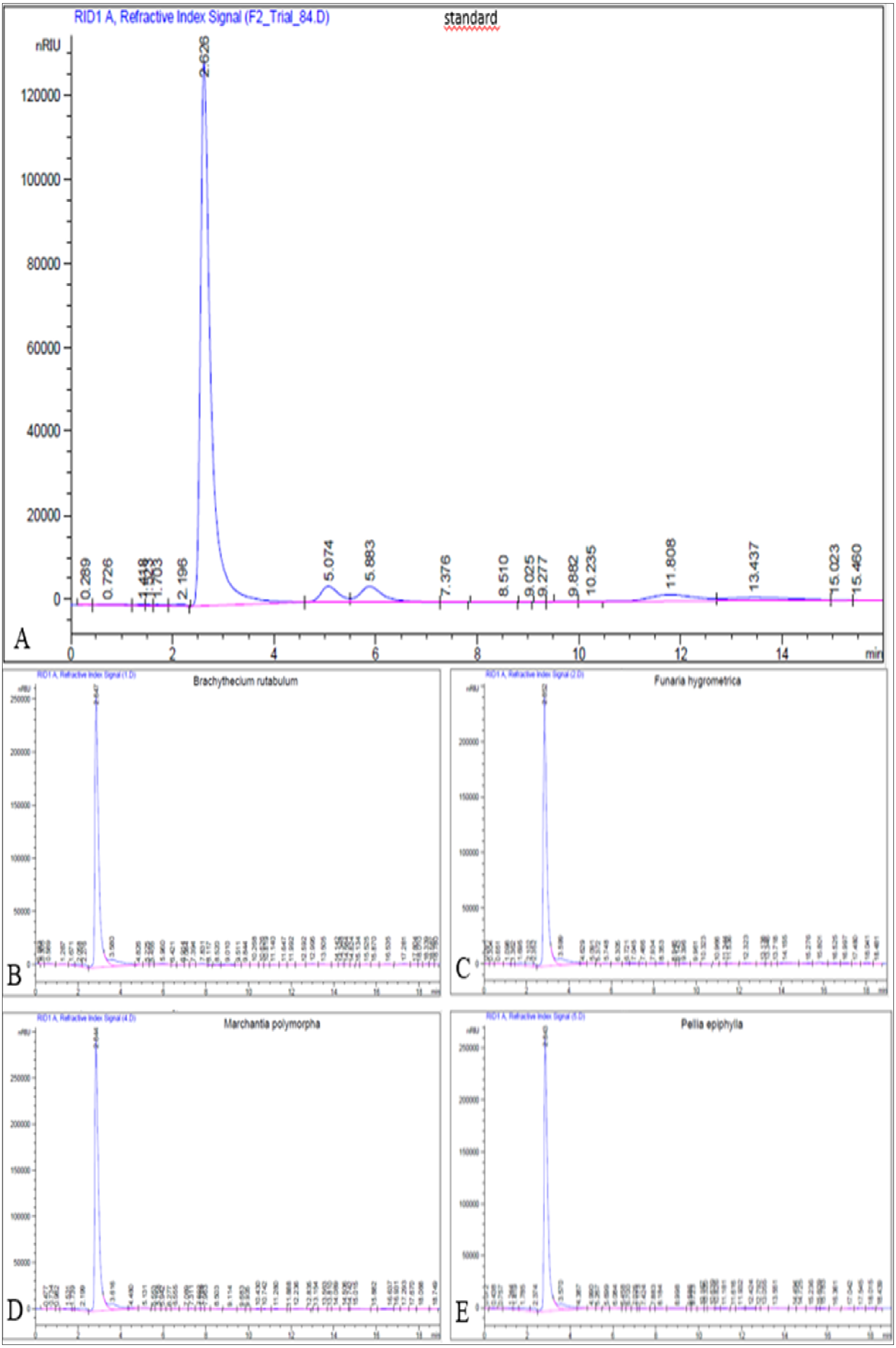

Fig. 3. High-performance liquid chromatography chromatogram of carbohydrates in investigated moss samples. A: Standard carbohydrates; B: *Brachythecium rutabulum*; C: *Funaria hygrometrica*; D: *Marchantia polymorpha*; E: *Pellia epiphylla*.

enhanced energy performance. These properties suggest that they may offer several health benefits, including anti-inflammatory and antioxidant effects, support for digestive health, aid in wound healing and revitalising energy.

Water soluble vitamins profiling

Table 4 displays the content of water-soluble vitamins (mg/g) in *B. rutabulum*, *F. hygrometrica, M. polymorpha and P. epiphylla*. Among these, *M. polymorpha* was found to contain the highest concentration of vitamins. Water-soluble vitamins include thiamine (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), pantothenic acid (vitamin B5), pyridoxine (vitamin B6), biotin (vitamin B7), folate (vitamin B9), cobalamin (vitamin B12) and ascorbic acid (vitamin C) are involved in fundamental metabolic pathways essential for the normal physiological functioning of cells (40). Some of these vitamins must be consumed regularly because they are not stored in the body, which means a constant supply is necessary to prevent deficiencies that could lead to serious health problems (41). Recent studies also indicate the importance of vitamin D in the study of the renal protective effects of *Bryophyllum pinnatum* (Lam.) Oken extract on acetaminophen-induced toxicity in albino rats (42).

An additional noteworthy finding of this study is the identification of several water-soluble vitamins (B1, B2, B3, B6, B9, B12 and C) in moss species. The presence of these vitamins further underscores the therapeutic potential of these mosses and highlights their role in various metabolic pathways that help maintain normal physiological homeostasis within cells.

Water-soluble vitamins also have important pharmacological properties for the body, in particular; lack of thiamine (B1) causes several diseases in the body. Deficiency leads to cheilosis (inflammation of lips and fissures of the mouth) and corneal vascularization. Of note, ultraviolet (UV) light can destroy riboflavin; hence it is always packaged in opaque containers, it is critical for the formation of red blood cells and deficiency can result in sideroblastic anaemia, hyperirritability, convulsions, peripheral neuropathy and mental confusion. Peripheral neuropathy is a potential side effect of isoniazid; a key drug used in treating tuberculosis and it is customary to supplement treatment with B6. Vitamin C (ascorbic acid, ascorbate) is needed for collagen growth, wound healing, bone formation, enhancing the immune system, absorption of iron, strengthening blood vessels and acting as an antioxidant (43, 44). Below is an image of a chromatogram of medicinal bryophytes (Fig. 4).

Mineral elements profiling

These medicinal mosses were also analysed for their mineral element composition, revealing the presence of 41 mineral elements, including macro-, micro- and trace elements (Table 5). The different essential elements exhibited varying concentrations across the moss species, highlighting their potential as resources for pharmacological purposes. The range of variation (mg/g DW) of all identified elements was determined. The range of variation of macroelements was (376.13–19994.39), the range of variation of microelements was (-53.97–113.55) and the range of variation of ultra microelements was (-0.858–5.794) mg/g DW. The macro elements potassium, calcium and phosphorus were found in relatively high amounts. Among the studied species, *M. polymorpha* had the highest levels of potassium (K^+) and calcium (Ca^{2+}) while *P. epiphylla* exhibited notable amounts of sulfur. The high levels of Zn, Mn and Cu in *F. hygrometrica* indicate the biological significance of these elements for enzyme systems, demonstrating their role in modulating metabolic and antioxidant functions. The mineral composition of moss samples provides a reliable basis for ecological and substrate-related analyses, while *B. rutabulum* had significant levels of boron and *M. polymorpha* had high levels of aluminum (Table 1). Lithium and strontium were the most abundant ultra-trace elements in *F. hygrometrica* and *P. epiphylla*. Traces of mercury (Hg) or tin (Sn) were not detected.

These results indicate that bryophytes may serve as potential sources of nutritionally relevant elements. Potassium is essential for heart activity and myocardial function (45), while calcium plays a critical role in various body systems, including nervous system excitability, muscle contraction, blood clotting and inhibition of anti-inflammatory responses, as well as enzyme activation (46). Iron, manganese, zinc, molybdenum, selenium, copper and other trace elements are also important for human and plant health. In addition, it activates enzymes and hormones, preventing allergies and acidosis with various anti-inflammatory effects (47).

Globally, there are established requirements for permissible levels of toxic heavy metals in bioactive food products (BFQ) derived from medicinal plants and regulations vary from country to country. In the Russian Federation, regulations limit the presence of 4 heavy metals in food products, namely Hg, Pb, As and cadmium (Cd). International hygienic food safety standards typically include seven elements: mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As), cobalt (Co), vanadium (V) and molybdenum (Mo). In many foreign countries, this number ranges from eight to ten (48).

In the Republic of Uzbekistan, the regulatory framework also sets limits for these 4 heavy metals, with arsenic not exceeding 3.0 mg/kg (49). Chemical analysis of heavy metal salts, in particular Pb and Cd, showed that their concentrations in *B. rutabulum*, *F. hygrometrica, M. polymorpha and P. epiphylla* do not exceed the limits of the above International and Republican SanPin regulations.

Table 4. Vitamin composition of some medicinal mosses

No.	Vitamins	Concentration mg/g			
		A	B	C	D
1	B-1	1.335323	0.28099	0.320776	0.096979
2	B-2	1.585239	2.83264	3.508316	1.793139
3	B-6	0.469243	1.12776	0.658517	0.962145
4	B-9	1.85781	0.716139	4.59782	4.494032
5	B-12	5.579015	2.264875	1.740243	1.983365
6	PP	0.112246	0.071713	0.034297	0.268142
7	C	4.286865	5.36664	1.192587	4.625302

A: *Bryum rutabulum*; B: *Funaria hygrometrica*; C: *Marchantia polymorpha*; D: *Pellia epiphylla.*

Table 5. Composition of chemical elements of medicinal mosses

Elements (mg/L)	A	B	C	D
Macro elements				
K 39	4584.263	7756.933	12928.094	11733.117
Ca 42	4280.671	4601.829	14456.210	19994.388
P 31	531.600	747.441	492.018	376.628
S 32	910.882	862.744	743.486	983.068
Mg 24	2569.673	2530.450	3545.342	1871.304
Fe 57	545.776	1347.771	1350.812	1051.930
Si 28	946.781	1365.283	1014.697	847.115
Al 27	814.453	2130.522	3970.341	1379.990
Na 23	713.324	983.478	509.357	390.134
Micro elements				
Zn 66	1.965	113.552	2.404	1.805
Mn 55	6.470	16.687	12.554	8.291
Co 59	0.106	0.291	0.241	0.190
Ni 60	0.466	1.083	0.886	0.866
Cu 63	0.481	1.488	0.858	0.864
B 11	12.581	4.384	6.591	4.032
Ti 48	-15.018	-3.306	-37.720	-53.973
Cr 52	0.863	2.323	1.380	1.066
Ba 138	3.361	2.767	5.688	3.270
Ag 107	0.008	0.004	0.002	0.002
Rb 85	0.454	1.957	0.490	0.704
Ultramicro elements				
Hg 202	-0.027	-0.003	-0.013	-0.027
Li 7	0.840	2.199	1.526	1.006
Be 9	0.067	0.099	0.087	0.081
V 51	0.640	1.376	1.552	1.053
Ga 69	0.608	0.545	0.983	0.587
Ge 74	0.003	0.006	0.003	0.013
As 75	0.109	0.290	0.180	0.151
Se 82	0.072	0.028	0.134	0.563
Sr 88	4.403	4.673	4.815	5.794
Zr 90	0.066	0.153	0.158	0.052
Nb 93	0.009	0.030	0.012	0.006
Mo 98	0.074	0.071	0.070	0.028
Cd 111	0.005	0.015	0.007	0.004
Sn 118	0.610	-0.047	-0.570	-0.858
Sb 121	0.034	0.021	0.004	0.010
Cs 133	0.010	0.032	0.013	0.018
W 184	0.004	0.006	0.001	0.001
Ti 205	0.001	0.002	0.002	0.002
Pb 208	0.231	0.520	0.126	0.072
Bi 209	0.004	0.003	0.004	0.001
U 238	0.018	0.025	0.017	0.015

A: *Bryum rutabulum*; B: *Funaria hygrometrica*; C: *Marchantia polymorpha*; D: *Pellia epiphylla*. In the table, some elements are below the quantitative detection limit (Ti, Hg, Sn) and the quantitative values of these elements are given with a minus (-) sign.

Fig. 4. HPLC chromatogram of vitamins in tested moss samples. A: *Brachythecium rutabulum*; B: *Funaria hygrometrica*; C: *Marchantia polymorpha*; D: *Pellia epiphylla*.

Conclusion

This study investigated the amino acid, vitamin, carbohydrate and mineral composition of 4medicinal bryophyte species and assessed their potential as sources of bioactive compounds. *Funaria hygrometrica* has a high amino acid content, while *B. rutabulum* has a high carbohydrate content. *Marchantia polymorpha* is rich in vitamins. The presence of essential elements and safe levels of heavy metals in all these species indicate their potential for therapeutic use. These findings encourage further study of mosses as important resources in natural medicine and nutrition. Also, for the first time, information was presented about the third medicinal bryophyte species in Uzbekistan, which are used in traditional medicine by peoples of the world.

Acknowledgements

The authors extend their appreciation to the Institute of Biochemistry of Samarkand State University, Uzbekistan, for their support and resources provided throughout the course of this research.

Authors' contributions

FA prepared the original draft of the manuscript. AA and MA contributed to editing and critical review of the manuscript. KZ was responsible for data curation and formal analysis. SP provided valuable input on the methodology. MK and MM contributed to manuscript writing and conducted the field survey. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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