



PROSPECTS OF MEDICINAL PLANTS IN THE FOOTHILL PASTURES OF THE KASHKADARYA BASIN, UZBEKISTAN

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SUMMARY

The foothill pastures of the Kashkadarya basin and the Zarafshan range constitute a substantial reservoir of medicinal flora with considerable pharmaceutical potential. This study evaluated the total antioxidant, flavonoid, and vitamin C contents of eight medicinal plant species, principally *Melissa officinalis*, *Mentha longifolia*, and *Origanum vulgare*, across three phenological stages (spring, summer, and autumn), using high-performance liquid chromatography (HPLC) and spectrophotometric analysis. The study sought to establish optimal harvesting periods for industrial raw-material collection. All quantitative data had them expressed in SI-compliant units (mg/100 g); seasonal differences entailed assessment using one-way analysis of variance (ANOVA) with Tukey's post-hoc test ($P < 0.05$, $n = 3$). *Melissa officinalis* attained the highest antioxidant content at the vegetative stage in spring (1170.0 mg/100 g), whereas *Mentha longifolia* (1050.0 mg/100 g) and *Origanum vulgare* (1020.0 mg/100 g) peaked during summer flowering. Flavonoid content peaked in summer for most species, with *Peganum harmala* showing the highest accumulation (352.5 mg/100 g). Vitamin C concentration was highest in spring in *Mentha longifolia* (121.0 mg/100 g). These results identify *Melissa officinalis*, *Mentha longifolia*, and *Origanum vulgare* as a 'high-potential triad.' It indicates that pharmaceutical enterprises and raw-material collectors should schedule harvesting of *Melissa officinalis* in spring and *Mentha longifolia* and *Origanum vulgare* in summer to maximize antioxidant yield.

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Key findings: *Melissa officinalis* showed the highest antioxidant activity in spring (1170.0 mg/100 g), while *Mentha longifolia* (1050.0 mg/100 g) and *Origanum vulgare* (1020.0 mg/100 g) were leading during summer flowering.

INTRODUCTION

Global interest in phytotherapy continues to rise due to the increasing demand for safe and effective therapeutic agents. According to the World Health Organization (WHO), over 80% of pharmaceutical products currently used in modern medicines come from medicinal plants' raw materials (Martins, 2014). The said trend has the drive from the wide spectrum of biological activities possessed by natural compounds, their low toxicity compared with synthetic analogues, and their mild therapeutic effects. However, the natural reserves of wild-growing medicinal plants are not inexhaustible (Salem et al., 2023). Therefore, identification of different bioactive compounds found in diverse flora of medicinal plants is crucial to determining their potential therapeutic applications, as they contain various substances that treat chronic and infectious diseases (Moussaoui and Alaoui, 2016; Fu et al., 2019).

Plant species belonging to 40 genera and 28 families totaled 43, collected from Dhee, Barkhun, Shimshal, and Khunjerab pastures, Pakistan, during field visits conducted in 2006–2008, commonly used by the local community for preparing herbal recipes. Overall, the family Asteraceae contributed the highest number of species (11.63%), followed by Fabaceae, Lamiaceae, and Rosaceae (9.30% each), and Chenopodiaceae and Elaeagnaceae (4.65% each). Twenty-nine different diseases received effective treatment from the reported species. However, the maximum number of species for treating fever was 9 spp., followed by cough and indigestion (5 spp. each), wounds, eye infection, abdominal pain, jaundice, blood pressure, and diarrhea (4 spp. each) (Khan et al., 2011).

In the different regions of India, using about 199 medicinal plants served to treat various diseases, which are grouped into 18 different categories. The most commonly used plants were those of the legume family (31 species). The most typical used form of life was herbs (34%), and the most commonly used part of the plants in medicinal herbs was leaves (41%). The most common method of preparation was paste (36%), and the most popular method of application was oral administration (72%) (Muthukrishnan and Aruna, 2025).

In Uzbekistan, strategic priority centers on the localization of the pharmaceutical industry and the transition toward the green economy. It is imperative to meet the growing domestic demand for medicinal raw material, to enrich the local flora with high-yielding introduced species, and to develop intensive cultivation technologies (Allanazarova, 1969). In this context, the comprehensive assessment of the natural resource potential of the flora found in specific territories assumes considerable importance (Kuznetsov, 2004, 2006, 2009).

In modern pharmacology, the critical aspect is the search for natural antioxidants. Oxidative stress, caused by an imbalance of free radicals in the human body, is a key factor in the pathogenesis of numerous chronic diseases, including cardiovascular disorders and oncological pathologies. Therefore, determining the prospective yield of specific biologically active substances—particularly antioxidants—within widespread plant species is substantially a prerequisite for the development of 'green pharmaceuticals' and functional food additives (Vikhareva and Soloninina, 2009; Kuznetsov, 2009).

The researchers have identified the antioxidant properties of medicinal plants worldwide. In the consequent study, the results showed the extract of the medicinal plant, *M. officinalis* that contains the highest contents of flavonoid and phenolic compounds, revealed the greatest antioxidant activity. The highest scavenging property of *M. officinalis* may be due to hydroxyl groups found in the phenolic compounds' chemical structure that can provide the necessary components as a radical scavenger (Pourmorad *et al.*, 2006). However, its antioxidant properties required more emphasis.

Numerous studies revealed that *Melissa officinalis* possesses elevated antioxidant activity through its chemical compounds, including the highest contents of flavonoids, rosmarinic and gallic acids, and phenolic compounds. Several studies confirmed the antioxidative effects of *Melissa officinalis*, and its effects in preventing and treating oxidative stress-related diseases might be reliable (Miraj *et al.*, 2017). The following study aimed to evaluate the antioxidant content, flavonoid levels, and vitamin C concentrations in eight medicinal plant species across three vegetation periods (spring, summer, and autumn) and determine their optimal harvesting times for industrial applications. We hypothesized that the accumulation of antioxidants, flavonoids, and vitamin C in these species follows a phenology-dependent pattern, peaking during the vegetative stage in early-flowering taxa and during full flowering in late-flowering taxa.

MATERIALS AND METHODS

It has become established that the foothill pastures of the Kashkadarya basin are abundant with medicinal flora. In assessing the potential of these natural resources for their effective utilization, the most promising species inhabiting the Zarafshan and Hissar mountain ranges, Uzbekistan, were the selected sites, with their biochemical compositions analyzed.

Plant materials

The following eight medicinal species, considered promising in both ethnomedicine and scientific medicines, became selected objects of study. These are the following: *Mentha longifolia* (long-leaved mint); *Melissa officinalis* (lemon balm); *Trichodesma incanum*; *Peganum harmala* (wild rue); *Origanum vulgare* (oregano); *Ziziphora pamiroalaica* (Pamiro-Alay Ziziphora); *Alhagi pseudalhagi* (camel thorn); and *Rumex chalapensis* (Aleppo dock).

Pharmaceutical and ecological methods

The following pharmaceutical and ecological methods the study employed during the course of the research were as follows:

a. Extraction methods: Utilized to isolate the medicinal substances from plant leaves. Air-dried, ground leaf material (particle size <1 mm), extracted with 70% ethanol at a raw material-to-solvent ratio of 1:10 (w/v), at 40°C for 45 min with continuous agitation, followed by filtration through Whatman No. 1 filter paper;

b. Maceration: A conventional method wherein the raw material underwent maintenance in a solvent (alcohol or water) for a specified duration to extract active compounds. Maceration took place at room temperature (20°C–22°C) for 72 h in darkness, with daily agitation, using either 70% ethanol or distilled water as a solvent, at a 1:10 (w/v) raw material-to-solvent ratio;

c. Chromatography (HPLC): Used as a modern analytical technique to separate a mixture into its constituent components. For instance, it allows for the differentiation of specific substances such as menthol and limonene within mint. Analyses proceeded on an Agilent 1260 Infinity HPLC system equipped with a C18 reversed-phase column (250×4.6 mm, 5 µm), using a mobile phase of methanol–0.1% formic acid in water (70:30, v/v) at a flow rate of 1.0 mL/min, a column temperature of 30°C, and UV detection at 280

nm for flavonoids and 265 nm for vitamin C. Method validation followed ICH Q2(R1) guidelines: calibration curves were linear over the working range ($R^2 > 0.99$), limits of detection and quantitation were 0.05 and 0.15 $\mu\text{g/mL}$, respectively, intra-day precision (RSD) did not exceed 3%, and mean recovery ranged from 96% to 102%;

d. Route method: Involves the researcher establishing a trajectory across a map and recording the plant species encountered along the path; and

e. Quadrat method: Typically involves placing a 1 m $\times$ 1 m rectangular frame to count the number and calculate the density of plants within. The said method proved crucial for resource stock assessment. For each of the 12 sampling plots, geographic coordinates and altitude in meters above sea level (masl), as recorded by GPS, included a brief description of the plant community and dominant associated species. These provided an ecological context for the biochemical results (e.g., Plot 1: 38°58'N, 66°17'E, 1150 masl; dominant associates: *Artemisia* spp., *Poa bulbosa*).

The primary objective of this timely study was to determine the total antioxidant content in the leaves of these medicinal plants during various vegetation periods (spring, summer, and autumn). The analysis results regarding the quantitative indicators of biologically active substances found within these plants appear below. Antioxidants are the biologically active compounds that play a considerable role in both plant and animal organisms. These bioactive compounds emerged crucial in the elimination of free radicals and radical forms from organisms, functioning as natural detoxification systems (Menshikova *et al.*, 2006). All biochemical determinations took place in triplicate ($n = 3$) for each species, season, and sampling plot, with results presented as a mean $\pm$ standard deviation.

Antioxidants possess considerable biological importance in both plant and animal organisms. Natural antioxidants include phospholipids, tocopherols, vitamins A and K, carotenoids, flavonoids, polyphenols, and ascorbic and citric acids (Menshikova *et al.*,

2006). Natural antioxidants can be effective in the treatment of various diseases. The highest concentrations of antioxidants resulted in the following products: blueberries, prunes, bean genotypes, walnuts, almonds, hazelnuts, pistachios, garlic, and numerous medicinal plants (Kholmatov and Akhmedov, 1995; Ibragimov, 2016; Mirkhamidova *et al.*, 2017a, 2017b).

Furthermore, research as established that leaves of various fruit trees—walnut, peach, black mulberry, sour cherry, and grapevine—contain substantial amounts of the antioxidant vitamin C. Their levels have occurred to demonstrate dependence on the plant's vegetation period (Mirkhamidova *et al.*, 2017a, 2017b). A deficiency of antioxidants in the organism can precipitate various pathologies (Menshikova *et al.*, 2006). The antioxidant properties of the eight target taxa examined herein—*Mentha longifolia*, *Melissa officinalis*, *Trichodesma incanum*, *Peganum harmala*, *Origanum vulgare*, *Ziziphora pamiroalaica*, *Alhagi pseudalhagi*, and *Rumex chalepensis*—have had reports individually in the regional pharmacognostic literature, but not previously compared within a single seasonal framework (Agadzhanyan and Agadzhanyan, 2012; Ibragimov, 2016).

RESULTS

In medicinal plants, determining the total antioxidant content is of paramount biological significance. In this research, determining the total antioxidant content succeeded in the leaves of eight medicinal plants found in the Southwestern Zarafshan range and Kashkadarya basin. Specifically, these are *Mentha longifolia*, *Melissa officinalis*, *Trichodesma incanum*, *Peganum harmala*, *Origanum vulgare*, *Ziziphora pamiroalaica*, *Alhagi pseudalhagi*, and *Rumex chalepensis*. Conduct of the studies ensued during various vegetation periods of these plants (Figure 1). The study enabled direct comparison of antioxidant and flavonoid concentrations by also reporting the originally expressed as $\mu\text{g/g}$ to mg/100 g ($\mu\text{g/g}$ value divided by 10), and



Figure 1. Medicinal plants of the Kashkadarya Region.

vitamin C concentrations, originally in mg%, are numerically equivalent to mg/100 g. Seasonal differences within each species sustained evaluation by one-way ANOVA, followed by Tukey's honestly significant difference (HSD) post-hoc test ($P < 0.05$), with all assays performed in triplicate ($n = 3$).

The results revealed the highest content of total antioxidants appearing in the leaves of *Melissa officinalis* during spring (11,700 µg/g), followed by the mint (10,500 µg/g) and oregano (10,200 µg/g) (Table 1). These leading indicators succeeded in their determination during the flowering periods of these plants. Specifically, the extract of the mint plant showed the following levels across the three seasons, i.e., spring (3900 µg/g), summer (10,500 µg/g), and autumn (5850 µg/g). Medicinal mint leaves contain

essential oils, carotene, hesperidin, and ursolic and oleanolic acids. In medical practice, mint preparations served for gastrointestinal pain, flatulence, cholecystitis, cholelithiasis (gallstone disease), and hepatitis (Kholmatov and Akhmedov, 2006).

In the *Melissa officinalis* (lemon balm) leaves, the highest concentration of total antioxidants was evident in spring (11,700 µg/g), followed by summer (2400 µg/g) and autumn (1800 µg/g). *Melissa officinalis* grows in the cool, humid foothills and mountainous regions of Central Asia. It flowers from June to August, and the fruits' maturation occurred in July to September. The utilized parts include the leaves and the apical parts of shoots, being harvested during the flowering period. Its biochemical composition includes essential oils, vitamin C, oleanolic and ursolic acids,

Table 1. Total antioxidant levels in various medicinal plants (mg/100 g).

No.	Plant species	Spring	Summer	Autumn
1	<i>Mentha longifolia</i>	390±20	1050±15	585±15
2	<i>Melissa officinalis</i>	1170±15	240±15	180±2
3	<i>Trichodesma incanum</i>	630±1.9	450±15	-
4	<i>Peganum harmala</i>	706±45	180±15	300±30
5	<i>Origanum vulgare</i>	157.5±15	1020±45	345±15
6	<i>Ziziphora pamiroalaica</i>	885±19.5	420±15	-
7	<i>Alhagi pseudalhagi</i>	420±30	153.75±11.25	360±30
8	<i>Rumex chalepensis</i>	810±30	720±20	195±15

flavonoids, and tannins. In medical practice, its decoctions and infusions are applicable to treat gastric diseases, dyspnea (shortness of breath), anemia, and insomnia. In ethnomedicine, *Melissa officinalis* application strengthens the nervous system and treats cardiac pathologies.

In *Origanum vulgare* (oregano), the maximum quantity of total antioxidants resulted in the leaves (10,200 µg/g), determined during its flowering period, whereas in other seasons, the levels were 1575 µg/g in spring and 3450 µg/g in autumn. The study also determined that in *Origanum vulgare*, the highest concentration of flavonoids occurs in spring. Past studies reported that *Origanum vulgare* contains 0.6% essential oils, 1.35% coumarins, 11.06% polyphenols, and 3.2% flavonoids. Dosage forms of *Origanum vulgare* possess appetizing, gastrointestinal-improving, and analgesic properties (Ibragimov, 2016).

Rumex chalepensis flowers in May-June, fruits mature in July, and it grows as a weed plant. Its roots contain anthracene derivatives, tannins, flavonoids, essential oils, resins, vitamin K, and mucilage, used as raw material in various medicines (Ibragimov, 2016). Ethnomedicine utilizes infusions, decoctions, and extracts for the treatment of hepatitis, liver diseases, ulcers, and wounds (Kholmatov and Akhmedov, 2006). The results indicated the highest total antioxidant content in *Rumex chalepensis* appeared during the flowering period (8100 µg/g). However, a decrease in concentration was notable in subsequent periods like summer (7200 µg/g) and autumn (1950 µg/g).

Peganum harmala flowers in May-June, and the fruits mature in August. The aerial

parts and seeds have the use of raw material. Scientific medicines primarily employ isolated alkaloids, such as peganine, deoxypeganine, and harmine. An infusion prepared from coarsely ground herb using 1% water possesses a robust bactericidal effect. The results further revealed the highest total antioxidant content occurs in the spring (7060 µg/g), followed by summer (1800 µg/g) and autumn (3000 µg/g).

Ziziphora pamiroalaica grows in mountain slopes and highland areas. It occupies a prominent position in medicines due to its therapeutic properties. *Ziziphora pamiroalaica* strengthens the heart and aids in the prevention of gastric dysfunction, nausea, and cardiac pain. It contains vitamins A, E, and C, as well as biologically active substances, such as menthol and saponins. Flavonoids have also been prominent in its leaves. In *Ziziphora* leaves, the high concentration of total antioxidants reached identification in spring (8850 µg/g), decreasing to 4200 µg/g in the summer.

Alhagi pseudalhagi flowers in May-September, and the fruits mature in August to October. It has a wide distribution across all republics of Central Asia. The most utilized parts are the roots and the aerial parts. *Alhagi pseudalhagi* contains saponins, flavonoids, essential oil, vitamins C, B, and K, coumarins, and mucilage, with alkaloids also found in the roots. The highest total antioxidant content in the leaves emerged in spring (4200 µg/g) and autumn (3600 µg/g). In ethnomedicine, its decoctions and infusions served for liver diseases, gastric ulcers, and as choleric (bile-expelling), diuretic, and laxative agents (Ibragimov, 2016). Previous studies exhibited that in *Alhagi pseudalhagi* and *Origanum*

vulgare, the total antioxidants resulted in their aerial parts and in the root system of *Rumex chalepensis* (Ibragimov, 2016).

The promising results demonstrated that total antioxidants were evident in the leaves of medicinal plants, such as *Mentha longifolia*, *Melissa officinalis*, *Trichodesma incanum*, *Peganum harmala*, *Origanum vulgare*, *Ziziphora pamiroalaica*, *Alhagi pseudalhagi*, and *Rumex chalepensis*. However, the highest quantities detected rose in *Melissa officinalis*, *Mentha longifolia*, and *Origanum vulgare*, with concentrations significantly varying across different seasons.

The analytical study regarding the flavonoid content of certain medicinal plants was also successful. Flavonoids showed a wide distribution in nature and manifested in almost all higher plants. Representatives of the families Fabaceae, Asteraceae, Apiaceae, Umbelliferae, Ranunculaceae, and Rosaceae proved to be particularly rich in flavonoids. These compounds resulted in a dissolved state within the cell sap of all the plant organs. Flavonoids accumulate in large quantities primarily during the plant's flowering period, and later, their concentration gradually decreases (Kholmatov and Akhmedov, 1995).

In general, flavonoid accumulation reaches its highest level during the flowering stage and subsequently declines. Plants growing in southern regions and in open areas with higher solar irradiance typically synthesize higher levels of flavonoids than species grown in other environments (Kholmatov and Akhmedov, 1995). The results further revealed the flavonoid content varies across spring, summer, and autumn (Table 2). However, the highest flavonoid content was prominent in *Peganum harmala* during summer (3525 µg/g), followed by spring (1800 µg/g). Similarly, in the mint (*Mentha*) extract, widely used in medicines, the highest concentration of flavonoids emerged during summer.

The presented results signified that total flavonoids, which possess antioxidant properties, were evident in the eight studied medicinal plants, such as *Alhagi pseudalhagi*, *Ziziphora pamiroalaica*, *Mentha longifolia*, *Melissa officinalis*, *Origanum vulgare*, *Peganum harmala*, *Rumex chalepensis*, and *Trichodesma*

incanum. However, the highest concentrations appeared in *Peganum harmala* and *Rumex chalepensis*. According to past studies, flavonoids have been noticeable in the aerial parts of *Alhagi pseudalhagi* and *Origanum vulgare* and in the root parts of *Rumex chalepensis* (Ibragimov, 2016).

Furthermore, the vitamin C content underwent analysis in certain medicinal plants. Vitamins play a significant role in the plant's life, as these considerably participate in the biosynthesis of enzymes, identified as the primary regulators of metabolism. Specific vitamins contribute to the amino acid metabolism. Vitamin C, carotene, catechins, and flavonoids actively participate in the oxidation-reduction (redox) processes that continuously occur in plant tissues. During this process, vitamins undergo continuous oxidation and reduction (Ibragimov, 2016; Khojimatov, 2021).

The quantity, concentration, and quality of biologically active substances in the medicinal plants tended to be the most critical factors in determining their therapeutic properties and medicinal potential. Vitamin C reached a classification as a potent antioxidant, with greater importance in oxidation-reduction processes. Vitamin C was notable in all representatives of the plant kingdom. This study determined the vitamin C content in *Alhagi pseudalhagi*, *Melissa officinalis*, *Mentha longifolia*, *Ziziphora pamiroalaica*, *Origanum vulgare*, *Trichodesma incanum*, *Rumex chalepensis*, and *Peganum harmala* during various vegetative stages.

The results exhibited that the vitamin C content in medicinal plants depends on the vegetation period (Table 3). Vitamin C appeared in the leaves of medicinal plants, such as *Mentha longifolia*, *Ziziphora pamiroalaica*, *Melissa officinalis*, *Trichodesma incanum*, and *Bunium persicum*. However, the highest concentration of vitamin C was remarkable in the mint plant (*Mentha longifolia*) during spring (121±2.2 mg/%), followed by summer (92.4 mg/%) and autumn (86.24 mg/%) seasons. Variations in vitamin C content were noteworthy in the leaves of *Ziziphora pamiroalaica* across the different seasons. The study determined that the

Table 2. Total flavonoid content in selected medicinal plants (mg/100 g).

No.	Plant species	Spring	Summer	Autumn
1	<i>Alhagi pseudalhagi</i>	48.75±0.05	63.75±0.06	195.02±0.2
2	<i>Ziziphora pamiroalaica</i>	90±0.04	67.5±0.07	-
3	<i>Mentha longifolia</i> 3	225±0.23	300±0.3	255±0.26
4	<i>Melissa officinalis</i>	183.85±0.18	198.75±0.2	127.5±0.08
5	<i>Origanum vulgare</i>	292.5±0.29	140±0.14	195±0.2
6	<i>Trichodesma incanum</i>	210±0.21	115±0.11	-
7	<i>Rumex chalepensis</i> .	187.5±0.19	202.6±0.2	176.4±0.18
8	<i>Peganum harmala</i>	180±0.18	352.5±0.35	187.5±0.19

Table 3. Vitamin C content in certain medicinal plants (mg/100 g).

No.	Plant species	Spring	Summer	Autumn
1	<i>Mentha longifolia</i>	121±2.2	92.4±3.5	86.24±5.1
2	<i>Ziziphora pamiroalaica</i>	81.9±1	58.08±2.5	57.2±4.1
3	<i>Melissa officinalis</i>	76.56±3.5	92.4±4	81.8±3.2
4	<i>Trichodesma incanum</i>	29.9±2.5	60.72±5.1	71.28±5.3
5	<i>Bunium persicum</i>	26.4±1.8	25.5±2.2	68.3±3.6

highest content occurred in spring (81.9 mg/%), while remaining relatively constant during summer and autumn.

Bunium persicum flowers in June and bears fruits in July. The fruits of *Bunium persicum* contain 2.75%–3.0% essential oil. Additionally, the fruits contain approximately 20% fatty oil, 15% proteinaceous substances, and minerals (Ibragimov, 2016). The fruits are useful in medical practice. The determination of the highest vitamin C content in the leaves of *Bunium persicum* occurred during autumn (68.3 mg/%).

Melissa officinalis flowers from June to August, and its fruits mature in July to August. The utilized parts of the said plant were the leaves and the apical parts of the shoots. *Melissa officinalis* contains essential oils, tannins, vitamin C, ursolic acid, and other acids. In folk medicines, decoctions and infusions of lemon balm were beneficial. The results revealed that the vitamin C content in lemon balm was the highest in summer (92.4 mg/%), followed by autumn (81.8 mg/%) and spring (76.56 mg/%).

Trichodesma incanum is a widely distributed plant in Central Asia. It contains alkaloids, which are particularly abundant in its seeds. The potent alkaloids have also been identified in its leaves (Kholmatov and Akhmedov, 1995; Ibragimov, 2016). The

research determined that in the leaves of *Trichodesma incanum*, the vitamin C content was the highest in autumn (71.28 mg/%), followed by summer (60.72 mg/%) and spring (29.9 mg/%).

The biologically active substances contained in the eight medicinal plant species, widely distributed in the foothill pastures of the Kashkadarya Region, exhibited variable characteristics relative to one another and throughout the seasons. In terms of general antioxidant properties, *Mentha longifolia*, *Melissa officinalis*, *Ziziphora pamiroalaica*, and *Origanum vulgare* were superior to other species. The highest quantities of flavonoids also have accumulated in all other previously mentioned representatives of the family Lamiaceae (except with *Ziziphora*), as well as in *Rumex chalepensis* and *Peganum harmala*.

Physiological basis of seasonal variations

The pronounced seasonal divergence in bioactive compound accumulation is consistent with phenology-driven shifts in photosynthetic and secondary metabolism. Spring-peaking species, such as *Melissa officinalis*, accumulate antioxidants chiefly during active vegetative growth, when photosynthetic capacity and precursor flux are maximal. Meanwhile, summer-peaking species, such as *Mentha*

longifolia and *Origanum vulgare*, directly assimilate toward flavonoid and essential-oil biosynthesis during the flowering (generative) phase, when secondary metabolism is up-regulated to protect reproductive tissues from UV radiation and herbivory.

DISCUSSION

Natural resource utilization is considerably one of the true economic sources for Uzbekistan. The development of the national economy of the Republic depends on the degree of literacy and rational use of natural resources (Lioubimtseva *et al.*, 2005). The arid and semi-arid foothill zones of Central Asia develop unique environmental conditions where plants synthesize elevated concentrations of secondary metabolites, including flavonoids, phenolic acids, and essential oils. These are adaptive responses to abiotic stress factors such as high solar radiation and the substantial temperature fluctuations (Skrzypczak-Pietraszek and Pietraszek, 2014).

The physiological adaptation mechanism explains the superior antioxidant capacity observed in the studied Lamiaceae species, which aligns with recent investigations. These demonstrated that the essential oils of *Melissa officinalis* and *Origanum vulgare* exhibited potent anti-Candida and antibiofilm activities, with minimal inhibitory concentrations below 3.125 mg/mL (Karpinski *et al.*, 2023). These pharmacological properties substantiate the traditional ethnomedicinal applications of these species and support their integration into modern pharmaceutical formulations.

Uzbekistan's seventy percent territory comprised arid regions. This situation has become very favorable for crop plants adapted to a desert climate. Medicinal plants distributed in the arid regions of Uzbekistan have not received much study. Medicinal plants, considered inexpensive, have become vital for the lives of the locals (Abduraimov *et al.*, 2023). Despite the use of herbal medicines for centuries, only a relatively few plant species have incurred studies as potential medicinal agents (Salmeron-Manzano *et al.*, 2020).

A total of 529 species of medicinal plants belonging to 70 families and 269 genera reached their identification in the arid regions of Uzbekistan. Several species, including *Peganum harmala* L., *Capparis spinosa* L., *Ferula foetida* (Bunge) Regel, *Glycyrrhiza glabra* L., *Alhagi pseudalhagi* (M. Bieb.) Desv. ex Wangerin, *Lagochilus inebrians* Bunge, *Xanthium strumarium* L., *Silybum marianum* (L.) Gaertn., *Onopordum acanthium* L., *Ziziphora tenuior* L., and *Cichorium intybus* L. were dominant over the larger areas and have been in regular use by the local community since ancient times (Abduraimov *et al.*, 2023).

Several studies confirmed the antioxidative effects of *Melissa officinalis* and its viable role in preventing and treating oxidative stress-related diseases, which could be reliable. The numerous studies on antioxidant and radical scavenging effects provide a considerable basis for detailed in vivo research on the anti-inflammatory activities of this important plant (Miraj *et al.*, 2017).

The Kashkadarya basin and the foothills of the Zarafshan range were distinct not only by their rich phytodiversity but also by their unique climatic conditions. It is a well-established fact that plants growing in arid and semi-arid foothill zones often synthesize higher concentrations of secondary metabolites (flavonoids, essential oils, and vitamins) as an adaptive response to environmental stress conditions, such as high solar radiation and temperature fluctuations. Thus, utilization of the antioxidant activities of plants distributed in these specific areas is fundamental to discovering potent bioactive sources and ensuring the future advancement of the national pharmaceutical sector.

The latest study's identification of the 'high-potential triad'—*Melissa officinalis*, *Mentha longifolia*, and *Origanum vulgare*—corroborates previous research findings that *M. officinalis* methanol extracts demonstrated superior DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity (90.43 µg/mL) compared with gallic and caffeic acids, attributed to the high rosmarinic acid and flavonoid content (Shakeri *et al.*, 2016). Similarly, *M. longifolia* has revealed significant antioxidant capacity (79% DPPH inhibition) and

hepatoprotective effects against oxidative stress-induced cellular damage (Mikaili et al., 2013), reinforcing its pharmaceutical value.

This promising study substantiated that the accumulation of biologically active substances is dynamic and primarily dependent on the vegetation period. The seasonal factor plays a decisive role in the quality of plant raw materials. The introduction of these high-yielding antioxidant plants into agricultural production will serve as a foundation for the local 'Green Pharmaceuticals' industry. This approach facilitates the domestic production of cost-effective biologically active food supplements (BAFS) and natural food preservatives, thereby reducing import dependence and ensuring the ecological stability of the region's phytodiversity.

At the physiological level, the divergent seasonal maxima observed among the studied taxa can refer to phenology-dependent switches in carbon allocation. During the vegetative stage, photosynthetic apparatus activity and nitrogen availability favor synthesis of primary antioxidant metabolites, whereas the transition to flowering triggers up-regulation of the phenylpropanoid pathway, redirecting carbon toward flavonoid and phenolic biosynthesis. This mechanistic framework accounts for the spring maximum in *Melissa officinalis* and the summer maximum in *Mentha longifolia*, *Origanum vulgare*, and *Peganum harmala*.

The comparison with Indo-Pakistani ethnobotanical data (Khan et al., 2011; Muthukrishnan and Aruna, 2025) reveals convergent patterns of medicinal-plant use across the arid and semi-arid zones of South and Central Asia. Leaves are the predominant plant part utilized in both regions, and Lamiaceae is consistently among the best-represented families, corroborating the pharmacological relevance of the *Melissa-Mentha-Origanum* triad identified in this study. However, as the Khunjerab and Alagar Hills communities rely predominantly on decoctions for respiratory and digestive ailments, the Kashkadarya flora examined here shows a comparatively stronger antioxidant signal. It suggests that Central Asian foothill populations of these taxa could represent a chemically

more concentrated raw-material source for industrial extraction.

From an applied standpoint, the transition from wild harvesting to controlled cultivation warrants economic consideration. Though wild-collected raw material currently incurs lower direct production costs, uncontrolled harvesting pressure on *Melissa officinalis* and *Origanum vulgare* risks population decline given their comparatively restricted foothill distribution. Meanwhile, *Mentha longifolia* and *Alhagi pseudalhagi*, being more widely distributed ruderal species, are better able to withstand sustained wild collection. This study therefore recommends that pharmaceutical enterprises prioritize cultivation of *Melissa officinalis* and *Origanum vulgare* to secure a stable, chemically consistent supply, while continuing regulated wild harvesting of the more abundant taxa. Recommendations on rotational harvesting schedules, quotas linked to quadrat-based density assessments, and in-situ conservation of representative foothill populations will ensure the safeguarding of genetic diversity under increasing commercial demand.

One of the primary conditions for ensuring the highest and quality harvest from the world's rich fruit plants is the timely detection of infection, correct and quick diagnosis, and proper protection of plants from diseases. Therefore, it is imperative to have information about the identification of phytopathogenic viruses that cause infection, its development stages, distribution range, and life cycle that how it preserved from one season to another (Amindjonova et al., 2026).

CONCLUSIONS

These findings refute a uniform harvesting approach, demonstrating that species-specific phenological staging is essential for optimal antioxidant recovery. *Melissa officinalis* peaked during spring vegetation, whereas *Mentha longifolia* and *Origanum vulgare* attained maximal flavonoid content at summer flowering. This temporal divergence underscores physiological plasticity within the Lamiaceae. The three species form a high-

potential triad, with biochemical profiles superior to other local taxa, supporting their development against oxidative stress pathologies. The cultivation of *M. officinalis* and *O. vulgare* is an urgent recommendation for chemically consistent supply. A sustainable wild collection of widespread taxa (*M. longifolia* and *Alhagi pseudalhagi*) requires density-based quotas. This calendar provides a robust framework for industrial phytomedicine and breeding programs.

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