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DETERMINATION AND ANALYSIS OF MACRO-ELEMENTS, VITAMINS, AND FLAVONOIDS IN THE LEAVES OF PAULOWNIA AND ROSMARINUS PLANTS

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Abstract
This scientific study focuses on the determination and comprehensive analysis of macroelements, water-soluble vitamins, and flavonoid in the leaves of **Paulownia** and **Rosmarinus officinalis** (commonly known as rosemary), two plant species introduced and cultivated in the Fergana region of Uzbekistan. The main objective of this research is to examine the chemical composition of these plants using advanced analytical techniques and to assess their potential applications in pharmaceutical, nutraceutical, and food industries as sources of biologically active compounds.
The elemental composition of the plant leaves was investigated using **Inductively Coupled Plasma Optical Emission Spectroscopy (I CP-OES)**. This modern and highly sensitive analytical method enables the detection and quantification of various macro and micro-elements in complex biological matrices. The results revealed the presence of essential macro-elements including **calcium (Ca), potassium (K), phosphorus (P), magnesium (Mg), and sodium (Na)** in both plant species. Paulownia leaves were particularly rich in calcium and potassium (68,000 mg/kg and 22,000 mg/kg, respectively), while Rosmarinus leaves

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demonstrated notably high concentrations of potassium and magnesium (64,000 mg/kg and 14,000 mg/kg, respectively). These elements play vital physiological roles in both plant growth and human health. For instance, potassium is crucial for cardiovascular and muscular functions, while calcium is essential for bone health and metabolic processes.

Further, the study examined the content of **water-soluble vitamins** using **High-Performance Liquid Chromatography (HPLC)**. This technique is recognized for its accuracy and efficiency in identifying and quantifying low concentrations of organic compounds such as vitamins. The vitamins detected in both Paulownia and Rosmarinus leaves included **vitamin B1 (thiamine), B2 (riboflavin), B3 (niacin or PP), B6 (pyridoxine), B9 (folic acid), and vitamin C (ascorbic acid)**. Among these, **folic acid (B9)** was found in the highest concentration—23.57 mg/kg in Paulownia and 19.61 mg/kg in Rosmarinus—followed by riboflavin (B2). These vitamins are essential micronutrients involved in numerous metabolic functions such as energy production, nervous system support, red blood cell formation, and immune response regulation. The high levels of folic acid are particularly beneficial for pregnant women, individuals with cardiovascular conditions, and those with weakened immune systems.

Keywords: Macro-elements, inductively coupled plasma optical emission spectroscopy (ICP-OES), vitamins, thiamine (B1), riboflavin (B2), pyridoxine (B6), folic acid (B9), nicotinic acid (PP) B3, ascorbic acid (C).

INTRODUCTION

Paulownia (Paulownia spp.) is a tree belonging to the Paulowniaceae family. Native to China, Paulownia species have been used as agroforestry trees for over 2600 years due to their numerous positive traits and versatile applications [1]. Historical records dating back to ancient times mention Paulownia, and it has been part of Japanese tradition since the 2nd century CE. Paulownia grows rapidly, has broad, heart-shaped deciduous leaves, and blooms with fragrant, tubular flowers in purple or pink hues before leafing [2]. The tree can reach

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heights of 25–30 meters depending on environmental conditions [3]. Its leaves contain various macro and microelements, vitamins, proteins, and flavonoids. Paulownia is one of the most exploited medicinal plants in traditional medicine due to the medicinal properties of its various parts [4–6].

Rosmarinus officinalis L. (commonly known as rosemary) is an evergreen shrub rich in essential oils and belongs to the Lamiaceae family. It can grow up to 1.5–2 meters tall and is native to the Mediterranean region [2]. Cultivated and used for more than 2000 years, it is widely grown in Spain, France, Algeria, Tunisia, Yugoslavia, and India as a key essential-oil crop. It also occurs in parts of Turkey and Lebanon [3]. Its essential oil contains pinene, cineole, borneol, and camphor, and it is used in both the perfumery and food industries. Scientific studies suggest it has potential as a medicinal plant and natural preservative [7]. Dried rosemary is widely used to add flavor and aroma in international cuisines.

Flavonoids are a structurally diverse group of polyphenolic compounds widely distributed in nature, with over 8,000 types identified [8]. Their health benefits are mainly attributed to their antioxidant activity [9]. Flavonoids support immune function, enhance lymphocyte activity, reduce radiation-induced immune suppression, and protect DNA from damage and mutation [10].

Materials and Methods

Mineral Composition Analysis:

Leaf samples of Paulownia and Rosmarinus were collected in July from the Fergana region. Samples were air-dried in a cool environment. The elemental composition was analyzed using an inductively coupled argon plasma emission spectrometer. 0.500 g of each sample was weighed and placed into Teflon digestion vessels. Concentrated nitric acid and hydrogen peroxide were added, and digestion was performed using a Berghof MWS-3+ microwave system. After digestion, the solutions were diluted to 50 mL with 0.5% nitric acid.

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Vitamin Analysis (HPLC):

Water-soluble vitamins were determined using High-Performance Liquid Chromatography (HPLC), with acetate buffer and acetonitrile as the eluent. Conditions: Agilent-1200 chromatograph (equipped with autosampler), EclipseXDBC 18 column (5 µm, 4.6 × 250 mm), diode array detector at 250 nm, flow rate 0.8 mL/min, temperature 25°C, injection volume 5 µL. Working standard and sample solutions were injected accordingly.

Flavonoid Analysis:

For flavonoid content, leaf samples collected in June were air-dried at 30–40°C and ground. 5–10 g of the sample was extracted with 50 mL of 70% ethanol using a magnetic stirrer and reflux condenser for 1 hour at 70–80°C. After cooling and standing for 2 hours, the extract was filtered. Additional extractions were performed with 25 mL of 70% ethanol twice, and the filtrates were combined and diluted to 100 mL. The extract was centrifuged at 6000–8000 rpm for 20–30 minutes. The supernatant was used for analysis. Identification of flavonoids was performed by comparing the retention times of standards: dihydroquercetin, quercetin, rutin, luteolin, sennoside, and salidroside.

RESULTS AND DISCUSSION

Macro-element Content:

ICP-OES analysis revealed the following macro-element concentrations in the plant leaves:

Table 1. Macro-elements content (mg/kg)

Element	Paulownia	Rosmarinus
Phosphorus (P)	11,400	2,400
Potassium (K)	22,000	64,000
Calcium (Ca)	68,000	5,400
Sodium (Na)	860	770
Magnesium (Mg)	920	14,000

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The data indicate that both species are rich in essential macro-elements, with potassium and calcium particularly abundant.

Vitamin Composition:

High-Performance Liquid Chromatography revealed the following vitamin concentrations:

Table 2. Water-soluble vitamin content (mg/kg)

Vitamin	Paulownia	Rosmarinus
B1 (Thiamine)	5.54	6.42
B2 (Riboflavin)	18.51	17.92
B6 (Pyridoxine)	6.57	11.43
B9 (Folic acid)	23.57	19.61
B3 (Niacin/PP)	6.57	10.23
C (Ascorbic acid)	5.64	8.34

All tested vitamins were present in both plants. Folic acid (B9) and riboflavin (B2) were found in the highest amounts. The vitamin content increased in the following order: B1 < C < B6 < B3 < B2 < B9.

Flavonoid Composition:

The presence of six flavonoids was confirmed in the leaf extracts of both plants:

Table 3. Flavonoid content (mg/kg)

Flavonoid	Paulownia	Rosmarinus
Dihydroquercetin	5.97	11.60
Rutin	2.32	2.64
Salidroside	3.72	1.32
Sennoside	2.91	2.45
Luteolin	1.52	1.11
Quercetin	1.01	0.12

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Flavonoids are potent natural antioxidants. The detected order of flavonoid abundance was: quercetin < luteolin < sennoside < salidroside < rutin < dihydroquercetin.

OVERALL COMPARATIVE INSIGHTS

Macro-elements such as calcium, potassium, magnesium, phosphorus, and sodium are essential for maintaining physiological homeostasis, and their influence on immune function and inflammatory processes is well-documented. Paulownia leaves contain exceptionally high calcium levels (68,000 mg/kg), which is critical for immune cell signaling. Calcium ions play a pivotal role in the activation of T-cells and other immune responses. Adequate calcium levels facilitate proper cytokine production, which regulates inflammation. By contrast, Rosmarinus has significantly less calcium, indicating that Paulownia may have superior immunomodulatory potential through calcium-dependent pathways. Rosmarinus shows a remarkable abundance of potassium (64,000 mg/kg), which contributes to cellular function and fluid balance. Potassium channels regulate immune cell activation and cytokine release. Dysregulation of potassium homeostasis can exacerbate inflammation, so the high potassium content in Rosmarinus suggests a role in stabilizing immune responses and preventing excessive inflammatory reactions. Magnesium is a known modulator of inflammation and immune function. Rosmarinus contains a notably high level of magnesium (14,000 mg/kg), which can suppress pro-inflammatory cytokines such as TNF-α and IL-6. Magnesium deficiency has been associated with increased inflammation and immune dysfunction, so the rich magnesium content supports Rosmarinus's role in reducing inflammation and enhancing immune competence. Phosphorus, abundant in Paulownia, is vital for energy metabolism and immune cell proliferation. Both plants have relatively low sodium levels, beneficial since excessive sodium intake is linked to immune dysregulation and inflammatory diseases.

Water-soluble vitamins present in both plants contribute significantly to anti-inflammatory processes and immune system maintenance. Rosmarinus has a

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higher vitamin C content (8.34 mg/kg) compared to Paulownia. Vitamin C is a potent antioxidant that neutralizes free radicals generated during inflammatory responses, thereby reducing tissue damage. It also supports the function of phagocytes and promotes the proliferation of lymphocytes, boosting immune defense.Higher in Rosmarinus, vitamin B6 is essential for the synthesis of neurotransmitters and cytokines involved in immune regulation. It modulates inflammatory pathways by influencing homocysteine metabolism, reducing vascular inflammation, and enhancing lymphocyte proliferation. Paulownia is richer in folic acid, which plays a critical role in DNA synthesis and repair. Folic acid deficiency is linked with impaired immune responses and increased susceptibility to inflammatory diseases. Its presence supports the regeneration of immune cells and modulation of inflammation. Both plants contain substantial riboflavin levels, vital for antioxidant enzyme systems that mitigate oxidative stress during inflammation.

The flavonoid profiles of *Paulownia* and *Rosmarinus* reveal several compounds with documented anti-inflammatory and immune-enhancing properties. Significantly higher in Rosmarinus, dihydroquercetin exhibits strong antioxidant effects by scavenging reactive oxygen species (ROS) generated during inflammatory processes. It inhibits pro-inflammatory enzymes like cyclooxygenase (COX) and lipoxygenase (LOX), reducing inflammatory mediator production. More abundant in Paulownia, quercetin is a well-known flavonoid that suppresses inflammation by inhibiting nuclear factor-kappa B (NF-κB) signaling pathways and downregulating pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α. Quercetin also stabilizes mast cells, reducing allergic and inflammatory responses. Present in both species, rutin reinforces blood vessel integrity and reduces inflammation by modulating nitric oxide (NO) production and scavenging free radicals. Higher in Paulownia, salidroside is known for adaptogenic and neuroprotective effects, which can mitigate inflammation-induced neurodegeneration. It also modulates immune responses by enhancing the activity of natural killer (NK) cells and macrophages. Both compounds have anti-inflammatory and immunoregulatory roles. Luteolin suppresses cytokine

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production and inhibits inflammatory enzymes, while sennoside exhibits mild immunomodulatory effects.

The combined antioxidant properties of vitamins C, B2, and flavonoids reduce oxidative stress, a major driver of chronic inflammation. Flavonoids specifically target key inflammatory signaling pathways, leading to reduced production of pro-inflammatory cytokines and enzymes. Essential minerals like calcium, magnesium, and potassium support immune cell function and signaling. Vitamins such as B6 and folic acid ensure proper immune cell proliferation and antibody synthesis, enhancing host defense mechanisms. Given their biochemical profiles, extracts from these plants could be developed as **nutraceuticals** or **functional foods** to support patients with chronic inflammatory conditions (e.g., arthritis, inflammatory bowel disease) and immunodeficiencies (e.g., post-infection recovery, autoimmune disorders). Paulownia's strength in calcium, folic acid, and quercetin combined with Rosmarinus's richness in potassium, magnesium, vitamin C, and dihydroquercetin may provide a broad spectrum of bioactivities targeting different facets of immune health and inflammation control. **Paulownia** is characterized by exceptionally high levels of calcium, phosphorus, folic acid, salidroside, and quercetin. These features suggest a pronounced role in **bone health, cellular repair, neurological protection, and adaptation to stress**. **Rosmarinus officinalis** is rich in potassium, magnesium, vitamins B6, B3, and C, and dihydroquercetin, positioning it as a **strong candidate for cardiovascular support, antioxidant defense, immune enhancement, and metabolic regulation**. Both plants complement each other nutritionally and phytochemically. Their combined use or extracts may offer synergistic benefits in **preventing metabolic disorders**, **reducing oxidative stress**, and supporting **overall health maintenance**.

CONCLUSION

The comparative chemical analysis highlights that *Paulownia* and *Rosmarinus* leaves possess distinct yet complementary profiles of macro-elements, vitamins, and flavonoids. The richness of **calcium and folic acid in Paulownia** aligns with

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benefits for **skeletal and cellular health**, while **Rosmarinus's elevated potassium, magnesium, and vitamin C** suggest a potent role in **cardiovascular protection and immune function**. The flavonoid profiles further reinforce their **antioxidant and anti-inflammatory properties**. Given these findings, leaf extracts from both species hold great promise as **functional food additives** or **nutraceutical ingredients** aimed at mitigating metabolic and degenerative diseases such as osteoporosis, hypertension, cardiovascular diseases, and neurodegenerative disorders. Based on chemical analysis, the leaves of Paulownia and Rosmarinus cultivated in the Fergana region are rich in macro-elements, water-soluble vitamins, and flavonoids. Given their beneficial bioactive compounds, leaf extracts from these plants could be used as functional food additives to help prevent and manage metabolic disorders in humans.

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