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Isolation, characterization, and biological activity of ethanolic extracts from dandelion (*Taraxacum officinale*) root

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Abstract

This study aimed to evaluate chemical composition, total phenolic and flavonoid content, antioxidant activity, and elemental composition of dandelion root extracts collected from an urban area. Three extraction techniques were applied using 70%v/v ethanol as a solvent – maceration, ultrasound, and microwave-assisted extraction, each performed at solvomodule of 1:10, 1:15, and 1:20. The application of LC-MS analysis allowed identification of numerous bioactive compounds from the group of polyphenols, which provided an insight into the composition and biological potential of the extracts. The DPPH and FRAP assays were used to assess antioxidant potential, while total phenolics and flavonoids were quantified by the Folin-Ciocalteu and AlCl3 colorimetric methods, respectively. The results showed that microwave-assisted extraction achieved the highest extractive matter yield (7.1 mg/ml), phenolic content (22.21 mgGAE/g d.e.), and flavonoid content (10.88 mgRE/g d.e.), accompanied by the highest antioxidant activity. ICP-OES analysis confirmed the presence of essential macroelements in significant amounts; it also revealed the presence of heavy metals, with arsenic and mercury significantly exceeding the limits set by EU Regulation. The presented results showed that the biological potential of the isolated extracts must be considered in light of safety from the aspect of the heavy metal composition.

Introduction

The genus *Taraxacum* (commonly known as dandelion) is a perennial plant belonging to the family *Asteraceae.* As a well-known and extensively studied genus, *Taraxacum* comprises numerous species, some of which are widely used in both modern and traditional medicine for reducing fever, promoting detoxification, stimulating blood circulation, relieving fluid retention, and enhancing diuresis. Multiple pharmacological studies have highlighted its broad therapeutic potential, including antibacterial, antioxidant, anticancer, and antirheumatic effects (Li et al. 2021). The bioactive compounds responsible for these effects include sesquiterpenoids, phenolic compounds, essential oils, saccharides, flavonoids, sphingolipids, triterpenoids, sterols, and coumarins, among others (Li et al. 2021). Dandelion (*Taraxacum officinale*) is easily recognizable, simple to identify, and inexpensive to collect. It requires approximately 85 – 95 days to reach full maturity (Stewart-Wade et al 2002). This perennial weed develops a strong taproot, typically measuring 15 – 30 cm in length and 2 – 3 cm in diameter, though roots up to 60 – 100 cm have also been reported. The root is fleshy and brittle, brown on the outside and white and milky on the inside. Even when the aerial parts are cut, the root can regenerate new plants (Cogger 2005).

Dandelion is a highly adaptable and successful weed that thrives abundantly in urban environments. These plants exhibit pronounced seasonal variations in their physiological traits. It can be assumed that fluctuations in meteorological factors within urban habitats, characterized by alternating increasing and decreasing trends across seasons, play a crucial role in shaping phenotypic responses related to physiological characteristics. Therefore, dandelion can serve as an important bioindicator of urban habitat quality.

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In traditional medicine, all parts of dandelion, particularly the root, have been used for their mild aperitive, cholagogue, depurative, potent diuretic, hepatoprotective, laxative, stomachic, and tonic properties. Documented and reported therapeutic uses of dandelion concern treating gout, diarrhea, blisters, and ailments of the spleen and liver, kidney diseases, dyspepsia, and heartburn, eczema and other skin conditions, diabetes and bacterial infections, bronchitis, pneumonia, fever, ulcers, eye disorders, etc. (Petrovska 2012). Finally, in modern phytotherapy, dandelion is primarily valued for its diuretic, hepatoprotective, and digestive effects. Preparations made from its roots and aerial parts are commonly used in the form of teas, tinctures, and extracts. Furthermore, due to its content of polyphenolic compounds, vitamins, and minerals, dandelion has attracted increasing attention in the pharmaceutical, cosmetic, and food industries as a natural source of bioactive substances and a potential functional food ingredient (Escudero et al. 2003).

As mentioned, the dandelion is among the most widespread herbaceous plants in urban environments, possessing a high potential for accumulating environmental elements (Mikołajczak et al., 2017), in addition to an abundance of bioactive molecules. This study aimed to examine the chemical composition and biopotential with an emphasis on the potential of dandelion as a bioindicator for assessing the urban habitat quality.

Materials and methods

Chemicals and reagents

Gallic acid, Folin-Ciocalteu reagent, aluminum chloride ($AlCl_3$) (Sigma Chemical Co., St. Louis, USA), ethanol, rutin, 2,2-diphenyl-1-picrylhydrazyl (DPPH), and dimethyl sulfoxide (DMSO) from Merck, Darmstadt, Germany. Standards for ICP–OES analysis from Sigma Chemical Co., St. Louis, USA.

Plant material

The fresh roots of *Taraxacum officinale* Weber (Asteraceae) were used for this study. The plant material was collected in Bobište, near Leskovac, Serbia, during July 2025. After collection, the roots were cleaned of soil and other impurities and washed with distilled water. Fresh roots were then chopped and ground using a mortar and pestle prior to extraction.

Extraction procedures

Maceration was carried out using three different solvomodules (1:10, 1:15, and 1:20, w/v). For each ratio, 10 g of freshly ground dandelion root was placed in separate Erlenmeyer flasks containing 70 %v/v ethanol (100, 150, and 200 mL, respectively). The samples were left to macerate for eight days, at room temperature, protected from direct sunlight. Aliquots of 5 ml were taken every 24 hours, filtered, and processed for further analyses. From each filtrate, 1 ml was stored in vials for LC-MS analysis, while 2 ml was dried at 105 °C (in duplicate) to a constant weight to determine the dry residue. Based on the dry residue mass, the concentration of the liquid extract (mg/ml) was calculated. After the eighth day, the macerates were decanted and stored in a refrigerator until further analysis.

Ultrasonic extraction was performed using three solvomodules (1:10, 1:15, and 1:20, w/v), following the same material preparation procedure as for maceration. Each sample, consisting of 10 g of ground dandelion root, was extracted with 100, 150, or 200 ml of 70 %v/v ethanol. The extraction was conducted in an ultrasound bath for 30 minutes at room temperature. Aliquots of 5 ml were collected after 10, 20, and 30 minutes for further analyses. Upon completion, the extracts corresponding to each ratio were decanted and stored under refrigeration until subsequent analysis.

Microwave-assisted extraction was carried out using three solvomodules (1:10, 1:15, and 1:20, w/v). In this procedure, 5 g of ground dandelion root was placed in three Erlenmeyer flasks and extracted with 50, 75, and 100 ml of 70 %v/v ethanol, respectively. The extraction was performed in a household microwave oven operated at medium power for 2 minutes. Aliquots of 5 ml were collected after 30, 60, and 120 seconds for subsequent analyses. After completion, the final extracts corresponding to each ratio were decanted and stored in a refrigerator until further analysis.

Total phenolic content (Folin–Ciocalteu method)

The total phenolic content of the ethanol extracts was determined using the Folin–Ciocalteu method, with slight modifications to the standard procedure (Stanojević et al. 2013). An aliquot of 0.5 ml of the extract or gallic acid standard solution (in the concentration range of 0.00625 – 0.2 mg/ml), was transferred into a 25 ml volumetric flask and diluted with 4.5 ml of distilled water. The blank sample contained 5 ml of distilled water instead of the extract. Subsequently, 0.5 ml of Folin–Ciocalteu reagent was added to each sample, followed by 5 ml of a 7 % sodium carbonate (Na_2CO_3) solution after 5 minutes. The mixtures were thoroughly shaken and

incubated for 90 minutes at room temperature. The absorbance was measured at 765 nm. For quantification, a calibration curve was prepared using standard gallic acid solutions of known concentrations. The total phenolic content in the samples was calculated according to the regression equation: y = 0.4564 + 5.73618x. The coefficient of determination (R^2 = 0.98941) confirmed excellent linearity of the applied method. Each measurement was performed in triplicate, and the results were expressed as mean value ± standard error (SE). The total phenolic content was expressed as milligrams of gallic acid equivalents per gram of dry extract (mg GAE/g d.e.), or per gram of plant material (mg GAE/g p.m.).

Total flavonoid content

The total flavonoid concentration in ethanol extracts was determined spectrophotometrically, using the aluminum chloride colorimetric method, with certain procedural modifications (Stanojević et al. 2013). For each sample, 2 ml of the extract or rutin standard solution (0.005 – 0.1 mg/ml) was mixed with 0.1 ml of 10 % $AlCl_3 \times 6H_2O$, 0.1 ml of 1M CH_3COOK, and 2.8 ml of distilled water. After incubation for 40 minutes at room temperature, the absorbance of the reaction mixture was measured at 415 nm against a blank containing distilled water instead of the extract. The total flavonoid content was calculated using the calibration curve of rutin, and expressed as milligrams of rutin equivalents per gram of dry extract (mg RE/g d.e.), or per gram of plant material (mg RE/g p.m.). Calibration curve was constructed from rutin standards of known concentrations. The absorbance of the standard solutions was measured at 415 nm. Results are expressed as rutin equivalents per gram of dry extract (mg RE/g d.e.). Total flavonoid content in the extracts was calculated using the equation: y = -0.02913 + 10.78996x, with a determination coefficient of R^2 = 0.98078.

Antioxidant activity

DPPH test. The antioxidant potential of the extracts was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging test, based on the ability of antioxidants to scavenge (neutralize) the stable violet DPPH radical to its yellow or colorless form (Stanojević et al. 2009). A working solution of DPPH was prepared in 70 %v/v ethanol.

For each extract, a serial dilution was prepared using six test tubes labelled C_0 to C_5, along with corresponding blanks. In the blank tubes, 0.4 ml of 70 %v/v ethanol was added, while 2 ml of the same solvent was added to the sample tubes C_1 – C_5. From 5 ml of diluted extract, 1 ml was transferred into tube C_0 and 1 ml into $Blank_0$. Subsequently, 2 ml was added to tube C_1, then 1 ml from C_1 was transferred to $Blank_1$, and 2 ml to C_2. This procedure was repeated for all subsequent dilutions. The final tube (C_5) contained 1 ml of the diluted extract. To initiate the reaction, 0.4 ml of DPPH reagent was added to each of the sample tubes, followed by incubation for 20 minutes at room temperature in the dark. The absorbance was then measured at 517 nm using 70 %v/v ethanol as a reference. The scavenging activity was calculated according to the following equation:

$$\%inhibition = 100 - (A_s - A_b)\,X\,\frac{100}{A_k}$$

where:
A_s – absorbance of the sample (extract in adequate dilution treated with DPPH).
A_b – absorbance of the blank (extract in adequate dilution without DPPH).
A_c – absorbance of the control (DPPH diluted by ethanol in adequate proportion).

FRAP test. Total antioxidant capacity of the extracts was also evaluated by FRAP (Ferric Reducing Antioxidant Power) test, based on the reduction of the Fe^{3+}-TPTZ complex to Fe^{2+}-TPTZ under acidic conditions, resulting in a blue-colored complex (Stanojević et al. 2013). The working FRAP reagent was freshly prepared before analysis by mixing acetate buffer (300 mM, pH 3.6), 10 mM TPTZ solution in HCl, and 20 mM $FeCl_3 \cdot 6H_2O$ in a 10:1:1 volume ratio.

For the test, 0.1 ml of the sample was mixed with 3 ml of FRAP reagent. A blank containing 0.1 ml of 70 %v/v ethanol was prepared in parallel. The mixtures were incubated in a water bath at 37 °C for 30 minutes, and the absorbance was measured at 593 nm.

A standard curve was prepared using $FeSO_4 \cdot 7H_2O$ solutions (200-1000 µM), by dissolving 0.0695 g in 250 ml water and diluting appropriate volumes to obtain the desired concentrations. Aliquots of 0.1 ml of each standard were mixed with 3 ml of FRAP reagent, and absorbance was measured against a blank containing 3 ml FRAP reagent and 0.1 ml distilled water. The calibration curve was constructed by plotting absorbance versus known Fe^{2+} concentrations. The linear correlation between absorbance and standard concentration (y = 0.0632 + 0.651x; R^2 = 0.99776) allowed calculation of FRAP values, representing the Fe^{2+} equivalents present in the extracts (mmol/L).

UHPLC-MS analysis

Dionex Ultimate 3000 UHPLC+ system, equipped with a diode array (DAD) detector and an LCQ Fleet Ion Trap Mass Spectrometer (Thermo Fisher Scientific, Waltham, MA, USA), has been used for the ultra-high performance liquid chromatographic (UHPLC) separation of the extracts on a Hypersil gold C18 column (50×2.1 mm, 1.9 µm) at 25 °C. The injection volume of the samples was 2 µL. The mobile phase was composed of 0.1 % formic acid in water (A) and methanol (B), at a 0.250 mL/min flow rate, in a linear gradient program:

10-30 % (B) in the first 2 min, 35-40 % (B) in 4-5 min and 60-90 % (B) in 8-11 min, followed by an isocratic run at 90 % in 11-15 min and 90-10 % (B) in 15 to 15.01 min with the isocratic run at 10 % (B) to the 20th minute. DAD signals were measured in the full 200-800 nm spectral range. Mass spectrometric (MS) analysis was performed using a 3D ion trap with electrospray ionization (ESI) in negative ionization mode. The ESI source parameters were: capillary temperature 350 °C, nitrogen sheath and auxiliary gas flow 32 and 8 arbitrary units. The source voltage, capillary voltage, and tube lens voltage were 4.5 kV, -41 V, and -95 V. Full range acquisition in (m/z 100-1000) was performed with a data dependent scan: the collision-induced dissociation of detected molecular ion peaks ([M-H]-) was tuned at 30 eV in He collision gas. Xcalibur software (version 2.1) was used for instrument control, data acquisition, and data analysis. Compounds were identified by UHPLC-DAD-MS/MS analyzing the retention times, UV-Vis spectra, molecular ion masses, and MS/MS fragmentation patterns. Due to the absence of authentic reference standards, identifications are considered putative (MSI Level 2-Putatively annotated compounds) according to the Metabolomics Standards Initiative. PubChem Compound IDs (CIDs) are included to aid in compound verification and data transparency.

The UHPLC-MS analysis was done for three selected extracts, the one that showed the highest antioxidant activity from each extraction technique: maceration in solvomodule 1:20 (M), ultrasonic extraction in solvomodule 1:10 (UE) and microwave extraction in solvomodule 1:15 (ME).

ICP-OES Analysis

The measurements were performed using the ICP-OES instrument for quantitative elemental analysis; the operational conditions of the instrument, and the parameters used for determining the concentrations of the elements, are presented in Table 1.

Table 1. Operating conditions of the ICP-OES instrument

Plasma power (W)	1400
Gas flow rate (L/min)	
-*Coolant*	12
-*Auxiliary*	1
Type of nebulizer	Cross flow
Nebulizer flow rate (L/min)	1
Plasma observation mode	Axial

An accurately measured volume of each sample known concentrations was transferred to a standard container (5 ml) and diluted to the mark with HPLC-grade distilled water. The samples were subsequently filtered through a 0.45 μm membrane and analyzed using ICP-OES. The detection wavelengths (λ), correlation coefficients (R^2), and limits of detection (LOD) for each element are summarized in Table 2.

Argon 5.0 (99.999 % purity) was used as the carrier gas. Multi-element standard solutions were used for the preparation of calibration standards solutions. Calibration solutions for the selected elements were prepared by diluting the stock standards so that the concentrations of the standards covered the expected range of the analyzed elements.

Results and discussion

Total extractive matter content

The total extractive matter content represents one of the fundamental indicators of extraction efficiency. It reflects the overall amount of soluble constituents, transferred from the plant matrix into the solvent under specific extraction conditions. The yield, expressed as the mass of dry residue obtained from 1 ml of extract, provides a direct measure of the extraction capacity of each applied technique. This parameter is influenced by several experimental factors, including the extraction method, the ratio of plant material to solvent (solvomodule), and the extraction time. In the present study, extraction yield was determined for three different techniques – maceration, ultrasonic extraction, and microwave-assisted extraction, using three solvomodules (1:10, 1:15, and 1:20), allowing for a comparative assessment of extraction efficiency under varying conditions (Table 3).

In this study, the yield of dandelion root extracts reached its maximum on the fourth day of maceration (8.05 mg/ml at a 1:10 solvomodule), after which a gradual decline was

Table 2. Calibration curve parameters for determined elements, wavelength of detection λ, correlation coefficient R^2, and limit of detection LOD

Element	λ (nm)	R^2	LOD (µg/L)
As	189.042	0.99997	0.8800
Ag	328.100	0.99940	0.1900
B	249.773	0.99999	6.4300
Ba	233.527	0.99963	0.1567
Bi	223.061	0.99980	2.7100
Ca	183.801	0.99990	3.1600
Cd	214.400	0.99955	0.1688
Co	228.802	0.99946	0.1798
	228.616	0.99958	1.0380
Cr	283.563	0.99989	0.2859
Cu	224.700	0.99985	0.7303
	324.700	0.99999	0.2746
Fe	259.900	0.99989	0.3370
	241.331	0.99964	2.1890
In	325.609	0.99996	0.5240
K	404.721	0.99967	482.00
	766.491	0.99921	0.8665
Mg	279.553	0.99995	0.0297
	285.200	0.99970	0.1447
Mn	257.600	0.99990	0.0600
Na	330.200	0.99934	2.2980
	598.500	0.99944	1.3220
Ni	231.600	0.99993	0.2720
P	177.495	0.99982	2.0260
Pb	220.353	0.99998	1.7800
S	180.731	1.00000	2.9000
Si	251.600	0.99952	1.0190
Sr	407.781	1.00000	0.1200
Ta	240.053	0.99979	1.3890
Tl	190.864	0.99999	1.7200
Hg	184.950	0.99930	0.6260
Zn	213.856	0.99908	0.0154

Table 3. Total extractive content (mg/ml) obtained by different extraction techniques and solvomodules

Extraction methods	Extraction time (unit)	Solvomodule 1:10	Solvomodule 1:15	Solvomodule 1:20
Maceration	1 (day)	6.20	4.40	1.50
	2	7.40	5.15	3.65
	3	6.80	5.10	4.05
	4	8.05	5.60	4.45
	7	5.95	4.40	3.70
	8	7.05	4.25	3.40
Ultrasonic extraction	10 (min)	4.10	4.35	2.90
	20	6.05	5.20	3.70
	30	6.95	5.75	3.80
Microwave-assisted extraction	30 (s)	4.65	2.75	1.85
	60	5.75	3.70	4.10
	120	7.10	5.35	5.20

observed. In the case of microwave-assisted extraction, the highest yield was achieved after 120 seconds (7.10 mg/ml at a 1:10 solvomodule), while ultrasonic extraction produced a slightly lower value after 30 minutes (6.95 mg/ml at a 1:10 solvomodule). The order of extraction efficiency obtained here differs from that reported for the extraction of propolis (Oroian et al. 2020). In that study, ultrasound treatment yielded the highest extractive content, followed by microwave extraction and maceration. Such discrepancies in extraction efficiency can be attributed to differences in experimental design. As reported by Oroian et al. (2020), a double maceration with continuous stirring over 24 hours was applied, as well as repeated microwave and ultrasound treatments, whereas extraction was performed in a single series without repetition in the present work. In contrast to the findings of Ramesh et al. (2024), who suggested that an increase in the solvent-to-solid ratio enhances extraction efficiency, the present study demonstrated an opposite trend. The decrease in extractive content with higher solvomodule may be attributed to dilution effects and a reduced concentration gradient between the plant matrix and the solvent, resulting in slower diffusion of soluble compounds. Furthermore, in systems without intensive agitation, a larger solvent volume can reduce effective contact between plant particles and the solvent, thereby lowering extraction yield.

In the case of maceration, a decline and oscillation in extractive content after the fourth day may be associated with the physicochemical characteristics of dandelion root. The presence of polysaccharides (Qiao et al. 2024), gums, and resins can lead to matrix swelling during prolonged soaking, which limits solvent penetration and hinders the diffusion of soluble metabolites. In addition, partial oxidation or degradation of phenolic (Ramesh et al 2024) compounds over extended extraction time, could further contribute to the observed decrease in yield.

Antioxidant Activity (DPPH test)

Based on the obtained results of antioxidant activity determined by the DPPH method, it can be observed that the IC_{50} values varied significantly depending on the extraction method, solvomodule, and duration of the process (Table 4). Lower IC_{50} values indicate a stronger ability to neutralize free radicals, i.e., higher antioxidant activity of the extracts.

The IC_{50} values were determined based on the correlation of DPPH radical inhibition with the extract concentration. For each sample series, the data were processed using Microsoft Excel 2016 with a polynomial function, which enabled the generation of an appropriate regression curve. Using the obtained equations, the extract concentrations causing 50 % inhibition of free radicals (IC_{50}) were determined.

Table 4. Antioxidant activity of extracts determined by the DPPH test (IC_{50} values, mg/ml) at different solvomodule and extraction times.

Extraction methods	Extraction time (unit)	Solvomodule 1:10	Solvomodule 1:15	Solvomodule 1:20
Maceration	1 (day)	0.930	1.170	0.570
	2	0.760	0.480	0.500
	3	2.050	1.910	1.200
	4	2.180	2.150	1.480
	7	1.430	1.450	0.950
	8	3.290	2.270	0.980
Ultrasonic extraction	10 (min)	0.680	2.800	3.160
	20	0.780	1.500	2.470
	30	0.650	2.440	2.320
Microwave-assisted extraction	30 (s)	0.530	0.340	0.183
	60	0.530	0.266	0.234
	120	0.325	0.266	0.176

Maceration

During the eight-day maceration period, IC_{50} values exhibited notable fluctuations. Starting from the second day, antioxidant activity gradually increased, followed by a decrease after the fourth day, and then a subsequent rise until the eighth day. The lowest IC_{50} values (0.48 – 0.5 mg/ml) were observed on the second day, particularly for samples with solvomodules of 1:15 and 1:20, suggesting that the highest amount of readily accessible phenolic compounds is released during the early stages of the process. Subsequently, partial depletion and possible oxidative losses of these compounds likely explain the increase in IC_{50} values, observed on the third and fourth days. Interestingly, samples with a higher solvomodule (1:20) often showed lower IC_{50} values compared to more concentrated extracts, which may result from improved diffusion and extraction of polar antioxidants at higher solvomodules.

Ultrasonic extraction

In the case of ultrasonic extraction, treatment duration was found to have a significant impact on antioxidant activity. The lowest IC_{50} values were recorded at the shortest duration of 10 minutes (particularly for the 1:10 sample – 0.68 mg/ml), while longer treatments resulted in a slight increase in IC_{50}. This suggests that prolonged exposure to ultrasound may lead to partial degradation of sensitive phenolic compounds, especially at higher amplitudes and local temperature increases. Overall, ultrasonic extraction demonstrates solid antioxidant efficiency, although with somewhat lower stability of results compared to microwave extraction.

Microwave extraction

Among all the extraction techniques applied in this study, microwave extraction consistently yielded the lowest IC_{50} values, indicating the highest antioxidant efficiency. The samples treated for 120 seconds were particularly remarkable, with IC_{50} values ranging from 0.176 to 0.325 mg/ml. This demonstrates that the rapid heating and localized micro-explosions within the plant tissue facilitate an efficient release of phenolic compounds, while minimizing their degradation. Even at shorter treatment durations of 30 and 60 seconds, the IC_{50} values remained low, highlighting that microwave-assisted extraction can achieve optimal extraction in a fraction of the time required by conventional maceration or ultrasound techniques. Overall, these results suggest that microwave extraction not only improves the yield of bioactive compounds but also ensures superior preservation of antioxidant activity.

Comparative overview of extraction techniques - A comparison of the three applied extraction methods indicates the following trend in antioxidant efficiency:

Microwave-assisted extraction > Ultrasonic extraction > Maceration

observation aligns with literature data (Guojun et al. 2025), which frequently reports that non-conventional extraction methods, particularly microwave-assisted extraction, are more effective in preserving and releasing thermolabile phenolic compounds. The lower IC_{50} values observed for microwave extraction can be attributed to enhanced mass transfer, faster solvent heating, and the formation of micro-fractures within plant cells, leading to higher concentrations of bioactive antioxidant compounds in the extract. In contrast, prolonged maceration promotes oxidation of phenolics, which explains the fluctuations in IC_{50} values over the course of the extraction period.

The DPPH assay results indicate that both the extraction technique and its operational parameters strongly influence the antioxidant potential of the extracts. Among the tested methods, microwave-assisted extraction demonstrated superior efficiency, shorter processing time, and more consistent outcomes, whereas maceration and ultrasonic extraction showed greater variability depending on the duration and the solvomodule.

Antioxidant activity (FRAP test)

The FRAP test evaluates the antioxidant compounds' ability to reduce the Fe^{3+}-TPTZ complex to Fe^{2+}-TPTZ, resulting in a deep blue color that is proportional to the concentration of reducing agents present. Unlike the DPPH test, which reflects the capacity to scavenge free radicals, FRAP provides a measure of the total reducing power of the extract, i.e., its electron-donating potential. For this reason, these two assays are often combined, offering a more comprehensive assessment of the antioxidant activity in biological samples (Pooja and Modi 2015).

The antioxidant capacity of the samples was quantified using the FRAP test (Table 5), based on a calibration curve prepared.

Table 5. The FRAP values according to solvomodule and extraction times (mmol/L)

Extraction methods	Extraction time (unit)	Solvomodule 1:10	Solvomodule 1:15	Solvomodule 1:20
Maceration	1 (day)	0.341	0.392	0.179
	2	0.367	0.270	0.265
	3	0.800	0.573	0.633
	4	0.758	0.730	0.644
	7	0.716	0.660	0.584
	8	0.665	0.558	0.513
Ultrasonic extraction	10 (min)	0.466	0.500	0.390
	20	0.865	0.700	0.440
	30	0.776	0.640	0.527
Microwave-assisted extraction	30 (s)	0.796	0.724	0.610
	60	1.085	1.100	1.377
	120	1.340	1.680	1.618

The FRAP test results for all three extraction methods revealed notable differences depending on the extraction time and the applied solvomodule. In the case of maceration, a gradual increase in antioxidant activity was observed during the first few days, likely associated with the enhanced release of phenolic compounds from the plant matrix. The highest values were recorded between the third and fourth day of extraction (particularly at the 1:10 solvomodule), followed by a slight decline, probably due to the degradation of sensitive compounds or the attainment of extraction equilibrium. This trend is consistent with the pattern previously observed in the DPPH test, where the mean IC_{50} values also indicated an optimum within a similar timeframe.

In ultrasonic extraction, a marked increase in FRAP values was observed already after 20 minutes of treatment, particularly at lower solvomodules (1:10, 1:15). This indicates that ultrasound cavitation forces efficiently release phenolic compounds and accelerate the extraction process. Further prolongation of the extraction time did not lead to a significant increase in activity, suggesting that most readily available antioxidants were extracted within the first 20 minutes. This trend aligns with the decrease in IC_{50} values observed in the DPPH assay for the same samples, confirming a strong correlation between the reducing power and radical-scavenging ability.

The highest FRAP values were obtained using microwave-assisted extraction, with a clear continuous increase in activity observed as the treatment time was extended. After 120 seconds, FRAP values were several times higher compared to maceration, particularly for samples with lower solvomodules. This demonstrates that microwaves enable rapid and efficient extraction of compounds with pronounced reducing properties. A similar pattern was observed in the DPPH assay, where microwave-extracted samples exhibited the lowest IC_{50} values, reflecting the highest antioxidant activity.

A correlation was indicated between the FRAP and DPPH results, indicating that samples with higher reducing power in the FRAP assay also exhibited lower IC_{50} values in the DPPH test. This consistency between the two methods is in line with previous findings (Kenny et al. 2014), confirming that both assays provide complementary insights into the antioxidant capacity of plant extracts. However, certain differences were noted, particularly among samples with higher solvomodules, suggesting the presence of different types of antioxidants – some more effective in reduction reactions, and others more active in radical scavenging.

Overall, the FRAP test confirmed that accelerated extraction techniques, particularly microwave-assisted extraction, enable a significantly shorter processing time for obtaining compounds with high antioxidant potential, compared to conventional maceration. The results indicate that by optimizing extraction time and solvomodule, the overall efficiency of the process can be further improved, yielding extracts with enhanced biological activity.

A comparative analysis of the results obtained by the DPPH and FRAP methods revealed a strong correlation between the two assays, confirming the reliability of the measured antioxidant potential of the investigated extracts. For all extraction techniques, samples with higher reducing power simultaneously exhibited lower IC_{50} values, indicating the presence of compounds capable of acting both as electron donors and as free radical scavengers (Kiss et al., 2025). Although a slower process, maceration demonstrated a gradual increase in antioxidant activity up to the fourth day, while the DPPH test reached its plateau after approximately 48 hours, suggesting a steady release of active components (Azmir et al., 2013). Ultrasonic extraction achieved comparable or even higher activity levels, in significantly shorter time periods, whereas microwave-assisted extraction provided the highest antioxidant potential in both assays, along with the shortest extraction time. These findings confirm that accelerated extraction techniques, particularly microwave extraction, can effectively replace traditional methods while maintaining or even enhancing the antioxidant efficiency of the obtained extracts. Overall, it can be concluded that careful optimization of extraction parameters, such as duration, solvomodule, and extraction method, plays a crucial role in obtaining extracts with maximum biological effectiveness (Pereira et al., 2023).

Total phenolic content

The total phenolic content in ethanol extracts was determined using a slightly modified Folin-Ciocalteu procedure and the results are shown in Table 6.

Table 6. Total phenolic content (mg GAE/g d.e.) in extracts from different extraction methods and solvomodules

Extraction methods	Solvomodule 1:10	Solvomodule 1:15	Solvomodule 1:20
Maceration	12.40±0.062	15.65±0.103	19.31±0.128
Ultrasonic extraction	14.15±0.063	8.31±0.076	10.85±0.115
Microwave-assisted extraction	12.87±0.061	22.21±0.081	20.09±0.840

The total phenolic content in the tested extracts ranged from 8.31±0.076 to 22.21±0.081 mg GAE/g of dry extract, depending on the extraction method and solvomodule. The highest phenolic content was obtained with microwave-assisted extraction at a solvomodule of 1:15 (22.21±0.08 mg GAE/g d.e.), while the lowest content was observed in the ultrasonic extraction at the same solvomodule (8.31±0.08 mg GAE/g d.e.).

Compared to the study of Aung and Das (2025) where total phenolic content of spray-dried dandelion root extract was reported as 9.07±0.54 mg GAE/g, the values obtained in the present work were generally higher, reaching up to 22.21±0.08 mg GAE/g s.e. This difference can be attributed to the extraction techniques applied, the selected solvomodules, and the absence of a drying step that could affect phenolic content.

During maceration, an increase in total phenolic content was observed with higher solvomodule, likely reflecting more efficient release of phenolic compounds when more solvent is available. In contrast, ultrasonic extraction did not display a clear pattern with changing solvomodule, which may result from localized overheating and partial degradation of polyphenols during extended sonication. Microwave-assisted extraction, on the other hand, generally yielded higher total phenol levels compared to the other techniques, highlighting the effectiveness of microwave energy in disrupting cell walls and accelerating the release of phenolic constituents.

The results indicate that microwave-assisted extraction is the most efficient technique for isolating phenolic compounds from the investigated plant material, particularly at a solvomodule of 1:15. This method is known to heat the solvent from the inside, promoting faster penetration into the plant matrix and enhanced release of phenolic constituents (Álvarez-Romero 2023). Extracts obtained *via* microwave treatment exhibited the highest total phenol content, which corresponded to the strongest antioxidant activity in both DPPH and FRAP assays, demonstrating a clear positive correlation between phenolic content and antioxidant capacity. Notably, samples with the highest total phenol levels (microwave extraction at solvomodules 1:15 and 1:20) also showed the lowest IC_{50} values in the DPPH assay and the highest FRAP values, indicating strong reducing potential and free radical scavenging ability. In comparison, ultrasonic extraction was less effective than microwave extraction and maceration, likely due to the instability of phenolic compounds under mechanical and thermal stress, as well as possible losses from oxidation during prolonged treatment. These trends are consistent with previous studies (López-Salazar et al. 2023), which reported that microwave-assisted extraction significantly reduces extraction time and enhances polyphenol yield compared to conventional techniques, especially in ethanol extracts. This confirms that the kinetics of phenol release depends not only on solvent concentration, but also on the type of energy applied during the extraction process (Azmir et al., 2013).

Total flavonoid content

Total flavonoid content was determined spectrophotometrically using the aluminium (III) chloride method and the results are shown in Table 7.

Table 7. Total flavonoid content (mg RE/g d.e.) in the final extracts obtained using different extraction techniques at various solvomodule

Extraction method	Solvomodule 1:10	Solvomodule 1:15	Solvomodule 1:20
Maceration	9.12±0.029	7.70±0.048	10.16±0.059
Ultrasonic extraction	9.25±0.029	4.00±0.035	4.67±0.053
Microwave-assisted extraction	9.05±0.028	10.88±0.038	10.42±0.039

The results presented in Table 7 indicate that the total flavonoid content in the extracts is strongly influenced by the extraction method applied and the plant material to solvent ratio. For the maceration, the highest flavonoid content was observed at a 1:20 ratio (10.16±0.059 mg RE/g d.e.), while the lowest value was recorded at 1:15 (7.70±0.048 mg RE/g d.e.). This trend can be explained by the fact that a larger volume of solvent facilitates better diffusion of compounds from the plant matrix, increasing the extraction yield, whereas a lower solvent-to-material ratio may limit the mass transfer (Xuereb et al. 2025). In the case of ultrasonic extraction, significantly lower flavonoid contents were noted, especially at higher dilutions, suggesting that lower extract concentrations may reduce the efficiency of ultrasound cavitation and mass transfer, resulting in decreased flavonoid recovery.

UHPLC-MS analysis

The representative UHPLC-MS chromatogram of the extract obtained by ultrasonic extraction after 30 min, in solvomodule 1:10, is shown in Fig.1. The other chromatograms have shown similar pattern, they were not presented, but the list of the compounds detected in the selected extracts is given in Table 8.

Table 8. List of the compounds detected by UHPLC-DAD-MS/MS analysis in negative ionization mode

Peak No.	t_R, min MS	λ_{max}, mm	Molecular ion $[M-H]^-$ *m/z*	MS/MS fragment ions	Assignment (reference)	Sample M	UE	ME
1	0.77	-	191	173,127(100 %),111,93,85	Quinic acid (Masike 2007)	+	+	+
2	0.87	-	343	191(100 %),169,125	Galloyl-quinic acid Navarro et al. 2019)	+	+	+
3	0.99	-	169	125(100 %)	Trihydroxybenzoic acid (*PubChem CID: 66520)	+	+	+
4	1.25	274	169	125(100 %)	Gallic acid (standard)	+	+	+
5	1.42	274	343	191,173,169(100 %), 155,125,111	Galloyl-quinic acid (Navarro et al. 2019)	+	+	+
6	2.50	-	353	-	Neochlorogenic acid (standard)	+	+	+
7	5.01	280	483	331,313,271(100 %), 211,193,169	Digalloyl hexoside (Bouaoudia-Madi et al. 2019)	+	+	+
8	5.45	-	353	-	Chlorogenic acid (standard)	+	+	+
9	5.46	-	483	331,313,271(100 %), 211,169	Digalloyl hexoside (Bouaoudia-Madi et al. 2019)	+	+	+
10	5.75	323	353	191,179,173(100 %)	Cryptochlorogenic acid (Clifford et al. 2003)	+	+	+
11	6.00	279 355	291	247(100 %)	Brevifolincarboxylic acid (PubChem CID: 516563456)	+	+	+
12	6.43	273	633	463,301(100 %),275	Corilagin (Navarro et al. 2107)	+	+	+
13	6.61	277	785	633,483,301(100 %), 275	Digalloyl-hexahydroxydiphenoyl-glucose (Rodrigues et al. 2023)	+	+	+
14	7.15	280	787	635,617(100 %),573, 465,447,403	Tetra-O-galloyl hexose (Navarro et al. 2019)	+	+	+
15	7.50	280	461	415(100 %)	n.i.	+	+	+
16	7.70	-	461	415(100 %)	n.i.	+	+	+
17	8.07	257 359	755	609,591,489, 300(100 %)/301, 271, 255	Quercetin-hexoside-rhamnoside (*Pubchem CID: 6325870)	+	+	+
18	8.12	-	319	273(100 %)		+	+	+
19	8.25	255 358	609	301/300(100 %),271,255	Quercetin-deoxyhexose-hexose (PubChem CID: 25080064)	+	+	+
20	8.93	-	463	-	Quercetin-3-*O*-galactoside (standard)	+	+	+
21	8.93	255	301	301(100 %),284,373, 257,229,185	Ellagic acid (standard)	+	+	+
22	8.84	-	447	-	Luteolin-7-*O*-glucoside (standard)	+	+	+
23	9.05	-	463	-	Quercetin-3-*O*-glucoside (standard)	+	+	+
24	9.06	-	609	-	Rutin (standard)	+	+	+
25	9.44	259 355	433	301/300(100 %), 271,179	Quercetin arabinoside or xyloside (**MB: PR100900)	+	+	+
26	9.73	256 353	447	327,315, 285/284(100 %),255	Kaempferol-hexoside (*PubChem CID: 5480982)	+	+	+
27	10.02	255 350	593	285(100 %)/284,255	Kaempferol-rutinoside (**MB: PR100664)	+	+	+
28	10.10	-	447	301,285(100 %)/284,255	Kaempferol-hexoside (*PubChem CID: 5480982)	+	+	+
29	10.27	-	461	446,439,315(100 %), 299/300,284/283	Methyl ellagic acid deoxyhexoside (Spínola et al. 2015)	-	+	+
30	11.09	257 360	301	273,229,179(100 %),151	Quercetin (standard)	+	+	+

Table 8. List of the compounds detected by UHPLC-DAD-MS/MS analysis in negative ionization mode

Peak No.	t_R, min MS	λ_{max}, mm	Molecular ion $[M-H]^-$ *m/z*	MS/MS fragment ions	Assignment (reference)	Sample M	UE	ME
31	12.09	266						
		365	285	-	Kaempferol (standard)	+	+	+
32	12.51	267						
		349	299	285/284(100 %),255	Kaempferide (**MB: BS003218)	+	+	+
33	13.33	336	343	328(100 %),313	Dihydroxy-trimethoxyflavone, e.g. Eupatorin (Pacifico et al. 2016)	+	+	+
34	13.50	282						
		338	373	358(100 %),343	Dihydroxy-tetramethoxyflavone (Pacifico et al. 2016)	+	+	+
35	13.68	318	343	328(100 %),313	Dihydroxy-trimethoxyflavone (Pacifico et al. 2016)	+	+	+
36	13.84	269						
		348	313	298(100 %),283	Dihydroxy-dimethoxyflavone (Pacifico et al. 2016)	+	+	+
37	13.91	269						
		348	313	298(100 %),283	Dihydroxy-dimethoxyflavone (Pacifico et al. 2016)	+	+	+
38	14.80	-	265	97(100 %)	n.i.	+	+	+
39	15.34	-	309	123,97(100 %)	n.i.	-	+	+
40	15.50	271	353	353(100 %),123	n.i.	-	+	+
41	15.90	-	293	236,97(100 %)	n.i.	-	+	+
42	17.14	-	297	-	n.i.	-	-	+

* - https://pubchem.ncbi.nlm.nih.gov
**- https://massbank.eu/MassBank/Search
n.i. - not identified

The UHPLC-MS analysis of the extracts showed the presence of phenolic acids, including gallic, ellagic, and trihydroxybenzoic acids, which confirm the antioxidant potential of the material. The presence of chlorogenic acids (chlorogenic, neochlorogenic, cryptochlorogenic) indicates a wealth of hydroxycinnamic derivatives, which are known for their anti-inflammatory (Ma et al. 2022) and antioxidant properties (Bagdas et al. 2012). Ellagic acid derivatives (brevifolin-carboxylic acid, methyl-ellagic acids, deoxyhexoside) suggest complex polyphenolic structures present in the dandelion root, which may contribute to the bioactivity of the extract. These compounds contribute to the total phenol content and may be associated with the antioxidant activities of the extract. Different isomers (neochlorogenic, cryptochlorogenic) indicate structural diversity that can influence pharmacological properties. Glycosides such as digaloyl-hexosides and tetra-O-galloyl-hexosides have been identified, indicating the presence of simple gallotannins or multiply galloylated sugars. These compounds contribute to the overall hydrolyzable tannin component of the extract. Galloyl derivatives are known for their antimicrobial, antioxidant, and anti-inflammatory effects (Peng et al. 2024). Their presence in dandelion root may partly explain the bioactive profile of the extract. The extract contains corilagin and digaloyl-hexahydroxy-difenoil-glucose, confirming the presence of ellagitannins and complex hydrolyzable tannins. HHDP-type structures and gallic additions indicate a high degree of polyphenol complexity. These compounds may contribute to the antioxidant capacity of the extract, as well as potential cardioprotective and anticancer effects described in the literature for ellagitannins (Mantzourani et al. 2024). The association with gallic units may influence the solubility and bioavailability of active compounds. Aglycones (quercetin, kaempferol) and their glycosides (quercetin-3-O-glucoside, quercetin-3-O-

galactoside, rutin, kaempferol-hexoside, kaempferide) have been identified. Methylated flavonoids (dihydroxy-trimetoxyflavon, eupatorin) also indicate a diverse flavonoid profile. Flavonoids contribute to the antioxidant, anti-inflammatory, and hepatoprotective effects of the extract (Iwashina et al. 2012). Rutin and quercetin glycosides may additionally affect the stability of blood vessels and the modulation of enzymes involved in oxidative stress (Başaran et al. 2022). Different sugar units (glucose, galactose, rhamnose, arabinose/xylose) suggest a diversity of glycosidic forms, which can influence absorption and bioactivity (Mantzourani et al. 2024).

ICP-OES analysis

The concentration of detected elements determined by ICP-OES analysis are presented in Table 9.

Table 9. Concentrations (μg/ml) of the elements detected by of ICP-OES analysis in the final extracts obtained by all three extraction techniques (in all three solvomodules)

	Extracts*								
Element	1	2	3	4	5	6	7	8	9
As	0.685	1.200	0.470	1.010	1.380	0.775	0.955	1.065	0.51
Ag	0	0	0	0	0	0	0	0	0
B	0.985	0.510	0.275	0.160	0.075	0.080	0.115	0.095	0
Ba	0.085	0.115	0.050	0.065	0.050	0.055	0.060	0.055	0.050
Bi	1.055	1.105	1.100	1.115	1.070	1.055	1.065	1.065	1.085
Ca	16.615	22.11	13.535	13.32	15.235	18.765	19.055	19.290	14.095
Cd	0.040	0.040	0.040	0.040	0.040	0.035	0.035	0.040	0.035
Co	0	0	0	0	0	0	0	0	0
Cr	0	0	0	0	0	0	0	0	0
Cu	0.040	0.060	0.025	0.050	0.060	0.045	0.030	0.030	0.025
Fe	0	0	0	0	0	0	0	0	0
In	0	0	0	0	0	0	0	0	0
K	61.365	88.590	83.650	89.635	125.895	75.810	65.780	72.46	56.915
Mg	1.865	3.765	2.580	2.980	4.810	3.535	2.945	2.830	1.240
Mn	0	0	0	0	0	0	0	0	0
Na	24.935	41.530	6.875	10.445	14.765	73.805	37.940	45.425	18.380
Ni	0	0	0	0	0	0	0	0	0
Pb	0	0	0	0	0	0	0	0	0
Sr	0.090	0.150	0.050	0.055	0.050	0.085	0.105	0.105	0.065
Tl	0	0	0	0	0	0	0	0	0
Zn	0.360	0.425	0.400	0.295	0.295	0.320	0.300	0.300	0.225
Hg	3.235	3.655	3.805	3.745	3.615	3.440	3.415	3.490	3.575
Si	0.335	0.420	0.255	0.290	0.375	0.460	0.205	0.280	0.270
P	101.88	133.565	201.705	219.460	293.585	110.465	96.215	105.255	104.285
S	29.215	40.560	29.370	33.530	37.035	40.700	28.195	29.355	25.420

*1. Maceration (1:10)
2. Maceration (1:15)
3. Maceration (1:20)
4. Ultrasonic extraction (1:10)
5. Ultrasonic extraction (1:15)
6. Ultrasonic extraction (1:20)
7. Microwave extraction (1:10)
8. Microwave extraction (1:15)
9. Microwave extraction (1:20)

The ICP-OES analysis is particularly important given that dandelion is a plant of high nutritional value, rich in numerous bioactive compounds (Tanasa Acretei et al 2025; Hulea et al. 2025; Skubic et al. 2025). Moreover, it is well known for its pronounced ability to accumulate micronutrients from the soil, especially in its roots (Babayan

et al. 2025). Due to this property, when cultivated under controlled conditions, dandelion can serve as a valuable source of beneficial bioactive substances, including antioxidants, vitamins, and essential macro- and microelements (Babayan et al. 2025). At the same time, because of its strong ability to absorb elements from the environment, not only from the soil but also from the atmosphere through particle deposition on its aerial parts, dandelion can be used as a sensitive bioindicator of soil, air, and overall environmental quality (Djingova and Kuleff 1993; Kabata-Pendias and Dudka 1991; Keane et al. 2001). This property has been exemplified in studies from eastern Croatia, where higher arsenic concentrations were detected in both soils and plants, including *Taraxacum officinale*, particularly in regions affected by past wartime activities (Ćavar et al., 2005; Ujević et al., 2010). Such findings demonstrate that dandelion not only reflects the natural geochemical background but can also signal localized contamination events (Ćavar et al., 2005; Ujević et al., 2010). Recent studies on dandelions have shown seasonal variations in rare earth elements (REEs) in soils and plants, with lower total REEs in roots and leaves during autumn compared to spring. These results further support the use of dandelion as a bioindicator of environmental element distribution (Lisiak-Zielińska et al. 2025).

The ICP-OES analysis of dandelion roots provided insights into both the nutritional and environmental aspects of this plant. The concentrations of major and trace elements varied, highlighting the capacity of dandelion to selectively accumulate elements from its environment. Notably, elements such as Ag, Co, Cr, Ni, Pb, and Tl were below the detection limit in all samples, indicating the absence of broad contamination and confirming the overall clean status of the sampling site for these metals. Conversely, the presence of arsenic (As) and mercury (Hg) in measurable concentrations suggests potential localized environmental influences. The elevated levels of these elements may reflect specific anthropogenic sources in the vicinity, such as industrial activities or accidental releases. While these concentrations warrant attention and could serve as indicators of local pollution, they do not by themselves confirm that the dandelion roots are unsafe for consumption. A detailed risk assessment, including comparison with established safety thresholds, would be required to make any definitive statements regarding their suitability for human or animal use. The absence of several potentially toxic elements reinforces the notion that, in general, the sampling site remains largely uncontaminated.

Among the essential nutrients, potassium (K) was present in relatively high concentrations, which aligns with the traditional use of dandelion as a natural diuretic (Yao et al. 2022; Maideen et al. 2023). Other macroelements such as calcium (Ca), magnesium (Mg), phosphorus (P), and sulphur (S) were also detected in appreciable amounts, supporting the nutritional value of dandelion roots. Trace elements like boron (B), barium (Ba), bismuth (Bi), strontium (Sr), silicon (Si), and zinc (Zn) were present in low but detectable amounts, providing additional insight into the elemental profile of this species.

Conclusion

This study provides a comprehensive evaluation of the bioactive and elemental composition of dandelion (*Taraxacum officinale*) roots. The comparative analysis of extraction methods revealed that microwave-assisted extraction is the most efficient for obtaining phenolic and flavonoid compounds, resulting in the highest antioxidant activity as measured by both DPPH and FRAP assays. These findings demonstrate that the choice of extraction technique, as well as the solvent-to-material ratio, has a critical impact on the recovery of biologically active compounds. The quantification of total phenolics and flavonoids confirmed a strong correlation with antioxidant activity, highlighting the contribution of these compounds to the redox properties of dandelion extracts. LC-MS/MS analysis showed the presence of a wide range of phenolic acids, hydrolyzable tannins,

galloyl derivatives, and flavonoids, including different isomers and glycosidic forms. This chemical diversity contributes to the plant's antioxidant and pharmacological activities, while the presence of complex ellagitannins and methoxylated flavones suggests the possibility of synergistic action of polyphenols. The obtained chemical profile confirms the significance of dandelion root as a potential source of bioactive compounds with a broad spectrum of biological effects. ICP-OES analysis showed a rich elemental profile, with significant levels of potassium, calcium, magnesium, phosphorus, and sulphur, supporting the nutritional and traditional medicinal value of dandelion roots. The presence of arsenic and mercury in measurable amounts indicates the potential of dandelion to act as a bioindicator of localized environmental contamination. At the same time, the absence of several toxic metals, including silver, cobalt, chromium, nickel, lead, and thallium, confirms that the sampling site is largely uncontaminated.

Overall, the data confirm the dual role of dandelion as both a nutritious plant and a bioindicator of environmental quality. The selective accumulation of mercury and arsenic underscores its sensitivity to localized contamination events, while the high potassium content supports its traditional medicinal use. These findings contribute to understanding the elemental composition of dandelion roots and their potential applications, in both nutrition and environmental monitoring. So, optimization of extraction methods can significantly enhance the recovery of bioactive compounds, providing a foundation for both nutritional and phytochemical applications, as well as environmental monitoring.

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References

Aung T, Das SK 2025. Quantitative investigation of total phenolics content in spray-dried dandelion extract powder. Int J Environ Sci **11**(4S): 600-607

Álvarez-Romero M, Ruíz-Rodríguez A, Barbero GF, Vázquez-Espinosa M, El-Mansouri F, Brigui J, Palma M 2023. Comparison between ultrasound- and microwave-assisted extraction methods to determine phenolic compounds in barley (*Hordeum vulgare* L.) Foods **12**(14): 2638

Azmir J, Zaidul ISM, Rahman MM, Sharif KM, Mohamed A, Sahena F, Jahurul MHA, Ghafoor K, Norulaini NAN, Omar AKM 2013. Techniques for extraction of bioactive compounds from plant materials: A review. Journal of Food Engineering, **117**(4), 426–436.

Babayan B, Yesayan A, Sevoyan G, Yesayan T 2025. Genetic changes in common dandelion (Taraxacum officinale) induced by high concentrations of heavy metals in soil. Funct Food Health Dis 15(9): 625-633

Bagdas D, Cinkilic N, Ozboluk HY, Ozyigit MO, Gurun MS 2013. Antihyperalgesic activity of chlorogenic acid in experimental neuropathic pain. J Nat Med **67**(4): 698-704.

Başaran E, Öztürk AA, Şenel B, Demirel M, Sarica Ş 2022. Quercetin, rutin and quercetin-rutin incorporated hydroxypropyl β-cyclodextrin inclusion complexes. Eur J Pharm Sci **1**:172:106153.

Bouaoudia-Madi N, Boulekbache-Makhlouf L, Madani K, Silva AMS, Dairi S, Oukhmanou–Bensidhoum S, Cardoso S 2019. Optimization of ultrasound-assisted extraction of polyphenols from *Myrtus communis* L. pericarp. Antioxidants (Basel) 2:**8**(7):205.

Clifford MN, Johnston KL, Knight S, Kuhnert N 2003. Hierarchical scheme for LC-MSn identification of chlorogenic acids. J Agric Food Chem **51**(10) 2900-2911.

Cogger CG 2005. Potential compost benefits for restoration of soils disturbed by urban development. Compost Sci Util **13**: 243-251.

Djingova R, Kuleff I 1993. Monitoring of heavy metal pollution by *Taraxacum officinale*. Wiley-VCH Verlag GmbH: 435-460.

Escudero NL, De Arellano ML, Fernández S, Albarracín G, Mucciarelli S 2003. *Taraxacum officinale* as a food source. Plant Foods Hum Nutr **58**: 1-10.

Guojun D, Yuxuan L, Sen F, Cuntang W 2025. Microwave-assisted extraction of dandelion root polysaccharides: extraction process optimization, purification, structural characterization, and analysis of antioxidant activity. Int J Biol Macromol **299**:139732.

Hulea C, Obistioiu D, Hulea A, Suleiman MA, Floares Oarga D, Alexa E, Imbrea IM, Neacşu AG, Pentea M, Popescu CA, Imbrea F 2025. Integrated assessment of antibacterial activity, polyphenol composition, molecular docking, and ADME properties of Romanian oak and fir honeydew honeys. Antibiotics (Basel) *14*(6): 592.

Iwashina T, Smirnov S, Damdinsuren O, Kondo K 2012. Flavonoids from Reaumuria soongarica (*Tamaricaceae*) in Mongolia. Bull Natl Mus Nat Sci Ser.B, 38(4) 189-195

Kabata-Pendias A, Dudka S 1991: Trace metal contents; Taraxacum officinale (dandelion) as a convenient environmental indicator. Environ Geochem Health **13**: 108-113

Kenny O, Smyth TJ, Hewage CM, Brunton NP 2014. Antioxidant properties and quantitative UPLC-MS/MS analysis of phenolic compounds in dandelion (*Taraxacum officinale*) root extracts. Free Rad Antiox **4**(1):55-61.

Keane B, Collier MH, Shann JR, Rogstad SH 2001: Metal content of dandelion (*Taraxacum officinale*) leaves in relation to soil contamination and airborne particulate matter. Sci Total Environ **281**: 63-78.

Kiss A, Papp VA, Pál A, Prokisch J, Mirani S, Toth BE, Alshaal T. 2025. Comparative study on antioxidant capacity of diverse food matrices: Applicability, suitability and inter-correlation of multiple assays to assess polyphenol and antioxidant status. Antioxidants, **14**(3), 317.

Li C, Tian Y, Zhao C, Li S, Wang T, Qiao B, Fu Y 2021. Application of fingerprint combined with quantitative analysis and multivariate chemometric methods in quality evaluation of dandelion (*Taraxacum mongolicum*). R Soc Open Sci **8**: 210614.

Lisiak-Zielińska M, Borowiak K, Budka A, Mleczek P, Cakaj A, Kanclerz J, Hanć A 2025. Seasonal variation of rare earth elements in *Taraxacum officinale* as an indicator of changes in urban pollution. Sci Rep **15**, 29496.

Ma X, Okyere SK, Hu L, Wen J, et al. 2022. Anti-inflammatory activity and mechanism of cryptochlorogenic acid from Ageratina adenophora. Nutrients **14**(3), 439.

Maideen NMP, Balasubramanian R, Muthusamy S 2023. A comprehensive review of the pharmacologic perspective on loop diuretic drug interactions with therapeutically used drugs. Curr Drug Metab **23**(3): 188-199.

Mikołajczak P, Borowiak K, Niedzielski P 2017. Phytoextraction of rare earth elements in herbaceous plant species growing close to roads. Environ Sci Pollut Res **24**: 14091-14103.

Mantzourani C, Kakouri E, Palikaras K, Tarantilis PA, Kokotou MG 2024. Urolithins and their precursors ellagic acid and ellagitannins: natural sources, extraction and methods for their determination. Separations **11**(6), 174.

Masike K, Mhlongo MI, Mudau SP, Nobela O, Ncube EN, Tugizimana F, George MJ, Madala NE 2017. Highlighting mass spectrometric fragmentation differences and similarities between hydroxycinnamoyl-quinic acids and hydroxycinnamoyl-isocitric acids. Chem Cent J **11**(1): 29.

Navarro M, Moreira I, Arnaez E, Quesada S, Azofeifa G, Vargas F, Alvarado D, Chen P 2017. Flavonoids and ellagitannins characterization, antioxidant and cytotoxic activities of Phyllanthus acuminatus Vahl. Plants **6**(4), 62.

Navarro M, Arnaez E, Moreira I, Quesada S, Azofeifa G, Wilhelm K, Vargas F, Chen P 2019. Polyphenolic characterization, antioxidant, and cytotoxic activities of *Mangifera indica* cultivars from Costa Rica. Foods **8**(9), 384.

Oroian M, Dranca F, Ursachi F 2020. Comparative evaluation of maceration, microwave and ultrasonic-assisted extraction of phenolic compounds from propolis. J Food Sci Technol **57**: 70-78.

Pacifico S, Piccolella S, Papale F, Nocera P, Lettieri A, Catauro M 2015. A polyphenol complex from *Thymus vulgaris L*. plants cultivated in the Campania Region (Italy): new perspectives against neuroblastoma. J Functional Foods **20**: 253–266.

Peng J, Chen G, Guo S, Lin Z, Li J, Yang W, Xiao G, Wang Q 2024. The galloyl group enhances the inhibitory activity of catechins against LPS-triggered inflammation in RAW264.7 cells. Foods **13**(16), 2616.

Pereira AG, Cruz L., Cassani L, Chamorro F, Lourenço-Lopes C, Freitas V, Otero P, Fraga-Corral M, Prieto MA, Simal-Gandara J, Perez-Gregorio R 2023. Comparative study of microwave-assisted extraction and ultrasound-assisted extraction techniques (MAE vs. UAE) for the optimized production of enriched extracts in phenolic compounds of Camellia japonica var. Eugenia de Montijo. Engineering Proceedings, **37**(1), 124.

Pooja S, Modi HA 2015. Comparative study of DPPH, ABTS and FRAP assays for determination of antioxidant activity. IJRASET **3**(6): 636-641.

Petrovska BB 2012. Historical review of medicinal plants' usage. Pharmacogn Rev **6**: 1-5.

Qiao Q, Song X, Zhang C, Jiang C, Jiang R 2024. Structure and immunostimulating activity of polysaccharides derived from the roots and leaves of dandelion. Chem Biol Technol Agric **11**, 51.

Ramesh MM, Shankar NS, Venkatappa AH 2024. Driving/critical factors considered during extraction to obtain bioactive enriched extracts. Pharmacognosy Rev **18**(35): 68–81.

Skubic M, Baša Česnik H, Velikonja Bolta Š, Rusjan D, Šircelj H 2025. Is common dandelion (*T. officinale agg*.) foraged for food pesticide residues free? Foods **14**(4): 684.

Spínola V, Pinto J, Castilho PC 2014. Identification and quantification of phenolic compounds of selected fruits from Madeira Island by HPLC-DAD–ESI-MSn and screening for their antioxidant activity. Food Chem **15**:173:14-30.

Stanojević Lj, Stanković M, Nikolić V, Nikolić Lj, Ristić D, Čanadanovic-Brunet J, Tumbas V 2009. Antioxidant activity and total phenolic and flavonoid contents of *Hieracium pilosella* L. extracts. Sensors **9**(7): 5702-5714.

Stanojević Lj, Zdravković A, Stanković M, Cakić M, Nikolić V, Ilić D 2013. Antioksidativna aktivnost vodeno-etanolnih ekstrakata iz lista koprive (*Urtica dioica* L.). Savremene tehnologije **2**(1): 51-59.

Stewart-Wade SM, Neumann S, Collins LL, Boland GJ 2002. The biology of Canadian weeds. 117. Taraxacum officinale G.H. Weber ex Wiggers. Can J Plant Sci **82**: 825-853.

Tanasa Acretei MV, Negreanu-Pirjol T, Olariu L, Negreanu-Pirjol BS, Lepadatu AC, Anghel Cireasa L, Rosoiu N 2025. Bioactive compounds from vegetal organs of *Taraxacum* species (dandelion) with biomedical applications: a review. Int J Mol Sci **26**(2): 450.

Ujević M, Duić Ž, Casiot C, Šipoš L, Santo V, Dadić Ž, Halamić J 2010. Occurrence and geochemistry of arsenic in the groundwater of eastern Croatia. Appl Geochem **25**: 1017-1029.

Xuereb M.A, Psakis G, Attard K, Lia F, Gatt R. A 2025. Comprehensive Analysis of Non-Thermal Ultrasonic-Assisted Extraction of Bioactive Compounds from Citrus Peel Waste Through a One-Factor-at-a-Time Approach. Molecules, 30, 648.

Yao J, Ma Z, Wang Y, Wang Y, Sun L, Liu X 2022. Effects of dandelion addition on antioxidant property, sensory characteristics and inhibitory activity against xanthine oxidase of beer. CRFS **5**: 927-939.