An Analytical Approach for Determining Macro- and Micro- Elements in Two Different Growing Periods of Artemisia abrotanum L

İslam Cansever

islam.cansever@ikcu.edu.tr

Izmir Kâtip Çelebi University

Ozlem Sogut

Ege University

Research Article

Keywords: Artemisia abrotanum L., ICP-MS, trace element, infusion, microwave digestion, chemometry

Posted Date: December 16th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-5095986/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at BioMetals on July 12th, 2025. See the published version at https://doi.org/10.1007/s10534-025-00718-1.

Abstract

The widespread use of medicinal plants has led to the cultivation of *Artemisia abrotanum* L., which grows wild in Turkey. The amount of trace elements contained in plants is important for health therefore,analyses of microwave and infusion extracts of the plant were performed using ICP-MS. The evaluation of the elemental content of the harvest time of *Artemisia abrotanum* L. using a validated method constitutes the aim of the study. Na, K, Mg, Fe, P, S, Ca, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Cd, Ba, Tl, Li, U were determined. It was observed that the element distribution varied depending on the element in the pre-flowering and flowering periods of the plant. In both extraction methods, Na, Mn, Ni, Co, As, Se, Sr, and Ba concentrations were higher in the blooming period and K, Mg, Ca, Zn, Mo, Cd, and Pb concentrations were higher in the pre-blooming period of *Artemisia abratonum* L. The amounts of P, Fe, Al, V, Cr, and Tl concentrations differed according to the extraction method. Cu and S concentrations were determined to be similar in both extraction methods and at both harvest times. The results were classified by chemometric analysis and the preparation method and elemental relationships were evaluated. When evaluating the amounts of essential, beneficial, and harmful elements present in *Artemisia abrotanum* L., consumed as an infusion by the public, independent of harvest time, we found that the detected levels of these elements exceeded the required or harmful thresholds for human health.

Highlight

Essential, beneficial, and toxic element levels of *Artemisia Abrotanum* L. were determined using a validated method in ICP-MS. The changes in analysis results according to harvest time and sample preparation method were shown using chemometric methods.

Introduction

Medicinal plants are widely used worldwide because of their potential use in treatment. The ease of access to these medicinal herbs, their affordable price, thought to have no side effects, and the trend of replacing conventional medicines have made them popular. Infusions and formulations obtained from medicinal plants, such as flowers, fruits, seeds, bark, and roots, support the medical treatment of several chronic diseases and play preventive roles [1]. Artemisia is a recognized genus of the Asteraceae (Compositae) family, consisting of approximately 500 species. It is also economically important in the food and pharmaceutical industries. Some species of the plant are allergenic, some are toxic, and some are weeds that grow spontaneously in the field [2].

Artemisia abrotanum L. is used as a tonic because it has an aromatic character and is widely grown in Europe. It is effective against stomach diseases and has antiseptic, anthelmintic, and diuretic properties [2, 3].

Living organisms need elements for processes such as the activation of enzymes and the production of hormones. Some of these are involved in growth, whereas others are important parts of the bone

structure. Essential minerals are classified in various ways according to their nutritional roles and body. The elements that the human body needs more are macro-elements (Ca, K, Na, S, P, Mg, Cl), and the less needed are microelements (Co Cr, I, Mo, Zn, Cu, Fe, Mn, Se, Al, B, F, Pb, Ni, Si, V, As, Br, Ge, Li, Rb, Sn). This definition does not mean that microelements play a lesser role in the body. The main function of the elements in the body is to provide structural support [4–6].

Contamination is a problem that arises in medicinal plant cultivation and processing. Additionally, plants play a big role in helping people absorb trace elements from the soil. The variety and quantity of elements found in plants depend on the soil, as well as the plant's selectivity for some of these elements and its need to accumulate them [7].

The study aimed to investigate the macro- and micro- element content of *Artemisia abrotanum* L. during the pre-and blooming periods using a validated analytical method and to classify them by chemometry.

Materials and methods

Plant material

Artemisia abrotanum L. was harvested in the Lisinia Nature Project Area near the Karakent village of Burdur (Turkey) before blooming (Pre-Blooming Period, PBP) and during the blooming periods (BP) and dried in the shade at room temperature for a week. The plant was confirmed morphologically by the herbarium of Izmir Katip Çelebi University Faculty of Pharmacy (IKCE- No-135). It was then ground up and stored in lidded plastic containers.

Sample preparation

Microwave Digestion

Approximately 0.5 g of sample and also certified reference material (LGC7162 Strawberry Leaves from NML, Germany) were weighed into Teflon (PTFE) tubes and treated with 8 mL HNO_3 and 2 mL H_2O_2. After waiting for gas release in the fume hood, the samples were digested by the digestion system (Ethos Easy, Milestone Srl., IT) according to the program of microwave oven. The temperature was increased to 200°C within 15 min. and kept at that temperature for 15 min. Then the final solutions were diluted to 50 mL with ultrapure water.

Infusion

Approximately 2.5 g of each sample was weighed to prepare infusions of the plant samples. Then, 100 mL of boiling distilled water was added, the mixture was left for 5 minutes, and it was filtered using 0.45 µm PTFE filters. Measurements were performed on the same day by ICP-MS.

Reagents, Reference Materials, and Standard Solutions

All acids used for digestion were Supra-pure grade; 65% (m/m) HNO3 and 30% (m/m) H2O2 were purchased from Merck (Darmstadt, DA, Germany). Stock solutions for each element (1000 mg/L), internal solutions (100 µg/mL), and tuning solutions (10 µg/mL) were purchased from Agilent Technologies (USA). NIST (Gaithersburg, MD, USA) 1640a natural water was used to determine the limit of detection (LOD) and limit of quantitation (LOQ) of the method. Ultrapure water was supplied from an ultrapure water purification system (Human Power II, KR) with a resistivity of 18.2 MΩ·cm at 25°C.

Instrumentation

The multi-element determinations were conducted in an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS 7800, Agilent, USA). ^{6}Li, ^{45}Sc, ^{72}Ge, ^{89}Y, ^{115}In, ^{159}Tb, ^{209}Bi were used as internal standard and ^{7}Li, ^{89}Y, ^{205}TI were used as tuning solvents. ICP-MS operating conditions are given in Table 2.

Table 1
ICP-MS Operating Conditions

Parameters	Value
RF Power	1500 W
RF Voltage	1,80 V
S/C Temp.	2 ºC
Sampling Depth	10 mm
Nebulizer Gas	1,03 L/dk
Nebulizer Pump	0,10 rps
Internal Standards	^{6}Li, ^{45}Sc, ^{72}Ge, ^{89}Y, ^{115}In, ^{159}Tb, ^{209}Bi
Tune Solution	^{7}Li, ^{89}Y, ^{205}Tl

Method validation

The analytical method was validated following the guidelines set forth by the International Conference on Harmonisation (ICH, 2005) and the recommendations from the International Union of Pure and Applied Chemistry (IUPAC) [9]. Key parameters including accuracy, precision, linearity, sensitivity, repeatability, limits of detection (LOD), and limits of quantification (LOQ) were thoroughly investigated.

Accuracy, which measures the proximity of results to the true value, and precision, indicating the consistency of experimental results, were assessed using LGC7162-CRM (LGC, Germany). Precision and repeatability were evaluated using standard solution 3, which was also used for constructing the calibration curve.

Linearity was determined by injecting five different mixtures of standard solutions, each diluted from a 1000 µg/g stock solution of each element, into the device three times. Sensitivity, derived from the slope

of the calibration curve, demonstrates the method's ability to detect small changes in concentration, as indicated by the regression line from the linearity assessment.

The limits of detection (LOD) and quantitation (LOQ) were experimentally determined as 3.3σ/S and 10σ/S, respectively, where σ represents the standard deviation of the response from 10 blanks (Digested NIST 1640a natural water) and S is the slope of the calibration curve (EURACHEM 2000). Statistical analysis was conducted in triplicate, and data are presented as mean ± standard deviations.

Chemometric Analysis

Chemometric methods, including Principal Component Analysis (PCA) from multivariate analysis and hierarchical cluster analysis, were used to evaluate the experimental results using the JMP16 statistical software program. The Ward method was used for dendrogram analysis.

Results and Discussion

Elemental analysis in medicinal plants is of great importance for human health. In the analysis of trace elements, sample preparation steps affect the results. The microwave digestion technique is the most sensitive method for the extraction of the plant. However, *Artemisia abrotanum* L is consumed by infusing among the public. For this purpose, two methods were used in the sample preparation stage: microwave digestion in an acidic environment and infusion.

Na, Mg, Al, P, S, K, Ca, Al, Sr, Ni, Cu, Mn, Zn, Co, As, Se, V, Cr, Mo, Cd, Ba, T, Pb, U were analyzed in *Artemisia abrotanum* L. A multi-element analysis by its optimum range, standards were given to ICP-MS for the determining linearity, sensitivity, LOD, and LOQ of the method. Correlation coefficients, which are indicators of the linearity and sensitivity of the method, are given for all elements (Table 2).

The CRM sample results were derived from averaging six parallel runs. Thallium (Tl) and uranium (U) were absent from the certificate. Sodium (Na), copper (Cu), vanadium (V), and selenium (Se) values were listed in the certificate as indicative. These indicator values were also included in Table 3, and their recovery was calculated accordingly.

Table 2
The calibration data of ICP-MS analysis provides linearity and precision information

Parameters	Calibration Equation	R
Na	Y = 13.412 + 0.855X	0,99998
Mg	Y = 6.028 + 0.007X	1,00000
Fe	Y = 105.18 + 0.157X	0,99999
P	Y = 0.075 + 0.002X	0,99999
S	Y = 0.018 + 0.004X	0,99994
K	Y = 2.315 + 0.156X	1,00000
Ca	Y = 0.024 + 0.0003X	0,99999
Al	Y = 0.001 + 0. 001X	0,99993
V	Y = 689.5 + 1.33X	0,99998
Cr	Y = 0.118 + 0.007X	0,99998
Mn	Y = 0.0365 + 0.004X	0,99999
Co	Y = 2175 + 16.67X	0,99990
Ni	Y = 0.076 + 0.019X	0,99995
Cu	Y = 0.226 + 0.047X	0,99997
Zn	Y = 0.227 + 0.228X	0,99996
As	Y = 0.014 + 0.0005X	0,99999
Se	$Y = 0.002 + 3.5x10^{-5}X$	0,99997
Sr	Y = 0.04 + 0.004X	1,00000
Mo	Y = 0.002 + 0.0002X	0,99999
Cd	$Y = 0.0007 + 2.4x10^{-6}X$	0,99998
Ba	$Y = 0.0004 + 9.6x10^{-6}X$	0,99999
Tl	Y = 0.023 + 0.0005X	0,99999
Pb	Y = 0.015 + 0.002X	1,00000
U	$Y = 0.033 + 9.8x10^{-6}X$	1,00000

Table 3
Method validation results for the analysis of *Artemisia abrotanum* L. by ICP-MS.

Parameters	LOD ($mgkg^{-1}$)	LOQ ($mgkg^{-1}$)	Recovery (%)	Accuracy (CV)	Precision (RSD)	Repeatability (RSD)
Na	$1.1x10^{-2}$	$3.8x10^{-2}$	87.4	3.4	1.90	2.38
Mg	$1.3x10^{-3}$	$4.3x10^{-2}$	93.5	1.9	2.47	2.73
Fe	$5.8x10^{-4}$	$1.9x10^{-3}$	77.2	1.8	1.76	2.49
P	$1.4x10^{-2}$	$4.7x10^{-2}$	93.6	2.0	1.37	6.13
S	$3.4x10^{-2}$	$1.1x10^{-1}$	93.6	2.1	0.05	1.02
K	$2.0x10^{-2}$	$6.5x10^{-2}$	92.9	1.7	1.40	4.40
Ca	$2.7x10^{-3}$	$9.2x10^{-3}$	98.0	1.1	0.97	1.09
Al	$1.2x10^{-3}$	$3.9x10^{-3}$	91.2	8.1	5.19	6.63
V	$8.0x10^{-6}$	$2.6x10^{-5}$	73.5	1.7	0.98	1.75
Cr	$3.4x10^{-5}$	$1.1x10^{-4}$	82.8	4.9	2.6	4.28
Mn	$1.7x10^{-4}$	$5.5x10^{-4}$	90.5	1.4	2.92	4.75
Co	$1.1x10^{-5}$	$3.8x10^{-5}$	92.1	5.4	0.75	1.11
Ni	$5.8x10^{-5}$	$1.9x10^{-4}$	94.8	1.9	1.80	4.15
Cu	$8.3x10^{-5}$	$2.8x10^{-4}$	106.1	4.8	2.54	3.74
Zn	$4.0x10^{-3}$	$1.3x10^{-2}$	90.5	8.6	5.23	7.18
As	$2.4x10^{-5}$	$7.9x10^{-5}$	92.1	3.1	1.93	3.27
Se	$3.3x10^{-5}$	$1.1x10^{-4}$	85.0	3.9	0.68	0.91
Sr	$1.7x10^{-4}$	$5.8x10^{-4}$	90.0	1.3	2.15	5.16
Mo	$4.9x10^{-4}$	$1.6x10^{-3}$	89.9	3.0	0.72	2.77
Cd	$6.0x10^{-6}$	$2.2x10^{-5}$	87.0	4.5	0.91	1.27
Ba	$7.8x10^{-5}$	$2.6x10^{-4}$	89.6	2.0	3.22	3.59
NA: Not Available						

Parameters	LOD ($mgkg^{-1}$)	LOQ ($mgkg^{-1}$)	Recovery (%)	Accuracy (CV)	Precision (RSD)	Repeatability (RSD)
Tl	$5.0x10^{-6}$	$1.7x10^{-5}$	N.A.	5.9	0.66	0.90
Pb	$2.2x10^{-5}$	$7.4x10^{-5}$	90.8	8.2	0.52	0.71
U	$1.0x10^{-6}$	$2.0x10^{-6}$	N.A.	6.8	0.82	0.66
NA: Not Available						

The validated method was used to compare the element contents of *Artemisia abrotanum* L. before and during flowering. The results of samples obtained after both microwave digestion and infusion were evaluated. As expected, the results obtained with microwave digestion were higher than the results obtained with infusion. The purpose of preparing samples by infusion is to determine how much of the elements present in the plant are released into the water. The aim here is to compare the pre-blooming and blooming period element contents of *Artemisia abrotanum* L. rather than comparing sample preparation techniques. The results summarized in Table 4.

Table 4
Elemental content of *A. abrotanum* L. in pre-blooming and blooming periods

Element	Mod	Unit	PBP-MW ± SD	BP-MW ± SD	PBP-INF ± SD	BP-INF ± SD
Na	He	mg/kg	670.1 ± 13.2	1137.7 ± 50.8	175.55 ± 7.80	257.66 ± 13.62
K	He	mg/kg	38332 ± 560	29387 ± 490	11445 ± 528	9922 ± 319
Mg	He	mg/kg	1701.8 ± 26.1	1676.6 ± 33.1	1205.6 ± 52.8	1017.8 ± 51.9
P	He	mg/kg	3653.1 ± 134.3	2109 ± 98.8	1847 ± 166.9	1974.8 ± 13.5
S	H_2	mg/kg	3588.7 ± 92.9	3862.1 ± 70.8	2796 ± 102.6	2783 ± 102.1
Fe	He	mg/kg	253.32 ± 17.15	385.80 ± 15.52	4.02 ± 0.21	2.96 ± 0.18
Ca	H_2	mg/kg	8793.2 ± 257.3	8103.6 ± 119.2	2669.8 ± 71.1	2581.2 ± 49.5
Mn	He	mg/kg	161.05 ± 11.87	182.21 ± 3.75	49.33 ± 2.11	51.44 ± 1.81
Cu	He	mg/kg	14.31 ± 1.07	14.98 ± 0.47	5.91 ± 0.29	5.90 ± 0.18
Zn	He	mg/kg	45.72 ± 1.77	19.32 ± 0.26	12.43 ± 0.53	5.94 ± 0.16
Ni	He	mg/kg	6.33 ± 0.46	11.25 ± 0.21	5.42 ± 0.26	9.08 ± 0.25
Al	He	mg/kg	306.88 ± 12.23	348.81 ± 11.77	4.80 ± 0.30	3.04 ± 0.19
V	He	µg/kg	595.50 ± 13.99	952.29 ± 39.42	58.60 ± 2.48	48.27 ± 2.98
Cr	He	µg/kg	1140.58 ± 36.46	2001.81 ± 188.23	70.66 ± 6.87	58.61 ± 3.74
Co	He	µg/kg	422.31 ± 14.28	590.87 ± 25.52	246.41 ± 3.88	306.01 ± 15.64
As	He	µg/kg	131.33 ± 8.14	233.35 ± 18.95	31.93 ± 2.64	72.19 ± 3.19
Se	H_2	µg/kg	17.94 ± 1.71	35.14 ± 1.72	17.06 ± 0.92	22.70 ± 1.82
Sr	He	mg/kg	6.76 ± 0.30	19.39 ± 0.69	1.41 ± 54.58	3.51 ± 0.13
Mo	He	µg/kg	466.32 ± 40.90	357.44 ± 21.09	110.81 ± 4.21	65.51 ± 3.80
Cd	He	µg/kg	157.66 ± 11.25	89.79 ± 7.10	39.53 ± 2.64	27.30 ± 1.37
Ba	He	µg/kg	4272.5 ± 391	4546.6 ± 214.9	536.28 ± 23.94	718.71 ± 15.49
Tl	He	µg/kg	5.74 ± 0.49	5.65 ± 0.35	0.81 ± 0.05	1.03 ± 0.05
Pb	He	µg/kg	391.40 ± 37.89	176.21 ± 3.97	240.38 ± 9.10	126.77 ± 4.41

n = 6, SD: Standard deviation, MW: Microwave digestion, INF: Infusion

It is observed that element concentrations change according to the harvest time of the plant. In both extraction methods, Na, Mn, Ni, Co, As, Se, Sr, and Ba concentrations were higher in BP (Blooming Period) and K, Mg, Ca, Zn, Mo, Cd, and Pb concentrations were higher in PBP (pre-Blooming Period) of *Artemisia abratonum* L. The amounts of P, Fe, Al, V, Cr, and Tl concentrations differed according to the extraction method. Cu and S concentrations were determined to be similar in both extraction methods and at both harvest times (Fig. 1–3).

There are a few studies on *Artemisia abrotanum* L. Therefore, the elemental content of the plants was compared with those of other Artemisia species. There is a review article in which the elemental contents of some Artemisia species are summarized, but *Artemisia abrotanum* is not included in this article [8].

Generally, our study revealed higher elemental values compared to plants grown in Pakistan, as indicated by this review. Likewise, there were significant differences between the elemental analysis results of the infusion samples of the *Artemisia absinthium* L. conducted by Szparaga et al. and the analysis results of the infusion samples in our study, and the data obtained in our study were found to be higher [9].

There are some studies on *Artemisia absinthium* L. In this study, the amounts of K, Ca, Mg, and Na were determined in *Artemisia absinthe* L. as 417.903, 116.0225, 26.2250, and 15.9825 $\mu g L^{-1}$, respectively. These values were also lower than our results [10]. In another study, the concentrations of Ba, Cr, Zn, Mn, Cu Ni, and Pb in *Artemisia absinthium* L. were found to be 185, 0.72, 15.6, 13.6, 15.5, 3.1, and 1.1 $mg kg^{-1}$, respectively. According to the results of this study, these values are higher for elements other than Pb and Ba element concentrations [11]. When evaluated in general, it is normal for trace amounts to vary. However, the lack of elemental analysis data for the species used in this study made the discussion difficult.

The multivariate analysis design for classification of the plant was used as the most basic analysis design. When the data in Fig. 4 is evaluated, it can be seen that 74.9% of the data variance can be explained using two main factors. PCA based on the correlation matrix of the data provides the results in different procedure and in different harvest time of *Artemisia abrotanum L.* samples were given in Fig. 4 in the scores and loadings. It was found that it was possible to group the obtained score according to collection times and sample preparation method. The loading graph shows us the similarities between the elements, for example, we can state that there is a high correlation between Mo and K, which are on the same line. A similar situation can be said for other elements.

Hierarchical Cluster analysis gives more information about element correlation. The dendrogram obtained by cluster analysis using Ward's software was used to separate the raw ICP-MS data into groups. When Fig. 5 is evaluated, it can be concluded that there are two main element groups in the data.

Hierarchical Clustering

Method = Ward, Standardized by Column Robust

-+Dendrogram

Principal Component Analysis (PCA) of elements is crucial for understanding their impact on human health. The classification of elements based on their effects includes; **essential elements** (Na, Mg, K, Ca, P, S, Mo, Mn, Fe, Co, Cu, Zn) b**eneficial elements** (V, Cr, Se, Ba, Sr), p**olluting elements** (Ni, Al, As, Cd, Hg, Pb).

In the PCA of *Artemisia abrotanum* L., eigenvectors, eigenvalue scores, and loading plots are utilized to analyze and understand the distribution and relationships of these elements. This method helps in identifying which elements contribute positively or negatively to overall health outcomes.

When evaluating the amounts of essential, beneficial, and harmful elements present in *Artemisia abrotanum* L., which is consumed as an infusion by the public, independent of harvest time, we found that the detected levels of these elements exceeded the required or harmful thresholds for human health (Table 5).

Table 5
Effects of some toxic elements on health and comparison of toxic doses of these elements with samples prepared by infusion of *Artemisia abrotanum* L. according to the harvest time

Element	Daily intake (mg)	Some Biologic effects	*Artemisia abrotanum* L. inf. PBP/BP (mg)	References
Fe	8	In many enzymes and respiratory proteins	4 / 3	[12]
Zn	10	In hydrolytic enzymes, nucleic acid synthesis	12 / 6	[12]
Cu	0.9	In enzymes and oxygen transport	6 / 6	[12]
Mn	2	In photosynthesis, enzyme activation	49 / 51	[12]
Mo	0.045	In redox enzymes, nitrogenase	0.111 / 0.066	[12]
Co	0.007	In colabamine	0.246 / 0.306	[13]
V	0.1	In bromperoxidase	0.059 /0.0 48 µg	[14]
Ni	0.07	In hydrogenase	5 / 9	[15]
Ca	1000	In bone, teeth, muscle activationrogenase	2670 / 2581mg	[12]
Mg	350	In photosynthesis, nucleic acid processes	1206 / 1018	[12]
Na	2000	In control body fluid balance, nervous system	176 / 258	[12]
K	2600	In nervous sytem	11445 / 9922	[12]
Cr	0.02	In cholesterol, fat and protein synthesis	0.071 / 0.059	[12]
Se	0.055	In glutathione peroxidase enzyme	0.017 / 0.023	[12]
S	50	In skin, bone, muscle, enzymes	2796 / 2783	[16]
P	700	Bones, cell membrane, nucleic acid	1847 / 1975	[12]

Table 6
The impact of toxic elements on human health and a comparison of the concentrations of these elements in samples prepared by infusing the plant Artemisia abrotanum L. with levels deemed toxic to human health.

Element	Toxic doses	Side effects	*Artemisia abrotanum* L. inf. PBP/BP	References
Al	1 mg/kg/week	In nervous system, bone and blood system	4.8 / 3 mg	[17]
As	2-20mg/kg	In DNA, protein	32 / 72 µg	[18]
Cd	*	Cytotoxic, cancer	40 / 27 µg	[19]
Pb	0.03-0.07mg/day	In nervous system, blood cell	240 / 127 µg	[20]
Ba	*	In nervous system, brain, metabolic disorder	0.536 / 0.718	[21]

Conclusion

Nowadays, plants are traditionally used in various fields. When examining the essential, beneficial, and toxic elements in *Artemisia abrotanum* L. during the blooming and pre-blooming periods, it was found that the levels of these elements were higher than what is considered necessary or harmful for humans. Thus, even if the source is natural, it is crucial to be mindful of the quantity consumed.

The elemental content of plants typically depends on environmental factors, climatic conditions, and soil composition. Therefore, medicinal plants must be compatible with the environmental conditions of the region where they are cultivated.

Declarations

Author Contribution

I.C .wrote the main manuscriptI.C. performed ICP-MS analysisI.C. and O.S. prepared figures and tablesO.S. performed chemometric analysisAll authors reviewed the manuscript

References

1. Pohl P, Dzimitrowicz A, Jedryczko D, et al (2016) The determination of elements in herbal teas and medicinal plant formulations and their tisanes. J Pharm Biomed Anal 130:326–335. https://doi.org/10.1016/j.jpba.2016.01.042
2. Obistioiu D, Cristina RT, Schmerold I, et al (2014) Chemical characterization by GC-MS and in vitro activity against Candida albicans of volatile fractions prepared from Artemisia dracunculus,

Artemisia abrotanum, Artemisia absinthium and Artemisia vulgaris. Chem Cent J 8:1–11. https://doi.org/10.1186/1752-153X-8-6

3. Cubukcu B, Bray DH, Warhurst C, et al (1990) In Vitro Antimalarial Activity of Crude Extracts and Compounds from Artemisia abrotanum L. 4:203–204
4. Ngigi AN, Muraguri BM (2019) ICP-OES determination of essential and non-essential elements in Moringa oleifera, Salvia hispanica and Linum usitatissimum. Sci African 6:e00165. https://doi.org/10.1016/j.sciaf.2019.e00165
5. Tokalioğlu Ş (2012) Determination of trace elements in commonly consumed medicinal herbs by ICP-MS and multivariate analysis. Food Chem 134:2504–2508. https://doi.org/10.1016/j.foodchem.2012.04.093
6. McDowell LR (2003) General Introduction. In: McDowell LR (ed) Minerals in Animal and Human Nutrition, 2. Elsevier, pp 1–32
7. Başgel S, Erdemoğlu SB (2006) Determination of mineral and trace elements in some medicinal herbs and their infusions consumed in Turkey. Sci Total Environ 359:82–89. https://doi.org/10.1016/j.scitotenv.2005.04.016
8. Aziz MA, Adnan M, Begum S, et al (2016) A review on the elemental contents of Pakistani medicinal plants: Implications for folk medicines. J Ethnopharmacol 188:177–192. https://doi.org/10.1016/j.jep.2016.05.011
9. Szparaga A, Kocira S, Kapusta I, Zaguła G (2021) Prototyping extracts from Artemisia absinthium L. for their biostimulating properties yield-enhancing, and farmer income-increasing properties. Ind Crops Prod 160:113125. https://doi.org/https://doi.org/10.1016/j.indcrop.2020.113125
10. Akzhigitova Z, Baiseitova A, Ye Y, Jenis J (2018) Investigation of chemical constituents of Artemisia absinthium. Int J Biol Chem 11:169–177. https://doi.org/10.26577/ijbch-2018-1-304
11. M□zyk Z, Wia□ckowski SK (1999) Studies of Trace Element Content in Selected Medical Herbs. Polish J Environ Stud 8:129–130
12. National Institute of Health Office of Dietary Supplements. https://ods.od.nih.gov
13. Cobalt - Health Encyclopedia - University of Rochester Medical Center. https://www.urmc.rochester.edu/encyclopedia/content.aspx?contenttypeid=19&contentid=cobalt. Accessed 5 Aug 2024
14. Kohlmeier M (2003) Vanadium. Nutr Metab 762–766. https://doi.org/10.1016/B978-012417762-8.50112-5
15. Nielsen F (2021) Nickel. Adv Nutr 12:281–282. https://doi.org/10.1093/advances/nmaa154
16. Cabaroglu T, Canbaş A (1993) The use and importance of sulphur dioxide in wine making. GIDA 18:139–144
17. NİZAMLIOĞLU F, NİZAMLIOĞLU M (2023) Alüminyum Maruziyeti ve Sağlık. İstanbul Gelişim Üniversitesi Sağlık Bilim Derg 20:735–747. https://doi.org/10.38079/igusabder.1228435

18. DEÜTF İlaç ve Zehir Danışma Merkezi- Güncel. https://web.deu.edu.tr/zdm/tr/index_dosyalar/page0004.html. Accessed 5 Aug 2024
19. Genchi G, S S, Graziantono L, et al (2020) The Effects of Toxicity. Int J Environ Res Public Health 17:1–24
20. Dündar Y, Aslan R (2005) Effects of Lead as a Life Surrounding Heavy Metal. Med J Kocatepe 6:1–5
21. Peana M, Medici S, Dadar M, et al (2021) Environmental barium: potential exposure and health-hazards. Arch Toxicol 95:2605–2612. https://doi.org/10.1007/s00204-021-03049-5

Figures

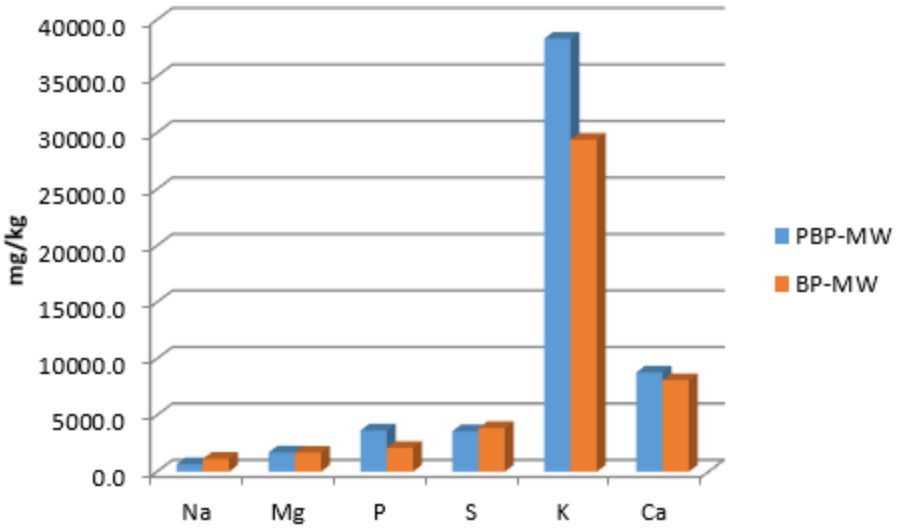

Figure 1

Elemental distribution of macro elements according to collection time of *Artemisia abrotanum*L.

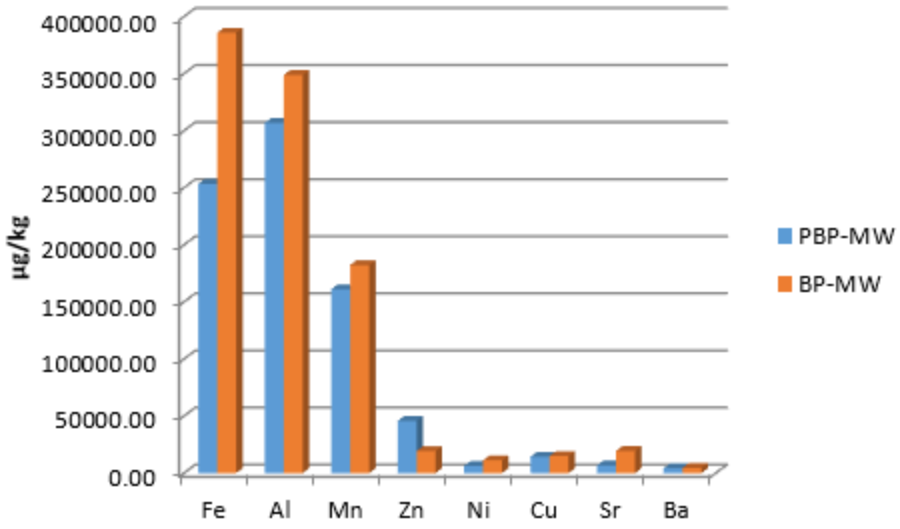

Figure 2

Elemental distribution of some elements according to collection time of *Artemisia abrotanum*L.

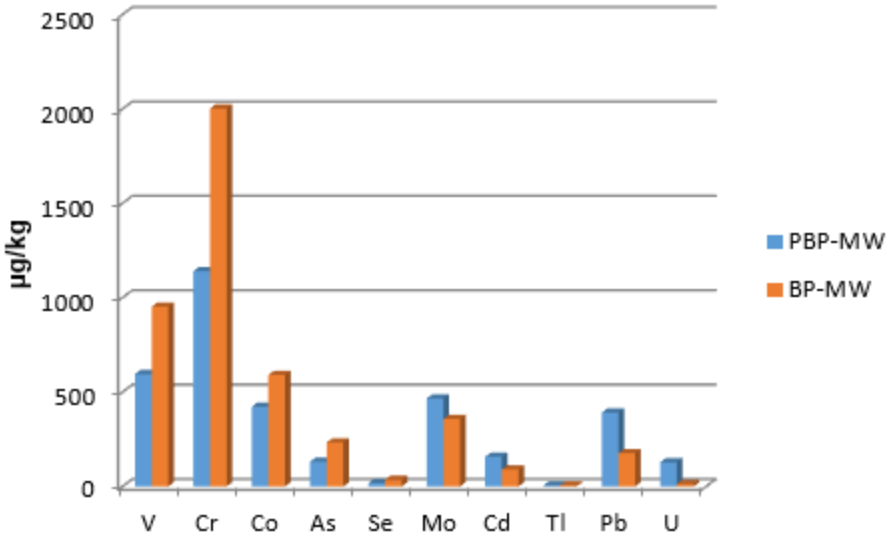

Figure 3

Elemental distribution of some elements according to collection time of *Artemisia abrotanum* L.

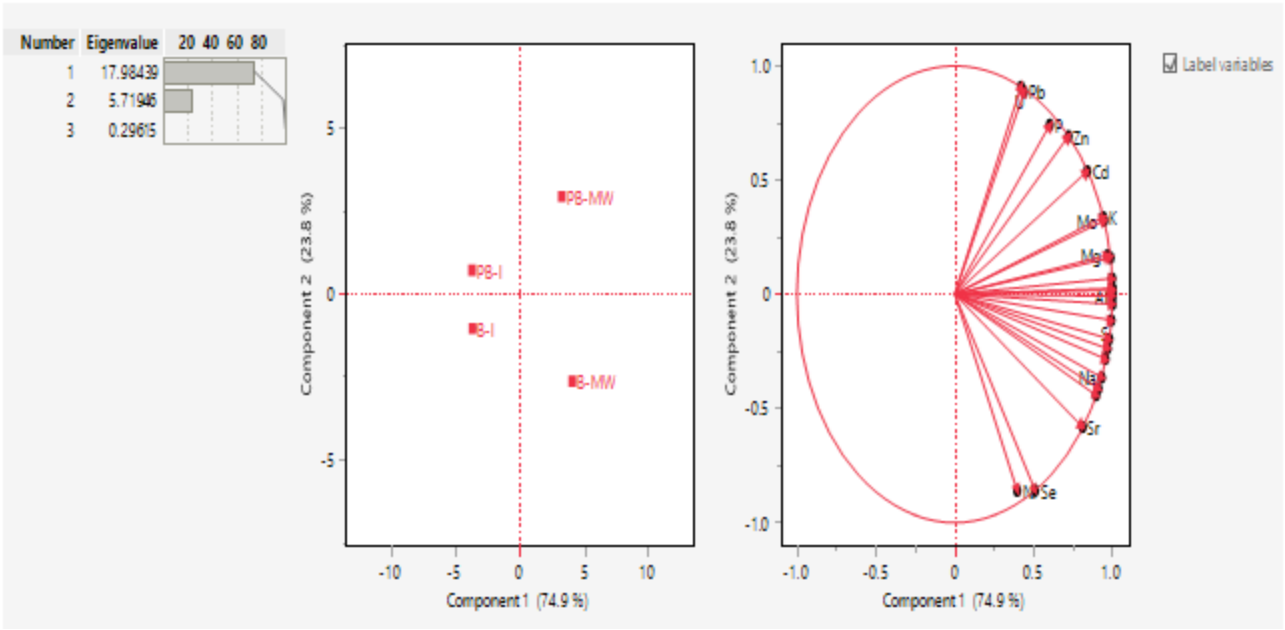

Figure 4

Figure 5. PC analysis of some elements in *A. abrotanum L* Eigenvectors, eigenvalues Score and Loading plots.

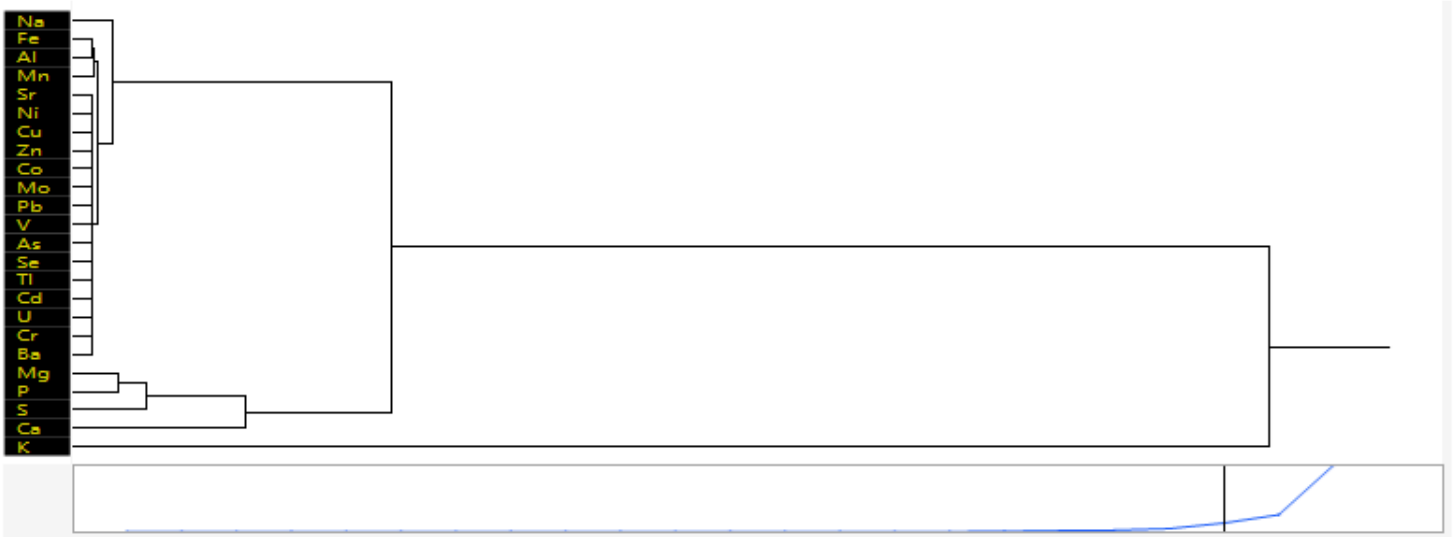

Figure 5

Figure 6. Cluster analysis of *Artemisia abrotanum L* samples according to elemental structure: Distance and Dendogram

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GraphicalAbstract.png