Comparison of Wet and Microwave Sample Digestion Method for the FAAS and GFAAS Determination of Heavy Metal Concentrations in Moss and Lichen Samples

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INTRODUCTION

The accumulation of heavy metal ions causes chronic damage to the environment and the ecosystem. Heavy metal pollution must be carefully monitored taking into account the uptake movement and the effect of contamination on the environment and its impact on the biology of man and animals (1-7).

Elemental pollution of the atmosphere is the sum of anthropogenic pollution and metal pollution emitted from other sources and may vary over time. Mosses, plants, and lichens are used as bioindicators for the determination of heavy metal pollution in the atmosphere (8-11). In addition, lichens and mosses are cryptogenic organisms which can adapt to all terrestrial ecosystems and all kinds of environmental conditions (12).

Various instrumental techniques such as inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS), total reflection X-ray fluorescence spectrometry (TXRF), isotope dilution mass spectrometry (IDMS), neutron activation analysis (NAA), flame atomic absorption spectrometry (FAAS), and graphite furnace atomic absorption spectrometry (GFAAS) are used for the determination of heavy metal ions in environmental samples (2, 13-15). Of the

ABSTRACT

In this study, 10 different moss and five different lichen samples were collected from an industrial area in Tokat, Turkey. Control samples were collected from uncontaminated locations. The concentrations of Fe, Mn, Zn, Pb, Ni, Cr, Cu, and Cd in moss and lichen species were determined by flame and graphite furnace atomic absorption spectrometry. Digestion of the samples was performed by using the wet and microwave digestion method. Digestion methods were found suitable for the quantitative recoveries of the analyte ions from moss and lichen samples. The accuracy of the method was confirmed by analysis of standard reference material (IAEA-336 Lichen). The maximum trace elemental concentrations were found to be 949 µg/g (Fe), 290 µg/g (Mn), 82.6 µg/g (Zn), 18.7 µg/g (Pb), 51.9 µg/g (Ni), 23.9 µg/g (Cr), 32.6 µg/g (Cu), and 3.21 µg/g (Cd) in moss samples and 456 µg/g (Fe), 174 µg/g (Mn), 38.9 µg/g (Zn), 8.41 µg/g (Pb), 13.4 µg/g (Ni), 5.30 µg/g (Cr), 15.8 µg/g (Cu), and 2.95 µg/g (Cd) in the lichen samples. The heavy metal levels in the lichen and moss samples collected from an industrial area were found to be higher than the control samples.

above methods mentioned, the FAAS and GFAAS techniques are low cost, easy to use, and offer good sensitivity.

Sample preparation methods are very important for the digestion of solid samples. Dry ashing, wet ash-

ing, and microwave digestion are used for the digestion of biological and environmental samples. However, the wet and dry ashing methods are slow, there is contamination risk, and the volatile elements may be lost during digestion. Microwave digestion methods are faster, easy to use, reliable, and offer high recovery (2, 3).

The main purpose of this study was to compare the advantages of wet and microwave sample digestion for the determination of Fe, Mn, Zn, Ni, Cr, and Cu, and Cd by FAAS and Cd and Pb by GFAAS in moss and lichen samples obtained at an industrial area.

EXPERIMENTAL

Instrumentation

A PerkinElmer® AAnalyst™ 700 (PerkinElmer, Inc., Shelton, CT, USA) atomic absorption spectrometer, equipped with HGA® graphite furnace and deuterium background corrector, was used for the determination of the elements. The elemental and instrumental operating parameters are listed in Table I. The elements Fe, Mn, Zn, Ni, Cr, and Cu were determined by flame AAS using a 10-cm long slot burner head, a lamp and an air-acetylene flame. The elements Pb and Cd were determined by graphite furnace AAS using argon as an inert gas. An Elektro-mag, m5040p model furnace/heating system (Istanbul, Turkey), Milli-Q® deionized water system (Millipore Corporation, USA), and an Ethos D microwave closed system (Milestone, Sorisole-Bg, Italy) were used.

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Samples

Ten types of moss samples and five types of lichen samples were collected from an industrial area of Tokat, Turkey. The control samples were collected from uncontaminated locations. The samples were dried at 105 °C for 24 hours (Elektro-mag Oven, m5040p, Turkey), then homogenized using an agate homogenizer (Turkey), and stored in cleaned polyethylene bottles until analysis.

The accuracy of the method was confirmed by analyzing standard reference material (SRM) IAEA-336 Lichen obtained from International Atomic Energy Agency (Portugal).

Reagents

Analytical reagent grade chemicals were used for all experimental studies. Nitric acid (65%) and hydrogen peroxide (35%) were obtained from E. Merck (Darmstadt,

Germany). Double deionized Milli-Q® water (18 MΩ cm⁻¹ resistivity, Millipore Corporation, USA) was used. The element standard solutions used for calibration were prepared by diluting stock solutions of 1000 mg/L of each element supplied from Sigma Chemicals Co. (St. Louis, MO, USA). The matrix modifiers of NH₄H₂PO₄, Pd and Mg(NO₃)₂ were purchased from Sigma Chemicals Co. (St. Louis, MO, USA).

DIGESTION PROCEDURES

Microwave Digestion

The SRM IAEA-336 Lichen sample (0.25 g) and the 10 moss and five lichen samples (1.0 g each) were digested with 6 mL of HNO₃ (65%) and 2 mL of H₂O₂ (30%) in the microwave digestion system (maximum pressure 1450 psi, maximum temperature 300 °C) and diluted to 25 mL with deionized

water. A blank digest was carried out in the same way. The digestion conditions used for the microwave system were 2 minutes at 250 W, 2 minutes at 0 W, 6 minutes at 250 W, 5 minutes at 400 W, 8 minutes at 550 W, vent for 8 minutes.

Wet Digestion

An oxi-acidic mixture (HNO₃:H₂O₂ (6:2)) was used for wet digestion of the SRM IAEA-336 Lichen sample (0.25 g) and the moss and lichen samples (1.0 g each). This mixture was heated on a hot plate until dryness for 4 hours. This procedure was repeated two times. The samples were filtered with blue ribbon filter paper and brought to 25-mL volume with deionized water. The blank digestions were carried out in the same way.

ANALYTICAL PROCEDURE

Elemental Analysis

The elements Fe, Mn, Zn, Ni, Cr, and Cu were determined by flame AAS. The elements Pb and Cd were determined by GFAAS using pyrolytically coated graphite tubes (PerkinElmer® part no. B3001264) with a platform. The atomic absorption signal was measured as a peak area mode against an analytical curve. All metal concentrations were determined on a dry weight basis. The detection limit is defined as the concentration corresponding to three times the standard deviation of 10 blanks. The detection limits were 24 µg L⁻¹ for Fe, 28 µg L⁻¹ for Cu, 30 µg L⁻¹ for Mn, 12 µg L⁻¹ for Zn, 35 µg L⁻¹ for Cr, 25 µg L⁻¹ for Ni. The elements of Pb and Cd were found to be below the detection limit of flame AAS. These elements were determined using graphite furnace AAS. An amount of 200 µg NH₄H₂PO₄ for Pb determination and 15 µg Pd+10 µg Mg(NO₃)₂ for Cd determination was used as the matrix modifier.

TABLE I
FAAS Instrumental Conditions for the Different Elements

Element	Acetylene (L/min)	Air (L/min)	Wavelength (nm)	Slit width (nm)
Fe	2.0	17.0	248.3	0.2
Cu	2.0	17.0	324.8	0.7
Mn	2.0	17.0	279.5	0.2
Zn	2.0	17.0	213.9	0.7
Ni	2.0	17.0	232.0	0.2
Cr	2.0	17.0	357.9	0.7

GFAAS Instrumental Parameters

Instrumental Conditions	Pb	Cd
Argon flow	250 mL/min	250 mL/min
Sample volume	20 µL	20 µL
Modifier	5 µL	10 µL
Heating Program	Ramp time (s)	Hold time (s)
Drying 1	100 °C (5, 20)	100 °C (5, 20)
Drying 2	140 °C (15, 15)	140 °C (15, 15)
Ashing	700 °C (10, 20)	850 °C (10, 20)
Atomization	1800 °C (0, 5)	1650 °C (0, 5)
Cleaning	2600 °C (1, 3)	2600 °C (1, 3)

RESULTS AND DISCUSSION

The accuracy of the quantification of analytical data and the comparison of wet and microwave digestion was checked by using SRM (IAEA-336 Lichen, International Atomic Energy Agency, Vienna, Austria). Selection of the best digestion method was evaluated by the concentration of Fe, Mn, Zn, Pb, Ni, Cr, Cu, and Cd found in the SRM. The relative standard deviation (%RSD) and the recovery values for the analytes were compared with the results of the wet and microwave digestion procedures. The results listed in Table II show that the RSD of Fe, Mn, Zn, Pb, Ni, Cr, Cu, and Cd in the SRM IAEA-336 Lichen using microwave digestion is lower than the RSD of the analytes obtained by wet digestion. The recovery values were quantitative (>95%) for both digestion methods. Microwave digestion of the samples was faster and easier than with wet digestion,

and sample contamination and analyte loss by evaporation was eliminated. Therefore, the microwave digestion procedure was used for the determination of Fe, Mn, Zn, Pb, Ni, Cr, and Cu in the moss and lichen samples.

The Cu, Cd, Pb, Zn, Mn, Fe, Cr, and Ni levels in the moss and lichen samples are listed in Table III and Figures 1 – 4. In this study, the heavy metal concentrations were found to be higher in the moss samples than in the lichen samples.

Moss Samples

The metal concentrations in the moss samples were 106-949 µg/g for Fe, 64.6-290 µg/g Mn, 7.91-82.6 µg/g Zn, 3.51-18.7 µg/g Pb, 8.82-51.9 µg/g Ni, 4.13-23.9 µg/g Cr, 5.41-32.6 µg/g Cu, and 0.95-3.21 µg/g Cd. The levels of the trace metals in the moss samples followed the order of Fe>Mn>Zn>Ni>Cu>Cr>Pb>Cd. The highest metal accumulation levels in the

moss species were found in *Syntrichia ruralis* for Fe, *Syntrichia papillosissima* for Mn and Zn, *Grimmia donniana* for Pb, Ni, Cr, and Cu, and *Tortula inermis* for Cd.

Iron (Fe)

The lowest and highest iron concentrations were found at 949 µg/g in *Syntrichia ruralis* (Hedw.) F. Weber & D. Mohr, and 106 µg/g in *Homalothecium sericeum* (Hedw.) Schimp. (Figure 1). The Fe values were reported as 443-3494 µg/g in the literature for different moss species (16). The values (obtained in the present study for the unpolluted samples) are lower than the reported data in the literature (1, 17-18). The Fe concentration in *Syntrichia ruralis* (Hedw.) F. Weber & D. Mohr. and in *Syntrichia calcicola* (Sm.) were found to be 9 times and 7 times higher than those of the control samples (*Homalothecium sericeum* (Hedw.) Schimp., respectively.

Manganese (Mn)

Manganese is one of the least toxic metals, but if inhaled as MnO₂ dust it is more hazardous than ingested manganese (18-19). The Mn concentrations were 290 µg/g in *Syntrichia papillosissima* (Coppey) Loeske and 64.6 µg/g in *Tortula inermis* (Brid.) Mont. (Figure 1). In the moss samples, Mn was present at the second highest concentration after Fe. The Mn value is almost higher than in the control samples. The Mn values are lower than those reported by Rahman et al. (860 µg/g) (20).

Zinc (Zn), Lead (Pb), and Nickel (Ni)

The highest zinc concentration found in the moss samples was 82.6 µg/g (Figure 2). The Zn average values are in agreement with literature values at 86.69 µg/g and 86.0 µg/g, respectively (20, 21). The average Pb concentration in the mosses were 18.7-3.51 µg/g

TABLE II
Determination of Heavy Metals (µg/g) in SRM IAEA-336 Lichen
After Wet and Microwave Digestion

Element	Method MWD ^a or WD ^b	Certified Values (µg/g)	Present Values ^c (µg/g)	Recovery (%)
Fe	MWD	426 ^d	424±14	99
	WD	426 ^d	411±16	96
Mn	MWD	64	63±3	98
	WD	64	60±4	94
Zn	MWD	31.6	31 ±1	98
	WD	31.6	29±2	92
Pb	MWD	5	4.9±0.3	98
	WD	5	4.7±0.4	94
Cr	MWD	1.03 ^d	1.05±0.07	101
	WD	1.03 ^d	0.94±0.10	92
Cu	MWD	3.55	3.48±0.10	98
	WD	3.55	3.30±0.17	93
Cd	MWD	0.117	0.115±0.01	98
	WD	0.117	0.110±0.01	94

^a MWD=Microwave digestion.

^b WD=Wet digestion.

^c Data presented as mean ± standard deviation.

^d Not certified

TABLE III
Level of Trace Elements (µg/g) in Lichen and Moss Species (mean±standard deviation)

Species	Source ^a	Fe	Mn	Zn	Pb	Ni	Cr	Cu	Cd
Moss Species									
Homalothecium sericeum (Hedw.) Schimp..	p	191±12	255±24	55.2±5.51	10.7±1.1	48.8±4.42	12.3±1.21	20.4±1.61	1.21±0.11
	u	106±10	114±10	11.9±10.1	4.21±0.3	17.7±1.21	4.13±0.40	8.91±0.82	1.11±0.10
Syntrichia calcicola Sm.	p	740±56	187±16	62.5±6.72	13.6±1.3	50.8±4.51	14.1±1.20	21.5±2.11	1.12±0.11
	u	266±21	86.7±6.91	21.6±2.11	8.11±0.8	22.5±1.82	5.62±0.51	5.41±0.42	1.11±0.10
Homalothecium philippeanum W.P.Schimp.	p	649±62	281±24	60.6±5.71	15.9±1.3	40.7±3.63	23.3±2.12	23.2±2.12	1.22±0.10
	u	305±28	65.2±6.32	16.3±1.50	7.81±0.2	19.8±1.61	6.62±0.51	10.2±1.11	1.13±0.12
Syntrichia intermedia Brid.	p	394±31	192±18	73.3±7.13	10.5±1.0	35.4±3.22	15.2±1.31	22.7±2.10	1.30±0.11
	u	121±11	107 ±10	23.7±2.11	3.51±0.6	21.7±2.00	4.48±0.41	7.70±0.76	1.18±0.10
Syntrichia papillosissima (Coppey) Loeske	p	550±46	290±25	82.6±8.21	17.7±1.5	41.5±4.11	21.3±2.00	27.9±2.31	1.40±0.12
	u	275±24	112±10	19.8±16.7	5.62±0.5	8.82±0.83	6.40±0.51	12.7±1.11	1.10±0.10
Syntrichia laevipila Brid.	p	641±50	268±25	80.2±7.50	13.1±1.2	51.8±4.61	22.3±1.92	29.6±2.91	1.70±0.10
	u	343±22	101±10	25.3±2.42	7.13±0.7	18.1±1.42	10.9±1.00	11.9±1.10	0.95±0.10
Homalothecium lutescens (Hedw.) H. Rob.	p	840±78	173±15	48.1±4.11	9.80±1.0	15.9±1.33	13.6±1.13	31.2±3.10	2.21±0.12
	u	344±33	69.2±6.12	11.8±1.00	5.83±0.4	11.7±1.11	5.13±0.51	13.3±1.12	0.98±0.10
Grimmia donniana Sm.	p	776±67	256±22	64.6±6.32	18.7±1.6	51.9±5.10	23.9±2.11	32.3±3.10	2.10±0.20
	u	389±36	78.3±5.83	7.91±7.13	6.44±0.5	12.2±1.10	10.5±1.00	10.1±1.00	0.98±0.10
Syntrichia ruralis (Hedw.) F.Weber & D. Mohr.	p	949±91	219±18	49.4±4.41	9.55±1.0	35.7±2.91	17.4±1.30	32.6±3.21	1.12±0.11
	u	403±39	98.4±8.8	16.9±1.40	7.62±0.7	11.7±1.00	8.70±0.74	17.2±1.45	1.10±0.10
Tortula inermis (Brid.) Mont.	p	507±50	184±14	55.6±4.32	11.3±1.1	46.7±4.52	23.4±2.13	24.4±2.33	3.21±0.31
	u	302±22	64.6±4.5	27.9±2.10	6.81±0.5	9.62±0.83	10.6±1.10	9.51±0.88	1.21±0.11
Lichen Species									
Aspicilia calcarea (L.) Modd.	p	162±15	174±18	35.2±2.62	8.41±0.81	10.6±1.10	2.45±0.21	5.70±0.43	1.30±0.12
	u	56.1±4.71	93.7±8.72	7.81±6.71	3.22±0.32	3.51±0.32	1.21±0.11	1.81±0.13	1.17±0.11
Cladonia foliacea (Huds.) Wild.	p	204±19	129±11	30.4±2.90	7.91±0.72	11.3±1.21	4.31±0.35	15.8±1.41	2.62±0.21
	u	80.8±8.21	56.3± 4.91	5.91±0.51	2.80±0.21	7.72±0.61	2.80±0.25	4.41±0.41	1.11±0.10
Phaeophyscia orbicularis (Neck.) Moberg.	p	84.5±7.91	153±14	38.9±3.22	6.51±0.61	13.4±1.40	5.30±0.46	12.5±1.11	1.61±0.10
	u	128±11	46.7±4.53	11.7±1.00	1.96±0.20	2.41±0.21	2.31±0.21	3.71±0.32	0.81±0.10
Peltigera fufescens (Weis) Humb.	p	413±40	164±15	34.6±3.20	8.22±0.80	10.7±1.11	2.11±0.10	9.11±0.81	2.95±0.30
	u	189±17	56.1±4.71	4.72± 0.33	4.82±0.42	3.41±0.32	1.00±0.10	4.31±0.31	0.98±0.10
Physcia biziana (A. Massal.) Zahlbr.	p	456±45	166±16	32.6±2.61	5.61±0.51	9.81±0.92	3.71±0.30	10.7±1.00	1.63±0.11
	u	121±11	81.7±7.61	6.71±0.52	1.80±0.11	5.32±0.42	1.21±0.11	2.82±0.25	1.21±0.10

^a p = From polluted area. u = From unpolluted area.

(Figure 2). Tuzen (13) previously reported values of 28.1–4.6 µg/g Pb in samples from high density traffic areas. Figueira et al. (22) reported 22.80 µg/g Pb in moss used as bio-monitor in Portugal. Our value is lower than reported by Tuzen and Figueira et al. The lead level of the present study is lower than reported by Culicov et al. (46 µg/g)

(21). The highest and lowest nickel levels were found in *Grimmia donniana* Sm. (51.9 µg/g) and in *Syntrichia papillosissima* (Coppey) Loeske (8.82 µg/g) (Figure 3).

Chromium (Cr)

The minimum and maximum values of Cr were obtained in *Homalothecium sericeum* (Hedw.)

(4.13 µg/g) and *Grimmia donniana* Sm. (23.9 µg/g) (Figure 3).

Copper (Cu)

The Cu concentrations were between 32.6 µg/g and 5.41 µg/g in the samples (Figure 4). These values are in agreement with reported data from the literature (20). Riget et al. (23) reported Cu concentra-

Fig 1. Distribution of iron and manganese in polluted and unpolluted moss and lichen samples.

1. *Homalothebium sericeum* (Hedw.) Schimp., 2. *Syntrichia calcicola* Sm., 3. *Homalothebium philippeanum* W.P.Schimp, 4. *Syntrichia intermedia* Brid., 5. *Syntrichia papillosissima* (Coppey) Loeske, 6. *Syntrichia laevipila* Brid., 7. *Homalothebium lutescens* (Hedw.) H. Rob., 8. *Grimmia donniana* Sm., 9. *Syntrichia ruralis* (Hedw.) F.Weber & D. Mohr., 10. *Tortula inermis* (Brid.) Mont., 11. *Aspicilia calcarea* (L.) Modd., 12. *Cladonia foliacea* (Huds.) Wild., 13. *Phaeophyscia orbicularis* (Neck.) Moberg., 14. *Peltigera fufescens* (Weis) Humb., 15. *Physcia biziana* (A. Massal.) Zahlbr.

Fig 2. Distribution of zinc and lead in polluted and unpolluted moss and lichen samples.

1. *Homalothebium sericeum* (Hedw.) Schimp., 2. *Syntrichia calcicola* Sm., 3. *Homalothebium philippeanum* W.P.Schimp, 4. *Syntrichia intermedia* Brid., 5. *Syntrichia papillosissima* (Coppey) Loeske, 6. *Syntrichia laevipila* Brid., 7. *Homalothebium lutescens* (Hedw.) H. Rob., 8. *Grimmia donniana* Sm., 9. *Syntrichia ruralis* (Hedw.) F.Weber & D. Mohr., 10. *Tortula inermis* (Brid.) Mont., 11. *Aspicilia calcarea* (L.) Modd., 12. *Cladonia foliacea* (Huds.) Wild., 13. *Phaeophyscia orbicularis* (Neck.) Moberg., 14. *Peltigera fufescens* (Weis) Humb., 15. *Physcia biziana* (A. Massal.) Zahlbr.

tions of 18.8 µg/g. Control samples had Cu concentrations of 5.41 and 7.70 µg/g.

Cadmium (Cd)

The mean Cd level in the sam-

ples was between 3.21-0.95 µg/g (Figure 4). The Cd levels in all moss samples were higher than those found in earlier studies (7, 20, 24). It is known that Cd is one of the most toxic metals. The main route

of absorption is through inhalation of industrial cadmium oxide dust or fumes. Cadmium can also accumulate in moss from soil.

Fig 3. Distribution of nickel and chromium in polluted and unpolluted moss and lichen samples.

1. *Homalothecium sericeum* (Hedw.) Schimp., 2. *Syntrichia calcicola* Sm., 3. *Homalothecium philippeanum* W.P.Schimp, 4. *Syntrichia intermedia* Brid., 5. *Syntrichia papillosissima* (Coppey) Loeske, 6. *Syntrichia laevipila* Brid., 7. *Homalothecium lutescens* (Hedw.) H. Rob., 8. *Grimmia donniana* Sm., 9. *Syntrichia ruralis* (Hedw.) F.Weber & D. Mohr., 10. *Tortula inermis* (Brid.) Mont., 11. *Aspicilia calcarea* (L.) Modd., 12. *Cladonia foliacea* (Huds.) Wild., 13. *Phaeophyscia orbicularis* (Neck.) Moberg., 14. *Peltigera fufescens* (Weis) Humb., 15. *Physcia biziana* (A. Massal.) Zahlbr.

Fig 4. Distribution of copper and cadmium in polluted and unpolluted moss and lichen samples.

1. *Homalothecium sericeum* (Hedw.) Schimp., 2. *Syntrichia calcicola* Sm., 3. *Homalothecium philippeanum* W.P.Schimp, 4. *Syntrichia intermedia* Brid., 5. *Syntrichia papillosissima* (Coppey) Loeske, 6. *Syntrichia laevipila* Brid., 7. *Homalothecium lutescens* (Hedw.) H. Rob., 8. *Grimmia donniana* Sm., 9. *Syntrichia ruralis* (Hedw.) F.Weber & D. Mohr., 10. *Tortula inermis* (Brid.) Mont., 11. *Aspicilia calcarea* (L.) Modd., 12. *Cladonia foliacea* (Huds.) Wild., 13. *Phaeophyscia orbicularis* (Neck.) Moberg., 14. *Peltigera fufescens* (Weis) Humb., 15. *Physcia biziana* (A. Massal.) Zahlbr.

Lichen Samples

The Fe, Mn, Zn, Pb, Ni, Cr, Cu, and Cd concentrations in the lichen samples were found as 456–56.1 µg/g, 174–46.7 µg/g, 38.9–4.72 µg/g, 8.41–1.80 µg/g, 13.4–2.41

µg/g, 5.30–1.00 µg/g, 15.8–1.81 µg/g, and 2.95–0.81 µg/g, respectively.

Iron (Fe)

Iron concentrations in the lichen

samples were found in the range of 456–56 µg/g (Figure 1). The Fe values for the lichen species were reported as 410–75 µg/g and 1130–844 µg/g, respectively (11, 25).

Manganese (Mn)

The average Mn concentration was found at 174-46.7 µg/g in lichens (Figure 1). The results of this study are higher than the results reported earlier (12, 26).

Zinc (Zn)

Zinc concentrations were found at 38.9 µg/g in *Phaeophyscia orbicularis* (Neck.) Moberg. and at 4.72 µg/g in *Peltigera fufescens* (Weis) Humb. (Figure 2). The Zn average values of this study are lower than the literature values (12, 26).

Lead (Pb)

The maximum Pb level was found at 8.41 µg/g in *Aspicilia calcarea* (L.) Modd. (Figure 2). These values are lower than the values reported by Tuzen (12.5 µg/g) and are in agreement with the values reported by Loppi et al. (25, 27). The values of this study are twice as high than the earlier reported values of 5.78 µg/g (28).

Nickel (Ni), Chromium (Cr), and Copper (Cu)

The Ni, Cr, and Cu concentrations in the lichen samples were 13.4-2.41, 5.30-1.00 and 15.8-1.81 µg/g, respectively (Figures 3 and 4). Mendil et al. (26) reported Ni, Cr, and Cu concentrations of 2.6-11.4, 1.6-5.9, and 2.3-14.0 µg/g, respectively. The mean Cd concentrations in the lichen species (see Figure 4) were found between 2.95 µg/g and 0.81 µg/g and were higher than earlier reports (11, 3, 26-28).

CONCLUSION

Microwave digestion was found suitable for the quantitative recovery of Fe, Mn, Zn, Pb, Ni, Cr, Cu, and Cd from moss and lichen samples. This method is simple, easy, and more accurate than the wet digestion method. The recovery values of the heavy metal ions were higher than with the wet digestion method. Thus, the analytical parameters obtained make this method suitable for the determination of

heavy metals in biological and environmental samples. The heavy metal concentrations of the analyzed lichen and moss samples collected at an industrial area were found to be higher than in the control samples. This species can be used as bioindicator for the monitoring of heavy metal pollution in the air and at industrial sites.

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