Determination of inorganic elements in poppy straw by scanning electron microscopy with energy dispersive spectrometry as a means of ascertaining origin

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ABSTRACT

Cultivation of poppy as a source of opium alkaloids for legitimate medical purposes has a long tradition in Turkey. The main products are poppy straw and concentrate of poppy straw, obtained from dried poppy capsules.

The aims of the study reported in the present article were to establish inorganic element profiles for the poppy-growing provinces of Turkey by means of X-ray analysis by scanning electron microscopy with energy dispersive spectrometry (SEM/EDS) and to explore the potential of the technique for determination of origin. Ten elements (sodium, magnesium, silicon, phosphorus, sulphur, chlorine, potassium, calcium, copper and zinc) were analysed in poppy straw samples from 67 towns in nine provinces.

As regards the determination of origin, the most significant finding was the presence of copper and zinc in the poppy straw samples from 8 of the 15 towns in Afyon Province. Since those elements are not normally found in soil, it is assumed that their presence is the result of environmental (industrial) contamination.

Differences in the samples from the other eight provinces were less significant, possibly a result of their geographical proximity. Nevertheless, differences in the samples were apparent. Because the findings are relative rather than absolute in terms of presence or absence of individual inorganic elements, further research is required to convert them into operationally usable results.

The inorganic element profiles generated in the study have been used to form the basis for the development of a comprehensive database on poppy straw samples, which may be used in comparing samples and determining their origin.

Keywords: Inorganic elemental analysis; scanning electron microscope; poppy straw

Introduction

Opium poppy, which was cultivated in Anatolia during the Hatti empire, around 3000 B.C., continues to be one of the most significant economic and industrial elements in Turkey. The plant, which is grown mainly in west and central Anatolia, where the climate and ecological conditions are conducive to high alkaloid content, is cultivated as a source of opium alkaloids used for legitimate medical purposes. Because of its long tradition of cultivating the opium poppy, Turkey, like India, is officially recognized as a traditional supplier of international markets.

The production of opium alkaloids in Turkey involves the use of dried poppy capsules (poppy straw) and the concentrate of poppy straw (CPS) method, so as to prevent the diversion of raw poppy straw into illicit channels. Thus, the ancient technique of lancing unripe poppy capsules to obtain opium has been replaced by extraction and concentration of dry material by means of the CPS technique. Processing of poppy straw is centralized in one specialized factory to maintain systematic overall control. The Afyon-Bolvadin Alkaloids Factory has the capacity to process 20,000 tons of poppy straw per year.

Because of the potential for diversion from legitimate into illicit channels, determination of the origin of the various opium poppy products—opium and poppy straw—has always been of prime interest. Since the relative content of the five main opium alkaloids (morphine, codeine, noscapine/narcotine, thebaine and papaverine) varies according to country and region, traditionally, for opium, the percentage of major and minor alkaloids has been used to determine origin. However, that technique allows only for satisfactory classification of samples by region of origin (e.g. South-West Asia or South-East Asia), not by country or by area within a country. It therefore does not suffice to use only one analytical method for comparison and determination of origin.

For the samples from Turkey used in the study under review, the provinces of origin were located in a limited area close to each other (west and central Anatolia). The climatic conditions were thus similar, a fact reflected in the absence of characteristic, distinct alkaloid profiles of the samples. In view of this, alternative means of sample comparison might be advantageous, such as methods to identify inorganic elements. The content and the relative concentration of such elements in plant materials depend on soil characteristics, environmental contamination and climatic conditions.

Many studies have been made of determination of inorganic element contents of samples of opium poppy, heroin and other drugs. For example, Chiarotti and others [1] determined iron and zinc levels in heroin samples by atomic absorption spectrometry (AAS). Sanger and others [2] used AAS and the neutron activation method to evaluate inorganic compounds in illicit drugs. AAS was also used by Hernandez and others [3] for the determination of lead in heroin samples. In studies by Bermejo and others [4], electrothermal AAS was used for the analysis of metal in cocaine samples. Bermejo and others [5-11] also used electrothermal AAS and flameless AAS methods for analysis of inorganic elements in cocaine and heroin. Infante and others [12] analysed 198 illicit heroin samples by AAS. Bora and others [13] used electrothermal AAS and inductively coupled plasma-atomic emission spectrometry (ICP-AES) for the analysis of levels of trace and major elements in illicit heroin. Those techniques might also be useful for determinating the the origin of poppy capsules and poppy straw.

In Turkey, inorganic elements have traditionally been analysed by colorimetry, AAS and AES. In the present study, 10 inorganic elements (sodium (Na), magnesium (Mg), silicon (Si), phosphorus (P), sulphur (S), chlorine (Cl), potassium (K), calcium (Ca), copper (Cu) and zinc (Zn)) were determined by X-ray analysis using scanning electron microscopy with energy dispersive spectrometry (SEM/EDS).

In many fields of chemistry, material science, geology and biology, detailed knowledge of the physical nature and chemical composition of the surfaces of solids on a submicrometer scale is gaining importance. Since SEM provides morphological and topographical information about the surfaces of solids, it is often the first step in the study of the surface properties of a solid. In addition, SEM furnishes qualitative and quantitative information about the elemental composition of various areas of a surface. Compared with other techniques, such as colorimetry, AAS and AES, SEM/EDS enables the simultaneous determination of all inorganic elements in a non-destructive way. In addition, interference effects, which can cause difficulties in other methods, are not a problem if SEM/EDS techniques are used.

The purpose of the study was therefore to characterize poppy straw samples originating in provinces within a closely defined area of Turkey, based on their inorganic elements. The resulting profiles reflect the relationship between elemental composition and province of origin of the particular poppy straw sample and may thus contribute to studies of determination of origin. Another important aspect of the study was the provision of comparative data in the form of inorganic element profiles for the provinces in Turkey where opium poppy is grown. Those data may support the poppy straw industry in its efforts to introduce better production procedures, since inorganic element profiles reflect soil characteristics, including environmental contamination.

The inorganic element profiles generated in the study, together with data from other studies (e.g. alkaloid profiles), have been used to form the basis for the development of a comprehensive database on poppy straw samples. The database may be used for comparisons of samples and determination of origin, as also for comparison of unknown poppy straw samples to determine whether they came from licit or illicit opium poppy cultivation. Finally, the study was also aimed at helping to identify illicit trafficking from overseas, because poppy straw from different geographical regions is expected to differ not only in its alkaloid profiles, but also in its inorganic element profiles.

By using SEM/EDS, the present study aimed at developing a robust, fast and practical method, based on modern technology, which is convenient for routine use.

Analytical procedure

Samples

Poppy straw samples were collected in the third quarter of the year from 67 towns in nine Turkish provinces: Afyon, Amasya, Burdur, Denizli, Isparta, Konya, Kütahya, Manisa and Uşak. Tables 1-9 list the towns sampled in each province.

Method

Sample preparation prior to SEM/EDS analysis consisted of two steps:

1. *Homogenization*: The poppy straw samples were powdered, homogenized and sieved using a 100-mesh sieve.
2. *Introducing surface conductivity*: The surfaces of the samples were made conductive by coating with carbon, using a carbon coater tool under the following conditions:

   Vacuum pressure: 10^{-4} torr
   Arc temperature: 2,700°C
   Pressure: 6Pa/6x10^{-2} millibars
   Applied voltage: 5-6 volts
   Analysis period: 30 seconds
   Flow: 20 amperes

Each sample was analysed five times and the average results recorded. These are expressed as the percentage content of individual elements relative to the total inorganic element content.

Instrumentation

A SEM (JEOL 5410) EDS (NORAN) was used, under the following conditions:

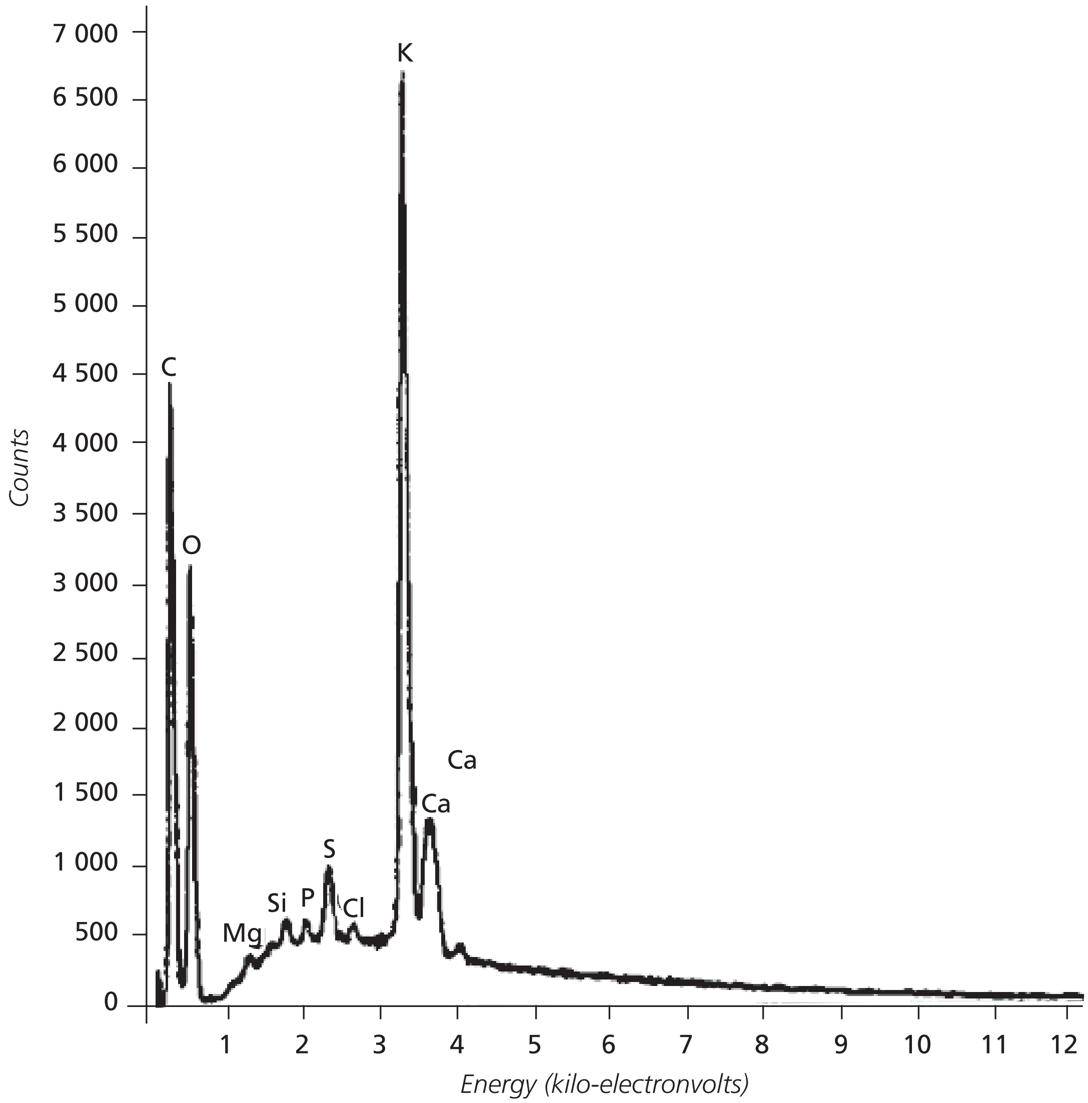
Voltage: 20 kV accelerated voltage, tailored to the elements of interest
Working distance: 25 millimetres
Take-off angle: 25°
Counting time: 100 seconds
Magnification: 100
Maximum energy: 20 kilo-electronvolts
Detector: lithium-added silicon detector on SEM/EDS

An instrument with carbon-coated evaporation power supply unit (POLARON CA 508) was used.

Results and discussion

The concentrations of 10 inorganic elements (Na, Mg, Si, P, S, Cl, K, Ca, Cu and Zn) in poppy straw samples from 67 towns in nine Turkish provinces (see above) were determined by SEM/EDS. An SEM/EDS spectrum of poppy straw is shown in figure I. The energy levels of the peaks in these spectra provide qualitative data on the elements present in the sample. Peak amplitudes also give quantitative data in terms of percentage concentration of elements.

Figure I. Example of a SEM/EDS spectrum of a sample of poppy straw



Mg = Magnesium
Si = Silicon
P = Phosphorus
S = Sulphur
Cl = Chlorine
K = Potassium
Ca = Calcium

Tables 1-9 summarize the SEM/EDS results for poppy straw samples from individual towns, grouped by province. Inorganic element profiles of samples from selected towns (one per province) are also presented graphically in figures II-X. Table 10 summarizes the ranges of the relative concentrations of the 10 elements detected in the samples from each of the nine provinces and table 11 lists the towns with the lowest and highest concentration percentages of individual elements.

Table 1. Average[a] content of inorganic elements in poppy straw from Manisa Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Kula	—	4.60	0.91	2.91	6.99	—	63.47	21.13	—	—
Selendi	—	2.01	0.76	1.41	4.00	—	74.76	17.06	—	—

[a]N=5.

Table 2. Average[a] content of inorganic elements in poppy straw from Isparta Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Şarkikara-ağaç	—	1.30	0.41	0.82	3.71	1.91	60.29	31.55	—	—
Gönen	—	1.41	0.34	0.33	4.10	—	73.15	20.67	—	—
Keçiborlu	—	0.94	0.80	1.23	5.57	—	76.54	13.50	—	—
Yalvaç	—	1.13	0.39	0.14	4.27	1.19	55.96	36.92	—	—
Gelendost	1.10	1.31	1.33	0.52	5.50	1.15	66.59	22.55	—	—
Merkez	—	0.74	0.61	0.52	3.31	2.64	76.42	15.75	—	—

[a]N=5.

Table 3. Average[a] content of inorganic elements in poppy straw from Amasya Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Göynücek	—	0.71	1.19	1.82	3.28	—	82.28	10.72	—	—
Gümüş-hacıköy	1.95	1.12	2.04	1.01	9.39	—	50.96	33.53	—	—
Merkez	—	3.26	1.19	2.12	4.56	1.27	69.99	16.80	—	—
Merzifon	—	1.59	0.69	2.14	4.37	—	68.44	22.78	—	—

[a]N=5.

Table 4. Average[a] content of inorganic elements in poppy straw from Konya Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Doğanhisar	—	0.96	0.51	1.52	5.38	3.65	50.11	37.77	—	—
Altınova	2.21	2.17	5.49	3.59	8.21	2.47	45.69	30.16	—	—
Derbent	—	0.50	0.61	1.22	3.10	1.41	71.49	21.67	—	—
Tuzlukçu	—	4.74	0.30	1.00	4.91	2.38	70.48	16.19	—	—
Ilgın	—	2.09	0.67	2.72	3.86	1.59	72.37	16.70	—	—
Seydişehir	1.28	1.23	0.48	0.50	4.52	0.78	63.36	27.86	—	—
Höyük	—	0.53	0.21	1.07	4.46	1.23	70.63	21.88	—	—
Selçuklu	—	1.75	0.95	2.45	4.11	1.90	56.58	32.27	—	—

[a]N=5.

Table 5. Average[a] content of inorganic elements in poppy straw from Kütahya Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Pazarlar	—	0.88	0.57	1.33	5.07	0.94	69.79	21.43	—	—
Tavşanlı	—	1.61	0.21	0.57	3.77	0.68	77.16	15.99	—	—
Merkez	1.66	1.71	0.59	2.21	4.60	0.88	68.23	20.12	—	—
Şaphane	2.83	0.84	5.82	2.09	9.87	2.64	52.12	23.79	—	—
Dumlupınar	1.46	0.88	0.38	1.26	5.60	0.48	62.90	27.05	—	—
Hisarcık	0.89	1.47	0.36	0.69	4.63	1.55	73.46	16.95	—	—

[a]N=5.

Table 6. Average[a] content of inorganic elements in poppy straw from Afyon Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Evciler	—	3.10	1.96	0.52	4.61	4.98	68.03	16.80	—	—
Íscehisar	—	0.64	0.70	1.90	4.62	1.22	60.23	10.96	10.70	8.96
Dazkırı	—	1.63	0.39	3.22	4.32	2.55	59.71	11.56	9.85	6.67
Çay	1.85	2.40	0.97	0.81	5.97	1.53	59.82	26.66	—	—
Çobanlar	—	1.19	0.66	2.29	3.91	2.07	57.73	32.16	—	—
Bolvadin	—	1.64	0.66	3.54	4.88	2.80	39.42	22.62	13.96	10.49
Sincanlı	—	0.65	0.76	1.67	5.53	3.58	50.02	37.79	—	—
Emirdağ	—	0.66	0.61	2.06	5.19	3.06	67.65	20.77	—	—
Hocalar	—	0.76	0.80	0.57	4.25	0.61	48.53	19.48	14.65	10.36
Merkez	1.75	0.92	1.77	1.08	9.48	—	66.85	18.14	—	—
Bayat	—	1.05	0.94	2.15	3.48	0.95	45.76	24.95	11.68	9.04
Sultandağı-Doğancık Köyü	0.85	1.81	0.42	1.24	4.44	0.70	44.17	21.50	14.95	9.90
Şuhut	—	0.68	0.30	1.29	4.34	1.10	59.00	10.10	12.29	10.90
Sandıklı	—	1.76	0.65	3.35	3.98	2.75	42.14	23.16	11.46	10.76
Sultandağı-Yakasenek Köyü	—	1.59	0.43	0.59	4.14	—	67.55	25.71	—	—

[a]N=5.

Table 7. Average[a] content of inorganic elements in poppy straw from Uşak Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Sivaslı	2.86	0.83	1.01	1.23	10.14	2.66	61.46	19.82	—	—
Ulubey	3.23	1.78	2.59	0.56	5.35	—	51.35	35.15	—	—
Banaz	—	0.64	2.40	1.73	5.70	—	51.88	37.66	—	—
Karahanlı	—	0.55	0.53	0.47	4.32	1.08	61.23	31.82	—	—
Eşme	—	1.40	0.26	0.41	5.03	1.64	66.12	25.14	—	—
Merkez	—	1.68	0.66	1.62	5.55	1.17	70.83	18.48	—	—

[a]N=5.

Table 8. Average[a] content of inorganic elements in poppy straw from Burdur Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Karamanlı	—	2.55	0.46	1.77	4.38	—	63.35	27.50	—	—
Tefenni	—	1.13	2.02	1.63	6.40	—	63.75	25.08	—	—
Bucak	—	0.55	0.93	1.44	5.84	—	69.21	22.02	—	—
Merkez	—	2.02	2.31	4.25	8.08	—	62.87	20.47	—	—
Çavdır	—	1.13	0.79	1.54	3.93	—	71.48	21.13	—	—
Yeşilova	—	2.27	0.74	2.05	4.46	—	73.97	16.51	—	—
Kemer	—	2.86	1.35	1.17	4.79	2.87	62.95	24.02	—	—
Çeltikçi	—	1.38	1.22	0.93	4.01	1.92	64.78	25.76	—	—
Ağlasun	—	0.64	0.61	1.94	2.30	—	77.21	17.30	—	—

[a]N=5.

Table 9. Average[a] content of inorganic elements in poppy straw from Denizli Province of Turkey
(Percentage)

Towns	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Çivril	1.86	2.93	0.49	1.42	6.92	—	69.53	16.86	—	—
Acıpayam	1.56	5.26	12.69	2.84	7.17	4.06	47.61	18.81	—	—
Çardak	—	3.75	4.31	0.95	5.61	2.91	62.21	20.24	—	—
Çal	1.64	3.33	0.37	0.59	5.38	1.16	73.53	14.01	—	—
Serinhisar	2.16	5.02	1.67	2.04	7.64	1.06	59.41	21.00	—	—
Buldan	1.49	0.99	1.28	0.81	6.48	1.55	59.46	27.95	—	—
Güney	2.88	1.22	0.63	1.43	9.17	1.38	63.00	20.30	—	—
Merkez	1.18	0.77	0.82	1.14	5.93	—	69.17	17.64	—	—
Tavas	—	0.79	2.15	1.24	5.30	3.20	58.70	28.62	—	—
Honaz	2.95	2.71	1.13	2.05	9.44	1.34	60.90	19.48	—	—
Bekilli	—	1.05	0.30	0.53	3.92	2.30	70.03	21.87	—	—

[a]N=5.

Table 10. Lowest and highest concentration, and mean, of inorganic elements in poppy straw samples from selected provinces of Turkey
(Percentage)

Provinces	*Sodium*	*Magnesium*	*Silicon*	*Phosphorous*	*Sulphur*	*Chlorine*	*Potassium*	*Calcium*	*Copper*	*Zinc*
Afyon										
Range	0.85-1.85	0.64-3.10	0.30-1.96	0.52-3.54	3.48-9.48	0.61-4.98	39.42-68.03	10.10-37.79	9.85-14.95	6.67-10.90
Mean	1.48	1.36	0.80	1.75	4.88	2.15	55.77	21.49	12.44	9.64
Amasya										
Range	1.95	0.71-3.26	0.69-2.04	1.01-2.14	3.28-9.39	1.27	50.96-82.28	10.72-33.53	—	—
Mean		1.67	1.28	1.77	5.40		67.92	20.96		
Burdur										
Range	—	0.55-286	0.46-2.31	0.93-4.25	2.30-8.08	1.92-2.87	62.87-77.21	16.51-27.50	—	—
Mean		1.61	1.16	1.86	4.91	2.40	67.73	22.20		
Denizli										
Range	1.49-2.95	0.77-5.02	0.30-12.69	0.53-2.84	3.92-9.44	1.06-4.06	47.61-73.53	14.01-28.62	—	—
Mean	1.97	2.53	2.35	1.38	6.63	2.11	63.05	20.62		
Isparta										
Range	1.06	0.74-1.41	0.34-1.33	0.33-1.23	3.31-5.57	1.15-2.64	55.96-76.54	15.75-36.92	—	—
Mean		1.14	0.65	0.59	4.41	1.72	68.16	23.49		
Konya										
Range	1.28-2.21	0.50-4.74	0.21-5.49	0.50-3.59	3.10-8.21	0.78-3.65	45.69-72.37	16.19-37.77	—	—
Mean	1.75	1.75	1.15	1.76	4.82	1.93	62.59	25.56		
Kütahya										
Range	0.89-2.83	0.85-1.71	0.21-5.82	0.57-2.21	3.77-9.87	0.48-2.64	52.12-77.16	15.99-27.05	—	—
Mean	1.71	1.23	1.32	1.36	5.59	1.20	67.28	20.89		
Manisa										
Range	—	2.01-4.6	0.76-0.91	1.41-2.91	4.00-6.99	—	63.47-74.76	17.06-21.13	—	—
Mean		3.31	0.84	2.16	5.50		69.12	19.10		
Usak										
Range	2.86-3.23	0.55-1.78	0.26-2.59	0.41-1.73	4.32-10.14	1.08-266	51.35-70.83	18.48-37.66	—	—
Mean	3.05	1.47	1.24	1.00	6.01	1.64	60.48	29.01		

Table 11. Towns and provinces in Turkey with the highest and lowest concentration of inorganic elements[a] *(Percentage)*

Element	*Highest concentration*	*Town (and province)*	*Lowest concentration*	*Town (and province)*
Sodium	3.23	Ulubey (Uşak)	0.85	Sultandaği-Doğancik (Afyon)
Magnesium	5.26	Acipayam (Denizli)	0.50	Derbent (Konya)
Silicon	12.69	Acipayam (Denizli)	0.21	Höyük (Konya)
			0.21	Tavşanli (Kütahya)
Phosphorus	4.25	Merkez (Burdur)	0.14	Yalvaç (Isparta)
Sulphur	10.14	Sivasli (Uşak)	2.30	Ağlasun (Burdur)
Chlorine	4.98	Evciler (Afyon)	0.48	Dumlupinar (Kütahya)
Potassium	82.28	Göynücek (Amasya)	39.42	Bolvadin (Afyon)
Calcium	37.79	Sincanli (Afyon)	10.10	Şuhut (Afyon)
Copper	14.95	Sultandaği-Doğancik (Afyon)	9.85	Dazkırı (Afyon)
Zinc	10.90	Şuhut (Afyon)	6.67	Dazkırı (Afyon))

[a]The results represent the average of five determinations.

Figure II. Inorganic element profile of poppy straw from Bolvadin, in Afyon Province of Turkey

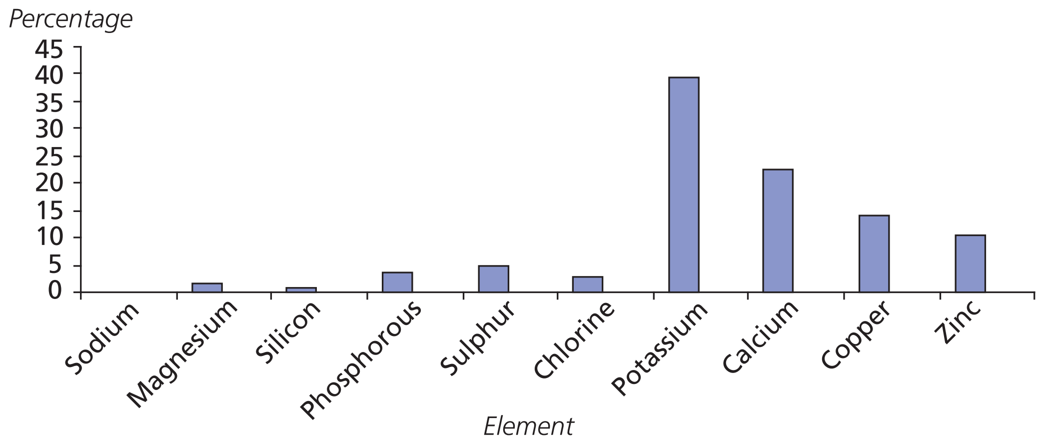


Figure III. Inorganic element profile of poppy straw from Altinova, in Konya Province of Turkey

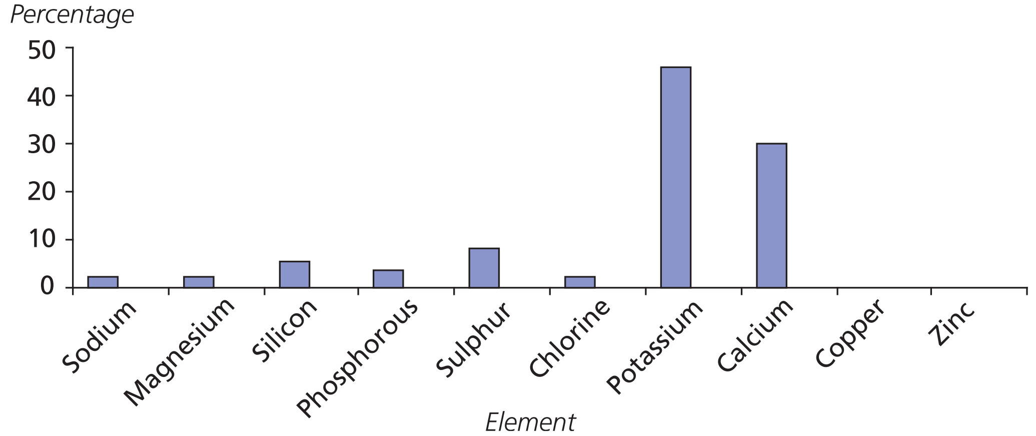


Figure IV. Inorganic element profile of poppy straw from Şaphane, in Kütahya Province of Turkey

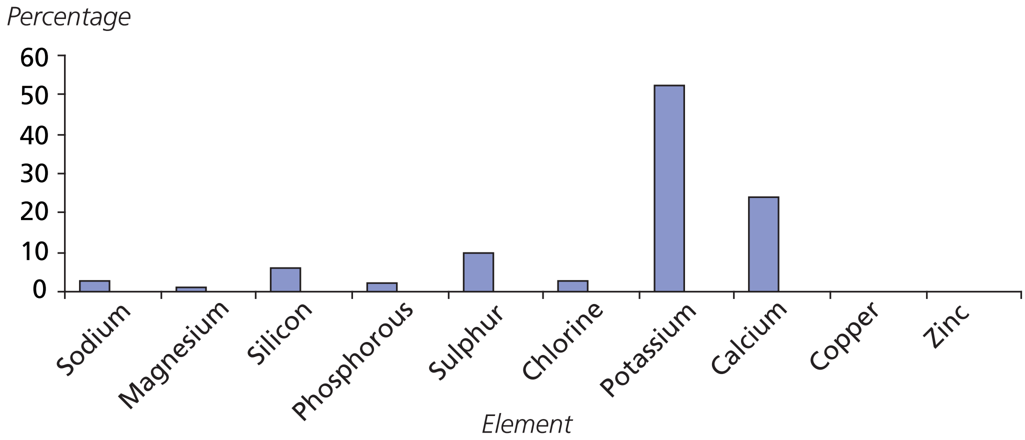


Figure V. Inorganic element profile of poppy straw from Tefenni, in Burdur Province of Turkey

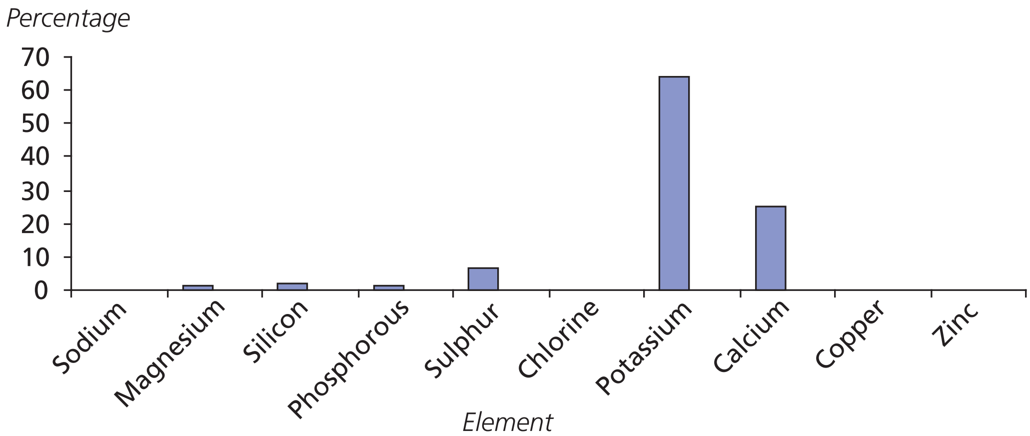


Figure VI. Inorganic element profile of poppy straw from Sivaslı, in Uşak Province of Turkey

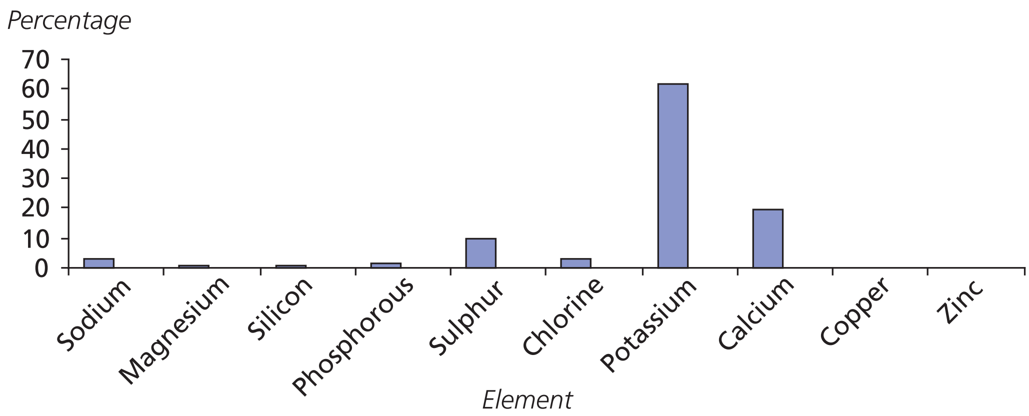


Figure VII. Inorganic element profile of poppy straw from Acıpayam, in Denizli Province of Turkey

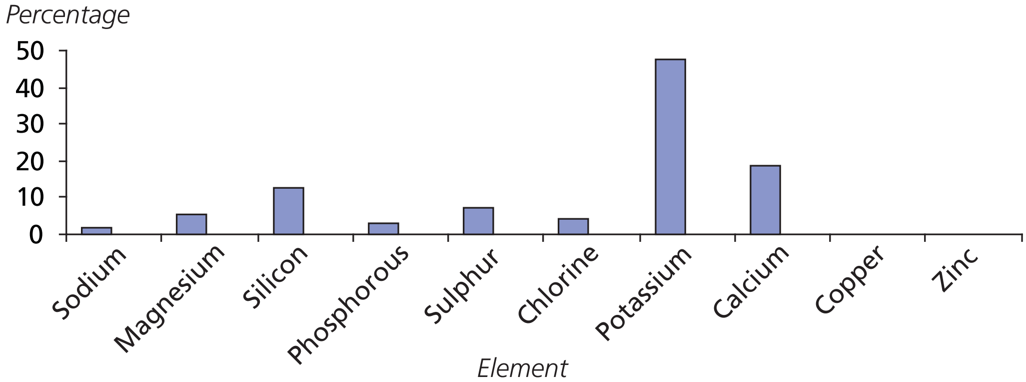


Figure VIII. Inorganic element profile of poppy straw from Göynücek, in Amasya Province of Turkey

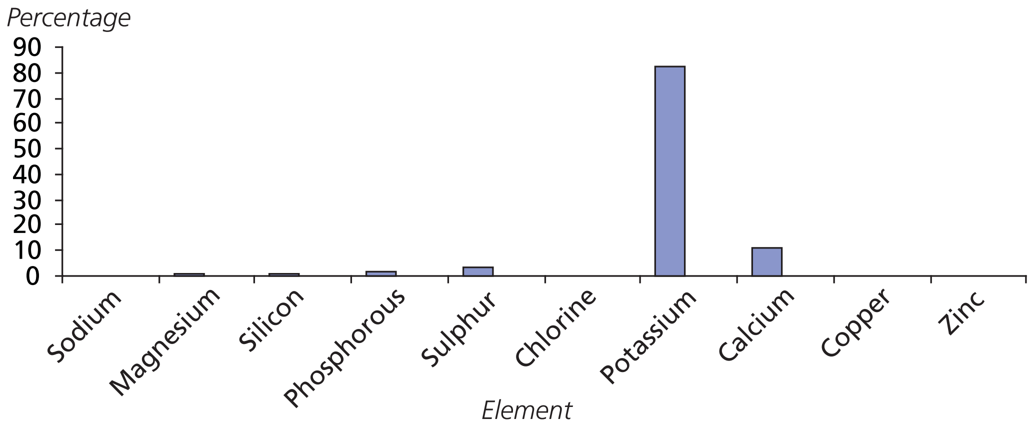


Figure IX. Inorganic element profile of poppy straw from Kula, in Manisa Province of Turkey

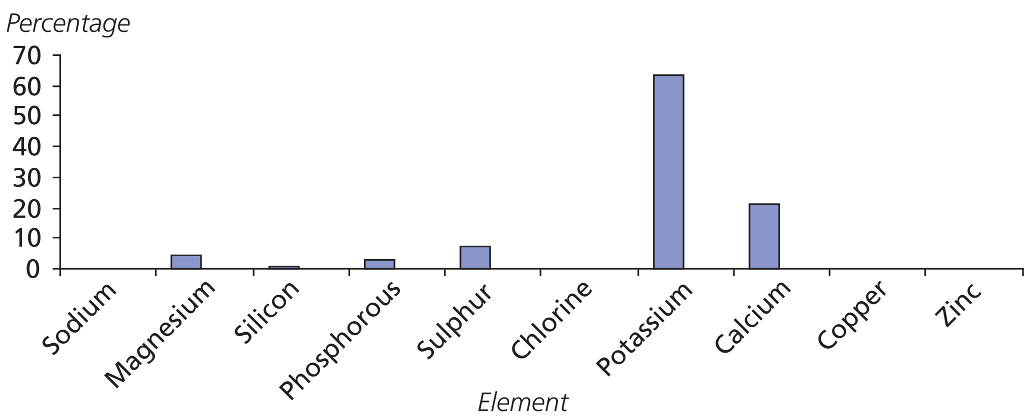
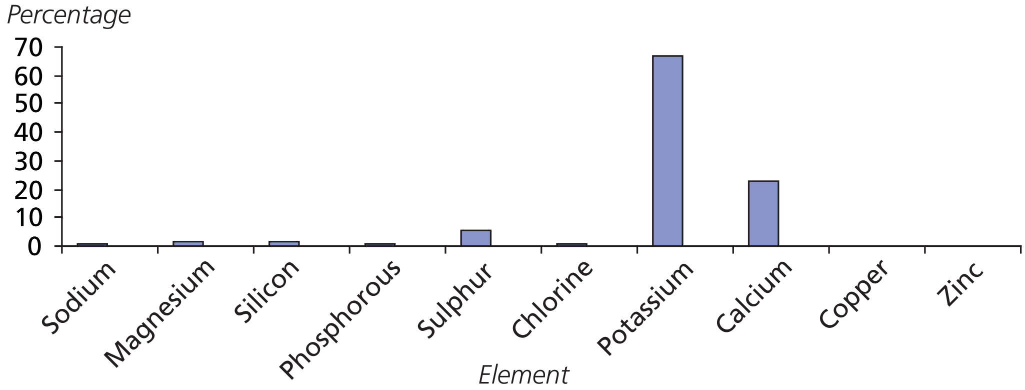


Figure X. Inorganic element profile of poppy straw from Gelendost, in Isparta Province of Turkey



Because it is used as a fertilizer, it is not surprising that potassium was found to be the element with the highest concentration in all the poppy straw samples. The second highest amount of inorganic element in poppy straw is calcium. Calcium infiltrates into poppy straw from water and calcareous soil. Sodium, magnesium, silicon and chlorine are naturally present in soil or as salts dissolved in water. The relative percentages of those elements therefore depend on the nature of the soil in which the opium poppy is grown. Phosphorous, similar to potassium, is usually added to soil by manuring. Sulphur is found mostly in land with clayey soil. However, opium poppy is not typically grown in overly clayey soils. Copper and zinc are not naturally present in soil. High concentrations of those elements suggest therefore that the soil had been exposed to environmental contamination, for example, in industrial areas.

The results presented in tables 1-9 show that, of the 10 elements, 6 (calcium, magnesium, phosphorous, potassium, silicon and sulphur) were present in straw samples from all 67 towns. Copper and zinc were only detected in samples from Afyon Province and only in samples from 8 out of the 15 towns in that province. The other two elements, sodium and chlorine, were present in some samples and absent in others, with similarities between towns of the same province. For example, sodium was not detected in any sample from Burdur or Manisa Province and only in a few samples from the five other provinces. By contrast, it was detected in almost all samples from Denizli Province and in most of those from Kütahya Province. In total, sodium was found in 21 samples. Chlorine was not detected in any sample from Manisa Province and only in a few samples from Amasya and Burdur provinces. It was detected in all samples from Konya and Kütahya provinces and in most of the samples from the remaining four provinces. In total, chlorine was detected in samples from 47 towns.

With the exception of samples from Afyon Province, which are characterized by the unique presence of copper and zinc, possibly from industrial contamination, differences in elemental profiles between other provinces were small. This may have been the result of the other provinces being close to each other geographically and very alike in soil and climatic conditions. In the absence of other characteristic environmental conditions, therefore, qualitatively similar element profiles can be expected. Figures XI-XX show for the 10 inorganic elements the average concentration percentages of the nine provinces. Quantitative differences are evident, reflected also in more detail in tables 1-9, and show the need for further research and refined statistical analysis to turn the findings into operationally usable results.

Figure XI. Average concentration of sodium in poppy straw samples from selected provinces of Turkey

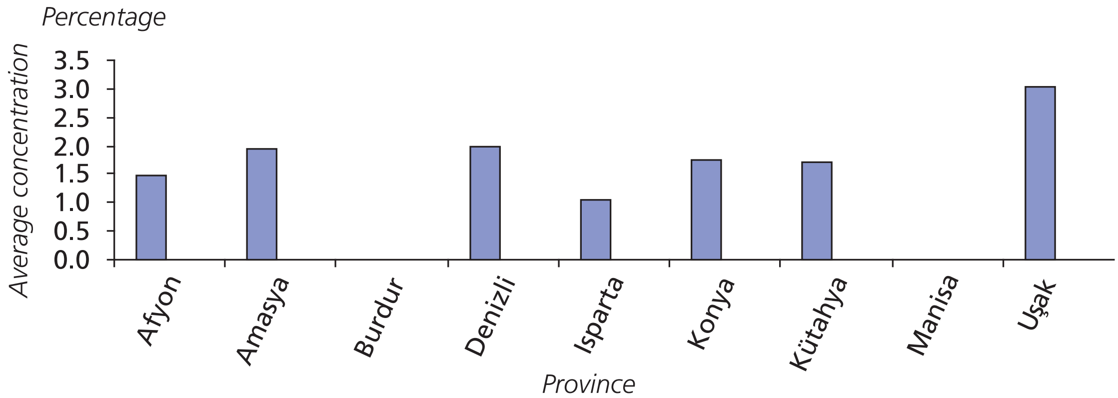


Figure XII. Average concentration of magnesium in poppy straw samples from selected provinces of Turkey

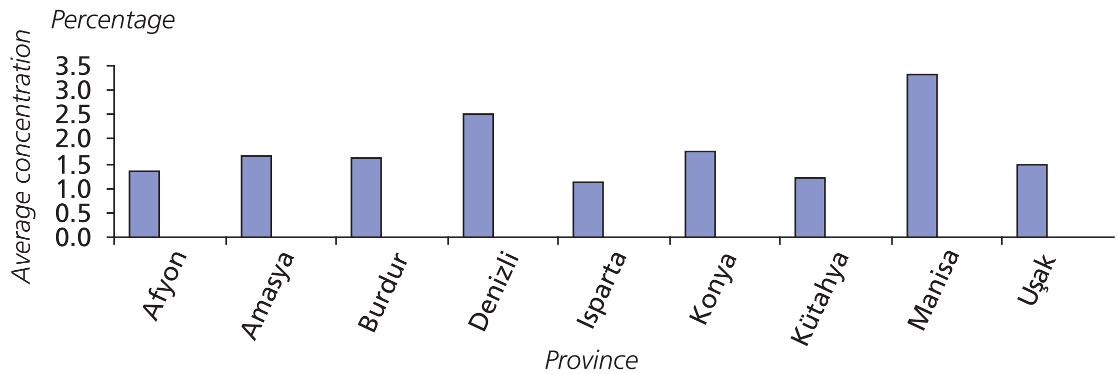


Figure XIII. Average concentration of silicon in poppy straw samples from selected provinces of Turkey

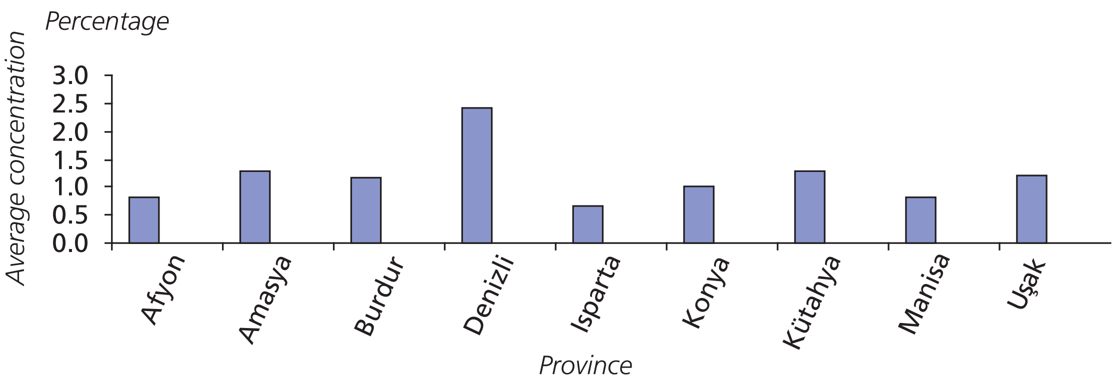


Figure XIV. Average concentration of phosphorous in poppy straw samples from selected provinces of Turkey

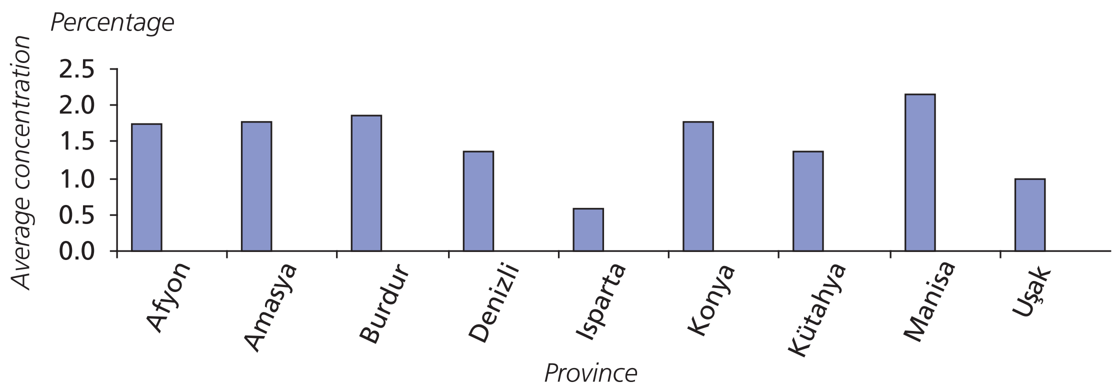


Figure XV. Average concentration of sulphurs in poppy straw samples from selected provinces of Turkey

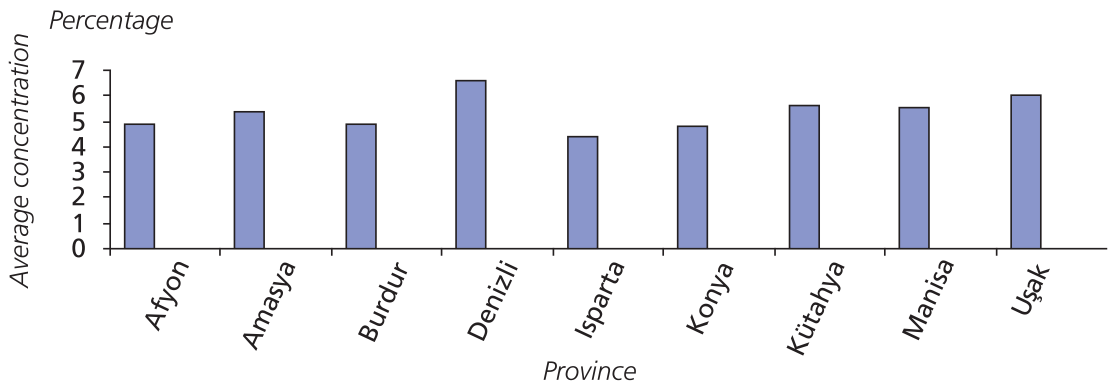


Figure XVI. Average concentration of chlorine in poppy straw samples from selected provinces of Turkey

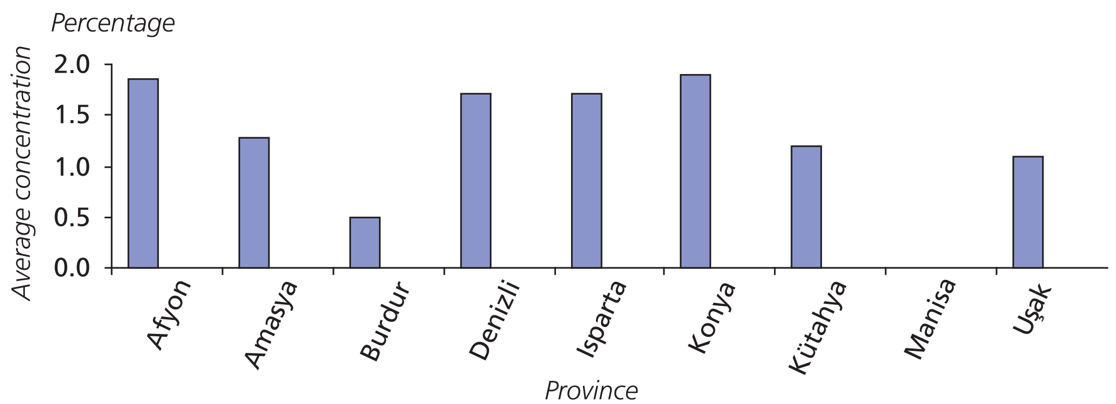


Figure XVII. Average concentration of potassium in poppy straw samples from selected provinces of Turkey

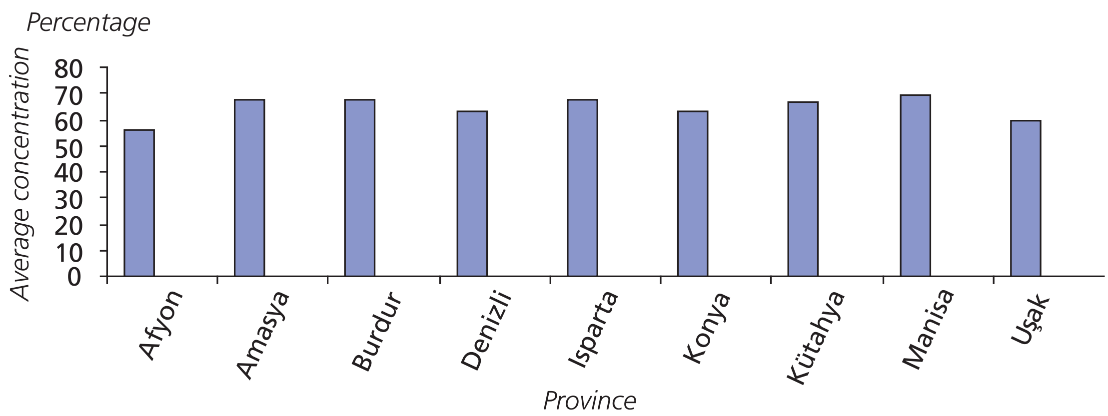


Figure XVIII. Average concentration of calcium in poppy straw samples from selected provinces of Turkey

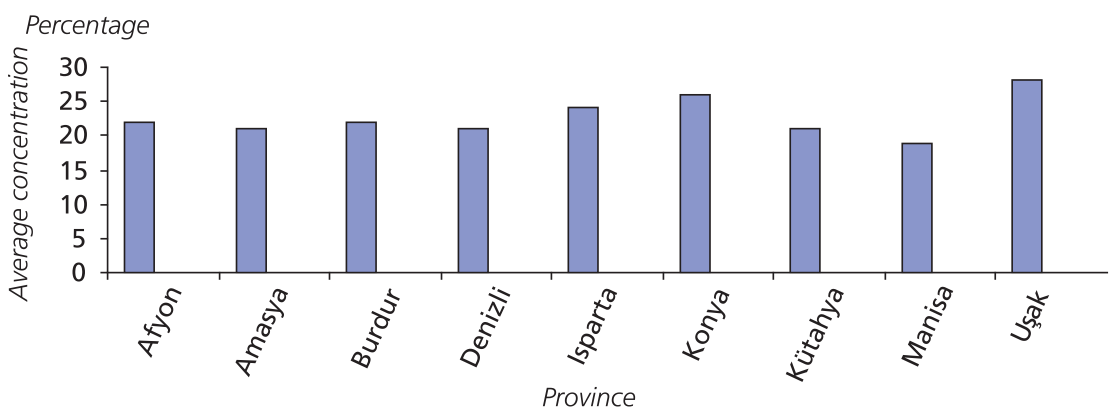


Figure XIX. Average concentration of copper in poppy straw samples from selected provinces of Turkey

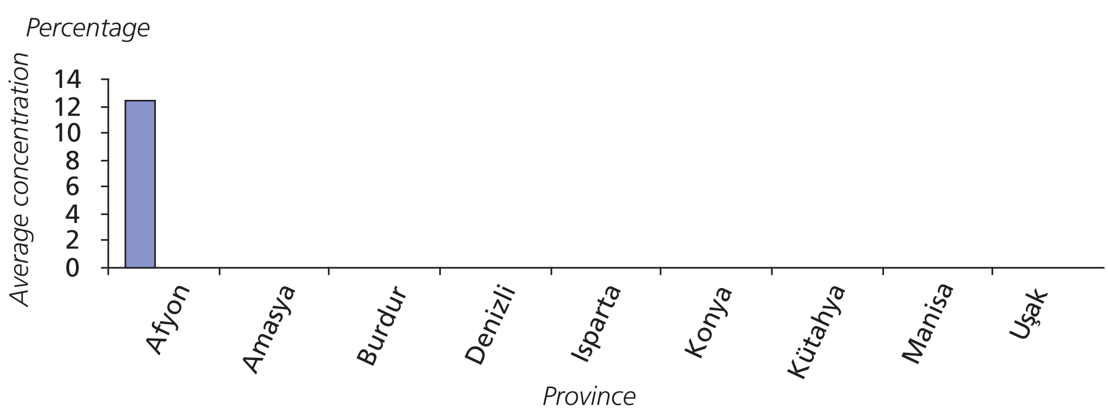
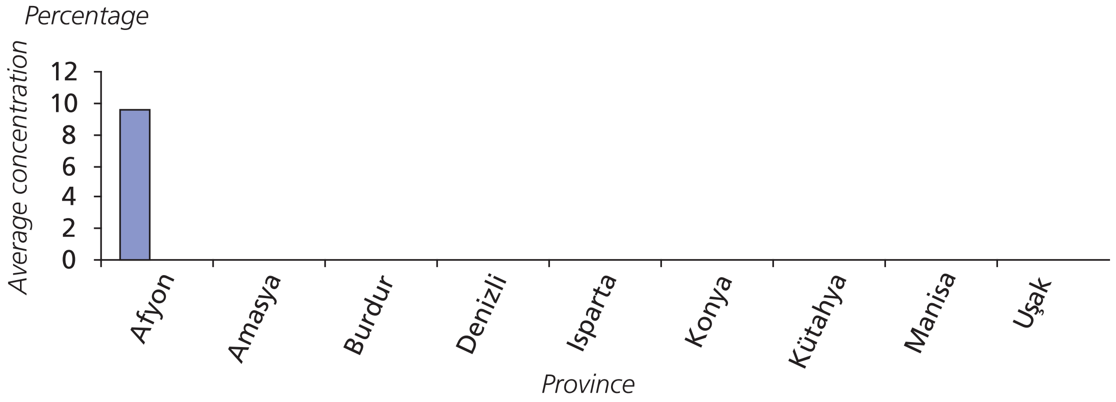


Figure XX. Average concentration of zinc in poppy straw samples from selected provinces of Turkey



With regard to the second objective of the study, to provide comparative data for poppy straw samples from the nine provinces in Turkey where opium poppy is grown, figures II-X show inorganic element profiles of samples from selected towns (one per province). From the figures, and despite the dominance of potassium and calcium in most profiles, it is clear that minor differences in element profiles do exist. However, those differences are relative rather than absolute in terms of presence or absence of individual inorganic elements.

For example, the straw sample from the town of Acıpayam, in Denizli Province showed a significantly higher silicon concentration (12.69 per cent, see table 9) than all the other samples analysed (see table 10). This is assumed to be the result of a higher silicon content of the soil at the high altitude of Acıpayam. The straw sample from the town of Göynücek, in Amasya Province is characterized by a slightly higher than average potassium content (82.28 per cent, see tables 3 and 10). The potassium content is also higher than average in four other provinces (Burdur, Isparta, Kütahya and Manisa, see table 10). Although potassium is also present in soil naturally, manuring practices are thought to be responsible for the high potassium content. Differences in manuring practices are also presumed to be responsible for the low phosphorous concentration (0.14 per cent) found in the sample from Yalvaç, in Isparta Province (see table 2). By contrast, calcareous soil or water could be responsible for the high concentration of calcium in samples from U şak Province (see table 7). Soil characteristics are also likely to explain the higher than average magnesium content of samples from Manisa Province (see table 10).

The reasons for these differences, and their implications, are not yet fully understood, but are the subject of further investigation.

Conclusion

In Turkey, inorganic elements have traditionally been analysed by colorimetry, AAS and AES. The study reported here explored the potential of SEM/EDS as a means of establishing inorganic element profiles for the opium-poppy-growing provinces of Turkey for comparative analysis and determination of origin. Ten inorganic elements (Na, Mg, Si, P, S, Cl, K, Ca, Cu and Zn) were identified in an initial set of 67 poppy straw samples from 67 towns in nine provinces in Turkey. The validity of SEM/EDS results has been confirmed by comparison with results gained using other basic methods for the measurement of inorganic elements.

For purposes of determination of origin, the most significant finding was the presence of copper and zinc in the poppy straw samples from Afyon Province. Differences in the samples from the other eight provinces were less significant, possibly as a result of their geographical proximity and the similarity of their soil and climatic conditions. Further studies will examine poppy straw samples from a wider area, including from different countries. In addition, the relationship between different climatic conditions and soil characteristics, on the one hand, and the inorganic element profiles of poppy straw samples, on the other, will be investigated further to determine more precisely the source of the inorganic elements.

The inorganic element profiles generated in the study have been used to form the basis for the development of a database, which will provide comprehensive sets of data on poppy straw samples, including inorganic element profiles, soil characteristics and traditional data, such as alkaloid profiles. These data may be useful not only in comparing samples and determining origin, but also for the poppy straw industry. More specifically, the detection of similarities or differences in inorganic element and/or alkaloid profiles of unknown samples in relation to straw samples of Turkish origin may contribute to controlling licit opium poppy cultivation and to the identification of illicit opium poppy cultivation or trafficking from overseas.

Ultimately, with a large enough set of samples analysed, it is hoped that the technique used here will also help to establish links between poppy straw and the seeds from which the poppies were grown.

In terms of analytical technique, SEM/EDS has proved to be a robust, fast and practical technique, which is convenient for routine use. Interference effects, which may be problematic in other techniques, are minimized. Additional advantages are that all inorganic elements can be determined simultaneously, in a non-destructive way, that is, SEM/EDS samples can be re-analysed using other methods (for example, AAS or AES).

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