

The content of chosen chemical elements in wool of sheep of different origins and breeds

BOŻENA PATKOWSKA-SOKOŁA¹, ZBIGNIEW DOBRZAŃSKI¹, KHALIL OSMAN², ROBERT BODKOWSKI¹ and KATARZYNA ZYGADLIK¹

¹Faculty of Biology and Animal Husbandry, Wrocław University of Environmental and Life Sciences, Wrocław, Poland, ²Faculty of Veterinary Medicine, Al-Baath University in Homs, Syria

Abstract

The following chemical elements in sheep wool originating from Poland (Polish Mountain Sheep), Greece (Karagounico breed), and Syria (Awassi breed) were analysed: macroelements (Ca, P, Na, K, Mg, S), trace elements (Al, Ba, Co, Cu, Fe, Mn, Mo, Sr, Ti, Zn) and heavy metals (As, Cd, Hg, Pb). Some statistically significant differences were observed between the content of the examined elements in sheep wool collected in the above countries. Sulphur, calcium, sodium and potassium were found in the highest amounts, while arsenic, cadmium and mercury occurred in the lowest quantity.

Keywords: sheep, wool, chemical elements, Poland, Greece, Syria

Zusammenfassung

Der Gehalt ausgewählter chemischer Elemente in Schafwollen unterschiedlicher Herkunft und Rasse

Für die Untersuchung standen Schafwollen aus Polen (Polnisches Bergschaf), Griechenland (Karagounischaf) und Syrien (Awassischaf) zur Verfügung. Untersucht wurden ausgewählte Makroelemente (Ca, P, Na, K, Mg, S), Spurenelemente (Al, Ba, Co, Cu, Fe, Mn, Mo, Sr, Ti, Zn) und Schwermetalle (As, Cd, Hg, Pb). Bei den Makroelementen Ca, P, Na, Mg und S bestanden signifikante Unterschiede zwischen den Länderpopulationen. Hervorzuheben ist der Mg Gehalt, dessen Wert in Syrien den polnischen Wert um das Fünffache übersteigt. Auch die Werte für die Spurenelemente differierten zwischen den Populationen signifikant. Die Werte der syrischen Wolle waren charakterisiert durch hohe Gehalte an Al, Fe, Ti und As. Bei den Schwermetallen unterschieden sich die Gehalte an As und Hg zwischen den Populationen. Eine Interpretation der Gehaltsunterschiede ist schwierig und nur bei Einbeziehung von Analysenwerten von Mineralgehalten in Böden Futter und Wasser möglich.

Schlüsselwörter: Schaf, Wolle, chemische Elemente, Polen, Griechenland, Syrien

Introduction

Sheep fleece, similar to other animals' coats, presents a specific chemical indicator, and a concentration of the elements it contains reflects both feed and nutrition quality, as well as climate and the state of the environment. It is obvious that many other factors, such as

breed, sex, age, physiological and health state (RAMIREZ-PEREZ *et al.* 2000), can modify the chemical composition of wool and coats. For instance, HUANG and CHEN (2001) report that in the wool of sheep and goats suffering from fleece-eating (Shimao Zheng) higher concentrations of Ca, P, Fe, Mn, Zn, Cu, Co, Se, F can be observed, while S and Mo are present in lower concentrations. GABRYSZUK *et al.* (2000) note some significant differences between Ca, Mg, K, Zn and Fe concentrations in Booroola and Polish Merino sheep wool. In the case of Merino sheep significant differences for Ca, Mg and Zn content were found between the perinatal period and the periods of resting and tugging.

Investigations by KROŚNICKA-BOMBAŁA (1996) prove that pigment content in sheep and goat coats affects the accumulation of certain elements. The author identified positive correlations between eumelanine content and Fe, Cu, Mn, K, Na and Mg concentration. ŻARSKI (1988) reported variable contents of Ca, Na, K, Mg, Fe, Zn, Mn and Cu in the hair of cattle and roe deer from different regions of Poland depending on the richness in those elements of soil and plants, and GALLO *et al.* (1996) about the relationship of minerals in soil, plants and animal tissues. Moreover, ŻARSKI (1988) confirmed statistically significant correlations between Na, Mg, Fe, and Zn content in the liver and hair of roe deer. The use of salt licks with zinc content did not cause any fundamental changes in the chemical content (with the exception of Zn) of these animals' hair. SZTYCH and SOROCZYŃSKA (1994) report about stages of lactation related to macro- and microelements in wool of sheep. A number of authors describe mineral components in the blood of sheep as indicators in connection to genotype, age, lactation, reproductive status or soil and environment (GALLO *et al.* 1996, CASTILLO *et al.* 1997, BARANOWSKI 2002, ANTUNOVIC *et al.* 2004, BARANOWSKI *et al.* 2004).

However, hair is considered to be a good bioindicator of the state of the environment, soil, water and air pollution, even better than blood, urine or animal milk.

ENNE *et al.* (1989) reported high concentrations of toxic metals (Cd, Cu, Pb, Zn) in sheep wool from mining regions in Italy, while KOŁACZ *et al.* (1999) observed significantly higher concentrations of As, Ba, Cd, Co, Fe, Mn, Mo, Pb, S, Ti and Zn in the case of sheep from areas under the influence of the copper industry in comparison to ecologically clean regions. PATKOWSKA-SOKOŁA *et al.* (2003), in research on Merino sheep from the National Reserve Park in Poland, detected significantly higher concentrations of Ba, K, Na and significantly lower ones of Cd, Co, Cu, Fe, Mn, Mo, Si, Ti and Zn as compared to similar sheep breeds from the Mesaria Lowland in Cyprus.

The aim of the present work is an assessment of chemical element composition in wool from sheep of similar performance types, but originating from three different countries: Poland, Greece and Syria.

Material and methods

The research material was obtained from 3-year-old sheep mothers of a similar performance type (meat-milk) and the same type of coat (mixed wool). The samples were collected in the late summer period when the sheep were in pastures. Sheep were typical for their region of origin.

The Polish material (W-Pl) involved sheep of the Polish Mountain Sheep breed. Those animals can be found across the whole Polish Carpathian region; however, most commonly in Podhale in the region of Nowy Sącz where the collection of samples took place. In Greece, samples (W-Gr) were obtained from the Karagounico sheep breed from the Thessaloniki region. Those sheep are the most characteristic for the lowlands of western Thessaly. The material from Syria (W-Sy) was wool samples from the Awassi sheep breed, commonly occurring in that country, collected in Syria central province of Homs.

Wool samples weighing 12-20 g were collected by cutting them out from the left and right sides of 10 animals representing each of three countries. Then the samples were subjected to cleaning and degreasing processes. Foreign substances and plant parts were separated prior to washing in warm water (50°C) with detergent. Samples were rinsed twice in distilled water, and then left for natural drying. Samples thus prepared were then subjected to chemical analysis after they had been mineralized using the MARS-5 (CEM, USA) microwave system. 100-fold diluted nitric acid (MERCK, Germany) solution was applied. The weight of analytical samples was 0.5 g. A VARIAN LIBERTY type 220 (USA) spectrophotometer was used for analysis. Mercury concentration was determined by a direct method using an analyzer of MA 200 type (NIC Japan). The weight of analytical samples ranged from 100 to 200 mg. In wool samples 6 macroelements (Ca, P, Na, K, Mg, S), 10 trace elements (Al, Ba, Co, Cu, Fe, Mn, Mo, Sr, Ti, Zn) and 4 heavy metals (As, Cd, Hg, Pb) were analysed.

Analytical analyses were conducted in the Analytical Laboratory of Wrocław University of Environmental and Life Sciences. The results obtained were statistically analysed using the Duncan test to calculate mean values, standard deviations, significance of differences between the groups on Statistica 7.1 software.

Results and discussion

The results of the analyses were presented in tabular format taking into account the division into macroelements, trace elements and heavy metals. All of them, regarding percentage weight, provided for 2.736% in the wool from Greece (W-Gr), 2.649% from Poland (W-Pl), and 2.522% from Syria (W-Sy).

Macroelements

Table 1 shows the results of the analysis of the main macroelements. Calcium (Ca) content ranged from 1 790 to 2 900 mg/kg. The highest amount of Ca was found in the case of W-Gr, while the lowest one in W-Pl (differences significant statistically, $P < 0.05$). Some authors (KROŚNICKA-BOMBAŁA 1996, GABRYSZUK *et al.* 2000) report the range of this basic macroelement in sheep wool from 645.6 to 1 720.6 mg/kg, although in the case of ill sheep even an amount of 0.44% (4 400 mg/kg) (HUANG and CHEN 2001) was detected. Amount of Ca determined by AYDIN (2008) in wool from male lambs collected in Turkey was on a level of 0.41-0.57%.

Phosphorus (P) concentration ranged from 148 to 284 mg/kg. Its highest values were recorded in W-Sy and the lowest content in the case of W-Pl ($P < 0.05$). Some authors (HUANG and CHEN 2001) determine a similar range of this important bioelement concentration, i.e. from 163 to 300 mg/kg.

Table 1
Content of macroelements in sheep wool from Poland, Greece and Syria (mg/kg)
Gehalt an Makroelementen in Schafwollen aus Polen, Griechenland und Syrien (mg/kg)

Element	Poland	Greece	Syria
Calcium (Ca)	1 790.0 ^a ± 392.0	2 900.0 ^b ± 591.0	1 800.0 ^a ± 351.0
Phosphorus (P)	148.0 ^a ± 32.3	206.0 ^b ± 49.2	284.0 ^c ± 59.8
Sodium (Na)	1 486.7 ^a ± 234.2	2 165.0 ^b ± 573.1	1 745.5 ± 1 152.6
Potassium (K)	718.6 ± 307.7	643.0 ± 312.9	755.0 ± 295.3
Magnesium (Mg)	120.8 ^a ± 17.2	383.5 ^b ± 65.4	590.8 ^c ± 133.5
Sulphur (S)	22 038.3 ^a ± 663.9	20 758.0 ^b ± 947.5	18 733.4 ^c ± 1 212.4

^{a, b, c} $P < 0.05$

The concentration of sodium (Na) ranged from 1 486.7 to 2 165 mg/kg. The highest amount of this element was observed in the case of W-Gr, while the lowest in W-PI ($P < 0.05$). Some authors (KROŚNICKA-BOMBAŁA 1996, PATKOWSKA-SOKOŁA *et al.* 2003) report a very wide range of Na concentrations, i.e. 172.2-1 463.5 mg/kg, while AYDIN (2008) reports a content of that element on a level of 0.28-0.36%.

Potassium (K) concentration ranged from 643 to 755 mg/kg. Its highest amount was observed in the case of W-Sy, while the lowest one in W-Gr, although the differences were not significant statistically. Certain authors (KROŚNICKA-BOMBAŁA 1996, GABRYSZUK *et al.* 2000, PATKOWSKA-SOKOŁA *et al.* 2003, AYDIN 2008) report a relatively wide range of potassium concentrations, i.e. from 204 to 2 499.2 mg/kg.

The determined magnesium (Mg) content was within the range of 120.8 to 590.8 mg/kg. The highest values were noted in the case of W-Sy, and the lowest ones in W-PI ($P < 0.05$). Some authors (KROŚNICKA-BOMBAŁA 1996, GABRYSZUK *et al.* 2000) report quite a wide Mg concentration range in sheep hair, i.e. 47.8-263.4 mg/kg, while AYDIN (2008) found a content of that element ranged from 0.09-0.13% in wool from male lambs.

Sulphur (S) concentration varied within the range of 18 733.4 to 22 038.3 mg/kg. It was the highest in the case of W-PL, and the lowest in W-Sy ($P < 0.05$). PATKOWSKA-SOKOŁA (1990) determined sulphur concentration in Merino sheep wool at a level of 2.90-3.28%, depending on its supply in animal diet and the season of the year, while other authors (GEORGIEVSKI *et al.* 1982, HUANG and CHEN 2001) generally report its values from 2.61% to as much as 4% (4 000 ppm).

Trace elements

Table 2 presents the results of the analysis of the main microelements. Aluminium (Al) concentration in sheep wool collected in the three countries varied within a wide range of 53.65 to 620.83 mg/kg. The highest amount was found in W-Sy, and the lowest one in W-PI ($P < 0.05$).

The observed concentration of barium (Ba) ranged from 1.56 to 9.42 mg/kg. The highest amount of this element was found in the case of W-Sy, while the lowest in W-PI ($p < 0.05$). Some authors (KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003) give a short range of barium content in wool from sheep from different habitats, i.e. 2.146-4.687 mg/kg. Generally, in the case of terrestrial animals the concentration of this toxic element is quite low, in soft tissues it is 0.1-2.5 and in bones 5-30 ppm of dry matter (KABATA-PENDIAS and PENDIAS 1999).

Table 2
Content of trace elements in sheep wool from Poland, Greece and Syria (mg/kg)

Gehalt an Spurenelementen in Schafwollen (mg/kg)

Element	Poland	Greece	Syria
Aluminium (Al)	53.65 ^a ± 5.46	127.00 ^b ± 24.58	620.83 ^c ± 304.51
Barium (Ba)	1.56 ^a ± 0.33	3.67 ^b ± 0.9	9.42 ^c ± 2.94
Cobalt (Co)	0.98 ^a ± 0.31	0.65 ^a ± 0.24	2.31 ^b ± 1.25
Copper (Cu)	5.30 ^a ± 1.86	6.79 ^a ± 1.33	10.30 ^b ± 3.09
Iron (Fe)	22.03 ^a ± 3.55	76.70 ^b ± 27.37	513.17 ^c ± 201.79
Manganese (Mn)	3.37 ^a ± 1.65	4.43 ^a ± 1.8	22.93 ^b ± 13.93
Molybdenum (Mo)	1.02 ^a ± 0.27	0.91 ± 0.18	0.77 ^b ± 0.19
Strontium (Sr)	2.83 ^a ± 0.52	8.46 ^b ± 1.43	14.07 ^c ± 1.52
Titanium (Ti)	0.54 ^a ± 0.29	3.54 ^b ± 1.57	40.47 ^c ± 18.32
Zinc (Zn)	88.80 ^a ± 5.45	75.02 ^b ± 3.88	73.62 ^b ± 9.16

^{a, b, c} $P < 0.05$

Cobalt (Co) content ranged from 0.65 to 2.31 mg/kg. The highest amount was in the case of W-Sy, and the lowest in W-Gr ($P < 0.05$). The authors (KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003) report Co range from 0.0186 to 0.1873 mg/kg, depending on the degree of environmental pollution or the country of origin. However, in the case of healthy sheep and goats in China quite low Co content values, i.e. 0.054 ppm on average, were recorded (HUANG and CHEN 2001), while AYDIN (2008) reports the content of Co in the case of male lambs in Turkey on a level of 0.59-1.36 mg/kg.

Copper (Cu) concentration ranged from 5.30 to 10.30 mg/kg. The highest values were found for W-Sy, while the lowest ones for W-PI ($P < 0.05$). Research by numerous authors (ENNE *et al.* 1989, SCOTT 1991, KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003, AYDIN, 2008) prove that copper concentration in sheep wool covers a wide range from 1.70 to 25 mg/kg. RAMIREZ-PEREZ *et al.* (2000) report that, to a large degree, it depends on its concentration in animal diet. Low Cu level in blood can affect its diminished content in wool.

Iron (Fe) concentration varied within the range of 22.03 to 513.17 mg/kg. The highest content of this element was observed in the case of W-Sy, while the lowest in W-PI ($P < 0.05$). Numerous authors (WÓJCIKOWSKA and SZTYCH 1994, KOŁACZ *et al.* 1999, RAMIREZ-PEREZ *et al.* 2000, PATKOWSKA-SOKOŁA *et al.* 2003) report a wide range of this element concentration, from 2.56 to 52.6 mg/kg. To a large degree it depends on this element's content in soil as well as in the feed that sheep intake while grazing. Very high values in sheep wool in China (365.4-788.5 mg/kg) were reported by HUANG and CHEN (2001), and in wool from lamb in Turkey (106.07-120.52 mg/kg) as reported by AYDIN (2008).

The observed manganese (Mn) concentration ranged from 3.37 to 22.93 mg/kg. The highest values were noted in the case of W-Sy, while the lowest ones in W-PI ($P < 0.05$). Some authors (GEORGIEVSKI *et al.* 1982, KROŚNICKA-BOMBAŁA 1996, HUANG and CHEN 2001, PATKOWSKA-SOKOŁA *et al.* 2003, AYDIN, 2008) report Mn content ranged from 0.35 to 20 mg/kg, depending on the state of the environment and the animal's origin.

Molybdenum (Mo) concentration ranged from 0.77 to 1.02 mg/kg. Its highest content was observed in W-PI, while the lowest in W-Sy ($P < 0.05$). Some authors (KOŁACZ *et al.* 1999, HUANG and CHEN 2001, PATKOWSKA-SOKOŁA *et al.* 2003) determined the molybdenum concentration at a level from 0.048 to 0.372 mg/kg. In terrestrial animal muscles this

element occurs in low concentrations ranging from 0.02 to 0.05 ppm, and in bones from 0.5 to 1 ppm in dry matter. Its availability in ruminants depends on Cu/Mo ratio in feed (KABATA-PENDIAS and PENDIAS 1999).

Strontium (Sr) content ranged from 2.83 to 14.07 mg/kg. The highest content of this element was noted in the case of W-Sy, while the lowest in W-PI ($P < 0.05$). The authors (KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003) report similar values of this element (8.044-9.303 mg/kg) for sheep originating from different environments. Strontium accumulates mainly in hard tissues (30-100 ppm DM [dry matter]) and it takes part in Ca metabolism (PORS NIELSEN 2004).

Titanium (Ti) content ranged from 0.54 to 40.47 mg/kg. The highest values were noted for W-Sy, and the lowest ones for W-PI. The authors (KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003) determined Ti concentration at a level from 0.64 to 2.35 mg/kg. There is not much published literature concerning this element. It is known that titanium accumulates in animal muscles in the amount of 0.5-2.0 ppm DM, and in bones at a level of 1.5 ppm DM; however, its role has not been sufficiently recognized so far (KABATA-PENDIAS and PENDIAS 1999).

Zinc (Zn) content ranged from 73.62 to 88.80 mg/kg. The highest values were observed in the case of W-PI, while the lowest in W-Sy ($P < 0.05$). Authors (GEORGIEVSKI *et al.* 1982, ENNE *et al.* 1989, KOŁACZ *et al.* 1999, HUANG and CHEN 2001, PATKOWSKA-SOKOŁA *et al.* 2003, AYDIN 2008) reported a wide range of this bioelement concentration, ranged from 18.3 to 336.9 mg/kg. According to SCOTT (1991), a normal Zn content in sheep wool ranges from 35 to 195 mg/kg, depending mainly on its supply in animal diet and the physiological state of sheep. RAMIREZ-PEREZ *et al.* (2000) proved significant differences in this element content between the Rambouillet and Suffolk ewes' wool.

Heavy metals

Table 3 shows the results of the main heavy metals analysis. The observed arsenic (As) content was within the range of 0.206 to 0.765 mg/kg. The highest values were found in the case of W-Sy, while the lowest ones in W-Gr ($P < 0.05$). Some authors (KOŁACZ *et al.* 1999, BODKOWSKI *et al.* 2006) report a concentration range from 0.029 to 0.23 mg/kg. That value may increase up to 1.505 mg/kg in urbanized areas (GEBEL *et al.* 1996), while sheep receiving seaweed (containing arsenosugar) cumulate even 13.03 µg/g of this element (7.08 on average) in fibre, and only 1.86 µg/g in lanolin (RAAB *et al.* 2002).

Table 3

Content of heavy metals in sheep wool from Poland, Greece and Syria (mg/kg)

Gehalt an Schwermetallen in Schafwollen (mg/kg)

Element	Poland	Greece	Syria
Arsenic (As)	0.233 ^b ± 0.055	0.206 ^b ± 0.046	0.765 ^a ± 0.249
Cadmium (Cd)	0.134 ± 0.032	0.342 ± 0.14	0.294 ± 0.112
Mercury (Hg)	0.010 ^a ± 0.002*	0.024 ± 0.021	0.081 ^b ± 0.056
Lead (Pb)	2.59 ± 1.34	2.32 ± 0.65	2.46 ± 0.85

^{a, b, c} $P < 0.05$, * one sample below the detection threshold of 0.2 ng/g

Cadmium (Cd) concentration ranged from 0.134 to 0.342 mg/kg. The highest amount of this element was found in W-Gr, while the lowest one in W-PI (differences insignificant

statistically). Some authors (ENNE *et al.* 1989, KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003, AYDIN 2008) report a relatively wide range of Cd concentration, i.e. from 0.0186 to 1.8 mg/kg.

Mercury (Hg) concentration ranged from 0.010 to 0.081 mg/kg. The highest amount of this element was noted in the case of W-Sy, and the lowest one in W-PI ($P < 0.05$). BODKOWSKI *et al.* (2006) observed an average concentration of Hg in the region of copper industry at the level of 0.19 ppm, GEBEL *et al.* (1996) reported an average Hg content in sheep wool of only 0.107 mg/kg in the area affected by mercury mines in Germany. It is known that mercury is available mainly in an organic form (KABATA-PENDIAS and PENDIAS 1999).

Lead (Pb) concentration was within the range of 2.32 to 2.59 mg/kg. Its highest amount were found in W-PI, and the lowest ones in W-Gr (differences insignificant statistically). Numerous authors (ENNE *et al.* 1989, KOŁACZ *et al.* 1999, PATKOWSKA-SOKOŁA *et al.* 2003, BODKOWSKI *et al.* 2006, AYDIN, 2008) report a wide concentration range of this toxic element, i.e. 0.015-6.94 mg/kg.

The results obtained from this research are difficult to interpret unequivocally. Except for K, other bioelements (Ca, P, Na, Mg and S) did significantly differ between the groups (countries). Special attention should be paid to the 5-fold higher Mg concentration in W-Sy as to compare to W-PI. It seems that such a high variability of macroelements content in the analysed samples may be due to nutritional and biogeochemical background. Only detailed analysis of the mineral composition of soil, water and feed could provide the answer, e.g. for the reason of especially high concentration of Al, Fe, Ti or As in the wool from Syria as compared to W-PI or W-Gr. The different values of the proportional content of the main elements, i.e. Ca/P, Na/K, Cu/Zn, Fe/Mn, Cu/Mo in particular groups (Table 4) is noteworthy. Except for S, Ca, Na and K, the order of descending values is different, and at the end of this sequence there are three heavy metals, As, Cd and Hg, in all groups (W-Sy, W-PI and W-Gr) (Table 5). In the case of As and Hg the highest concentration in W-Sy was observed, which is also difficult to explain without a biomonitoring investigation on their habitat. Cd and Pb, however, did not differ significantly between the analysed wool samples.

Table 4

Accumulation coefficients of main chemical elements in sheep wool from Poland, Greece and Syria
Kumulationskoeffizient der wichtigsten chemischen Elemente in Schafwollen

Country	Ca/P	Na/K	Cu/Zn	Fe/Mn	Cu/Mo
Poland	12.09	2.07	0.06	6.54	5.41
Greece	14.08	3.37	0.09	17.31	10.45
Syria	6.34	2.31	0.14	22.38	4.46

Table 5

Concentration of analysed elements in the wool from Poland, Greece and Syria in a descending order of values
Konzentration untersuchter chemischer Elemente in Wollen in absteigender Reihenfolge der Gehaltswerte

	Element																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Poland	S	> Ca	> Na	> K	> P	> Mg	> Zn	> Al	> Fe	> Cu	> Mn	> Sr	> Pb	> Ba	> Mo	> Co	> Ti	> As	> Cd	> Hg
Greece	S	> Ca	> Na	> K	> Mg	> P	> Al	> Fe	> Zn	> Sr	> Cu	> Mn	> Ba	> Ti	> Pb	> Mo	> Co	> Cd	> As	> Hg
Syria	S	> Ca	> Na	> K	> Al	> Mg	> Fe	> P	> Zn	> Ti	> Mn	> Sr	> Cu	> Ba	> Pb	> Co	> Mo	> As	> Cd	> Hg

References

- Antunovic Z, Speranda M, Steiner Z (2004) The influence of age and the reproductive status to the blond indicators of the ewes. *Arch Tierz* 47, 265-73
- Aydin I (2008) Comparison of dry, wet and microwave digestion procedures for the determination of chemical elements in wool samples in Turkey using ICP-OES technique. *Microchemical J* 90, 82-7
- Baranowski P (2002) Genetic and environmental factors of macroelements concentration in blood serum and osseous tissue of lambs in north-west Poland. *Arch Tierz* 45, 565-74
- Baranowski P, Klata W, Baranow-Baranowski S (2004) Macroelements concentration in the osseous tissue of caudal vertebrae in domestic sheep lambs and of mandibular bone in roe deer bucks coming from the northern and the southern region of Western Pomerania in Poland. *Arch Tierz* 47, 75-84
- Bodkowski R, Patkowska-Sokoła B, Dobrzański Z, Janczak M, Zygodlik K (2006) Exploitation of sheep wool for an assessment of environmental pollution with heavy metals. *Roczn Nauk PTZ* 2, 105-11 [in Polish]
- Castillo C, Hernandez JR, Lopez M, Miranda M, Garcia-Partida, P, Benedito JL (1997) Relationship between venous pH, serum calcium and proteins in the course of anoestrus, pregnancy and lactation in the ewe. *Arch Tierz* 40, 257-63
- Enne G, Leita L, Giardini I, Sequi P (1989) Relationship between the level of environmental contamination with heavy metals and their accumulation in sheep tissues. *Medycyna Wet* 9-10, 565-8
- Gabryszuk M, Klewicz J, Czuderna R, Baranowski A, Kowalczyk J (2000) The content of mineral compounds in sheep wool depending on the breed and physiological state. *Rocz Nauk Zoot Suppl* 5, 147-51 [in Polish]
- Gallo M, Gallo J, Sommer A, Flak P (1996) Influence of emission fall-out movement of heavy metals in the cycle soil, plant, animal. *Arch Tierz* 39, 195-202
- Gebel T, Kevekordes S, Schaefer J, Von Platen H, Dunkelberg H (1996) Assessment of possible genotoxic environmental risk in sheep bred on grounds with strongly elevated contents of mercury, arsenic and antimony. *Gen Toxicol* 368, 267-74
- Georgievski VI, Annenkov BN, Samokhin VT (1982) *Mineral Nutrition of Animals*. Butterworths, London, 91-222
- Huang Y, Chen H (2001) Studies on the pathogenesis of Shimao Zheng (fleece-eating) in sheep and goats. *Vet Res Com* 25, 631-40
- Iyengar GV (1998) Reevaluation of the trace element content in reference man. *Radiat Phys Chem* 51, 545-60
- Johnsson C, Sällsten G, Schütz A, Sjörs A, Barregård L (2004) Hair mercury levels versus freshwater fish consumption in household members of Swedish angling societies. *Environ Res* 96, 257-63
- Kabata-Pendias A, Pendias H (1999) *Biochemistry of trace elements*. Wyd Nauk PWN Warszawa [in Polish]
- Kołacz R, Bodak E, Dobrzański Z, Patkowska-Sokoła B (1999) Trace elements in the wool of Polish merino sheep grazed in polluted and unpolluted environment. *Czech J Anim Sci* 44, 509-14
- Krośnicka-Bombała R (1996) Influence of a season of the year and a colour on pigment and microelements content in a coat of differently coloured sheep and goats. *Zesz Nauk Przeg Hod PTZ* 23, 117-32 [in Polish]
- Patkowska-Sokoła B (1990) Investigations on effects of elemental sulphur (35S; 50) administration to Merino Sheep. *Zesz Nauk AR Wrocław Rozpr Habil* 83 [in Polish]
- Patkowska-Sokoła B, Dobrzański Z, Bodak E, Panyiotu P, Kołacz R (2003) Comparative study on the concentration of elements in the wool of sheep of Cyprus and Poland origin. *Chem Agric* 4, 182-9
- Pors Nielsen S (2004) The biological role of strontium. *Bone* 35, 583-8
- Raab A, Hansen HR, Zhuang L, Feldman J (2002) Arsenic accumulation and speciation analysis in wool from sheep exposed to arsenosugars. *Talanta* 58, 67-76
- Ramirez-Perez AH, Buntinx SE, Rosiles R (2000) Effect of breed and age on voluntary intake and the micromineral status of non-pregnant sheep. *Micromineral status. Small Rumin Res* 37, 231-42
- Scott G (1991) *The Sheepman's Production Handbook*, 4th ed Abegg Printing, USA
- Sztych D, Soroczyńska M (1994) Some chosen macro- and microelements in the wool of sheep in different stages of lactation. *Ann Warsaw Agricult Univ - SGGW, Anim Sci* 32, 47-53

Wojcikowska SM, Sztych D (1994) Selected microelements in wool of Polish sheep. *Ann Warsaw Agricult Univ* 30, 59-68

Żarski TP (1988) A recognition and an assessment of different methods of prevention and liquidation of mineral deficiencies in domestic and wild ruminants. SGGW-AR, Warszawa [in Polish]

Received 8 January 2008, accepted 2 May 2009.

Corresponding author:

Prof. Dr. BOŻENA PATKOWSKA-SOKOŁA

email: bozena.patkowska-sokola@up.wroc.pl

Institute of Animal Breeding, Wrocław University of Environmental and Life Sciences, Chelmonskiego 38c, 51-630 Wrocław, Poland
