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CONCENTRATION OF MINERALS IN THE COAT OF THE RED FOX (*VULPES VULPES* L.) OF VARIOUS COLOR MORPHS AND THEIR CROSSBREDS VS. HAIR STRENGTH PROPERTIES

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Abstract. The aim of the study was to quantitatively establish the concentration of minerals in the coat of red foxes and an attempt to relate their composition with the resistance properties of single hairs of the coat. The analyses were carried out on 122 hair samples of red foxes of various color morphs and their crossbreds, collected from 61 live animals, from the middle of the back and from the right side of the body. The study took place during autumn and winter in a fox farm located in the Wielkopolskie voivodship, Poland. The animals were as follows: 11 silver femals, 7 females and 3 males of the platinum morph, 8 platinum-pastel males, 10 females and 4 males of the pastel morph, 3 cross females, and 11 females and 4 males of the fire morph. The samples were analyzed for Mg, K and Ca by atomic emission spectrometry (AES) and for Cd, Cu, Co, Cr, Fe, Mn, Ni, Pb and Zn by flame atomic absorption spectrometry (FAAS). The concentration of minerals in the coat of the studied red foxes varied on the back and the side of the females and males. Most minerals in the coat of females was on both areas of the body in silver foxes, and the least – in the cross foxes. In males, more minerals were on both areas of the side of the platinum foxes compared to pastel and other color variants. Pastel foxes demonstrated the highers hair strength parameters among the color morphs.

Key words: red fox, color morphs, pelage, minerals

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INTRODUCTION

Mineral content in the body of an animal depends largely on their intake of the ration. There are many other factors that influence the minerals level, such as species and variety, sex, age, environment, and the season [Berestov et al. 1984, Prost 2006].

Many authors [including Anke and Risch 1979] recommend the hair as a suitable material for the assessment of the content of some minerals in the body. Their concentration in hair may be even greater than in the blood, hence hair can be as good a material for accurate analysis as, for example, serum [Kośla et al. 1989].

In terms of the analytical usability, hairs represent excellent research material; namely, they are easy to collect, store, and transport, but also readily demonstrated an excess or deficiency of an element. Their use in analytical processes can spare the animals unnecessary pain and stress, which is otherwise often inevitable; all these make hair a good material for measuring the contents of elements.

Hair analysis for the content of elements in the body is relatively easy and yet reliable method of assessing the physiological status of the animals. According to some authors [Combs 1987], the concentration of most of the minerals in hair is usually greater compared to what blood tests show.

The aim of this study was to determine the quantity of minerals in the coat of red foxes and an attempt to relate the results with individual hairs strength properties.

MATERIAL AND METHODS

Material

The analyses were carried out on hair samples of red foxes of various color morphs and their crossbreds, collected from live animals, from the middle of the back and the right side of the body. The study took place during autumn and winter in a fox farm located in the Wielkopolskie voivodship, Poland.

The samples were taken form 61 individuals (42 females and 19 males) representative for the given variety according to the conformation evaluation standards [Standard 1999]. These analyses had been carried out before 2010.

The samples came from 11 silver femals, 7 females and 3 males of the platinum morph, 8 platinum-pastel males, 10 females and 4 males of the pastel morph, 3 cross females, and 11 females and 4 males of the fire morph. Significance of differences between particular variety means was tested using the Tukey test. Also means and standard errors of means were estimated using STATISTICA 10 package [StatSoft 2011].

Methods

The initial weight of collected samples was above 2 g; after drying at 65–5°C for 72 hours and homogenization, of the weight of the samples ranged from 0.3 to 0.8 g. The samples were mineralized in a microwave digestion system (STAR 6, CEM International), in a semi-open system, with 10 mL of 65% HNO_3 (Fluka) and 2 mL of 30% H_2O_2. (Sigma-Aldrich). Digestion was carried out according to a temperature program comprising three consecutive steps, namely: (1) 5 min at 120°C with the power of 800 W, (2) 10 min at 180°C with 1600 W, and (3) 10 min at 200°C with 1600 W. The solutions obtained from digestion were filtered through 45-mm qualitative filter papers, grade 595, 4–7 m (Whatman), and the resulting supernatant was refilled with deionized water (Milli–Q Academic System, non-TOC) to a volume of 50 mL.

Hair coat samples were were analyzed for Mg, K and Ca by atomic emission spectrometry (AES) and for Cd, Cu, Co, Cr, Fe, Mn, Ni, Pb and Zn by flame atomic absorption spectrometry (FAAS). Analyses were performed using the Varian SpectrAA 200 spectrometer equipped only with a single-element coded hollow cathode lamp. The characteristics of the basic parameters of the analysis are shown in Table 1. In order to prepare calibration curves, analytical standards (Merek KGaA, Darmstadt, Germany) were used, which were solutions of nitrate salt (V) at a concentration of 1 $g \cdot L^{-1}$. Analysis of Ca concentration did not require an addition of any spectral buffer.

Due to unavailability of certified reference material for the same matrix and similar content of elements, in order to verify the quality of measurements, we carried out an analysis of randomly selected samples using inductively coupled plasma optical emission spectrometer (ICP–OES) Vista MPX (Varian), and – in some cases – inductively coupled plasma mass spectrometer (ICP-MS) Elan 9000 (Perkin Elmer).

RESULTS

The content of chemical elements in the coat of different varieties of red foxes are shown in Tables 1 and 1a.

Minimum concentration of the same minerals on the back changed alternately in females and males, whereas on the side it was higher in females for Co and Zn. The highest concentration was higher on the back of females, except for Fe and Pb, and with exception of Cd, K, and Fe on the side.

Table 1. Characteristics of concentration (mg · kg^{-1}) of selected minerals in fur of two body parts of female red fox (mean ± standard error of mean)

Tabela 1. Charakterystyka zawartości (mg · kg^{-1}) wybranych składników mineralnych okrywy na dwóch częściach ciała samic lisa pospolitego (średnia ± średni błąd średniej)

Minerals Pierwiastek	Color variety – Odmiana barwna					
	Fire Płomienista	Pastel Pastelowa	Platinum–pastel Platynowo–pastelowa	Platinum Platynowa	Silver Srebrzysta	Cross Krzyżak
	Back – Grzbiet					
Ca*	0.027^{c} ±0.002	0.047^{b} ±0.003	0.093^{a} ±0.008	0.043^{b} ±0.002	0.055^{b} ±0.003	0.043^{b} ±0.004
Cd	1.115^{c} ±0.062	1.846^{a} ±0.041	0.100^{c} ±0.008	0.335^{e} ±0.025	1.406^{b} ±0.034	0.693^{d} ±0.016
Co	0.957^{b} ±0.130	0.847^{c} ±0.033	0.891^{c} ±0.034	3.134^{a} ±0.103	1.397^{b} ±0.111	0.269^{d} ±0.030
Cr	0.431^{d} ±0.020	1.438^{b} ±0.030	0.785^{c} ±0.028	0.595^{d} ±0.016	4.251^{a} ±0.063	0.757^{c} ±0.019
Cu	12.421^{b} ±0.248	17.646^{a} ±0.310	8.095^{c} ±0.086	2.775^{d} ±0.117	8.906^{c} ±0.096	10.490^{b} ±0.110
Fe	27.165^{b} ±0.496	15.280^{c} ±0.213	27.090^{b} ±1.136	46.748^{a} ±0.501	43.939^{a} ±0.322	9.403^{d} ±0.229
K*	0.154^{a} ±0.019	0.148^{a} ±0.021	0.063^{b} ±0.006	0.202^{a} ±0.013	0.275^{a} ±0.014	0.283^{a} ±0.025
Mn	55.131^{b} ±0.770	55.828^{b} ±0.928	48.075^{b} ±1.598	42.877^{c} ±0.485	63.270^{a} ±0.515	42.303^{c} ±0.779
Pb	0.854^{c} ±0.029	2.893^{a} ±0.093	2.255^{a} ±0.051	2.505^{a} ±0.034	1.470^{b} ±0.023	0.560^{c} ±0.065
Zn	640.43^{b} ±10.90	253.60^{c} ±12.43	309.66^{d} ±9.14	541.12^{c} ±17.31	747.35^{a} ±16.18	572.76^{a} ±14.30
	Side – Bok					
Ca*	0.033^{b} ±0.003	0.065^{a} ±0.002	0.085^{a} ±0.006	0.040^{b} ±0.003	0.067^{a} ±0.003	0.040^{b} ±0.002
Cd	0.528^{c} ±0.032	0.766^{b} ±0.026	0.056^{c} ±0.003	0.927^{a} ±0.033	1.083^{a} ±0.036	0.448^{c} ±0.020
Co	0.672^{c} ±0.035	1.070^{b} ±0.028	0.595^{c} ±0.018	3.893^{a} ±0.064	1.302^{b} ±0.022	0.130^{d} ±0.028
Cr	0.345^{d} ±0.018	1.715^{b} ±0.065	0.520^{d} ±0.019	0.792^{c} ±0.028	5.401^{a} ±0.041	0.919^{c} ±0.017
Cu	8.705^{c} ±0.447	15.576^{a} ±0.232	8.225^{c} ±0.107	13.795^{a} ±0.173	11.485^{b} ±0.102	10.497^{b} ±0.095
Fe	24.833^{d} ±0.649	14.364^{c} ±0.161	32.460^{c} ±0.477	66.008^{a} ±1.352	44.961^{b} ±0.589	8.947^{f} ±0.124
K*	0.159^{b} ±0.023	0.130^{b} ±0.025	0.195^{b} ±0.018	0.275^{a} ±0.022	0.249^{a} ±0.013	0.273^{a} ±0.015
Mn	52.977^{b} ±0.722	52.017^{b} ±0.495	46.285^{b} ±0.746	37.563^{c} ±0.487	65.240^{a} ±0.198	37.727^{c} ±0.804
Pb	0.850^{d} ±0.021	2.151^{c} ±0.069	5.480^{b} ±0.058	14.378^{a} ±0.174	3.180^{c} ±0.026	2.387^{c} ±0.101
Zn	551.89^{c} ±15.61	234.93^{c} ±13.26	325.58^{d} ±17.54	672.60^{b} ±17.81	816.68^{a} ±12.46	662.05^{b} ±19.22

* – Concentration of Ca and K are presented as %.
* – Zawartość Ca i K podana w %.
The same letters (a, b, c, d, e, f) in rows indicate differences non-significant at $P \leq 0.05$.
Te same litery (a, b, c, d, e, f) w poszczególnych wierszach tabeli wskazują brak istotnych różnic $P \leq 0,05$.

Minimum concentrations of minerals were higher on the back of females than on their side, with exception of Cu, K, and Pb, and in males with exception of Cr, Cu, K, and Pb.

Table 1a. Characteristics of concentration [mg · kg^{-1}] of selected minerals in fur of two body parts of two male fox varieties (mean ± standard error)

Tabela 1a. Charakterystyka zawartości (mg · kg^{-1}) wybranych składników mineralnych okrywy na dwóch częściach ciała samców lisa pospolitego (średnia ± średni błąd średniej)

Minerals element Pierwiastki mineralne	Color variety Odmiana barwna			
	Fire Płomienista	Pastel Pastelowa	Platinum–pastel Platynowo–pastelowa	Platinum Platynowa
		Back – Grzbiet		
Ca*	0.036^{b} ±0.003	0.042^{b} ±0.004	0.074^{a} ±0.007	0.053^{a} ±0.003
Cd	0.752^{b} ±0.025	0.467^{d} ±0.022	0.104^{c} ±0.007	1.177^{a} ±0.116
Co	0.914^{b} ±0.022	0.093^{c} ±0.005	1.116^{b} ±0.067	3.051^{a} ±0.061
Cr	1.133^{b} ±0.041	0.880^{c} ±0.033	1.463^{b} ±0.035	2.280^{a} ±0.059
Cu	9.555^{a} ±0.215	8.790^{b} ±0.162	6.420^{b} ±0.135	10.867^{a} ±0.213
Fe	11.670^{c} ±0.176	10.365^{c} ±0.227	53.915^{b} ±0.686	71.813^{a} ±0.959
K*	0.175^{a} ±0.026	0.148^{a} ±0.018	0.046^{b} ±0.003	0.203^{a} ±0.008
Mn	44.465^{b} ±0.528	58.228^{a} ±0.566	52.874^{a} ±0.554	43.010^{b} ±0.543
Pb	0.840^{c} ±0.018	1.878^{c} ±0.341	3.474^{b} ±0.115	7.150^{a} ±0.021
Zn	237.003^{c} ±10.634	215.938^{c} ±5.872	302.973^{b} ±8.023	445.953^{a} ±19.907
		Side – Bok		
Ca*	0.042^{b} ±0.002	0.040^{b} ±0.003	0.062^{a} ±0.004	0.062^{a} ±0.003
Cd	0.870^{b} ±0.055	0.342^{c} ±0.039	0.094^{d} ±0.008	1.362^{a} ±0.037
Co	0.962^{b} ±0.034	0.091^{c} ±0.021	1.038^{b} ±0.027	3.219^{a} ±0.059
Cr	1.315^{b} ±0.018	1.008^{c} ±0.071	1.351^{b} ±0.022	2.493^{a} ±0.050
Cu	14.958^{a} ±0.181	10.550^{b} ±0.187	9.091^{b} ±0.109	11.667^{b} ±0.114
Fe	11.988^{c} ±0.190	10.145^{c} ±0.130	55.048^{b} ±0.660	73.247^{a} ±0.800
K*	0.170^{b} ±0.015	0.163^{b} ±0.015	0.206^{a} ±0.021	0.357^{a} ±0.028
Mn	45.545^{b} ±4.181	59.825^{a} ±0.991	53.019^{a} ±1.084	45.910^{b} ±0.364
Pb	1.400^{c} ±0.020	3.380^{b} ±0.127	3.935^{b} ±0.073	7.400^{a} ±0.122
Zn	219.288^{c} ±9.256	234.675^{c} ±12.201	300.634^{b} ±8.369	460.637^{a} ±25.421

* – Concentration of Ca and K are presented in %.
* – Zawartość Ca i K podana w %.
The same letters (a, b, c, d) in rows indicate differences non-significant at $P \leq 0.05$.
Te same litery (a, b, c, d) w poszczególnych wierszach tabeli wskazują brak istotnych różnic $P \leq 0{,}05$.

The maximum concentrations of minerals were higher in females on the back than on the side only for Cd and Cu, whereas in males in each case (Tables 1 and 1a).

We used a hierarchical system created by the small letters of the Latin alphabet, which represented the values of characteristics defining the content of individual minerals.

The letter ‘a’ denoted the highest value, and the letter ‘f’ – the smallest value. The former has been assigned to number 1, and the latter – to number 5. The means were calculated from the sum of particular minerals for each color variety, which are shown in Table 2.

According to the series ordered from a to f (1–6), most minerals in female coat hair was found on both sampled body areas of silver foxes, and the least in the coat of cross foxes. On the back, a similar content of minerals was found on the hair of pastel foxes, on the side – platinum foxes, the least minerals on the side, however, in cross foxes and fire foxes.

Among the males, most minerals were on both sampled body areas (nearly twice as much) in platinum compared with pastel foxes, as well as in the animals of the remaining color variants.

Based on the data in Table 2, we found foxes variety of both sexes that represent the extremes in mineral content. For these four color varieties of foxes, we calculated the physical characteristics of hair strength. These represented such aspects as: hair diameter (m), expansibility (%), ultimate tensile strength (cN) and tear resistance (daN/mm^2), which were applied to undercoat and guard hairs of the back and side of the body. The values of the parameters are shown in Table 3.

Table 2. Quantitative characteristics of mineral content in the pelage of red fox on a scale from 1 to 6 (1 – minimum, 6 – maximum)

Tabela 2. Charakterystyka ilościowa zawartości składników mineralnych w okrywie lisów pospolitych w skali od 1 do 6 (1 – wartość maksymalna, 6 – wartość minimalna)

Sex Płeć	Body area Okolica ciała	Color variety – Odmiana barwna					
		Silver Srebrzysta	Pastel Pastelowa	Platinum Platynowa	Platinum–pastel Platynowo–pastelowa	Fire Płomienista	Cross Krzyżak
Females Samice	back – grzbiet	1.6	1.7	2.3	2.4	2.4	2.7
	side – bok	1.5	2.3	1.6	2.7	3.0	2.9
Males Samce	back – grzbiet		2.5	1.1	1.9	2.1	
	side – bok		2.4	1.2	1.9	2.2	

Undercoat

A relatively small amount of minerals was found in the undercoat of pastel males, and – even less – cross fox females.

The thickest down hairs were measured iin patel males, whereas the thinnest in golden cross females. The most resistant in terms of elongation were down hairs of pastel males, more resistant than those of females.

Table 3. Strength properties of hairs of red fox in relation to variety and sex

Tabela 3. Cechy wytrzymałościowe włosów lisów pospolitych w zależności od odmiany barwnej i płci

Sex Płeć	Color variety Odmiana barwna			Properties – Cechy						
				Diameter, µm Grubość, µm		Expansibility, % Rozciągliwość, %		Ultimate tensile strength, cN Maksymalna siła rozciągania, cN		Tear resistance, daN/mm² Wytrzymałość na rozerwanie, daN/mm²
				$\bar{x}$	SEM	$\bar{x}$	SEM	$\bar{x}$	SEM	$\bar{x}$
Females Samice	silver srebrzysta (n = 11) (max.)	G	pd	15.5	0.3	33.8	1.4	4.8	0.8	25.4
			pk	83.4	6.5	26.1	2.4	26.3	1.9	4.8
		B	pd	16.4	0.2	35.2	1.1	3.9	0.6	18.6
			pk	73.9	6.0	21.0	1.6	27.8	3.6	6.5
	cross krzyżak (n = 3) (min.)	G	pd	14.8	0.2	37.3	1.0	3.0	0.4	17.6
			pk	78.8	6.4	31.1	2.2	31.4	3.4	6.4
		B	pd	15.2	0.2	34.1	0.9	3.3	0.6	18.2
			pk	78.6	7.2	24.4	1.9	27.2	4.7	5.6
Males Samce	platinum platynowa (n = 3) (max.)	G	pd	15.6	0.2	36.9	0.9	3.0	0.4	15.9
			pk	80.5	6.4	28.0	2.0	28.8	3.2	5.6
		B	pd	15.8	0.2	37.1	0.8	3.4	0.6	17.4
			pk	68.2	4.9	26.5	1.8	30.7	4.4	8.4
	pastel pastelowa (n = 4) (min.)	G	pd	16.0	0.2	39.0	0.5	4.1	0.6	20.2
			pk	69.2	5.7	24.8	2.3	30.0	3.5	8.0
		B	pd	17.6	0.2	38.7	0.6	4.6	0.6	19.1
			pk	61.2	5.0	21.1	1.8	33.1	4.6	11.3

G – back, B – side, pd – down hairs, pk – guard hairs.
G – grzbiet, B – bok, pd – włosy podszyciowe, pk – włosy pokrywowe.

Of the highest tear resistance were hairs on both studied body areas in pastel foxes, the lowest – in platinum foxes. The concentration of minerals in both these variants was reversed. No sex-related differences have been found in these traits.

Guard hairs

The guard hair of silver foxes were characterized by a high content of minerals, as opposed to pastel foxes, which had it on a very low level. The thickest guard hairs were found in silver foxes, the thinnest in pastels. Hairs on the back were thicker, and thinner in males compared to females.

Most resistant to elongation were the hairs of pastel foxes, more resistant on the back than on the side, on average. Females had more resistant guard hairs compared to males, especially on the back. The most tear-resistant hairs in both areas of the body were those in pastel foxes. This trait was greater on the side than on the back, males demonstrated a more pronounced upward trend compared to females.

DISCUSSION

The concentration of minerals in the pelage of the red fox of various color morphs varied on the back and the side of the males and females in terms of minimum and maximum values.

The results of this study are consistent with the data found in the subject literature. This applies for both the concentration of some minerals [Mertin et al. 1991, Mertin 1992, Filistowicz et al. 2011] and to other factors. It was also with conformity with variability of minerals concentration between sexes and with their change in the pelage of females and males of different color variants and on different areas of the body foxes [Mertin et al. 2003, Filistowicz et al. 2012].

The authors mentioned above also studied the concentration of selected elements in the fur of coypu and demonstrated that there are differences related to sex [Mertin et al. 1994], part of the body [Mertin et al. 1996], and genotype [Mertin et al. 1997].

Other authors previously determined the content of Mn, Cu, Sn, and Pb in the wool of certain breeds of sheep. The level of microelements was dependent on the breed of sheep, and was related to the thickness, strength and elongation of hair [Ralčev et al. 1970].

CONCLUSIONS

1. Hair samples in randomly selected individuals that trully represented the given color morth of the red fox were the basis to comparative characterization of some chemical and physical traits of the pelage. Chemical and physical properties of hair was studied on samples collected from the most highly valued parts of the coat – the back and the side.
2. Most minerals in the coat of females were found on both sampled areas of the body of silver foxes, the least – on the other hand – on cross foxes. In the coat of males, most minerals were found on both studied body areas (nearly twice more) in platinum foxes than in pastel foxes. It has been reflected in physical properties of individual hairs, more distinct in males.
3. The strongest hairs in terms of elongation and tearing were in pastel foxes, which was more apparent in the undercoat.

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ZAWARTOŚĆ SKŁADNIKÓW MINERALNYCH W OKRYWIE LISÓW POSPOLITYCH (*VULPES VULPES* L.) RÓŻNYCH ODMIAN BARWNYCH I ICH MIESZAŃCÓW A WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWE ICH WŁOSÓW

Streszczenie. Celem badań było oznaczenie ilościowe składników mineralnych w okrywie lisów pospolitych i próba zestawienia ich zawartości z właściwościami wytrzymałościowymi pojedynczych włosów. Badania wykonano na 122 próbkach włosowych lisów pospolitych różnych odmian i ich mieszańców pobranych od 61 zwierząt żywych ze środka grzbietu i prawego boku w okresie jesienno-zimowym na fermie w województwie wielkopolskim. Pochodziły one od 11 samic srebrzystych, 7 samic i 3 samców platynowych, 8 samców platyno-pastelowych, 10 samic i 4 samców pastelowych, 3 samic krzyżaków oraz od 11 samic i 4 samców płomienistych. Zebrane próbki poddano analizie na zawartość Mg, K i Ca metodą atomowej spektrometrii emisyjnej (AES), Cd, Cu, Co, Cr, Fe, Mn, Ni, Pb oraz Zn metodą atomowej spektrometrii z atomizacją w płomieniu (FAAS). Koncentracja składników mineralnych okrywy włosowej lisów pospolitych różnych odmian była zróżnicowana na grzbiecie i boku samic i samców. Najwięcej składników mineralnych w okrywie samic było na obu okolicach ciała w okrywie lisów srebrzystych, a najmniej – w okrywie krzyżaków. W okrywie samców więcej składników mineralnych było na obu okolicach boku u lisów platynowych niż pastelowych i pozostałych odmian barwnych. Największe wskaźniki wytrzymałościowe wśród zwierząt powyższych odmian barwnych miały lisy pastelowe.

Słowa kluczowe: lis pospolity, odmiany, okrywa włosowa, składniki mineralne

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