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CONTENT OF MACRO- AND MICROELEMENTS IN GOAT MILK IN RELATION TO THE LACTATION STAGE AND REGION OF PRODUCTION*

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Abstract

The content of macro- and microelements in milk depends on a variety of environmental, genetic and physiological factors. The aim of the study was to determine the effect of the region of production and stage of lactation, associated with the production season, on the content of selected macro- and microelements, including potentially toxic elements, in goat milk. The material consisted of goat milk samples collected from farms in two regions of Poland: 74 samples from central-eastern Poland (the Provinces of Lublin and Świętokrzyskie) and 149 from southern Poland (the Bieszczady mountains). The milk was collected in three seasons: winter (75 samples), summer (111) and autumn-winter (37). In each milk sample, the percentage of casein, protein, fat, lactose and dry matter was determined, as well as the concentrations of K, Ca, Na, Mg, Zn, Fe, Cu and Mn. K, Ca, Na, Mg and Zn using a Varian 240FS AA spectrometer, by the flame atomic absorption technique, while Fe, Cu and Mn were determined in a graphite furnace with the Zeeman background correction, using a Varian 240Z AA spectrometer. The goats' production peak was in the summer, when they were at pasture. From mid-lactation they produced milk with significantly ($p \leq 0.01$) higher concentration of components. Milk obtained in stage I of lactation (winter feeding) was the richest source of Zn, Fe and Cu, while stage II milk (summer feeding) had the highest K content, and stage III milk (autumn-winter feeding) had the highest content of Ca, Na, Mg and Mn. Concentration of Zn, Fe and Cu decreased over the course of lactation. Milk obtained in the Bieszczady mountain region had significantly ($p \leq 0.01$) higher content of dry matter, fat and protein. It also contained significantly ($p \leq 0.01$) more Ca, Na, and Mg, and less K and Zn in comparison with the milk of the goats raised in central-eastern Poland. The highest positive correlation coefficients were noted between the content of Ca and Mg, Zn and Fe, Zn and Cu, Na and Mg, and Fe and Cu, while K content was negatively correlated with that of Na, Ca and Mg ($p \leq 0,001$).

Key words: goat milk, macro- and microelements, lactation stage, production season, region of production.

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INTRODUCTION

Milk is a food of particular interest, both in terms of its nutritional value and its effect on health. Its high calcium content is the main argument put forward in milk promotion campaigns for maintaining the privileged position of milk in the daily diet (Hozyasz, Słowik 2013).

In Poland, most available milk is obtained from cows, but some small quantities originate from goats. Barłowska et al. (2013) demonstrated that goat milk is a more valuable source of calcium, potassium, iron, copper and manganese than cow milk. Studies by other authors confirm this observation, having detected more magnesium and zinc than in cow milk (Belewu, Aiyegbusi 2002, Soliman 2005, Park et al. 2007, Ceballos et al. 2009, Zamberlin et al. 2012). Thus goat milk can be an alternative source of calcium as well as other elements.

Nevertheless, the chemical composition of milk, including the content of macro- and microelements, is not constant. It depends on a variety of environmental, genetic and physiological factors (Danków, Pikul 2011).

The aim of the study was to determine the effect of the region of production and the stage of lactation (associated with the production season) on the content of selected macro- and microelements in goat milk.

MATERIAL AND METHODS

The material for the study consisted of 223 goat milk samples collected from two regions of Poland: 74 samples from central-eastern Poland (the Provinces of Lubelskie and Świętokrzyskie) and 149 from southern Poland (the Bieszczady mountains). The milk was collected during three production seasons, which were closely linked to the stage of lactation: winter – the beginning of lactation (75 samples), summer – the peak of lactation (111) and autumn-winter – the end of lactation (37).

The milk was transported in thermal bags with freezer packs to the laboratory of the *Department of Commodity Science and Processing of Raw Animal Materials*, University of Life Sciences in Lublin (AOAC 2000*b*).

The chemical composition of the milk was evaluated in an Infrared Milk Analyzer. The percentages of fat, protein, lactose and dry matter were determined. The casein content was measured by the Walker method according to AOAC (2000a). The concentration of selected macro- and microelements was determined by atomic absorption spectrometry. 1 ml of milk was poured into each polytetrafluoroethylene flask together with 6 ml suprapure nitric acid (65%). The solutions were mineralized under increased pressure in a CEM MARS 5 Xpress microwave digester. Then, the mineralized samples were quantitatively transferred using deionized water into 25 cm^3 volumetric flasks.

For the determination of Ca, Mg, K and Na, buffer was added to the samples according to Schinkel (10 g L^{-1} CsCl + 100 g L-1 La), so that the final solution contained 1% of the buffer. The concentrations of K, Ca, Na, Mg and Zn were determined on a Varian 240FS AA spectrometer, using the flame atomic absorption technique (air-acetylene flame). Fe, Cu and Mn were determined in a graphite furnace with the Zeeman background correction (in argon atmosphere) using a Varian 240Z AA spectrometer. Parallel to the experimental samples, the certified reference material NCS ZC 73015 Milk Powder and blank samples were analysed. The recovery of certified reference material for the analyzed elements ranged from 95 to 105%. Standard deviation between replicate measurements was no more than 5%.

The results were analysed statistically using Statistica ver. 6 (StatSoft Inc. 2003). Significance of differences between means was determined using the Tukey's test, at p (α) = 0.05 and $p = 0.01$. The Pearson's correlation coefficients between concentrations of macro- and microelements were calculated as well.

RESULTS AND DISCUSSION

In goats, as in sheep, the sexual activity is seasonal. Hence, the stage of lactation is closely linked to the season of production. Lactation usually begins in the first months of the year, that is during the winter feeding period, when goats are fed on roughage. After they are turned out to pasture, daily milk yield increases, and later (in the autumn months) it decreases steadily until the dry period. Table 1 shows that in the early lactation period (early spring – winter feeding) the mean daily yield of goats was 1.44 kg of milk. The peak production (2.04 kg) was noted in the summer, when goats were at pasture, but it fell to 1.16 kg per day near the end of lactation (autumn-winter feeding). From mid-lactation, goats produced milk with significantly ($p \leq 0.01$) higher concentrations of milk components. The lowest levels of these components were noted in the milk from the initial lactation period. A similar relationship was observed by Králíčková et al. (2012), who found that daily milk yield decreased from the beginning to the end of lactation, while the content of dry matter, protein, fat and casein increased from day 190 to the end of lactation.Strzałkowska et al. (2009) compared daily milk yield and the basic chemical composition of milk from Polish White Improved goats during three stages of lactation (day 60, 120 and 200). The highest milk yield was noted on day 120 of lactation (1.38 kg), with the lowest content of fat (3.38%) and dry matter (11.83%). The lowest protein content (2.98%), however, was observed on day 60 after parturition. Mestawet et al. (2012), in contrast, found that the concentration of dry matter, fat and protein in goat milk was significantly higher ($p < 0.001$) in the early and late stages of lactation than in the middle one.

Analysis of the effect of the production region on production parameters among goats revealed significant differences ($p \leq 0.01$) only in the content of dry matter, fat and protein, with higher levels noted in the milk from the Bieszczady mountain region (Table 1).

Table 1

Daily milk yield and basic chemical composition of the goat milk ($\bar{x}$, SD)

Specification	Stage of lactation (feeding period)			Region of production	
	stage I (winter-feeding)	stage II (summer-feeding)	stage III (autumn-winter feeding)	the southern--Poland (the Bieszczady mountains)	the central--eastern Poland (Lubelskie and Świętokrzyskie Provinces)
n	75	111	37	149	74
Daily yield of milk (kg)	1.44^{A} 0.90	2.04^{B} 1.04	1.16^{A} 0.88	1.66 1.10	1.77 0.88
Casein (%)	2.03^{A} 0.61	2.48^{B} 0.27	2.54^{B} 0.34	2.30 0.55	2.42 0.25
Protein (%)	2.85^{A} 0.62	3.12^{B} 0.45	3.14^{B} 0.40	3.17^{Y} 0.46	2.77^{X} 0.53
Fat (%)	3.43^{A} 0.89	3.70^{B} 0.61	3.79^{B} 0.48	3.82^{Y} 0.70	3.22^{X} 0.54
Lactose (%)	4.48^{B} 0.42	4.33^{A} 0.30	4.51^{B} 0.50	4.42 0.38	4.39 0.39
Drymater (%)	11.46^{A} 1.35	11.86^{B} 1.15	12.15^{B} 1.12	12.12^{Y} 1.25	11.08^{X} 0.85

A, *B* – differences between stage of lactation (feeding period) significant at $p \leq 0.01$; *a*, *b* – significant at $p \leq 0.05$; *X*, *Y* – differences between production regions significant at $p \leq 0.01$; *x*, *y* – significant at $p \leq 0.05$

Concentrations of most of the tested elements were found to vary over the course of lactation, which was linked to the season of production (Table 2). Milk collected during lactation stage II was the richest source of potassium (1938.8 mg L^{-1}), while milk from the final stage contained most calcium, sodium and magnesium. The lowest concentrations of these elements were noted in milk collected during stage II of lactation (the production peak), which was confirmed statistically ($p \leq 0.01$).

Zinc, copper and iron decreased over the course of lactation. The difference between lactation stages I and III was 0.92 mg L^{-1} and 0.065 mg L^{-1} ($p \leq 0.01$) for zinc and copper, respectively, and 0.136 mg L^{-1} for iron, although in the case of iron the difference was statistically insignificant, probably due to its substantial variability. A reverse tendency was noted in the case of manganese, whose concentration was the lowest at the beginning

Table 2

Content of selected mineral elements in goat milk ($\bar{x}$, SD)

Specification	Stage of lactation (feeding period)			Region of production	
	stage I (winter-feeding)	stage II (summer-feeding)	stage III (autumn-winter feeding)	the southern Poland (Bieszczady mountains)	the central eastern Poland (Lubelskie and Świętokrzyskie Provinces)
n	75	111	37	149	74
K (mg L^{-1})	1845.2^{a} 345.8	1938.8^{b} 241.5	1769.1^{a} 225.2	1835.1^{X} 252.3	1968.0^{Y} 325.3
Ca (mg L^{-1})	1190.5^{B} 460.5	1049.8^{A} 199.4	1241.3^{B} 337.7	1182.0^{Y} 367.3	1022.0^{X} 245.1
Na (mg L^{-1})	346.0^{Ab} 187.8	294.1^{Aa} 60.1	464.5^{Bc} 190.8	366.9^{Y} 156.3	285.4^{X} 127.3
Mg (mg L^{-1})	121.0^{Ab} 32.0	112.5^{Aa} 17.3	169.4^{B} 33.9	132.6^{Y} 35.4	109.1^{X} 19.8
Zn (mg L^{-1})	3.32^{B} 1.58	2.73^{A} 1.09	2.40^{A} 1.18	2.56^{X} 0.99	3.50^{Y} 1.67
Fe (mg L^{-1})	0.701 0.352	0.642 0.345	0.565 0.341	0.641 0.335	0.666 0.376
Cu (mg L^{-1})	0.161^{B} 0.095	0.113^{A} 0.061	0.096^{A} 0.044	0.124 0.063	0.131 0.96
Mn (mg L^{-1})	0.056^{A} 0.018	0.086^{B} 0.044	0.125^{C} 0.058	0.085 0.051	0.078 0.035

A, *B* – differences between lactation stage (feeding period) significant at $p \le 0.01$;
a, *b*, *c* – significant at $p \le 0.05$; *X*, *Y* – differences between production region significant at $p \le 0.01$;
x, *y* – significant at $p \le 0.05$

of lactation (0.056 mg L^{-1}), but more than twice as high at the final stage of lactation – 0.125 mg L^{-1} ($p \le 0.01$).

The results of our study are confirmed by MESTAWET et al. (2012), who report that the Ca concentration in goat milk was significantly higher ($p < 0.001$) in the first and last stages of lactation than in the middle stage. The Na and Mg content was the highest in the final stage, while Zn decreased over the course of lactation.TRANCOSO et al. (2009) evaluated the content of macro- and microelements in goat milk over the course of lactation from November to May, but did not observe any clear trends. The milk collected in December (second month of lactation) had the highest manganese content, while the milk from January (third month) was the richest in sodium, calcium, magnesium and iron. The milk with the highest concentration of heavy metals, i.e. zinc and copper, was collected in November. Only zinc was found to be decreasing over the course of lactation, which is confirmed by the present study. A study by AL-WABEL et al. (2008) on milk collected from goats raised in the dry climate of Saudi Arabia, determined the concentrations of Ca (751.7 mg kg^{-1}), K (123.85 mg kg^{-1}) and Na (101.3 mg kg^{-1}) in the second month of lactation, hence much lower than the ones noted in the present study, and a higher content of Fe (4.908 mg kg^{-1}), Mn (1.129 mg kg^{-1}) and Cu (0.570 mg kg^{-1}). Barłowska et al. (2013) report that the production season had a significant effect on most of the elements tested. The milk produced by goats contained more calcium, sodium, magnesium and copper in the autumn-winter season, and higher levels of potassium in the spring-summer season. An Italian study by Coni et al. (1996) found that goat milk collected in the summer had a higher content of copper, iron and magnesium, while winter milk had higher levels of manganese and zinc. Kondyli et al. (2007) also observed seasonal changes in the most important macroelements, i.e. Ca, P and K, and microelements, i.e. Cu and Zn.

The data in Table 2 show that the milk of goats raised in the Bieszczadys contained significantly ($p \le 0.01$) more calcium, sodium, and magnesium, while the milk from central-eastern Poland had a higher concentration of potassium. Higher concentrations of the heavy metals tested, i.e. zinc and copper, were noted in the milk from the central-eastern region of Poland (3.50 mg L^{-1} and 0.131 mg L^{-1}, respectively), in comparison with the Bieszczady mountains (2.56 mg L^{-1} and 0.124 mg L^{-1}). However, the differences were statistically significant ($p \le 0.01$) only in the case of Zn. Dobrzański et al. (2009) found a substantially higher copper concentration in goat milk than in the present study, both in industrial regions (0.672 mg L^{-1}), and in regions regarded as unpolluted (0.249 mg L^{-1}). Król et al. (2012), in a study on cow milk, also found that the season and region of production had a significant effect on content of Zn, Cu, Mn, Cd and Pb, but not Fe.

The correlation coefficients presented in Table 3 between concentrations of macro- and microelements show a positive correlation between calcium and magnesium (r = 0.65***), calcium and copper (r = 0.22***), zinc and iron (r = 0.42***), zinc and copper (r = 0.46***), sodium and magnesium (r = 0.41***) and iron and copper (r = 0.48***). The potassium content in

Table 3

Correlation coefficients between content of macro- and microelements in the goat milk (mg L^{-1})

Elements	K	Ca	Na	Mg	Zn	Fe	Mn
Ca	-0.36***	-					
Na	-0.52***	0.05	-				
Mg	-0.32***	0.65***	0.41***	-			
Zn	0.13*	0.20**	-0.06	0.11	-		
Fe	-0.10	0.15*	0.03	0.12	0.42***	-	
Mn	0.06	-0.02	0.11	0.20**	-0.04	-0.11	-
Cu	-0.05	0.22***	0.01	0.07	0.46***	0.48***	-0.21***

* values significant at $p \le 0.05$; ** at $p \le 0.01$; *** at $p \le 0.001$

goat milk, on the other hand, was negatively correlated with that of sodium (r = -0.52***), calcium (r = -0.36***) and magnesium (r = -0.32***), and the manganese content - with that of copper (r = -0.21***). Pilarczyk et al. (2013) evaluated milk of Holstein-Friesian and Simmental cows, obtaining high correlation coefficients between the content of magnesium and calcium (r = 0.62** and r = 0.89***) and between zinc and copper (r = 0.46* and r = 0.57**), which is confirmed by the present study. Sikirić et al. (2003) report higher correlation coefficients between Cu and Fe (r = 0.613), Cu and Zn (r = 0.629) and Cu and Ca (r = 0.629) than those observed in the present study.

CONCLUSIONS

1. The highest milk yield was observed during the summer season, when the goats were at pasture. From mid-lactation, the concentration of milk components increased significantly ($p \leq 0.01$). The milk from the Bieszczady region had a significantly ($p \leq 0.01$) higher content of dry matter, fat and protein compared with the Lubelskie and Świętokrzyskie Provinces.

2. Milk obtained from goats in stage I of lactation (winter feeding) was the richest source of Zn, Fe and Cu, while milk from stage II (summer feeding) was the highest in K, and milk from stage III (autumn-winter feeding) was the highest in Ca, Na, Mg and Mn. Concentrations of zinc, iron, and copper decreased over the course of lactation.

3. Milk obtained from goats raised in the Bieszczady mountain region contained significantly ($p \leq 0.01$) more Ca, Na and Mg, and less K and Zn than from the goats kept in central-eastern Poland.

4. The highest positive correlation coefficients were noted between the content of Ca and Mg, Zn and Fe, Zn and Cu, Na and Mg, and Fe and Cu, whereas the K content was negatively correlated with that of Na, Ca and Mg.

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