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Influence of sampling time during lactation on macromineral and trace element concentrations in goat milk

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Abstract

This study investigated the effect of milk sampling time during lactation on macromineral and trace element concentrations in goat milk. The goats were fed 2.0 kg/day/goat of hay and 0.65 kg/day/goat of cereal mixture. Samples of goat milk were taken on the 20th, 50th, 80th, 110th and 140th day of experiment, and the milk yield was also measured on those days. Milk samples were analyzed for concentrations of macrominerals (Ca, P, K, Na and Mg) and trace elements (Fe, Zn, Cu, Mn, Se, Mo and Co). Analysis of concentrations of macrominerals and trace elements in goat milk sampled during lactation period confirmed that the concentrations of K and Na were significantly increased, while the concentrations of P, Zn and Mn decreased. Significant decrease in Mo and Cu concentrations was also confirmed, yet those concentrations increased on the 110th and 140th day of lactation. Fe and Mg concentrations in milk remained stable throughout lactation. This research established significant correlations between concentrations of trace elements and macrominerals contained in goat milk when measured throughout the lactation period. Furthermore, this study confirmed significant differences related to the concentration of most of the identified trace elements and macrominerals in goat milk, which could be explained by the influence of different times of milk sampling during lactation, when both the quantity and composition of milk change.

Keywords: goats; lactation; milk; macrominerals; trace elements

Introduction

Goat milk is becoming increasingly important in human nutrition. In the last 50 years, production of goat milk has increased by 50 %, with growth projections of around 53 % until 2030 (Pulina et al., 2018). About 20.8 million tons of goat milk is produced annually, which refers to some 2.2 % of the global milk production (FAOSTAT, 2025). The most goat milk is produced in Asia (about 53 %), then in Africa, 26 %, in Europe 17 % and in USA 5 %, while the highest production of milk per goat is achieved in Europe (290 L), followed by USA with about 94 L, Asia with 76 L and Africa with 49 L (Pulina et al., 2018). According to FAOSTAT (2018), the majority of dairy goat breeds are kept in Asia (52.1 %), followed by Africa (39.6 %), while Europe (4.3 %) and the Americas (4 %) rank last. For European farming of goats, countries in the Mediterranean (France, Spain, Greece) and in the Black Sea basin (Turkey, the Russian Federation, Ukraine) are important, where approximately 11 % of the global goat population produces 19.1 % of the total world milk production (FAOSTAT, 2018). The Mediterranean basin is home to numerous indigenous goat breeds, which production characteristics are constantly improved. The Croatian spotted goat is indigenous to Croatia. Its production characteristics are improved primarily through selection and careful breeding, which includes high-quality nutrition (Mioč et al., 2008; Antunović et al., 2018). In Croatian register of domestic animals, there are 26,714 Croatian spotted goats registered, with an average herd size of 93 heads, while 2,144 breeding goats kept by 23 breeders are under selection (HAPIH, 2025). This refers to 27 % of the total population of breeding goats in Croatia. Analysis of the reproductive characteristics of the Croatian spotted goat confirmed a kidding index of 1.00 and a litter size of 1.11, and the performance test of bucklings showed average values of birth weights of 2.2 kg, daily gain of 200 g and full body weights of 23.05 kg. Croatian spotted goats are strong, durable and adaptable, with low requirements when it comes to shelter and feed. An adult goat reaches on average 44 kg and grows on average 61.32 cm, measured at withers. Average duration of the lactation period is 150-250 days, and during that time, a goat gives on average 100–250 L of milk (Mioč et al., 2008). Over the past decade, there have been numerous researches performed into the quality of goat milk. Goat milk gains on popularity over cow milk (Mishra et al., 2026). Among other things, quality of goat milk is measured according to the content of mineral substances. Milk of goats is rich in minerals (Biadała and Konieczny, 2018; Antunović et al., 2024; Pan et al., 2024). In comparison to cow milk, Turkmen (2017) emphasized that goat milk had a higher concentration and better bioavailability of certain essential minerals. Essential minerals are important for human nutrition as they are valuable contributors to overall humans' well-being (Gaucheron, 2013). Singh et al. (2019) stated that goat milk had significantly higher concentrations of Ca, K and P, and lower concentrations of Mg, Na, Zn, Fe and Cu than cow milk. Content of macrominerals (Ca, P, K, Na, Mg) and trace elements (Fe, Zn, Cu, Mn, Se, Mo, Co) in goat milk have been extensively studied, yet there are not enough studies into a wider spectrum of the aforementioned elements contained in goat milk (Antunović et al., 2018; Guo et al., 2021; Pan et al., 2024). This especially refers to studies into goat milk sampled throughout lactation. Many factors can affect goat milk quality, as well as the content of trace elements and macrominerals. Some of the most important factors are breed, feed, sequence and phase of lactation (Ponnampalam et al., 2024; Antunović et al., 2024; Pan et al., 2024; Klir Šalavardić et al., 2024). Lactation itself is very demanding period for goats (Antunović et al., 2013) and farmers need to provide support to goats in order for them to overcome that demanding physiological status. This research aims to investigate the influence of the milk sampling time during lactation on macromineral and trace element concentrations in goat milk.

Material and methods

Experiment design

The experiment was set up on the Kozarstvo Lepoglavec family farm, located in Beli Manastir, in the Osijek-Baranja County, in Croatia. The experiment was performed on 15 Croatian spotted goats kept in extensive breeding. On average, goats were 5 years old and all were in their fourth lactation. The investigated goats were selected from a herd of 50 goats, and all of the selected ones were healthy and in good physical condition. Goats were hand-milked twice daily. Production of milk was controlled by alternating monthly test (AT method; ICAR, 2018). Milk was sampled by hand milking once a month (every 30 days). Concentration of milk was measured and samples of milk were taken to be analysed for its chemical content. Milk yield was measured after morning milking on the 20th, 50th, 80th, 110th and 140th day of lactation. The milk yield measured in volume (ml), was converted into mass (kg) by using conversion factor of 1.032 for goat milk (ICAR, 2018). Morning milk yield on the 20th day was 0.74 kg, on the 50th day 0.80 kg, on the 80th day 0.92 kg, on the 110th day 0.83 kg, and on the 140th day it was 0.80 kg.

Animal nutrition and feed analysis

Goats were fed 2 kg/day/goat of a clover-grass hay mixture (based on 14 % crude protein) and 0.65 kg/day/goat of a cereal mixture (50 % barley and oat and 50 % corn) containing 10 % crude protein. Goats were given salt and fresh water *ad libitum*. The same feeding of goats throughout lactation (quantity and composition of ration) is part of the technological process on the aforementioned farm and was not changed during lactation to determine the impact of the milk sampling time throughout lactation on the concentrations of macrominerals and trace elements in goat milk. All plant samples (oat, barley, corn and hay) used in feeding were first dried and then processed by a heavy metal-free ultracentrifugal mill (Retsch ZM 200) or knife mill (GM 200) into powder. After that, 10 mL of a 5:1 mixture

Table 1. Concentrations of trace elements and macrominerals in feed and water given to the goats during the experiment

Elements (mg/kg DM)	Cereal's mixture		Hay	Water
	Oat and barley	Corn		
Macrominerals				
Ca	701	39.94	8740	29.71
P	3652	2084	2704	LD
K	5815	3208	17010	0.35
Na	36.64	4.35	82.31	8.21
Mg	1254	920.40	2334	19.72
Trace elements				
Fe	90.85	20.22	993.80	LD
Zn	26.88	17.34	23.95	0.03
Cu	4.892	1.301	6.438	0.001
Mn	18.600	4.116	46.010	0.0005
Se, µg/kg DM	29.155	21.271	137.839	0.743
Mo, µg/kg DM	643.62	123.08	3488.65	0.22
Co, µg/kg DM	29.61	6.46	353.80	LD

DM - dry matter; LD - instrumental limit detection

Table 2. Instrumental detection and quantification limits for the determination of macrominerals and trace elements in samples

Elements (mg/kg DM)	Instrumental detection limits	Instrumental quantification limits
Macrominerals		
Ca	0.01041	0.034670
P	0.01297	0.043233
K	0.06469	0.215633
Na	0.08956	0.298533
Mg	0.00458	0.015267
Trace elements		
Fe	0.00038	0.0012667
Zn	0.00053	0.0017667
Cu	0.00004	0.0001333
Mn	0.00008	0.0002667
Se, µg/kg DM	0.12563	0.4187667
Mo, µg/kg DM	0.02111	0.0703667
Co, µg/kg DM	0.01102	0.0367333

DM - dry matter

of HNO_3 and H_2O_2 was used to digest all plant samples in a microwave oven (Mars 6; CEM) at 180 °C for 60 min. Digested plant samples were tested for concentrations of minerals by inductively coupled plasma (ICP; Optima 2100 DV; PerkinElmer). Each batch of plant samples run on the ICP was analysed with an internal pooled plasma control and with the reference material prepared in the same way as other plant samples. All samples were double analysed. Concentrations of trace elements and macrominerals in the feed and water given to the goats are overviewed in Table 1.

Milk sampling, digestion and analyses

Goat milk samples were collected on 20th, 50th, 80th, 110th and 140th day of lactation (±3 days). Weaning of kids was due two weeks after kidding. After morning milking, the milk was sampled into 40 mL bottles, in which there was 0.3 mL of the azidiol. Bottles were cooled down to 4 °C and then frozen at -80 °C. After that, bottles got defrosted and samples were tested in order to determine the concentrations of macrominerals and trace elements (Ca, P, K, Na, Mg, Fe, Zn, Cu and Mn). The measured values were recorded in the expression of mg/kg. Concentrations of Se, Mo and Co were expressed as µg/kg. Samples of goats' feed and milk were mixed with 10 mL of solution that contained 5:1 HNO_3 and H_2O_2. The solution was heated at 180 °C during 60 minutes in a microwave oven (CEM Mars 6). Samples of both goats' feed and milk were processed according to Belete et al. (2014). The solution was diluted with 25 mL of deionized water. Inductively coupled plasma mass spectrometer (ICP-MS, Agilent 7500a, Agilent Technologies Inc., Santa Clara, CA, USA) using continuous flow hydride generation technique was employed to measure the concentrations of macrominerals and trace elements in samples of milk, as well as in feed and water. Tests were performed in the laboratory of the Faculty of Agrobiotechnical Sciences Osijek, Croatia. All samples were double analysed. In order to perform the pre-reduction of Se, the sample in the concentration of 20 mL was put into a 125-mL beaker and then 20 mL of HCl was added. The solution was then put into 50-mL polypropylene autosampler tube and mixed with deionized water to 50 mL. Limits of detection are showed in Table 2.

Statistical analysis

Data obtained by testing goat milk sampled on the 20th, 50th, 80th, 110th and 140th day of lactation were processed in a statistical software SAS® (9.4). The results were obtained using the MEANS procedure, and analysed using the GLM (general linear model) procedure with a fixed effect of the lactation day. Significant differences between the mean values of macrominerals and trace elements contained in milk of goats were determined with the Tukey test, and the level of significance was set at $p<0.05$. Pearson's correlation coefficients of macrominerals and trace elements contained in the milk of goats were used to determine correlations between variables, which were presented by heatmaps. Values referring to the correlation coefficient (r) and their description were the following: 0.00-0.19, very weak; 0.20-0.39, weak; 0.40-0.59, moderate; 0.60-0.79, strong; and 0.80-1.0, very strong, as described in Soeharsono et al. (2020).

Results and discussion

Obtained average concentrations of the investigated macrominerals and trace elements in the milk sampled during the goats' lactation period (Table 3) showed the highest average values and the lowest coefficient of variability for certain macrominerals (K, Ca and P), as well as the lowest values, yet the highest variability for trace elements (Co and Se), which was expected.

In this research, average concentrations of the investigated trace elements and macrominerals in milk of Croatian spotted goat throughout lactation period (Table 3) are similar to those obtained within previous studies. If compared to these research results, Antunović et al. (2018) reported on similar concentrations of Ca, Mg, Cu, and Mn, higher concentrations of Na, Fe and Zn, and lower concentrations of P, K and Mo in the milk of Croatian spotted goats sampled in the lactation period. In the milk of goats grown in the areas of Apulia and Basilicata in Italy, Miedico et al. (2016) determined average milk concentration of Mo 42 ng/g (2.8-123), Co 2.60 (1.27-4.20), Se 13.3 (8.60-25.0), Zn 3500 (880-5800), Mn 69 (42-124), Fe 850 (490-1220) and Cu 77 (32-193). In goat milk sampled in Algeria, Chenouf et al. (2024) determined similar concentration (μg/mL) of Na (336.29), and lower concentrations of Ca (536.98), K (155.13), Mg (76.73) and Co (0.009). However, they confirmed higher concentrations of Fe (1.78), Cu (0.24) and Mn (0.06). In the research performed by Lechuga-Arana et al. (2025), among all tested essential minerals, Se exhibited the lowest concentrations in the first and second lactations (50 to 400 ng/mL), which is significantly lower if compared to this research. In comparison to the results obtained in this research, Shuvarikov et al. (2021) established higher concentrations of Fe, Cu and Zn (0.76, 0.44 and 5.02 mg/kg, respectively) and lower concentrations of Ca, P, K and Mg (145.3, 844.0, 1521.1 and 0.13 mg/kg, respectively) within their research into milk of Alpine goats kept in Russia.

Analysis of trace elements and macrominerals in goat milk during lactation revealed significant decrease in the concentrations of P, Zn and Mn, and non-significant decrease in the concentrations of Ca, Se and Co (Table 4).

Significant decrease in the concentration of Mo was also confirmed up to the 110th day of lactation, yet afterward it

Table 3. Macrominerals and trace elements concentration in feed and water given to the goats during the experiment

Elements (mg/kg DM)	Mean	SD	Min	Max	CV, %
			Macrominerals		
Ca	1177.86	127.46	941.10	1570.00	13.98
P	979.22	81.38	827.60	1160.00	8.31
K	2051.07	175.04	1510.00	2467.00	8.53
Na	337.29	47.17	251.80	457.50	13.98
Mg	119.48	15.67	85.20	151.30	13.11
			Trace elements		
Fe	0.24	0.04	0.17	0.36	15.50
Zn	2.56	0.88	0.87	6.07	34.47
Cu	0.06	0.03	0.02	0.23	54.36
Mn	0.02	0.01	0.01	0.04	33.47
Se, μg/kg DM	10.14	5.72	LD	28.51	154.82
Mo, μg/kg DM	70.98	27.85	20.01	154.82	39.24
Co, μg/kg DM	0.17	0.19	0.01	1.55	111.99

DM - dry matter; SD- standard deviation; CV- coefficient variability; LD- limit detection

Table 4. Macrominerals and trace elements concentration in goat milk during lactation

Elements (mg/kg DM)	Lactation, days					SEM	P-value
	20th	50th	80th	110th	140th		
			Macrominerals				
Ca	1199.01	1178.93	1225.95	1174.84	1110.58	14.82	0.154
P	1039.85^{a}	961.34^{b}	972.71^{ab}	986.04^{ab}	936.17^{b}	9.46	0.007
K	1899.27^{b}	2033.40^{ab}	2066.47^{a}	2164.73^{a}	2091.47^{a}	20.35	<0.001
Na	291.68^{b}	334.89^{a}	353.16^{a}	355.75^{a}	350.95^{a}	5.48	<0.001
Mg	119.18^{b}	116.65^{b}	115.64^{b}	136.93^{a}	109.01^{b}	1.82	<0.001
			Trace elements				
Fe	0.225	0.227	0.228	0.260	0.253	0.004	0.015
Zn	3.02^{a}	2.814^{ab}	2.63^{ab}	2.03^{b}	2.29^{ab}	0.103	0.014
Cu	0.090^{a}	0.073^{ab}	0.055^{bc}	0.036^{c}	0.067^{abc}	0.004	<0.001
Mn	0.020^{a}	0.015^{ab}	0.016^{ab}	0.015^{ab}	0.014^{b}	0.001	0.048
Se, μg/kg	13.02	9.62	8.72	9.34	10.00	0.665	0.282
Mo, μg/kg	73.95^{bc}	45.41^{d}	76.37^{b}	55.04^{cd}	104.14^{a}	3.24	<0.001
Co, μg/kg	0.221	0.104	0.155	0.214	0.159	0.022	0.443

SEM - standard error of mean; means within a row with different superscripts differ (p<0.05).

significantly increased. The concentrations of Na and K in goat milk increased significantly as the lactation progressed. Concentration of Cu in goat milk significantly decreased as lactation progressed, except on the 140th day of lactation, when it got insignificantly increased. The concentration of Fe was stable during the whole lactation period. Concentration of Mg in goat milk did not change significantly and were relatively stable during the whole lactation period, except on the 110th day of measurement, when it increased significantly. Furthermore, this study confirmed significant differences related to the concentration of most of the identified trace elements and macrominerals in goat milk, which could be explained by the influence of different times of milk sampling during lactation, when both the quantity and composition of milk change. Namely, during peak lactation, when milk production is the highest, dry matter content in milk is low (Kędzierska-Matysek et al. 2015). Majid et al. (1994) published similar findings in the study on Saanen goats, which typically reached the peak production between the 8th and 12th week of postpartum period. Pavliček et al. (2006) and Antunović et al. (2024) published similar results in their research into milk of Alpine goats. Furthermore, Antunović et al. (2018) also found similar results in milk of Croatian spotted goats. In the research performed in Italy on milk produced by Italian local goats and Saanen goats, both during lactation, Curro et al. (2019) determined significant variations in macrominerals and trace elements. These authors also determined the lowest milk concentration of K and Na in the 4th and the 8th week of lactation, which was considered as peak lactation. Unlike the concentration of K, these authors reported that the concentrations of Na, Ca and P were similar from the lactation week 4 to the lactation week 16, which corresponds to the results obtained in the present research. Moreover, changes in Mg in milk showed the lowest concentrations in the early stage of lactation, which increased between lactation weeks 12-16, and such similar increase is also confirmed in this experiment. The increase of Na and K concentrations contained in the milk of goats during the lactation period can occur because of the decreased milk excretion as the lactation reaches its end. Günay et al. (2021) in Turkey performed an experiment on Turkish Saanen goat breed and Maltese breed during lactation to determine that the concentrations of Na and K in milk samples of all goat breeds got significant increased. However, higher concentrations of minerals during the final stage of lactation than at the initial stage could be influenced by environmental factors, as argued by Qeshlagh et al. (2016). Compared to our research results, Chen et al. (2018) also confirmed the decrease of concentrations of Ca with the lactation progress, but the differences were not significant. In comparison with present study, Kędzierska-Matysek et al. (2015) reported on similar findings obtained for goats' milk in Poland, but they found significant differences in concentrations of Na and K that they related to the lactation stage. Opposite trend was established for concentrations of Ca and Mg, however, the trend for concentrations of Zn and Cu was similar. In their study carried out on goats in Algeria, Chenouf et al. (2024) reported that the concentrations of Ca, Na, K and Mg were significantly increased, yet the concentration of Fe was insignificantly decreased in goat milk sampled during lactation. Similar to our research results, Kondyli et al. (2007) stated that the concentrations of Mg and Fe in the milk of indigenous Greek breed goats did not change significantly during lactation. Michlova et al. (2016) studied milk produced by Saanen goats bred in the Czech Moravian-Silesian region and reported that at the beginning of lactation, Mg, K, and Na concentrations were significantly lower, but Cu concentration was significantly higher. Similar to our research, Boroš et al. (1989) confirmed the increase in K and Na, yet there was an opposite trend applying to concentrations of P, Ca, and Mg contained in the goat milk along the advancement of lactation. Simos et al. (1991) found that the concentration of Ca was continuously decreasing during lactation, but the content of other elements, K, Na and P got higher. In their paper, Pan et al. (2024) wrote that the content of Ca and P got higher in during the early lactation stage if compared to that content measured at the end of lactation. Keeping the Ca content in goat milk at a stable level is important because casein levels are genetically conditioned and cannot be influenced by diet (Nayik et al., 2022), and such statement was also confirmed by our research. Stocco et al. (2019) reported that essential macrominerals and microminerals given to animals as dietary supplements or in form of mineral blocks affected their concentrations in the milk, yet it should be noted that the contents of some minerals (like Ca and P) were significantly influenced by animal factors (Gaignon et al., 2018). Curro et al. (2019) reported on similar changes as found in this research for concentrations of Zn in the milk produced by five local Italian goat breeds (Garganica, Girgentana, Jonica, Maltese and Mediterranean Red), where the highest concentration of Zn was observed in the lactation week 4 (2.94 μg/g), and it differed significantly than the concentration measured in the lactation week 8 (2.47 μg/g). In the study conducted in Greece on Greek local goats that were grazing from April to July, Kondyli et al. (2007) observed the greatest Zn concentration in milk during the lactation week 6 (4.6 μg/g) and the lowest Zn concentration when the lactation reached its end stage (3.1 μg/g). Günay et al. (2021) also confirmed the lowering of Zn concentrations in goat milk in Turkey sampled during lactation of goats. In the research performed by Lechuga-Arana et al. (2025), it was determined that Zn levels gradually decreased as the second lactation of goats progressed. Opposite trend for Zn concentrations in milk goat sampled during lactation was determined Antunović et al. (2018). Kondyli et al. (2007) and Antunović et al. (2018) found that the concentration of Fe contained in the milk of lactating goats was stable, which is aligned with the present research. However, in the milk of West African Dwarf goats during lactation from weeks 2 to 10, Ogunwole (2016) reported the decrease in concentrations of Zn (5.21-4.40 mg/L) and Mn (0.18-0.11 mg/L). Pan et al. (2024) also stated significant decrease in concentrations of Zn, Cu and Mn from days 1 to 3 up to the day 150 of lactation, yet there was a trend of the increase in the concentration of Mo in milk of goats sampled during lactation (from days 1-3 up to the 150th day). In comparison to this research, opposite trend related to the content of Se in the milk of lactating goats was determined by Rozenska et al. (2013), as Se in milk got slightly increased as lactation progressed (from 7.44 to 11.10 μg/kg). In the research of Rodríguez et al. (2022), milk was sampled from 20 Tinerfeña goats from a local farm in Tenerife every 30 days from March to August, upon the testing of which it was determined that Se and Cu in milk were significantly decreased, while concentrations of Na and Mg were significantly increased.

Analysis of correlation coefficients of macrominerals and trace elements in milk sampled during the goats' lactation proved significant correlations (Table 5). Strong positive correlation was confirmed between Mn:Zn (r=0.66; p<0.001) and moderate positive correlation was confirmed between Ca:P (r=0.57; p<0.001), P:Mn (r=0.54; p<0.001), P:Zn (r=0.50; p<0.001), and Zn:Se (r=0.42; p<0.001). Moderate negative correlation was established between K:Ca (r=0.42; p<0.001), K:Mg (r=0.42; p<0.001), K:Cu (r=0.56; p<0.001), and K:Zn (r = 0.58; p<0.001). Weak positive correlation was determined between Na:Fe (r=0.24; p=0.039), Mg:P (r=0.29; p=0.010), Mg:Mn (r=0.24; p=0.042), Mg:Fe (r=0.37; p=0.001), Mg:Mn (0.26; p=0.024), Ca:Cu (r=0.25; p=0.032), Ca:Zn (r=0.39; p<0.001), Ca:Se (r=0.21; p=0.066), Mn:Cu (r=0.27; p=0.013), Mn:Se (r=0.35; p=0.002), Fe: Co (r=0.28; p=0.014), Cu:Zn (r=0.37; p<0.001), and Cu:Se (r=0.33; p=0.004), while weak negative correlation was proven between P:K (r=0.354; p=0.002), and K:Se (r=0.24; p=0.040). Many positive correlations established in this research between trace elements and macrominerals in milk of lactation goats were expected if considering the metabolic intertwining of minerals in goat body. Such statement was also published by Antunović et al. (2018). Kędzierska-Matysek et al. (2015) run an experiment in Poland to determine similar significantly positive correlations between K:Zn (r=0.13; p<0.05), Ca:Zn (r=0.20; p<0.01); Ca:Cu (r=0.22; p<0.001), Mg:Mn (r=0.20; p<0.01), and Zn:Cu (r=0.46; p<0.001), and negative correlation between Ca:K (r=-0.36; p<0.001) in goat milk sampled during lactation. In the milk of Alpine goats that were in their first third part of lactation, Antunović et al. (2024) determined positive correlation between Ca:P (r=0.73; p<0.001), P:Mg (r=0.66; p<0.001), Ca:Se (r=0.42; p=0.006) and Ca:Cu (r=0.33; p=0.036). Voutsinas et al. (1990) performed an experiment in Greece on milk of Alpine goats and established that there were strong positive correlations between Ca:P (r=0.947) and Mg:P (r=0.630), which is also confirmed in the present research. Significant negative correlation between K:Ca (r=-0,39; p<0.05) in dairy cows' milk sampled during lactation in Sudan was established by Fadlalla et al. (2020).

The following studies are to be focused on analysis of the content of heavy metals in goat milk, while including also greater number of time intervals for milk sampling during the goats' lactation.

Table 5. Heatmap of correlation coefficients and p-values of minerals in goat milk sampled during lactation

	Na	Mg	P	K	Ca	Mn	Fe	Co	Cu	Zn	Se	Mo
Na	1.00											
Mg	0.15 0.191	1.00										
P	-0.22 0.053	0.29 0.010	1.00									
K	-0.04 0.738	-0.11 0.350	-0.35 0.002	1.00								
Ca	-0.09 0.439	0.13 0.270	0.57 <0.001	-0.42 <0.001	1.00							
Mn	0.08 0.486	0.24 0.042	0.54 <0.001	-0.42 <0.001	0.26 0.024	1.00						
Fe	0.24 0.039	0.37 0.001	0.09 0.457	-0.02 0.857	0.12 0.299	0.14 0.221	1.00					
Co	-0.18 0.133	0.04 0.713	0.12 0.310	0.06 0.585	0.17 0.139	0.07 0.543	0.28 0.014	1.00				
Cu	-0.02 0.894	-0.018 0.875	0.19 0.095	-0.56 <0.001	0.25 0.032	0.27 0.013	0.09 0.445	0.04 0.758	1.00			
Zn	0.13 0.265	-0.02 0.880	0.50 <0.001	-0.58 <0.001	0.39 <0.001	0.66 <0.001	-0.08 0.508	-0.01 0.912	0.37 <0.001	1.00		
Se	0.08 0.511	0.19 0.097	0.28 0.017	-0.24 0.040	0.21 0.066	0.35 0.002	-0.01 0.956	0.07 0.564	0.33 0.004	0.42 <0.001	1.00	
Mo	0.06 0.637	-0.31 0.007	0.16 0.168	-0.009 0.939	0.003 0.981	-0.02 0.888	0.10 0.412	0.05 0.658	0.03 0.828	0.14 0.222	0.01 0.904	1.00

Conclusion

The results demonstrated that milk sampling time during lactation significantly affected mineral composition of goat milk. Significant increase in K and Na concentrations and decrease in Zn, P and Mn concentrations in the milk of goats were determined. Mo and Cu concentrations decreased significantly, yet their increase was proven on the 110th and 140th day of lactation. Concentrations of Mg and Fe in goat milk were stable during the lactation period. Numerous significant correlations were established between trace elements and macrominerals in milk of goats sampled during lactation.

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Conflict of interest

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Utjecaj vremena uzorkovanja na koncentraciju makro minerala i elemenata u tragovima u kozjem mlijeku tijekom laktacije

Sažetak

Cilj ovoga istraživanja bio je utvrditi utjecaj vremena uzimanja uzoraka na promjene koncentracije makro minerala i elemenata u tragovima kozjeg mlijeka tijekom laktacije. Hranidba koza je provedena s 2,0 kg/dan/kozi sijena i 0,65 kg/dan/kozi smjese žitarica. Mužnja koza provedena je 20., 50., 80., 110. i 140. dana kada je izmjerena količina mlijeka. U uzorcima mlijeka određene su koncentracije makro minerala (Ca, P, K, Na i Mg) i elemenata u tragovima (Fe, Zn, Cu, Mn, Se, Mo i Co). Analizom koncentracija makro minerala i elemenata u tragovima u mlijeku koza tijekom laktacije utvrđeno je značajno povećanje koncentracija K i Na te smanjenje koncentracija P, Zn i Mn. Također je utvrđeno i značajno smanjenje koncentracija Mo i Cu, te njihovo povećanje 110., odnosno 140. dana laktacije. Koncentracije Fe i Mg u mlijeku bile su stabilne tijekom laktacije. Utvrđene su brojne značajne korelacije između makro minerala i elemenata u tragovima u mlijeku koza tijekom laktacije. Nadalje, ovo je istraživanje potvrdilo značajne razlike koncentracija većine istraživanih elemenata u tragovima i makro minerala u kozjem mlijeku, što bi se moglo objasniti utjecajem različitog vremena uzorkovanja mlijeka tijekom laktacije, kada se mijenjaju i količina i sastav mlijeka.

Ključne riječi: koze; laktacija; mlijeko; makro minerali; elementi u tragovima

References

1. Antunović, Z., Novoselec, J., Klir, Ž., Đidara, M. (2013): Hematološki pokazatelji u alpske koze tijekom laktacije. *Poljoprivreda* 19, 2, 40-43.
2. Antunović, Z., Marić, I., Lončarić, Z., Novoselec, J., Mioč, B., Klir, Ž. (2018): Changes in macroelements, trace elements, heavy metal concentrations and chemical composition in milk of Croatian spotted goats during different lactation stages. *International Journal of Dairy Technology* 71 (3), 621-628.
https://doi.org/10.1111/1471-0307.12496
3. Antunović, Z., Klir Šalavardić, Ž., Mioč, B., Novoselec, J. (2024): Analysis of 18 elements in Alpine goat milk in the first third of lactation. *Mljekarstvo* 74 (3), 185-194.
https://doi.org/10.15567/mljekarstvo.2024.0302
4. Belete, T., Hussen, A., Rao, V.M. (2014): Determination of concentrations of selected heavy metals in cows milk: Borena Zone, Ethiopia. *Journal of Health Science* 4, 105-112.
https://doi.org/10.5923/j.health.20140405.01
5. Biadała, A., Konieczny, P. (2018): Goat's milk derived bioactive components-a review. *Mljekarstvo* 68 (4), 239-253.
https://doi.org/10.15567/mljekarstvo.2018.0401
6. Boroš, V., Herian, K., Krčál, Z. (1989): Variations in mineral content of goat milk during lactation. *Prumysl Potravin* 40, 312-314.
7. Chen, D., Zhao, X., Li, X., Wang, J., Wang, C. (2018): Milk compositional changes of Laoshan goat milk from partum up to 261 days postpartum. *Animal Science Journal* 89 (9), 1355-1363.
https://doi.org/10.1111/asj.13062.
8. Chenouf, A., Yabrir, B., Khirani, A., Bokerch, A., Hakem, A., Houali, K. (2024): Mineral composition, nitrogen distribution of goat's milk produced under Algerian steppe condition across lactation stage. *Rural Sustainability Research* 346, 20-28.
https://doi.org/10.2478/plua-2024-0002
9. Curro, S., De Marchi, M., Claps, S., Salzano, A, De Palo, P., Manuelian, C.L., Neglia, G. (2019): Differences in the detailed milk mineral composition of italian local and saanen goat breeds. *Animals* 9 (7), 412-422.
https://doi.org/10.3390/ani9070412.
10. Fadlalla, I.M.T., Shadia, A., Omer, A., Atta, M. (2020): Determination of some serum macroelement minerals levels at different lactation stages of dairy cows and their correlations. *Scientific African* 8, e00351.
https://doi.org/10.1016/j.sciaf.2020.e00351 2468-2276.
11. FAOSTAT (Food and Agriculture Organization of the United Nations) (2018): Statistics database. Accessed: February 2, 2018.
12. FAOSTAT (Food and Agriculture Organization of United Nations) (2025): Production - Live animals Accessed: May 1, 2025.
13. Gaignon, P., Gelé, M., Hurtaud, C., Boudon, A. (2018): Characterization of the nongenetic causes of variation in the calcium content of bovine milk on French farms. *Journal of Dairy Science* 101, 4554-4569.
https://doi.org/10.3168/jds.2017-14043
14. Gaucheron, F. (2013): Milk minerals, trace elements, and macroelements. In: Milk and Dairy products in human nutrition: production, composition and health. Park, Y.W., Haenlein, G.F.W. (Eds.). John Wiley & Sons, Ltd.
https://doi.org/10.1002/9781118534168.ch9
15. Guo, X., Liu, H., Zhao, Q., Qin, Y., Zhang, J. (2021): Discrimination of goat, buffalo, and yak milk from different livestock, regions, and lactation using microelement contents. *Journal of Food Science* 86, 1283-1295.
https://doi.org/10.1111/1750-3841.15685.
16. Günay, E., Güneşer, O., Yuceer, Y.K. (2021): A comparative study of amino acid, mineral and vitamin profiles of milk from Turkish Saanen, Hair and Maltese goat breeds throughout lactation. *International Journal of Dairy Technology* 74 (3), 441-452.
https://doi.org/10.1111/1471-0307.12798.
17. HAPIH (2025): Annual report for sheep, goats and small animals breeding. Osijek, p. 161.
18. ICAR (2018): Section 16 Guidelines for performance recording in dairy sheep and dairy goats. Version February, 2018. p. 37.

19. Kędzierska-Matysek, M., Barłowska, J., Litwińczuk, Z., Koperska, N. (2015): Content of macro- and microelements in goat milk in reation to the lactation stage and region of production. *Journal of Elementology* 20, 107-114.
https://doi.org/10.5601/jelem.2013.18.4.549
20. Klir Šalavardić, Ž., Novoselec, J., Ćavar, S., Antunović, Z. (2024): Effect of dietary cold-pressed hempseed cake on the fatty acid profile of semi-hard, cheese made from goat milk. *Mljekarstvo* 74 (2), 142-155.
https://doi.org/10.15567/mljekarstvo.2024.0205
21. Kondyli, E., Katsiari, M.C., Voutsinas, L.P. (2007): Variations of vitamin and mineral contents in raw goat milk of the indigenous Greek breed during lactation. *Food Chemistry* 100 (1), 226-230.
https://doi.org/10.1016/j.foodchem.2005.09.038.
22. Lechuga-Arana, A.A., Rosiles-Martínez, R., Gutierrez-Chavez, A.J., Ghavipanje, N., Vargas-Bello-Pérez, E. (2025): Variations in the mineral profiles of the micellar and water-soluble fractions of goat milk between the first and second lactations. *International Journal of Agriculture and Natural Resources* 52 (1), 11-27.
https://doi.org/10.7764/ijanr.v52i1.2658
23. Majid, A.M., Cartwright, T.C., Yazman, J.A., Fitzhugh, H.J. (1994): Performance of five breeds of dairy goats in Southern United States. II. Lactation yield and curves. *World Review of Animal Production* 29, 30-37.
24. Michlova, T., Dragounova, H. Seydlova, R., Hejtmánkova, A. (2016): The hygienic and nutritional quality of milk from Saanen goats bred in the Moravian-Silesian region. *Agronomy Research* 14 (S2), 1396-1406.
25. Miedico, O., Tarallo, M., Pompa, C., Chiaravalle, A. (2016): Trace elements in sheep and goat milk samples from Apulia and Basilicata regions (Italy): Valuation by multivariate data analysis. *Small Ruminant Research* 135, 60-65.
https://doi.org/10.1016/j.smallrumres.2015.12.019
26. Mioč, B., Prpic, Z., Vnucec, I., Susić, V., Antunović, Z., Barac, Z., Pavic, V. (2008): Exterior characteristics of different categories of Croatian coloured goat. *Stočarstvo* 62, 439-447.
27. Mishra, S., Kannaujia, S., Dipt, A., Singh, S., Meena, S., Duary, R.K., Meena, K.K. (2026): Exploring the multifaceted potential of goat milk: Nutritional, processing, and commercial applications. *International Dairy Journal* 172, 106447.
https://doi.org/10.1016/j.idairyj.2025.106447
28. Nayik, G.A., Jagdale, Y.D., Gaikwad, S.A., Devkatte, A.N., Dar, A.H., Ansari, M. (2022): Nutritional profile, processing and potential products: A comparative review of goat milk. *Dairy* 3 (3), 622-647.
https://doi.org/10.3390/dairy3030044
29. Ogunwole, O.A. (2016): Manganese, zinc and chloride content of milk of West African Dwarf Goats as influenced bay stage of lactation. *International Journal of Biochemistry Reserach & Review* 12, 3, 1-6.
https://doi.org/10.9734/IJBCRR/2016/25927
30. Pan, J., Yu, Z., Jiang, H., Shi, C., Du, Q., Fan, R., Wang, J., Bari, L., Yang, Y., Han, R. (2024): Effect of lactation on the distribution of mineral elements in goat milk. *Journal of Dairy Science* 107 (5), 2774-2784.
https://doi.org/10.3168/jds.2023-23877
31. Pavliček, J., Antunović, Z., Senčić, Đ., Šperanda, M. (2006): Productionand goat milk content depending on number and stage of lactation. *Poljoprivreda* 12, 52-57.
32. Ponnampalam, E.N., Priyashantha, H., Vidanarachchi, J.K., Kiani, A., Holman, B.W.B. (2024): Effects of nutritional factors on fat content, fatty acid composition, and sensorial properties of meat and milk from domesticated ruminants: an overview. *Animals* 14, 840.
https://doi.org/10.3390/ani14060840
33. Pulina, G., Milán, M.J., Lavín, M.P., Theodoridis, A., Morin, E., Capote, J., Thomas, D.L., Francesconi, A.H.D., Caja, G. (2018): Current production trends, farm structures, and economics of the dairy sheep and goat sectors. *Journal of Dairy Science* 101, 6715-6729.
https://doi.org/10.3168/jds.2017-1401.5
34. Rodríguez, E.M.R., Alaejos, M.S., Romero, C.D. (2002): Mineral content in goats' milks. *Journal of Food Quality* 25, 4, 343-358.
https://doi.org/10.1111/j.1745-4557.2002.tb01030.x

35. Rozenska, L., Hejtmankova, A., Kolihova, D., Miholova, D. (2013): Effects of lactation stage, breed, and lineage on selenium and iodine contents in goat milk. *Czeh Journal of Food Science* 31, 4, 318-322.
https://doi.org/10.17221/82/2013-CJFS
36. SAS® 9.4 (2002-2012): SAS Institute Inc., SAS Campus Drive, Cary, North Carolina, USA.
37. Shuvarikov, A.S., Pastukh, O.N., Zhukova, E.V., Zheltova, O.A. (2021): The quality of milk of goats of Saanen, Alpine and Nubian breeds. *IOP Conference Series: Earth Environmental Science* 640, 032031, 15.
38. Simos, E., Voutsinas, L.P., Pappas, C.P. (1991): Composition of milk of native Greek goats in the region of Metsovo. *Small Ruminant Research* 4 (1), 47-60.
https://doi.org/10.1016/0921-4488(91)90052-R
39. Singh, M., Sharma, R., Ranvir, S., Gandhi, K., Mann, B. (2019): Profiling and distribution of minerals content in cow, buffalo and goat milk. *Indian Journal of Dairy Science* 72 (5), 480-488.
https://doi.org/10.33785/IJDS.2019.v72i05.004
40. Soeharsono, S., Mulyati, S., Utama, S., Wurlina, W., Srianto, P., Restiadi, T.I., Mustofa, I. (2020): Prediction of daily milk production from the linear body and udder morphometry in Holstein Friesian dairy cows. *Veterinary World* 13, 471-477.
https://doi.org/10.14202/vetworld.2020.471-477.
41. Stocco, G., Summer, A., Malacarne, M., Cecchinato, A., Bittante, G. (2019): Detailed macro- and micromineral profile of milk: Effects of herd productivity, parity, and stage of lactation of cows of 6 dairy and dual-purpose breeds. *Journal of Dairy Science* 102, 9727-9739.
https://doi.org/10.3168/jds.2019-16834.
42. Turkmen, N. (2017): The nutritional value and health benefits of goat milk components. In: Nutrients in dairy and their implications for health and disease. Watson, R., Collier, R.J., Preedy, V. (Eds.). Amsterdam, the Netherlands: Academic Press. pp. 441-449.
43. Voutsinas, L.R, Pappas, C.R, Katsiari, M.C. (1990): The composition of Alpine goat's milk during lactation in Greece. *Journal of Dairy Research* 57, 41-45.
https://doi.org/10.1017/S0022029900026595
44. Qeshlagh, F.M.A., Yonjalli, R.V., Ghorbani, A., Achachlouei, B.F. (2016): Milk composition and mineral concentration affected by elevation and grazing season in the Rangelands of North Sabalan mountain, Iran. *Journal of Advanced Agricultural Technologies* 3, 20-25.
https://doi.org/10.18178/joaat.3.1.20-25