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ORIGINAL PAPER

THE EFFECT OF MILK PRODUCTION PERFORMANCE OF POLISH HOLSTEIN-FRIESIAN (PHF) COWS ON THE MINERAL CONTENT OF MILK*

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Abstract

Milk of animal origin, characterized by high nutritional value and exceptional flavour, is one of the most popular and valuable components of the human diet. Milk is a rich source of protein, fat, lactose, vitamins and minerals such as calcium, phosphorus, potassium, magnesium, sodium, iodine, chlorine, iron and zinc. The mineral composition of milk may vary widely depending on genetic, physiological and environmental factors. The aim of this study was to determine the effect of milk production performance of Black-and-White Polish Holstein-Friesian (PHF) cows on the concentrations of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and zinc (Zn) in milk and its proximate composition. Mineralized milk samples were assayed for the content of K, Ca, Na by atomic emission spectroscopy (AES), while Mg and Zn were determined by atomic absorption spectrometry (AAS). The production performance of the evaluated PHF cows was high, at 11 028 kg of milk over 305-day lactation on average. Milk yield had a significant influence on the average content of lactose, K and Na in milk during the 305-day lactation period. The concentrations of Ca, Mg and Na in the analyzed milk samples were below the lower reference limits, whereas the levels of K and Zn were high. The K and Na content of milk varied considerably across lactation stages. In early lactation, K levels were particularly high in cows producing up to 10 000 kg of milk. The Na content of milk increased steadily from the fourth month until the end of lactation. Cow productivity was negatively correlated with the concentrations of lactose, K and Ca in milk. Highly significant positive correlations were found between the fat content of milk vs. the levels of Ca, Mg and Zn. The results of this study indicate that milk from high-producing cows may have insufficient concentrations of selected minerals, relative to the relevant standards.

Keywords: milk, yield, potassium, calcium, magnesium, sodium, zinc.

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INTRODUCTION

Milk is one of the most valuable and natural food products in the human diet. Cow's milk is rich in minerals including essential macronutrients and micronutrients. A glass (250 ml) of cow's milk contains on average 381 mg of K, 300 mg of Ca, 125 mg of Na, 32 mg of Mg and 0.90 mg of Zn (BRODZIAK et al. 2011, KUCZYŃSKA et al. 2013). Mineral salts, whose average content in milk is 0.9%, affect the physical properties of milk and protein stability. Contemporary consumers show a preference for the least-processed milk with high nutritional value. The wide popularity of dairy products can be attributed to their exceptional flavour profile and health-promoting properties, which are affected by the physicochemical composition of milk (JESIOŁKIEWICZ et al. 2011). Milk composition is determined by various genetic (breed, genotype), environmental (management system, nutritional regime, season) and physiological (lactation number and stage, udder health, production efficiency) factors. The profitability of dairy cattle production is largely dependent on high milk yields. Advanced genetic testing is increasingly applied to evaluate the production traits of dairy cows (milk, protein and fat yields). Such tools support selection for high milk yield and quality (JESIOŁKIEWICZ et al. 2011, RINCÓN et al. 2013). However, the above goals are often difficult to achieve in practice (NOGALSKI et al. 2012, DUSZYŃSKA-STOLARSKA et al. 2015). The mineral composition of milk can be significantly modified by the feeding regime (KHALILI et al. 2006, BARŁOWSKA 2007, SOLA-LARRAÑAGA, NAVARRO--BLASCO 2009). Black-and-White Holstein-Friesians are the most common and highest yielding dairy cattle breed which has the largest populations in the world and in Poland, where they make up 92% of all dairy cows. The majority of milk and milk products come to our tables from Holstein-Friesian cattle farms.

The objective of this study was to determine the effect of milk production performance of Black-and-White Polish Holstein-Friesian (PHF) cows on the concentrations of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and zinc (Zn) in milk and its proximate composition (content of fat, protein, lactose and dry matter).

MATERIAL AND METHODS

The experiment was performed on 65 Black-and-White PHF cows from two herds kept in the region of Warmia and Mazury (NE Poland). A total of 1128 milk samples were collected from the evaluated cows. Milk samples were taken once a week from 7 to 90 days of lactation and afterwards once a month to the end of lactation. Milk was collected as a pooled sample from morning and evening milking. Regular health examinations were performed in the herd once a week, by the same veterinary doctor. No samples were taken from cows with clinical mastitis. The cows were divided into three groups based on their milk production performance over 305-day lactation: group 1 – up to 10 000 kg of milk (18 cows), group 2 – from 10 000 to 12 000 kg of milk (26 cows) and group 3 – above 12 000 kg of milk (21 cows). The quality of genetic material, feeding regimes and cow productivity were comparable in both farms. The cows were housed in free-stall barns. To eliminate the effect of a calving season, cows with similar expected calving dates were selected for the experiment. Total mixed ration (TMR) was fed year-round. The TMR was composed of maize silage and haylage supplemented with farm-made concentrates (protein-vitamin-mineral) and feed additives that improve milk production efficiency and help balance complete diets (protein, rumen-protected fat, active yeast cultures and other energy supplements). Three TMRs were prepared for each performance level group 1.

Raw milk samples were assayed for the content of fat, protein, lactose and dry matter by infrared spectrophotometry using a Milkoscan 133B analyzer (FOSS Electric). The samples were subjected to high-pressure wet mineralization involving microwave-assisted digestion, with the use of a mixture of nitric acid and hydrochloric acid, in accordance with the relevant standards. Mineralized milk samples were assayed for the content of K, Ca, Na (by atomic emission spectroscopy – AES), Mg and Zn (by atomic absorption spectrometry – AAS). The results were analyzed statistically by one-way analysis of variance (ANOVA) for non-orthogonal designs using Statistica 10.0 software. The significance of differences between means was determined by the Tukey's range test at $P < 0.05$ and $P < 0.01$. The Pearson correlation coefficients were calculated for the analyzed traits.

RESULTS AND DISCUSSION

The production performance of the evaluated PHF cows was high, at 11 028 kg of milk over 305-day lactation on average (Table 1). The average milk yield recorded in dairy cattle herds in Poland is 5 395 kg, i.e. approximately two-fold lower (Statistical Yearbook of Agriculture 2016). The analyzed cows were divided into three groups based on their milk production performance over 305-day lactation: group 1 – up to 10 000 kg of milk, where average milk yield was 8 539 kg; group 2 – from 10 000 to 12 000 kg of milk, where average milk yield was 10 942 kg; group 3 – above 12 000 kg of milk, where average milk yield was 13 424 kg. Daily milk yield reached nearly 50 kg in the most productive group 3, and 29 kg in the least productive group 1. Unfortunately, the high production performance of PHF cows may be negatively correlated with production traits such as fertility, productive lifetime and the chemical composition of milk (Nogalski et al. 2012).

The production performance of the evaluated PHF cows had a significant

Table 1

Milk yield and the average content of proximate composition and mineral components in the milk of cows

Specification	Level of milk yield (kg)					
	under 10 thous.		10-12 thous.		over 12 thous.	
	x	SE	x	SE	x	SE
Number of cows	18		26		21	
Milk yield in 305-day lactation (kg)	8539^{A}	62,59	10942^{B}	33,92	13424^{C}	73.88
Maximum daily productivity (kg)	28.7^{A}	0.46	39.5^{B}	0.47	49.6^{C}	0.58
Fat content (%)	4.42	0.067	4.31	0.069	4.57	0.094
Protein content (%)	3.24	0.033	3.27	0.020	3.28	0.024
Lactose content (%)	4.98^{A}	0.061	4.82^{B}	0.016	4.76^{B}	0.022
Dry matter content (%)	13.29	0.134	13.08	0.075	13.06	0.109
Potassium (mg dm^{-3})	1636.5^{A}	25.29	1536.3^{B}	16.64	1436.5^{C}	15.95
Calcium (mg dm^{-3})	783.2	13.21	777.4	11.92	742.1	19.37
Magnesium (mg dm^{-3})	96.0	1.67	95.4	1.05	94.5	1.32
Sodium (mg dm^{-3})	336.5^{A}	4.66	372.6^{B}	6.05	360.7^{AB}	7.23
Zinc (mg dm^{-3})	4.45	0.09	4.49	0.07	4.53	0.09

A, B – $P < 0.01$

effect on the lactose content of milk, whereas no significant changes were noted in the concentrations of fat, protein or dry matter (Table 1). The lactose content of milk was significantly higher (4.98%) in the least productive cows (up to 10 000 kg of milk, group 1) than in the remaining two groups. A similar average lactose content of milk (4.8%) was reported by Pollott (2004). In the current study, the concentrations of lactose, the primary milk carbohydrate, remained within the normal physiological range of 4.5-5.2% (Litwińczuk et al. 2004).

Milk yield had a significant effect on the K and Na content of milk (Table 1). The levels of Ca, Mg and Zn did not vary significantly across groups of PHF cows differing in milk productivity. The average K content of milk was high, at 1 536.4 mg dm^{-3}. High K concentrations in milk (1 440 - 1 780 mg K dm^{-3}) were also reported by Zamberlin et al. (2012). In the present experiment, milk from the least productive cows was most abundant in K whose content was 5.6% above the upper reference limits of 1 350 - 1 550 mg dm^{-3} (Litwińczuk et al. 2004). An even narrower range of K concentrations in milk (1 330 – 1 490 mg K dm^{-3}) was reported by Rodriguez et al. (2001).

High K levels in milk (approx. 1 700 mg dm^{-3}) were noted in the least productive cows during the first 60 days of lactation (Figure 1). The K content of milk decreased significantly with increasing milk production, and remained within normal limits. A different trend was noted in the Na content of milk. Similarly to Ca and Mg, Na was a deficient mineral in milk. Accor-

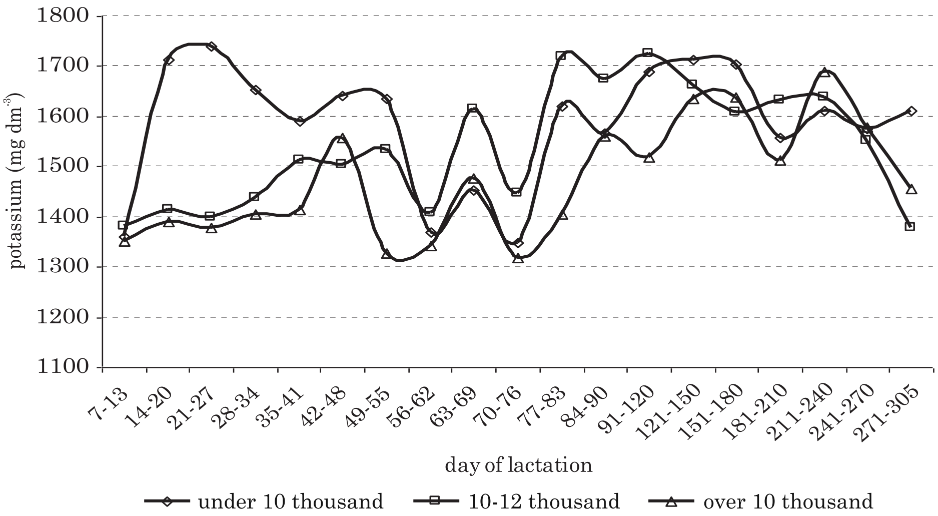

Fig. 1. Potassium content in the milk of cows in the subsequent days of lactation depending on the productivity of the cows

ding to many authors, the concentrations of Ca and Mg in milk from high--producing cows are often below the physiological ranges (Gaucheron 2005, Stasiuk, Przybyłowski 2011, Zamberlin et al. 2012, Nogalska et al. 2017). The Ca:Mg ratio in milk is also too low, at 10:1.

Sodium levels in milk ranged from 336.5 mg dm^{-3} in the least productive cows (group 1) to 372.6 mg dm^{-3} in group 2 cows, and the noted difference was statistically significant (Table 1). From the fourth month of lactation, when milk production began to decrease slowly, Na concentrations in milk increased steadily until the end of lactation, particularly in cows producing more than 10 000 kg of milk (Figure 2). It was only then that the Na content of milk was within the normal ranges of 350-600 mg dm^{-3} (Litwińczuk et al. 2004). According to other authors, the lower limit for the Na content of cow's milk is higher, at 391-644 mg dm^{-3} (Gaucheron 2005), 400-580 mg dm^{-3} (Zamberlin et al. 2012) or even 430-770 mg dm^{-3} (Rodriguez et al. 2001). Barłowska (2007) analyzed milk from cows of seven breeds raised in Poland and found that K and Na concentrations were highest in Black-and-White PHF cows. Rodriguez et al. (2001) compared the levels of K and Na in milk from Holstein cows in the Canary Islands and PHF cows, and found that they were considerably higher in the former. In another study (Sola-Larrañaga, Navarro-Blasco 2009), no significant differences were observed in the concentrations of K and Na in the milk of cows kept in Spain and Poland. Sodium chloride (NaCl) and lactose are responsible for maintaining the osmotic pressure of milk equal to the osmotic pressure of blood. A decrease in the lactose content of milk, observed e.g. in mastitis, increases the rate of NaCl diffusion from blood (Litwińczuk et al. 2004, Jesiołkiewicz et al. 2011).

Zinc is the key mineral component in milk. The average Zn content of

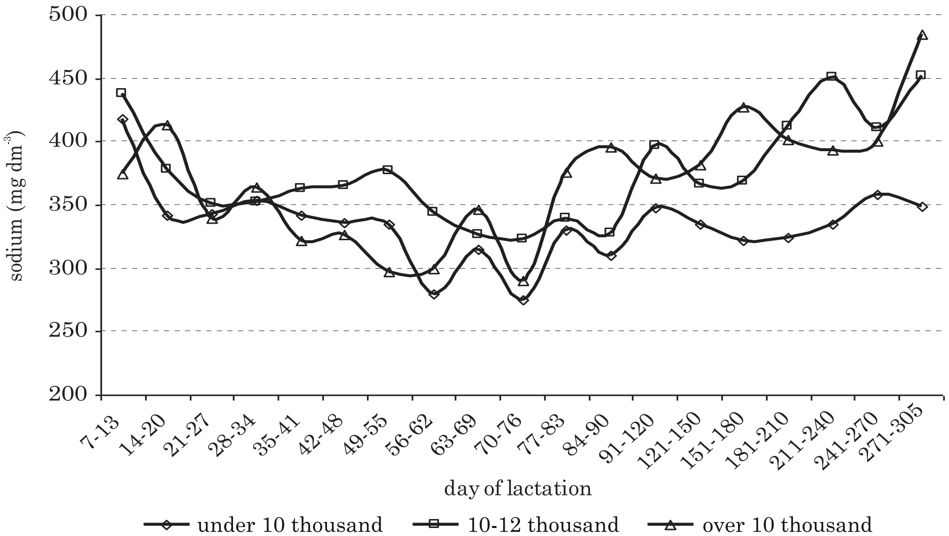

Fig. 2. Sodium content in the milk of cows in the subsequent days of lactation depending on the productivity of the cows.

milk falls in the range of 2 to 5 mg dm^{-3}, and according to the Polish Norms, it should not exceed 5.0 mg kg^{-1} (Litwińczuk et al. 2004). The analyzed milk had high Zn content (4.49 mg dm^{-3} on average), which increased with increasing milk production, but the noted increase was statistically non-significant (Table 1). In an experiment conducted by Bombik et al. (2006), the average Zn content of milk from cows whose production performance was below the national average (approx. 4 000 kg) was 2.8-fold lower than that determined in the current study of high-producing cows. Olsson et al. (2001) observed a positive correlation between Zn concentrations in the mammary gland and milk yield. According to some authors, the correlation between cow productivity and the Zn content of milk results from higher Zn supplementation levels in large dairy cattle farms (Hosnedlová et al. 2005, Król et al. 2016). Different results were reported by Litwińczuk et al. (2004) who demonstrated that the Zn content of milk is correlated with the use of galvanized utensils and containers for milking and storing milk rather than with Zn concentrations in feed.

The Pearson correlation coefficients calculated for the analyzed traits are presented in Table 2. Cow productivity, expressed as milk yield over 305-day lactation, was negatively correlated with the content of lactose (r = -0.34), K (r = -0.30) and Ca (r = -0.12) in milk. Genetic correlations between the yields of milk, protein and fat vs. lactose content were negative or close to zero. Therefore, selection for protein yield and fat yield should not induce changes in the lactose content of milk (Miglior et al. 2007, Jesiołkiewicz et al. 2011). In the current study, highly significant positive correlations were found between the fat content of milk vs. the levels of Ca, Mg and Zn.

Table 2

Correlation between milk components

Features	1	2	3	4	5	6	7	8	9	10
1. Milk yield	-	0.10*	0.05	-0.34**	0.05	-0.30**	-0.12*	0.05	0.07	0,07
2. Fat		-	0.36**	-0.14*	0.95**	-0.21**	0.49**	0.25**	0.06	0.37**
3. Protein			-	-0.19*	0.54**	-0.04	0.21**	0.25**	0.23**	0.08
4. Lactose				-	-0.02	0.19*	-0.05	-0.03	-0.32**	-0.20**
5. Dry matter					-	-0.15*	0.48**	0.28**	0.06	0.31**
6. Potassium						-	-0.15*	-0.18*	0.06	-0.11*
7. Calcium							-	0.37**	0.11*	0.51**
8. Magnesium								-	0.16*	0.31**
9. Sodium									-	0.11*
10. Zinc										-

** $P < 0.01$; * $P < 0.05$

Since consumers prefer milk with a high content of protein and mineral salts but a low fat content, hence efforts are being made to reduce fat and increase protein content of milk (Duszyńska-Stolarska et al. 2015). High milk yield is not always accompanied by high milk quality, which is why dairy products are fortified with minerals, in particular Ca and Mg, whose deficiencies have long been recognized in the human diet (Ziarno et al. 2009, Stasiuk, Przybyłowski 2011, Kuczyńska et al. 2013). Milk produced in low-input farms where native cattle breeds (White-backed, Polish Red and Simmental) are raised has higher concentrations of Na, Mg, Cu and Mn, and a lower content of Zn and Fe in comparison with milk from high-producing PHF cows; no significant differences were found for K and Ca levels (Król et al. 2016). Traditional, regional dairy products that owe their unique taste to local climate, soil conditions and vegetation, are highly appreciated by consumers.

CONCLUSIONS

The production performance of the evaluated PHF cows was high, at 11 028 kg of milk on average. Milk yield had a significant influence on the average content of lactose, K and Na in milk during the 305-day lactation period. The concentrations of Ca, Mg and Na in the analyzed milk samples were below the lower reference limits, whereas the levels of K and Zn were high. Cow productivity was negatively correlated with the concentrations of lactose, K and Ca in milk. Highly significant positive correlations were found between the fat content of milk vs. the levels of Ca, Mg and Zn. The results of this study indicate that milk from high-producing cows could contain insufficient concentrations of selected minerals, relative to the relevant standards. Therefore, dairy products should be fortified with deficient nutrients, mostly Ca and Mg.

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