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Genetic and nongenetic variation in concentration of selenium, calcium, potassium, zinc, magnesium, and phosphorus in milk of Dutch Holstein-Friesian cows

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ABSTRACT

Minerals found in milk, such as Se, Ca, K, Zn, Mg, and P, contribute to several vital physiological processes. The aim of this study was to quantify the genetic variation in levels of Se, Ca, K, Zn, Mg, and P in milk and to quantify the between-herd variation in the levels of these minerals in milk. One morning milk sample from each of 1,860 Dutch Holstein-Friesian cows from 388 commercial herds in the Netherlands was used. Concentration of minerals was determined by inductively coupled plasma-atomic emission spectrometry. Variance components were estimated using an animal model with covariates for days in milk and age at first calving; fixed effects for season of calving and effect of test or proven bull; and random effects for animal, herd, and error. Heritability and proportion of phenotypic variation that can be explained by herd were estimated using univariate analysis. The intraherd heritability for Se was low (0.20) whereas herd explained 65% of the total variation in Se. Variation between herds most likely results from variation in Se content in the feed, which partly reflects variation in Se levels in the soil. Intraherd heritabilities for Ca, K, Zn, Mg, and P were moderate to high and were 0.57, 0.46, 0.41, 0.60, and 0.62, respectively. For Ca, K, Zn, Mg, and P, the proportions of phenotypic variation that could be explained by herd were low (0.13–0.24). This study shows that there are possibilities for altering the mineral composition of milk. For Ca, K, Zn, Mg, and P, there are good prospects for selective breeding whereas, for Se, measures at farm level may be more effective.
Key words: milk mineral, heritability, nongenetic variation, dairy cow

INTRODUCTION

Human mineral intake worldwide varies widely, which results in different countries facing different health challenges. In several cultures, dairy products are an important source of minerals in the human diet (Jelen and Lutz, 1998). Minerals found in milk, such as Se, Ca, K, Zn, Mg, and P, contribute to several vital physiological processes. For example, Ca and P play an important role in bone metabolism, Se and Zn in immune responses, and Ca, K, and Mg in the regulation of blood pressure (Cashman, 2006; Haug et al., 2007).

Minerals represent a small fraction of milk solids compared with milk fatty acids and milk protein, but play an important role in the structure and stability of casein micelles. Caseins are important for cheese yield, milk coagulation time, and curd firmness (Wedholm et al., 2006). In addition, Ca appears to play a crucial role in cheese production. Insight into variation in mineral content of milk is, therefore, important for understanding the product properties of milk (Lucey and Fox, 1993).

Numerous studies have investigated nongenetic sources of variation in the mineral content of milk and have shown that mineral content is influenced by stage of lactation, nutritional status, and climate (Gaucheron, 2005; Cashman, 2006; Phipps et al., 2008). Information on genetic variation between cows as a factor in mineral content of milk is limited. Renner and Kosmack (1974) reported genetic variation in milk Ca content, which is related to high heritability of casein content. Davis et al. (2001) found a difference in milk Ca content between Jersey and Friesian cows. Furthermore, they found that cows with high or low Ca content maintained these characteristics within and across seasons. Their results are suggestive of a genetic basis to variation in milk Ca content. Recently, Soyeurt et al. (2008) found differences in Ca and P concentration measured using emission spectrometry in milk from different breeds. The existence of genetic variation in milk mineral content would offer the opportunity for novel breeding strategies that aim at producing milk with added value, such

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as increased levels of desired minerals, and the opportunity to determine the consequences of current breeding strategies for mineral content of milk.

The objective of this study was to quantify the genetic variation in levels of Se, Ca, K, Zn, Mg, and P in milk and to quantify the between-herd variation in the level of these minerals in milk.

MATERIALS AND METHODS

Animals

This study is part of the Dutch Milk Genomics Initiative (Wageningen University, Wageningen, the Netherlands), a project that focuses on the genetic background of detailed milk composition. As part of this study, milk samples were collected from 1,953 first-parity cows in 398 commercial herds in the Netherlands. At least 5 cows per herd were present at the start of the experiment. Data collection was designed for estimating genetic parameters (many small families) and linkage analysis (some large families). We aimed to include 20 offspring from 50 young bulls and 200 offspring from 5 proven bulls; we included 857 offspring from 50 young bulls and 909 offspring from 5 proven bulls. To obtain the minimum of 5 offspring per herd, we included 187 offspring from other proven bulls. Each cow was between 5 and 220 DIM at the start of the experiment, and each cow carried at least 87.5% Holstein-Friesian genes. Pedigrees and milk yield records of each of the 1,953 selected cows were provided by the cattle cooperative (CRV, Arnhem, the Netherlands).

Milk Samples

Morning milk samples (1 milk sample per cow) from 1,948 Dutch Friesian cows in their first lactation, located in 398 herds, were collected. The samples were preserved with 0.03% (wt/wt) sodium azide, transported refrigerated, and stored frozen at −40°C within 1 d. Cows were milked twice daily, but only the morning milk samples were analyzed for their concentrations of Se, Ca, K, Zn, Mg, and P. After data editing, information on 1,860 milk samples remained; all were used in the analysis.

Determining Mineral Concentrations

Milk mineral concentrations were determined by inductively coupled plasma-atomic emission spectrometry (**ICP-AES**; Vista Axial, Varian, Australia), which has the capability for simultaneous multi-element determination over a wide range, by using a modification of the method published by Asfaw and Wibetoe (2005). Briefly, 2.5 g of milk was accurately weighed into Teflon vessels and mixed with 6 mL of HNO_3 (70%, Suprapur grade quality, Merck, Darmstadt, Germany). The mixture was digested using microwave-assisted destruction (MarshXpress, Beun de Ronde, Abcoude, the Netherlands) as follows. Sealed samples were heated linearly to 200°C for 20 min, kept at 200°C for 35 min, and then cooled to 50°C. Subsequently, concentrated HCl was added to the mixture and the mixture was heated at 130°C for 10 min, followed by cooling to room temperature. Finally, the mixture was supplemented with urea (50% wt/vol) to minimize nitrous gases and filled up with MilliQ water (Millipore, Amsterdam, the Netherlands) to bring the volume to 25 g. Samples were diluted in MilliQ with cesium chloride (final volume 1%) and directly introduced into the ICP-AES for measurement of Ca, K, Zn, Mg, and P. For Se measurement, samples were first converted to the hydride form using a VGA hydride system (VGA-77, Varian, Mulgrave, Australia) containing sodium boron hydride and HCl and were subsequently introduced into ICP. Inductively coupled plasma standards were determined every 20 measurements. When the coefficient of variance of the standard exceeded 10%, samples were analyzed again. MilliQ water was subjected to the whole procedure to obtain blank measurements. If relevant, data were corrected for reagent blank.

To determine the coefficient of variation for the detection method, a reference milk sample was subjected to the whole procedure at every destruction cycle. In total, 105 reference samples were obtained for Se and 101 for non-Se samples. For Se, Ca, K, Zn, Mg, and P, the coefficients of variation for the reference samples were 14.3, 7.9, 9.3, 11.7, 6.2, and 5.7, respectively. When the concentrations of reference samples were plotted against the mean concentration of the samples of the corresponding destruction round, statistically significant ($P < 0.05$) positive correlations were observed for all minerals. Correlation coefficients were 0.63 for Se, 0.73 for Ca, 0.95 for K, 0.72 for Zn, 0.84 for Mg, and 0.80 for P. Therefore, it was decided to correct the samples for the between-destruction round variation according to the following formula:

$$y_{corr} = \frac{ref_{mean}}{ref} \times y,$$

where y_{corr} = the corrected mineral concentration of the milk sample, ref_{mean} = the mean mineral concentration of all reference samples, ref = the mineral concentration of the reference sample of the corresponding destruction run, and y = the mineral concentration of the milk sample.