Milk Protein Genotypes Explain Variation of Milk Protein Composition

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Summary and Implications

The data demonstrate that cows with the genotypes κ-casein BB and β-lactoglobulin BB produce milk with a protein composition that is favorable for increased cheese yield. For proportions of α_{S1}-casein, κ-casein, and β-lactoglobulin in total milk protein, κ-casein and β-lactoglobulin genotypes explained more than 50 and 25% of the heritability and repeatability estimates, respectively, and more than 14% of the phenotypic variance. Diet had only a minimal effect on milk protein composition. In conclusion, increasing cheese yield through modification of milk protein composition can be achieved most rapidly by selection for cows with κ-casein BB and β-lactoglobulin BB genotypes.

Introduction

The composition of bovine milk protein is an important factor for the profitability of the dairy industry. An increase in the proportion of casein, in particular of α_{S1}-casein and β-casein, increases cheese yield. The genotypes of milk proteins, in particular of κ-casein and β-lactoglobulin (β-LG), were found to affect milk protein composition. Genetically linked mutations in the noncoding regions of κ-casein and β-lactoglobulin are assumed to affect the transcription of of κ-casein and β-lactoglobulin, respectively. Therefore, the genotypes of κ-casein and β-lactoglobulin are a potential tool for modification of milk protein composition.

Our goal was to estimate the contribution of κ-casein and β-lactoglobulin genotypes to the heritability, repeatability, as well as the phenotypic variation of milk protein composition in U.S. Holstein-Friesian cows.

Materials and Methods

On one day each month over a 1-year period, morning and evening milk samples were collected and combined from Holstein-Friesian cows in the Iowa State University Breeding Herd. A total of 592 individual milk samples from 233 Holstein-Friesian cows was selected for determination of its protein composition. The six major milk proteins, α_{S1}-casein, β-casein, κ-casein, α_{S2}-casein, β-lactoglobulin, and α-lactalbumin (α-LA), were quantified, and the κ-casein and β-lactoglobulin genotypes were determined by reversed-phase HPLC.

The effects of κ-casein and β-lactoglobulin genotypes on the phenotypic and genetic variation of milk protein composition were estimated by using a single trait, mixed, linear animal model. Fixed factors of the statistical model were parity (1, 2, 3, and >3 parities), month of lactation (1, 2, …, 10, and >10 lactation months), sampling month (January, February, May, June, July, …, December), diet [low, medium, and high NE_L (Mcal/kg) and CP (percentage of dry matter) of 1.59 and 12.38, 1.72 and 14.67, and 1.76 and 15.56, respectively], severity of mastitis (<250,000, 250,000 - 1,000,000, and >1,000,000 somatic cell score/ml), κ-casein genotypes (κ-casein AA, κ-casein AB, κ-casein BB), and β-lactoglobulin genotypes (β-lactoglobulin AA, β-lactoglobulin AB, β-lactoglobulin BB). Random factors were additive genetic (233 cows with production records and 184 sires and dams without production records), permanent environmental (233 cows with production records), and residual effects (592 milk samples). The additive genetic, permanent environmental, and residual variances were estimated iteratively via derivative-free REML. Two different models were used for estimating variance components. For the polygenic background, the previously mentioned statistical model was used, which contained κ-casein and β-lactoglobulin genotypes, whereas, for the complete genome, the statistical model did not contain the genotypes. The heritabilites were estimated for the ratio between the additive genetic variance to the sum of additive genetic, permanent environmental, and residual variances. The repeatabilities were estimated from the ratio between the sum of additive genetic and permanent environmental variances to the sum of additive genetic, permanent environmental, and residual variances. The convergence criterion for the variance component estimates was 10^{-9}.

The contributions of κ-casein genotype, β-lactoglobulin genotype, cow, parity, sampling month, month of lactation, diet, severity of mastitis, and residual to the total phenotypic variation of the milk protein composition were computed in PROC MIXED of SAS by using a random model.

Results and Discussion

The κ-casein and β-lactoglobulin genotypes affected the milk protein composition (Table 1). Cows with κ-casein

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AA genotype produced milk that had a higher proportion of α_{S1}-casein and a lower proportion of κ-casein in total milk protein than did cows with κ-casein BB genotype. Cows with β-lactoglobulin AA genotype produced milk that had a higher proportion of β-lactoglobulin and a lower proportion of α_{S1}-casein and β-casein in total milk protein than did cows with β-lactoglobulin BB genotype. The B allele of κ-casein increased the proportion of κ-casein at the expense of the proportions of α_{S1}-casein and β-lactoglobulin in total milk protein. The A allele of β-lactoglobulin increased the proportion of β-lactoglobulin at the expense of the proportions of α_{S1}-casein and β-casein in total milk protein.

Milk protein genotypes of κ-casein and β-lactoglobulin contributed more than 50% of the heritability and more than 25% of the repeatability of the proportions of α_{S1}-casein, κ-casein, and β-lactoglobulin in total milk protein (Table 2). Our results indicate that the genetic control of the proportion of κ-casein and β-lactoglobulin in total milk protein is nearly complete by κ-casein and β-lactoglobulin genotypes, respectively. Furthermore, κ-casein and β-lactoglobulin genotypes also exert a significant part of the genetic control of α_{S1}-casein in total milk protein, whereas the effect of κ-casein and β-lactoglobulin genotypes on the proportions of other proteins in total milk proteins are minor or insignificant. The κ-casein and β-lactoglobulin genotypes explained not only a major proportion of the genetic variation of milk protein composition (Table 2) but also contributed a major proportion of the phenotypic variance of milk protein composition (Table 3): κ-casein and β-lactoglobulin genotypes accounted for more than 25% of the phenotypic variance of the proportions of κ-casein and β-lactoglobulin in total milk protein, respectively. Additionally, the κ-casein genotype explained 10.5% of the total variance of the proportion of α_{S1}-casein in the total milk protein, and β-lactoglobulin genotype explained 4.3 and 6% of the total variance of the proportions of α_{S1}-casein and β-casein in total milk protein, respectively. Feeding cows diverse diets had only a minimal effect on milk protein composition (Table 3). Therefore, we conclude that modification of milk protein composition can be achieved most rapidly by selection for specific κ-casein and β-lactoglobulin genotypes.

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Table 1. Phenotypic means for milk protein concentration and composition in Holstein-Friesian cows with different κ-casein and β-lactoglobulin genotypes.

Trait	κ-casein						β-lactoglobulin					
	AA n[1] = 409		AB n[1] = 163		BB n[1] = 20		AA n[1] = 60		AB n[1] = 297		BB n[1] = 235	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Total protein[2]	32.2	3.1	32.4	3.5	31.6	2.6	32.6	2.8	32.4	3.2	32.0	3.2
α_{S1}-casein[3]	32.6	2.0	31.7	1.8	30.9	1.5	31.7	2.1	32.1	2.1	32.8	1.8
β-casein[3]	28.8	2.7	28.7	2.4	28.9	2.2	27.8	2.4	28.6	2.7	29.3	2.5
κ-casein[3]	16.6	2.1	17.9	2.2	19.6	2.0	17.2	2.4	17.0	2.3	17.2	2.1
α_{S2}-casein[3]	7.6	1.9	7.5	1.5	7.5	1.7	7.0	1.6	7.5	1.8	7.8	1.8
β-lactoglobulin[3]	10.7	2.7	10.6	2.6	9.65	3.0	12.4	3.4	11.3	2.4	9.3	2.3
α-lactalbumin[3]	3.8	0.8	3.7	0.7	3.8	0.6	3.9	1.1	3.6	0.8	3.8	0.7

[1] n: number of daily samples.
[2] Expressed in grams of total milk protein per liter of milk.
[3] Expressed as weight percentage of an individual milk protein to total milk protein.

Table 2. Effect of κ-casein and β-lactoglobulin genotypes on the estimates (Est.) of heritability and repeatability for milk protein concentration and composition in Holstein-Friesian cows.

Trait	Heritability (h^2)				Repeatability (r)			
	Complete genome[1]		Polygenic background[2]		Complete genome[1]		Polygenic background[2]	
	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Total protein[3]	0.40**	0.13	0.41**	0.13	0.51***	0.05	0.52***	0.05
α_{S1}-casein[4]	0.18	0.10	0.07	0.08	0.29***	0.05	0.19***	0.05
β-casein[4]	0.01	0.07	0.02	0.07	0.16***	0.05	0.13**	0.05
κ-casein[4]	0.28**	0.11	0.12	0.09	0.43***	0.05	0.31***	0.05
α_{S2}-casein[4]	0.01	0.07	0.04	0.08	0.14**	0.05	0.14**	0.05
β-lactoglobulin[4]	0.36**	0.12	0.04	0.07	0.37***	0.05	0.07	0.05
α-lactalbumin[4]	0.00	0.07	0.00	0.07	0.06	0.04	0.05	0.04

[1] Statistical model does not account for κ-casein and β-lactoglobulin genotypes separately.
[2] Statistical model accounts for κ-casein and β-lactoglobulin genotypes separately.
[3] Measured in grams of total milk protein per liter of milk.
[4] Measured as weight percentage of an individual milk protein to total milk protein.
*P < 0.05 for hypothesis $h^2 = 0$ and r = 0, respectively.
**P < 0.01 for hypothesis $h^2 = 0$ and r = 0, respectively.
***P < 0.001 for hypothesis $h^2 = 0$ and r = 0, respectively.

Table 3. Contribution of different parameters to the total phenotypic variation of milk protein concentration and composition of daily samples from Holstein-Friesian cows.

Parameter	Total protein[1]	α_{S1}-CN[2]	β-CN[2]	κ-CN[2]	α_{S2}-CN[2]	β-LG[2]	α-LA[2]
	(proportion of total phenotypic variance expressed in %)						
κ-CN genotype	0	10.5	0	25.4	0.1	0.7	0.9
β-LG genotype	0	4.3	6.0	0.4	1.3	26.3	1.1
Cow[3]	33.0	12.0	8.4	15.7	7.8	3.3	6.8
Parity	1.4	2.6	1.3	4.8	0.1	0	0
Sampling month	7.2	10.6	33.0	6.3	33.4	33.2	23.3
Month of lactation	18.9	8.5	0.9	4.6	1.4	0.3	0
Diet	4.6	0	1.1	0	0	0	2.2
Severity of mastitis	0.7	7.9	1.7	11.6	12.3	4.9	0
Residual	34.2	43.6	47.6	31.2	43.6	31.3	65.7

[1] Measured in grams of total milk protein per liter of milk.
[2] Measured as weight percentage of an individual milk protein to total milk protein.
[3] The parameter cow includes the permanent environmental effect.