Effect of κ -casein B relative content in bulk milk κ -casein on Montasio, Asiago, and Caciotta cheese yield using milk of similar protein composition

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ABSTRACT

The aim of this study was to investigate the effect exerted by the relative content of κ -casein (κ -CN) B in bulk milk κ -CN on coagulation properties and cheese yield of 3 Italian cheese varieties (Montasio, Asiago, and Caciotta). Twenty-four cheese-making experiments were carried out in 2 industrial and 1 small-scale dairy plant. Detailed protein composition of bulk milk of 380 herds providing milk to these dairies was analyzed by reversed-phase HPLC. To obtain 2 experimental milks differing in the relative content of κ -CN B in κ -CN, herds were selected on the basis of bulk milk protein composition and relative content of κ -CN genetic variants. Milk was collected and processed separately for the 2 groups of selected herds. A difference of 20% in the relative content of κ -CN B in κ -CN was obtained for the 2 experimental milks for Montasio and a difference of 15% for Asiago and Caciotta. The 2 experimental milks were of similar protein and CN content, casein number, pH, CN composition, and β -CN genetic composition. For each cheese-making trial, amounts of milk, ranging from 2,000 to 6,000 kg, were manufactured. Each vat contained milk collected at least from 4 dairy herds. Cheese yield after brining and at the end of the aging was recorded. Milk with a greater proportion of κ -CN B in κ -CN (HIGHB) exhibited similar coagulation properties and greater cheese yield compared with milk with a lower proportion of κ -CN B in κ -CN (LOWB). The increased cheese yield observed for HIGHB when manufacturing Montasio cheese was ascribed to a greater fat content compared with LOWB. The probability of HIGHB giving a cheese yield 5% greater than that of LOWB ranged from 51 to 67% for Montasio cheese, but was less than 21% for Asiago and Caciotta cheeses. Variation in relative content of κ -CN B in κ -CN content did not relevantly affect industrial cheese yield when milks of similar CN composition were processed. An indirect effect due to the increased κ -CN content of κ -CN B milk is thought to explain the favor-

able effects of κ -CN B on cheese yield reported in the literature.

Key words: κ -casein, cheese yield, protein composition, genetic variant

INTRODUCTION

Cheese yield (CY) plays a fundamental role in the profitability of the dairy industry and it is influenced by many factors, such as casein content and milk protein polymorphisms. The effect of *CSN3* (κ -CN) B has generated considerable interest because it has been associated with improved milk coagulation properties (MCP) compared with the A genetic variant (van den Berg et al., 1992; Lodes et al., 1996b; Walsh et al., 1998a,b) and increased CY in a range of cheese varieties such as Cheddar, Mozzarella, Parmigiano-Reggiano, Svecia, and Gouda (Buchberger and Dovč, 2000). In addition, studies investigating Cheddar cheese-making have reported that milk produced by homozygous *CSN3* BB animals exhibited higher fat recoveries into cheese, which was likely associated with the finer gel structure of κ -CN BB milk (Walsh et al., 1998b). Because the 2 amino acid substitutions differentiating κ -CN A and B are not close to the site of action of rennet during the initial phase of coagulation, a direct effect of these substitutions on the enzymatic process can be excluded (Grosclaude, 1988).

Several causes have been considered to explain the enhanced properties of κ -CN BB milk. They involve the different net charge of the 2 protein variants, the content of citric acid in milk, the difference in the degree of glycosylation, and the increased homogeneity of micelle size in κ -CN BB milks (Grosclaude, 1988). Finally, these properties have been partly attributed to greater overall CN content associated with κ -CN B (Jakob and Puhán, 1992; Walsh et al., 1995) compared with κ -CN A milk.

To date, most studies have been pilot-scale cheese-making studies or have used bulk milk of genotyped cows (Buchberger and Dovč, 2000) in which total CN content (TCN) or contents of other protein fractions were unknown or unlike across compared milks. Genotypes at *CSN3* have been associated with differences

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in κ -CN content of milk (Heck et al., 2009; Bonfatti et al., 2010b). Increased κ -CN content is related to an increased number of small micelles in κ -CN BB milk, which results in more compact curds (Horne, 1998) when milk is processed. In addition, a marked effect of CN composition and *CSN2* (β -CN) genotypes on MCP has been recently reported (Bonfatti et al., 2010a). All of these factors may contribute to the observed variation in CY and MCP occurring when milk exhibiting different κ -CN variants content is processed. Studies reported in the literature have not clarified whether detected associations between CY and specific genotypes at *CSN3* are attributable to effects exerted by differences in structural properties of κ -CN protein variants or are largely due to modifications of CN composition of milk.

The aim of this study was to investigate the effect exerted by the relative content of κ -CN B in bulk milk κ -CN on industrial CY of Montasio (MO), Asiago (AS), and Caciotta (CA) cheeses when CN content and composition and contents of β -CN variants were alike in processed bulk milks.

MATERIALS AND METHODS

Data Collection

A total of 24 cheese-making trials were carried out in 3 commercial dairies located in the north of Italy: 1 small-scale plant that manufactured MO, and 2 industrial plants, 1 that manufactured AS and 1 that manufactured CA. The cheese-making trials were carried out from January to June 2009. An exploratory sampling of bulk milk of all herds (13 herds for MO, 125 for AS, and 242 for CA) supplying the 3 dairies involved in the study was initially performed to assess across-herd variation of detailed protein composition. After the initial assessment, herds selected to supply milk for the experimental cheese-making trials were sampled again a few days before each cheese-making experiment. This was performed to ensure that characteristics of experimental milk were consistent with the desired ones. Two samples were collected in each herd, stored in portable chilling devices immediately after collection, frozen at -20°C , and then transferred to the milk laboratory of the Department of Animal Science (Padova, Italy) to measure protein composition and MCP and to the milk quality laboratory of Veneto Agricoltura (Thiene, Italy) to measure fat content by infrared analysis with a Milko-Scan FT120 (Foss Electric, Hillerød, Denmark).

To assess the effect of freezing on MCP measurement, the Pearson product-moment correlation between MCP measured in refrigerated (4°C) and frozen (-20°C)

samples was previously performed in 80 individual milk samples. Milk was analyzed for MCP within 12 h of collection. Frozen samples were thawed at 35°C in a water bath for 30 min before MCP measurement.

Analysis of Protein Composition

Contents of α_{S1} -, α_{S2} -, β -CN, κ -CN, β -LG, and α -LA were measured in herd bulk milk samples, vat-milk and in cheese-whey samples, by reversed-phase HPLC, using the method proposed by Bonfatti et al. (2008). The method allows the separation and quantification of major CN and whey protein fractions and of their most common genetic variants. Contents of κ -CN A and B, of β -LG A and B, and of β -CN A¹, A², and B were quantified. The content of each genetic variant was quantified through the use of specific calibration equations as estimated by Bonfatti et al. (2008). Because γ -CN elutes in the same interval of elution of β -CN F, the peak eluting in this interval was considered to be composed of γ - and β -CN, and the total content of γ - and β -CN ($\gamma\beta$ -CN) was given. Total CN content was computed as the sum of α_{S1} -CN, α_{S2} -CN, $\gamma\beta$ -CN, and κ -CN content. Total whey protein content (WH) was calculated as the sum of α -LA and β -LG contents. Total protein content (PRT) was calculated as the sum of TCN and WH. Casein number was calculated as the ratio of TCN to PRT. Casein composition (i.e., relative contents of CN fractions in CN) was expressed as the percentage ratio of α_{S1} -CN (α_{S1} -CN%), α_{S2} -CN (α_{S2} -CN%), $\gamma\beta$ -CN ($\gamma\beta$ -CN%), and κ -CN (κ -CN%) contents to TCN. The glycosylated portion of κ -CN (glyco- κ -CN) was also quantified and expressed as percentage ratio to TCN. The relative content of κ -CN B in κ -CN (κ -CN_B%) was computed as the percentage ratio of glyco-free κ -CN B content to total content of glyco-free κ -CN.

Milk Coagulation Properties

Measures of MCP of bulk-milk and vat-milk samples were obtained by using a computerized renneting meter (CRM-48, Polo Trade, Monselice, Italy), within a few hours of sample collection. Samples (10 mL) were thawed at 35°C in a water bath. Then, they were pre-heated at 35°C immediately before MCP measurement, and 200 μL of diluted rennet was added. Rennet (Hansen standard 160, 80% chymosin, 1:14,900, Pacovis Amrein AG, Bern, Switzerland) was diluted 1.6% (vol/vol) in distilled water. Measures of rennet clotting time (RCT, min), curd firming time (K_{20} , min), and curd firmness (a_{30} , mm) were obtained. Trait definitions and details on used methods can be found in Dal Zotto et al. (2008). Noncoagulating milks (i.e., milk that did

not coagulate within 31 min of rennet addition) had no values for RCT and K_{20} . Measures of pH were carried out (pH-Burette 24, Crison, Barcelona, Spain) before rennet coagulation analysis.

Manufacture of Montasio, Asiago, and Caciotta Cheese

Technological characteristics and processing features of investigated cheese varieties are reported in Table 1. Two experimental milks, one with high (**HIGHB**) and one with low (**LOWB**) κ -CN B relative content

in κ -CN, were processed for the manufacture of the 3 types of cheese.

For the manufacture of MO cheese, weekly and over a period of 4 wk, HIGHB (κ -CN_B% = 60%) and LOWB (κ -CN_B% = 40%) were processed consecutively on the same day and using the same vat. Each experimental milk was derived from the blending of bulk milk of a minimum of 4 herds.

For the manufacture of AS cheese, HIGHB (κ -CN_B% = 40%) and LOWB (κ -CN_B% = 25%), were processed within a single vat on 3 consecutive days over 2 wk to obtain 2 replicates for each experimental milk. The

Table 1. Features of cheese making technologies and characteristics of Montasio, Asiago, and Caciotta cheeses

Item	Montasio	Asiago	Caciotta
European protected denomination of origin	Yes	Yes	No
Pasteurization	Yes	Yes	Yes
Curd making			
Vat capacity, t	4	11	1.9
Milk processed, t	2–3	50–55	1.9
Vat temperature, °C	37	37	41
Starter cultures	Mesophilic and thermophilic lactic cultures	Thermophilic lactic cultures	Mesophilic yeasts and lactic cultures
Natural milk starter, L/100 L of vat milk ¹	2.5–3.3	No	No
Incubation time, min	35	35	35
Salt added, kg/t	No	2.3	6
Rennet			
Origin	Calf	Calf	Calf
Powder, g/t	36	—	500
Liquid, mL/t	—	400	—
Strength ²	1:125,000	1:10,000	1:10,000
Chymosin to pepsin ratio	95:5	80:20	75:25
Cutting			
Equipment	Stainless blades	Stainless blades	Stainless blades
Cutting time, min	30	30	25
Curd size after cutting, ³ mm	6–10	10–12	12–18
Cooking	Yes	Yes	No
Temperature, °C	47	42	—
Cooking time, min	22	20	—
Molds			
Pressing	Yes	Yes	No
Shape	Cylindrical	Cylindrical	Spherical-cylindrical
Diameter, cm	30–40	30–40	10–15
Height, cm	6–10	11–15	7–9
Brine			
Time at rest, h	24	72	1
Duration of brining, h	24	48	12
Aging			
Length, d	60	20	10
Average temperature, °C	9–11	8–10	3–5
Relative humidity, %	80	80	80
Cheese characteristics			
Weight, kg	7–9	8–12	0.6–0.8
Texture	Semi-hard	Semi-hard	Soft
Color	White-straw	Pale yellow	White-pale yellow
Type of round-eyed	Small and diffuse	Small and diffuse	Small and rare

¹Natural milk starter was part of the milk of the day before that of the cheese-making trial, added with the same lactic culture used as starter in the vat.

²Strength is defined as the number of volumes of milk clotted by 1 volume of rennet in 40 min at 35°C.

³For Montasio cheese, a first cut of the curd was made after 6 min from the curd formation and the second was made after removing 15% of the whey contained in the vat and after a 10 min healing period. For Asiago, the healing time after cutting was 12 min.

volume of processed milk in each trial was 5,500 L. Each experimental milk was derived from the blending of bulk milk of a minimum of 5 herds.

For the manufacture of CA cheese, HIGHB (κ -CN_B% = 55%) and LOWB (κ -CN_B% = 35%) were processed simultaneously. Each experimental milk was processed into 3 industrial vats of equal volume (1,900 L). The experimental cheese making was repeated on 3 consecutive days over 1 wk, for 2 wk. Each experimental milk was derived from the blending of bulk milk of at least 8 herds.

Analysis of Vat Milk and Cheese Whey

Analysis of milk composition was carried out twice for milk sampled from the vat before the addition of the starter and for cheese whey sampled after curd extraction from the vat. The following traits were measured: pH with a pH meter (Crison Instruments SA, Alella, Spain), titratable acidity with 0.25 M NaOH according to the Soxhlet-Henkel method (Anonymous, 1963) using a Crison Compact D meter (Crison Instruments SA), and fat by infrared analysis with a Milko-Scan FT120 (Foss Electric). Analysis of protein composition was carried out by reversed-phase HPLC (Bonfatti et al., 2008). For vat milk, coagulation properties were also measured in duplicate (CRM-48, Polo Trade, Monseice, Italy).

Cheese Yield Recording and Analysis of Cheese

For all cheeses, the first measure of CY (**CY1**) was recorded after the brine period at d 2 or 3 for MO and CA or AS, respectively. Cheese yield at the end of the aging period (**CY2**) was also measured. At the end of the aging period, which lasted 60, 20, or 10 d for MO, AS, or CA, respectively, 3 molds per experimental milk in each day of processing were randomly sampled. Cheese samples were analyzed for moisture by vacuum oven at 100°C (method 926.08; AOAC, 2003), fat by the Mojonnier method (method 933.05; AOAC, 2003), ash using a muffle furnace at 550°C (method 935.42; AOAC, 2000), and total protein by macro-Kjeldahl (method 2001.14; AOAC, 2002). Because κ -CN variants have been reported (Walsh et al., 1998a) to exert trivial effects on primary and secondary proteolysis during aging or on the grading scores awarded for acceptability, cheese quality was not evaluated.

Statistical Analysis

The effects of the relative content of κ -CN B in milk κ -CN on variation of composition of vat milk and cheese whey, MCP of vat milk, CY at different aging periods,

and moisture, protein, and fat content of manufactured cheese was investigated through Bayesian analyses. Because differences in the relative content of κ -CN B in milk κ -CN across processed milks were different for MO, AS, and CA cheese-making trials, separated statistical analyses were carried out for each type of manufactured cheese. Models included the effect of the experimental milk (2 levels: HIGHB and LOWB) and the effect of the day of cheese making (4 d for MO, 2 d for AS, and 6 d for CA). Prior distributions for both effects were assumed to be uniform. A unique Gibbs chain of 100,000 iterations was run for each analysis, with a burn-in of 10,000 iterations. Samples were saved every 10 iterations. Convergence was tested for each chain using the Z criterion of Geweke (1992). Monte Carlo standard errors were also calculated (Sorensen and Gianola, 2002).

The parameter of interest was the relative difference between means of HIGHB and LOWB ($\Delta\%$) that was computed as

$$\Delta\% = \frac{\mu_{\text{HIGHB}} - \mu_{\text{LOWB}}}{\mu_{\text{LOWB}}} \cdot 100,$$

where μ_{HIGHB} and μ_{LOWB} are the means of HIGHB and LOWB milk, respectively. The marginal posterior distribution of $\Delta\%$ was estimated for each trait and the posterior probability for a relevant $\Delta\%$ was obtained from the estimated marginal distribution. For composition of milk and cheese and for MCP, $\Delta\%$ was considered to be a relevant difference between means of experimental milks when its absolute value was >8%; for CY, $\Delta\%$ was considered to be relevant when the absolute value was >5%. The thresholds for a relevant $\Delta\%$ for MCP and milk and cheese composition were established by considering the variability due to sampling and analytical procedures. For CY, the threshold was 5% because 5% was the minimum difference between κ -CN BB and AA milk reported in the literature (Buchberger and Dovč, 2000), with few exceptions (Schaar et al., 1985; Rahali and Ménard, 1991). The posterior median was used as a point estimate of parameters of concern.

RESULTS AND DISCUSSION

Protein Composition and MCP of Bulk Milk

The Pearson product-moment correlation between refrigerated and frozen milk was 0.94 for RCT and 0.88 for α_{30} , indicating that freezing did not affect the MCP measurement. According to de la Fuente et al. (1997), in comparison with fresh samples, renneting properties were less affected by storage temperature in

Table 2. Descriptive statistics for protein composition and milk coagulation properties (MCP) of bulk milk of sampled herds (n = 380)

Item ¹	Mean	SD	Minimum	Maximum
Protein, g/L	40.57	2.85	29.97	52.77
Casein, g/L	35.38	2.51	25.72	46.33
Whey protein, g/L	5.19	0.46	4.02	6.75
Casein number, %	87.21	0.67	85.45	91.01
Casein composition, %				
α_{S1} -CN	38.21	1.24	33.08	42.95
α_{S2} -CN	12.30	0.91	9.55	16.58
$\beta\gamma$ -CN	39.80	1.20	35.15	43.96
κ -CN	9.69	0.81	7.77	15.58
Whey protein composition, %				
α -LA	22.60	2.41	12.86	71.09
β -LG	77.40	2.41	28.91	87.15
κ -CN composition, %				
κ -CN A	56.98	16.02	4.11	89.00
κ -CN B	43.02	16.02	11.00	95.89
Glycosylated- κ -CN	45.94	3.69	34.95	60.30
β -CN composition, %				
β -CN A ¹	27.62	9.45	5.95	71.52
β -CN A ²	50.21	10.58	8.14	83.00
β -CN B	16.28	8.29	2.77	54.95
γ -CN + β -CN F	5.89	1.70	2.31	20.62
β -LG composition, %				
β -LG A	47.46	12.46	3.98	90.68
β -LG B	52.54	12.46	9.32	96.02
MCP of coagulated sampled ² (n = 354)				
RCT, min	20.00	3.56	7.08	29.57
K ₂₀ , min	2.97	2.10	0.00	8.95
a ₃₀ , mm	24.07	7.31	3.00	41.00

¹Protein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN + β -LG + α -LA; casein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN; casein number = (casein/protein) $\times$ 100; whey protein = β -LG + α -LA.

²RCT = rennet clotting time; K₂₀ = curd firming time; a₃₀ = curd firmness.

frozen samples than in refrigerated samples. Thus, in this study MCP measurements were performed using frozen samples.

Descriptive statistics for bulk milk protein composition and MCP of all herds supplying the 3 dairies involved in the study are reported in Table 2. The high average protein content of milk can be ascribed to the skimming of milk before chromatographic analysis. The exploratory sampling included all herds supplying the 3 dairies with no distinction in breed and herd size, thus resulting in a large variability of protein fraction content and presence of protein genetic variants in bulk milk. Composition of bulk milk of small herds is essentially determined by characteristics of few animals and also less-common protein genetic variants at the population level may be prevalent in those bulk milk samples. Genetic composition of κ -CN showed a large variability. Relative content of κ -CN A in total κ -CN ranged from 11.0 to 95.9%. Overall, relative content of κ -CN A in κ -CN was slightly greater than that of κ -CN B. Also, the β -CN fraction exhibited a great variability of genetic composition (i.e., relative content of genetic variants in β -CN) with a high prevalence of β -CN A² (50.2% on total β -CN). This was expected as

a consequence of the large frequency of this allele in many Italian dairy cattle breeds (Comin et al., 2008; Bonfatti et al., 2010b). However, bulk milk of sampled herds also exhibited a rather high content of β -CN A¹. Variant B of β -CN was also detected in milk of several herds, with an average relative content in total β -CN of 16.28%. The high content of this variant (which is a not common variant in Holstein-Friesians) could be attributable to the presence of Brown Swiss or Simmental cows in the sampled herds.

Whey protein composition exhibited a slight predominance (52.54%) of β -LG B over β -LG A. This result was expected, because of the slightly higher frequency of *BLG* B relative to *BLG* A in Holstein-Friesian and Simmental, and to its high frequency in Brown Swiss cattle (Formaggioni et al., 1999).

Of the investigated bulk milk samples, 7.4% coagulated within 15 min of rennet addition and exhibited a short RCT; 43.9% coagulated in the interval from 15 to 20 min, which is considered an optimal RCT range; and 33.9% coagulated between 20 and 25 min. The proportion of milk not suitable for processing (RCT >25 min) was 14.7%. Within this category of milk, a great proportion of noncoagulating milk (6.8% of all samples)

was observed. The high incidence of noncoagulating milk in the investigated sample and averages for RCT and a_{30} (20 min and 24 mm, respectively) confirm the poor coagulation ability of milk in Italy, which has been reported in previous studies (Mariani et al., 1992; Sandri et al., 2001).

Composition of Experimental Milks

Inferences were based on the estimated marginal posterior distributions for $\Delta\%$. Convergence of Monte Carlo Markov chains was obtained in all analyses, and Monte Carlo standard errors were very small (<0.004 ; data not reported in table).

In general, the range of variation of κ -CN_A% across experimental milks was smaller than that observed in the exploratory analysis of herd bulk milk. This was due to the constraint of keeping other characteristics similar across experimental milks when HIGHB and LOWB were obtained. Nevertheless, the range of variation of κ -CN_B% for experimental milks was approximately equal to 1 SD of bulk milk κ -CN_B% measured in all sampled herds and, for nearly half of these, κ -CN_B% was within the range of variation of the same trait in the experimental milks. Production of HIGHB and LOWB by exclusive blending of milk of the most extreme herds for κ -CN_B% was not feasible because those herds exhibited the most extreme total κ -CN contents and casein number, which would have led to experimental milks with large differences in terms of protein composition.

Features of the marginal posterior densities of means of experimental milk and of $\Delta\%$ are reported in Tables 3, 4, and 5 for milk and protein composition and for MCP and cheese yield and composition, respectively. The main advantage of using Bayesian techniques rather than classical statistics is the use of estimated posterior probability densities, which permits greater accuracy when evaluating the uncertainty associated with the estimated parameters and allows the construction of several types of probability intervals to test hypotheses. As an example, almost all differences between means of HIGHB and LOWB for protein composition had a high probability density interval that included zero. From a classical statistics point of view, this would have led us to conclude that there were no significant differences between milks. However, this interval is only an indication of the accuracy of the measurement of the difference across milks. To answer the question of whether milks are different or not in relation to traits of concern, the probability of difference (or similarity) needs to be investigated.

Montasio Cheese Milks. For MO cheese, the relative content of κ -CN B in HIGHB was approximately

60%, whereas in LOWB milk it was 40%. Because of large variability of fat content over time, equal contents of fat across experimental milks were not obtained and HIGHB exhibited a greater fat content (+13%) compared with LOWB. Moreover, HIGHB exhibited a slightly greater content of α_{S1} -CN and κ -CN, which also increased TCN and PRT content relative to that of LOWB. The proportions of CN fractions in TCN were comparable across experimental milks, but a lesser β -CN B content in β -CN, associated with a greater proportion of β -CN A², was observed for HIGHB. Allele B of *CSN2* is reported to have positive effects on MCP (Buchberger and Dovč, 2000; Wedholm et al., 2006; Bonfatti et al., 2010a), and variation of the content of this variant in milk is expected to affect coagulation ability and possibly CY. Although a relevant difference in the proportion of β -CN_B% in total β -CN was observed, the content of β -CN B was similar for the 2 experimental milks. Because the content of κ -CN B was associated with that of β -LG B, β -LG genetic composition was unbalanced across the 2 experimental milks, with HIGHB exhibiting a higher content of β -LG B relative to that of β -LG A. The literature results for the effect of β -LG genetic variants on MCP and CY are conflicting. No significant differences in CY or MCP for milks of different phenotypes for β -LG have been reported (Marziali and Ng-Kwai-Hang, 1986a), but in most studies (Schaar et al., 1985; van den Berg et al., 1992; Lodes et al., 1996b), increased content of β -LG B has been associated with increased CY because of greater TCN to PRT content ratio relative to β -LG A. In our study, HIGHB and LOWB had very similar casein numbers, and HIGHB, which was expected to give an increased CY, had the lowest content of β -LG B.

Asiago Cheese Milks. Two experimental milks were processed to investigate the effect of κ -CN composition on CY of AS cheese. No relevant differences of contents and composition were observed between HIGHB and LOWB. Experimental milks exhibited similar contents of fat and TCN, CN composition (relative contents of α_{S1} -, α_{S2} -, β -, and κ -CN in TCN), and WH composition (relative contents of β -LG and α -LA in WH). Contents of all genetic variants for major CN fractions were also similar, with only the desired exception of κ -CN A and κ -CN B contents. As for MO trials, an increased proportion of β -LG B was observed for HIGHB. For the manufacturing of AS cheese, the difference in the relative content of κ -CN B across experimental milks was limited (κ -CN_B% was 39 and 25% of total κ -CN for HIGHB and LOWB milks, respectively) compared with variation of κ -CN_B% across herds supplying the dairies. This was mainly because of the large amount of milk required for processing (a minimum of 5,500 L), which

Table 3. Median $\pm$ SD of marginal posterior densities of experimental milk means for milk and protein composition¹

Item ²	Montasio		Asiago		Caciotta	
	HIGHB	LOWB	HIGHB	LOWB	HIGHB	LOWB
Fat, %	4.4 $\pm$ 0.2	3.9 $\pm$ 0.2	3.9 $\pm$ 0.1	3.9 $\pm$ 0.1	3.6 $\pm$ 0.1	3.6 $\pm$ 0.1
Protein, g/L	40.9 $\pm$ 1.0	38.8 $\pm$ 1.0	39.3 $\pm$ 0.6	40.1 $\pm$ 0.6	39.5 $\pm$ 0.7	37.6 $\pm$ 0.7
Casein, g/L	35.8 $\pm$ 0.9	33.8 $\pm$ 0.8	34.1 $\pm$ 0.4	34.6 $\pm$ 0.4	34.5 $\pm$ 0.6	32.9 $\pm$ 0.6
Whey protein, g/L	5.1 $\pm$ 0.2	5.0 $\pm$ 0.2	5.2 $\pm$ 0.2	5.4 $\pm$ 0.2	5.0 $\pm$ 0.1	4.7 $\pm$ 0.1
Casein number, %	87.3 $\pm$ 0.4	87.5 $\pm$ 0.4	86.8 $\pm$ 0.2	86.5 $\pm$ 0.2	87.4 $\pm$ 0.1	87.4 $\pm$ 0.1
Casein composition, %						
α_{S1} -CN	37.3 $\pm$ 0.4	36.6 $\pm$ 0.4	38.0 $\pm$ 0.1	38.2 $\pm$ 0.1	36.8 $\pm$ 0.2	36.7 $\pm$ 0.2
α_{S2} -CN	12.9 $\pm$ 0.3	13.7 $\pm$ 0.3	12.1 $\pm$ 0.2	12.3 $\pm$ 0.2	13.3 $\pm$ 0.2	13.2 $\pm$ 0.2
$\beta\gamma$ -CN	39.3 $\pm$ 0.4	39.5 $\pm$ 0.4	40.1 $\pm$ 0.1	40.1 $\pm$ 0.1	39.6 $\pm$ 0.1	39.8 $\pm$ 0.1
κ -CN	10.5 $\pm$ 0.1	10.3 $\pm$ 0.1	9.9 $\pm$ 0.3	9.4 $\pm$ 0.3	10.4 $\pm$ 0.1	10.1 $\pm$ 0.1
Whey protein composition, %						
α -LA	24.0 $\pm$ 0.6	25.0 $\pm$ 0.5	24.9 $\pm$ 0.9	25.9 $\pm$ 0.9	25.4 $\pm$ 0.3	25.5 $\pm$ 0.4
β -LG	76.0 $\pm$ 0.6	75.0 $\pm$ 0.5	75.1 $\pm$ 0.9	74.1 $\pm$ 0.9	74.6 $\pm$ 0.3	74.5 $\pm$ 0.4
κ -CN composition, %						
κ -CN A	39.2 $\pm$ 0.4	60.5 $\pm$ 0.4	61.4 $\pm$ 0.7	75.4 $\pm$ 0.7	47.8 $\pm$ 2.8	65.4 $\pm$ 2.9
κ -CN B	60.8 $\pm$ 0.4	39.5 $\pm$ 0.4	38.6 $\pm$ 0.7	24.6 $\pm$ 0.7	52.2 $\pm$ 2.8	34.6 $\pm$ 2.9
Glycosylated κ -CN	45.5 $\pm$ 0.7	47.1 $\pm$ 0.7	48.3 $\pm$ 0.7	49.7 $\pm$ 0.8	47.5 $\pm$ 0.7	49.0 $\pm$ 0.7
β -CN composition, %						
β -CN A ¹	24.1 $\pm$ 0.9	25.0 $\pm$ 0.9	29.7 $\pm$ 0.8	28.2 $\pm$ 0.8	26.9 $\pm$ 1.2	30.9 $\pm$ 1.2
β -CN A ²	52.7 $\pm$ 1.5	49.8 $\pm$ 1.4	52.7 $\pm$ 1.4	55.1 $\pm$ 1.4	50.7 $\pm$ 1.1	47.7 $\pm$ 1.1
β -CN B	18.1 $\pm$ 1.7	19.5 $\pm$ 1.7	11.0 $\pm$ 0.6	11.1 $\pm$ 0.6	16.3 $\pm$ 0.3	15.2 $\pm$ 0.4
γ -CN + β -CN F	5.1 $\pm$ 0.5	5.7 $\pm$ 0.5	6.6 $\pm$ 0.7	5.6 $\pm$ 0.7	6.1 $\pm$ 0.2	6.2 $\pm$ 0.2
β -LG composition, %						
β -LG A	38.6 $\pm$ 0.8	63.4 $\pm$ 0.5	45.2 $\pm$ 3.8	53.0 $\pm$ 3.8	43.5 $\pm$ 1.3	49.8 $\pm$ 1.3
β -LG B	61.4 $\pm$ 0.8	36.6 $\pm$ 3.6	54.8 $\pm$ 3.8	47.0 $\pm$ 3.8	56.5 $\pm$ 1.3	50.2 $\pm$ 1.3

¹Experimental milks had high (HIGHB) or low (LOWB) κ -CN B relative content in κ -CN.²Protein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN + β -LG + α -LA; casein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN; whey protein = β -LG + α -LA; casein number = (casein/protein) $\times$ 100.**Table 4.** Median $\pm$ SD of marginal posterior densities of experimental milk means for coagulation properties, whey and cheese composition, and cheese yield¹

Item	Montasio		Asiago		Caciotta	
	HIGHB	LOWB	HIGHB	LOWB	HIGHB	LOWB
Acidity						
pH	6.74 $\pm$ 0.04	6.73 $\pm$ 0.04	6.81 $\pm$ 0.03	6.81 $\pm$ 0.03	6.76 $\pm$ 0.04	6.78 $\pm$ 0.04
Titratable acidity, °SH/50 mL ²	3.22 $\pm$ 0.16	3.37 $\pm$ 0.16	2.79 $\pm$ 0.40	3.27 $\pm$ 0.41	3.24 $\pm$ 0.18	3.30 $\pm$ 0.18
Milk coagulation properties ³						
RCT, min	21.8 $\pm$ 1.1	21.2 $\pm$ 1.1	24.4 $\pm$ 0.6	24.6 $\pm$ 0.5	22.0 $\pm$ 2.4	22.1 $\pm$ 2.3
K ₂₀ , min	2.3 $\pm$ 0.3	2.4 $\pm$ 0.2	3.5 $\pm$ 0.7	3.0 $\pm$ 0.7	2.7 $\pm$ 0.5	2.4 $\pm$ 0.5
a ₃₀ , min	37.1 $\pm$ 2.0	36.9 $\pm$ 2.0	27.9 $\pm$ 3.7	30.2 $\pm$ 3.5	36.4 $\pm$ 3.3	35.5 $\pm$ 3.3
Whey composition						
DM	6.4 $\pm$ 3.1	6.7 $\pm$ 3.1	7.0 $\pm$ 0.0	7.0 $\pm$ 0.0	7.2 $\pm$ 0.1	7.1 $\pm$ 0.1
Protein, % of DM	14.0 $\pm$ 5.9	14.3 $\pm$ 5.9	12.7 $\pm$ 0.2	12.9 $\pm$ 0.2	12.2 $\pm$ 0.2	12.7 $\pm$ 0.2
Fat, % of DM	9.8 $\pm$ 8.4	9.7 $\pm$ 8.4	10.1 $\pm$ 1.4	9.7 $\pm$ 1.4	15.9 $\pm$ 0.4	16.4 $\pm$ 0.4
Ash, % of DM	7.6 $\pm$ 3.8	7.9 $\pm$ 3.8	7.4 $\pm$ 0.0	7.3 $\pm$ 0.0	7.2 $\pm$ 0.2	6.9 $\pm$ 0.2
Cheese yield, %						
After brine	12.1 $\pm$ 0.2	11.4 $\pm$ 0.2	11.6 $\pm$ 0.1	11.4 $\pm$ 0.1	12.8 $\pm$ 0.2	12.5 $\pm$ 0.2
After aging	10.7 $\pm$ 0.2	10.2 $\pm$ 0.2	10.9 $\pm$ 0.1	10.8 $\pm$ 0.1	11.7 $\pm$ 0.2	11.4 $\pm$ 0.2
Cheese composition						
DM	63.5 $\pm$ 1.4	63.7 $\pm$ 1.3			56.5 $\pm$ 1.3	56.6 $\pm$ 2.1
Protein, % of DM	37.5 $\pm$ 0.4	38.3 $\pm$ 0.3			38.0 $\pm$ 0.7	37.2 $\pm$ 0.9
Fat, % of DM	50.1 $\pm$ 1.2	49.7 $\pm$ 1.1			49.8 $\pm$ 1.1	51.2 $\pm$ 1.1
Ash, % of DM	6.3 $\pm$ 0.2	6.3 $\pm$ 0.2			6.3 $\pm$ 0.4	6.3 $\pm$ 0.3

¹Experimental milks had high (HIGHB) or low (LOWB) κ -CN B relative content in κ -CN.²°SH/50 mL = Soxhlet-Henkel degree.³RCT = rennet clotting time; K₂₀ = curd firming time; a₃₀ = curd firmness.

Table 5. Median of marginal posterior densities and probability of relevance ($P|\Delta| > 8\%$) for the difference Δ between means of experimental milks in relation to milk, whey and protein composition, and milk coagulation properties¹

Item ²	Montasio		Asiago		Caciotta	
	Median	$P \Delta > 8\%$	Median	$P \Delta > 8\%$	Median	$P \Delta > 8\%$
Fat, %	13.0	74	1.9	1	0.2	0
Protein, g/L	5.7	21	4.4	6	4.9	10
Casein, g/L	6.2	25	-1.6	2	4.9	9
Whey protein, g/L	1.8	25	-4.8	19	5.0	14
Casein number, %	0.3	0	0.4	0	-0.0	0
Casein composition, %						
α_{S1} -CN	2.0	0	-0.5	0	-0.6	0
α_{S2} -CN	-5.5	15	-1.9	2	0.8	1
$\beta\gamma$ -CN	-0.4	0	-0.2	0	-0.5	0
κ -CN	2.4	0	5.4	23	3.4	1
Whey protein composition, %						
α -LA	-4.6	8	-4.0	20	1.6	10
β -LG	1.4	0	1.4	0	-0.5	0
κ -CN composition, %						
κ -CN A	-36.3	100	-18.6	93	-24.5	100
κ -CN B	51.4	100	57.4	82	53.4	95
Glycosylated κ -CN	-3.4	2	-2.8	2	-2.9	1
$\beta\gamma$ -CN composition, %						
β -CN A ¹	-3.6	21	5.5	22	-11.9	83
β -CN A ²	6.6	33	-4.3	13	6.1	25
β -CN B	-6.1	45	-1.7	21	8.7	62
γ -CN + β -CN F	-10.5	67	18.1	79	-1.7	10
β -LG composition, %						
β -LG A	-40.5	99	-14.6	96	-12.0	76
β -LG B	63.9	99	16.3	82	13.0	77
Acidity						
pH	0.2	0	-0.1	0	-0.2	0
Titratable acidity, °SH/50 mL ³	-4.7	66	-14.1	76	-1.7	26
Milk coagulation properties ⁴						
RCT, min	2.7	59	-0.7	43	-0.6	57
K ₂₀ , min	-3.7	74	16.3	83	8.5	75
a ₃₀ , min	0.5	51	-7.4	73	2.8	54
Whey composition						
DM	-4.5	0	0.0	0	1.4	0
Protein, %DM	-2.1	0	-1.6	0	3.9	10
Fat, %DM	0.1	0	4.1	16	-3.5	6
Ash, %DM	-3.8	9	0.1	0	4.3	18

¹Experimental milks had high (HIGHB) or low (LOWB) κ -CN B relative content in κ -CN; Δ was computed as (HIGHB - LOWB)/LOWB $\times$ 100; $P|\Delta| > 8\%$ is the probability that the absolute value of Δ is greater than 8%.

²Protein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN + β -LG + α -LA; casein = α_{S1} -CN + α_{S2} -CN + $\beta\gamma$ -CN + κ -CN; whey protein = β -LG + α -LA.

³°SH/50 mL = Soxhlet-Henkel degree.

⁴RCT = rennet clotting time; K₂₀ = curd firming time; a₃₀ = curd firmness.

reduced variation of κ -CN_B% and did not allow us to obtain experimental milks with greater differences in terms of κ -CN genetic composition.

Caciotta Cheese Milks. For the composition of vat milk of CA manufacture, a difference in the relative proportion of κ -CN B in κ -CN of approximately 20% for the 2 experimental milks was obtained. Compared with LOWB, HIGHB exhibited a slightly greater amount of PRT content because of increased CN and WH contents, but these differences were not relevant. Within CN fractions, HIGHB had a greater content of κ -CN (+8% compared with LOWB). However, the relative proportion of κ -CN to TCN was very similar in

both milks. Also, HIGHB exhibited a greater content of β -CN B and A², and a smaller amount of β -CN A¹, in β -CN compared with that in LOWB milk. The relative proportions of CN fractions were well balanced.

Whey Composition

No difference for pH and contents of protein fractions was observed in cheese whey from LOWB and HIGHB (data not reported in tables). In addition, DM, ash, protein, and fat contents of whey did not vary across experimental milks and exhibited a probability of a relevant difference, at most, of 18%. Conversely, other

authors reported decreased contents of fat in Cheddar (Walsh et al., 1995, 1998b), Gouda (van den Berg et al., 1992), and Mozzarella (Walsh et al., 1998a) cheese whey obtained when manufacturing κ -CN BB milk. These findings were attributed to finer gel networks and to the resulting smaller porosity of gels derived from κ -CN BB milks causing increased fat retention. Likely, this effect was reduced when milks with similar κ -CN contents were processed.

Milk Coagulation Properties

Posterior medians and highest posterior density (HPD) intervals for the effect of experimental milk on MCP are reported in Tables 3, 4 and 5, for MO, AS, and CA, respectively. The probability of a relevant $\Delta\%$ for MCP is also reported.

Although a slight variation of MCP across experimental milks was observed, MCP were not more favorable for HIGHB than for LOWB. Moreover, all the HPD intervals for the difference between experimental milks contained zero. A slightly higher titratable acidity was observed for LOWB compared with HIGHB, even if pH was similar across experimental milks. Because MCP are strictly related to acidity, a lacking difference in pH across experimental milks has likely reduced variation of MCP between HIGHB and LOWB.

In a previous study (Walsh et al., 1998b) conducted using milks with similar contents of CN, κ -CN BB milk had shorter RCT and higher a_{30} compared with κ -CN AA milk. It has been suggested (Horne et al., 1996) that the decreased RCT of κ -CN BB milk results from a lower critical level of κ -CN hydrolysis required for the onset of gelation. However, this property might be ascribed to the increased κ -CN content of BB milk. Because, for a given CN content, the curd firming rate has been reported to be inversely proportional to the cube of the micelle diameter (Horne et al., 1996) and the micelle size is smaller when κ -CN content is greater, the enhanced curd firming rate of κ -CN BB milk might be attributable to the decreased average micelle size exhibited by this milk, which increases the number of intermicellar bonds and ensures a more compact arrangement of the curd (Horne et al., 1996). In agreement with our results, when the statistical analysis of MCP data has accounted for variation in protein fraction content or protein composition, no significant effect of *CSN3* alleles on RCT and a_{30} has been observed (Marziali and Ng-Kwai-Hang, 1986b; Bonfatti et al., 2010a). Results of this study indicate that the favorable effects exerted by *CSN3* B on MCP are to be attributed to modifications of protein composition caused by the differential expression of this allele and not to direct

effects of the protein genetic variant on the coagulation process.

Cheese Yield

A difficulty when comparing CY of experimental milks is the small sample size achievable in this type of study. Moreover, relevance of effects is often difficult to evaluate. In this study, statistical inference for the difference between means of experimental milks was based on the estimated marginal posterior probability densities. These procedures ensured high flexibility for interpretation of results when the probability of a relevant difference across experimental milks was investigated.

The posterior median and 95% HPD interval for the relative difference between mean CY of HIGHB and LOWB are reported in Table 6. The probability that HIGHB gave greater CY compared with LOWB and the probability of a relevant (i.e., >5%) CY increase for HIGHB relative to LOWB are also reported.

All estimated HPD for CY1 and CY2 included zero. However, mean CY1 and CY2 for HIGHB were greater than those for LOWB with a probability that ranged from 70 to 98% across cheese varieties. In the literature, the minimum increase of CY for κ -CN BB milk relative to κ -CN AA milk was 5%. Hence, we considered a 5% increase in CY as a relevant $\Delta\%$ and focused on the posterior probability for $\Delta\%$ of being greater than 5%. The probability of a relevant $\Delta\%$ was much smaller than the probability of $\Delta\%$ of being greater than zero. Only for MO cheese, the probability that $\Delta\%$ was relevant was rather high (67 and 51% for CY1 and CY2, respectively). However, the increased CY observed in MO trials for HIGHB can be ascribed to its greater fat content compared with LOWB. Regression analyses reported by Marziali and Ng-Kwai-Hang (1986a) indicated that for a 1% increase in milk fat content a 1.07% increase in CY is to be expected, whereas, for a similar increase in CN content, a 1.59% increase in CY is likely to occur. For MO cheese, HIGHB had a fat content 13% higher than that of LOWB and the probability that this difference was relevant (i.e., greater than 8%) was nearly 75%. When CY data were adjusted for the fat content of milk, the increase of CY for HIGHB, compared with LOWB, was less than 1%, and the probability of obtaining a relevant difference across experimental milks was trivial (data not presented in tables).

Although a slightly higher CY was observed for HIGHB compared with LOWB, no relevant effect of the relative κ -CN B content in κ -CN on CY was detected for industrial-scale cheese making of AS and CA. When milk composition was comparable across experimental milks, as for AS and CA cheese-making trials,

Table 6. Median, 95% highest posterior density interval (HPD95%), and probability of being positive ($P\Delta > 0$, %) or relevant ($P|\Delta| > 5\%$, %) for the difference Δ between means of experimental milks in relation to cheese yield (%) after brine and after aging for Montasio, Asiago, and Caciotta cheese^{1,2}

Item	Cheese		
	Montasio	Asiago	Caciotta
Cheese yield after brine			
Median	5.9	1.3	2.3
HPD95%	−0.2 to 11.9	−0.8 to 3.2	−3.1 to 8.1
$P\Delta > 0$	98	92	83
$P \Delta > 5\%$	67	0	14
Cheese yield after aging			
Median	5.5	0.4	2.9
HPD95%	−1.1 to 11.7	−1.4 to 2.4	−3.2 to 9.7
$P\Delta > 0$	85	70	87
$P \Delta > 5\%$	51	0	21

¹Experimental milks had high (HIGHB) or low (LOWB) κ -CN B relative content in κ -CN; Δ was computed as $[(\text{HIGHB} - \text{LOWB})/\text{LOWB}] \times 100$; $P|\Delta| > 5\%$ is the probability that the absolute value of Δ is greater than 5%.

²Cheese yield after brine was measured at d 2 for Montasio and Caciotta and d 3 for Asiago cheese; cheese yield after aging was measured for Montasio, Asiago, and Caciotta at d 60, 20, or 10, respectively.

the probability that HIGHB gave a 5% higher CY than that obtained with LOWB was 21% at most. Likely, the slightly higher CY associated with HIGHB is to be attributed to its slightly higher TCN or κ -CN content.

In most investigations involving Parmigiano-Reggiano, Cheddar, or other cheese varieties, increases in yield of cheese ranging from 5 to 10% of that of κ -CN AA milk were obtained when manufacturing κ -CN BB milk (Buchberger and Dovč, 2000). For example, moisture-adjusted Cheddar CY of κ -CN BB milk was 8.2% greater than that of κ -CN AA milk, whereas, for Mozzarella cheese, moisture-adjusted CY was 12% greater for κ -CN BB milk (Walsh et al., 1998a,b).

In contrast with most studies, Schaar et al. (1985) obtained no significant effect of *CSN3* polymorphism on CY of Swedish cheese Svecia and attributed inconsistencies of results, relative to those obtained by Morini et al. (1982) for Parmigiano-Reggiano, to the higher cooking temperature used for manufacturing Parmigiano-Reggiano (55°C) than that used for Svecia (41°C), which supports syneresis and promotes fat retention in cheese. However, significant effects of *CSN3* polymorphism on CY were obtained by Walsh et al. (1998b) for Cheddar cheese with a cooking temperature of 31°C, indicating that inconsistencies of results reported by Schaar et al. (1985) for Svecia cannot be ascribed to differences in cooking temperature across cheese varieties.

To date, most studies investigated effects of κ -CN genetic variants on CY by processing milk of cows grouped on the basis of their *CSN3* genotype, with no assessment of milk protein composition (van den Berg et al., 1992; Lodes et al., 1996a). The only exception is the study by Marziali and Ng-Kwai-Hang (1986a).

In that study, significant effects of *CSN3* genotypes on CY were observed, even when accounting for variation in protein composition, and differences were detected between *CSN3* AB and BB genotypes but not between AA and BB genotypes. In addition, the content of the 2 κ -CN variants in milk was not quantified in that study. Several studies (Hallén et al., 2008; Heck et al., 2009) reported that milk produced by heterozygous animals contains intermediate amounts of both variants compared with milk from homozygous animals, suggesting that the effect observed by Marziali and Ng-Kwai-Hang (1986a) cannot be attributable to a difference in the relative content of genetic variants in κ -CN.

In the literature, evidence exists of differences in coagulation and cheese-making properties between κ -CN AA and BB milks containing similar CN levels in relation of milk. Using small milk volumes and a limited number of samples, Walsh et al. (1998b) reported that the *CSN3* genotype had a significant effect on Cheddar CY obtained from milks with similar contents of total CN. Although overall CN content did not differ across milks of different *CSN3* genotypes, content of κ -CN was not quantified in the study of Walsh et al. (1998b) and possible effects due to variation in protein composition associated with *CSN3* genotypes cannot be ignored. In that study, the average micelle size for κ -CN B bulk milk was significantly smaller than that for κ -CN A milk (Lodes et al., 1996b; Walsh et al., 1998b). A decreased average micelle size has been associated to the increased κ -CN content exhibited by κ -CN B milk (Lodes et al., 1996a).

The increased raw and moisture-adjusted CY of κ -CN BB milk has been attributed to its higher fat retention relative to AA milk. Such feature is related to finer

Table 7. Median, 95% highest posterior density interval (HPD95%), and probability of relevance ($P|\Delta| > 5\%$, %) for the difference Δ between means of experimental milks in relation to composition of Montasio and Caciotta cheese at the end of the aging period¹

Item	Cheese	
	Montasio	Caciotta
DM		
Median	-0.41	0.37
HPD95%	-2.57 to 1.85	-3.78 to 4.70
$P \Delta > 5\%$	0	6
Protein, % of DM		
Median	-2.11	0.34
HPD95%	-4.95 to 0.51	-2.00 to 2.67
$P \Delta > 5\%$	7	0
Fat, % of DM		
Median	0.70	-3.26
HPD95%	-3.43 to 4.99	-6.7 to 0.29
$P \Delta > 5\%$	7	21
Ash, % of DM		
Median	-0.53	-4.83
HPD95%	-5.55 to 4.97	-13.74 to 5.20
$P \Delta > 5\%$	14	56

¹The aging period was 60 d for Montasio and 10 d for Caciotta; experimental milks had high (HIGHB) or low (LOWB) κ -CN B relative content in κ -CN; Δ was computed as $[(\text{HIGHB} - \text{LOWB})/\text{LOWB}] \times 100$; $P|\Delta| > 5\%$ is the probability that the absolute value of Δ is greater than 5%.

gel structure and greater fat-retaining ability (Walsh et al., 1998b), resulting from the increased content of total κ -CN, of κ -CN BB milk relative to κ -CN AA milk. When Cheddar CY was adjusted for variation in protein and fat content, no difference was observed across milks of different *CSN3* genotypes (Walsh et al., 1998b), whereas, for Mozzarella, CY from κ -CN BB milk remained significantly higher than that from κ -CN AA milk (Walsh et al., 1998b). In both those studies the increase in CY associated with processing of κ -CN BB milk was nearly 5%. In all previous studies, milk containing exclusively κ -CN A or B was used, thus ensuring large variation in κ -CN genetic composition. In our study, the limited effect observed when comparing CY of HIGHB and LOWB might be partly due to the fact that variation in κ -CN genetic composition of experimental milks was too small to determine a relevant difference in CY.

Cheese Composition

Posterior median, HPD, and probability of being relevant for the difference between means of experimental milks relative to MO and CA cheese composition are reported in Table 7. Cheese composition did not vary across experimental milks in MO trials, but a variation in the ratio of protein to fat content in CA cheese was detected. In particular, for HIGHB, we observed a decrease in fat content of cheese associated with an

increase in protein content compared with LOWB. In 2 cheese-making experiments focusing on the manufacture of Gouda cheese, a slightly higher conversion of total nitrogen of milk into cheese nitrogen was observed for κ -CN BB milk relative to κ -CN AA milk (van den Berg et al., 1992). However, increased recovery of fat into cheese manufactured using κ -CN BB milks has been also observed in several studies (Walsh et al., 1995, 1998b). As a consequence of inconsistent results across studies, the effects of κ -CN genetic variants on cheese composition remain unclear.

CONCLUSIONS

Results of this study indicate that variation in cheese yield attributable to effects of genetic variants A and B at *CSN3* is small when milks of similar protein composition and contents are processed. It is likely that the favorable and widely recognized effect of κ -CN B on cheese yield is almost exclusively caused by the mediated effect of the increased κ -CN content of κ -CN B milk and not by a direct effect of this variant on the efficiency of the coagulation process. Further evidence might be provided by cheese-making experiments processing milks of similar κ -CN B content in κ -CN, but differing for the relative content of κ -CN in total CN. Cheese-making trials might be conducted to investigate the effect of variation in the relative content of β -CN in total CN and in the genetic composition of β -CN. Moreover, this protein fraction exhibits allele-specific expressions, occurring mostly with *CSN2* B, and its effect on cheese yields needs to be investigated more accurately. A major issue for industrial cheese-making trials is related to the amount of milk required, which markedly restricts the number of samples and the size of experiments. Methodologies that make feasible the assessment of cheese yield using a reduced amount of milk should be developed and implemented.

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