

Composition, coagulation properties and Parmigiano-Reggiano cheese yield of Italian Brown and Italian Friesian herd milks

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The authors report the results of a study aimed at the comparison of the basic chemical composition, the main protein fractions distribution, rennet coagulation properties and Parmigiano-Reggiano cheese yield of vat milk from Italian Brown and Italian Friesian herds. Parmigiano-Reggiano cheese factories which manufacture milk separately from Italian Brown herds and Italian Friesian herds were used in the study. Thirteen cheesemaking trials were performed at 10 different commercial cheese factories. The study was carried out from March to October 2003. For each cheesemaking trial in each factory, approximately 1100 kg milk from Italian Brown cows and from Italian Friesian cows were processed in parallel. The animals involved in the study came from farms with comparable management practices, size, location, number of lactation and days in milking. Each vat contained milk obtained by combining milk collected during the evening milking (partially skimmed milk by natural creaming) and the following morning milking (full-cream milk), from at least 2 dairy herds. Milk from Italian Brown cows is characterised by a higher casein content (27.1 v. 23.7 g/kg; $P \leq 0.0001$) than Italian Friesian cows' milk. Curd firming time (k_{20}) of Italian Brown cows' milk was markedly lower than that of Italian Friesian cows' milk (6.6 v. 10.0 min; $P \leq 0.001$). This implies a higher rate of aggregation of para-casein micelles for Italian Brown cows' milk. The coagulum of Italian Brown cows' milk had better rheological properties and lower losses of fat in the cheese whey. Parmigiano-Reggiano cheese yield at 24 h was also higher for Italian Brown cows' milk, +0.99 kg cheese for every 100 kg vat milk.

Keywords: Cattle breed, rennet coagulation properties, cheese yield, Parmigiano-Reggiano cheese.

Genetic factors play an important role in defining milk quality for cheesemaking (Martin et al. 2003; Ng-Kwai-Hang & Grosclaude, 2003; Coulon et al. 2004). Differences in milk production and chemical composition are quite apparent between cattle breeds (Mariani & Pecorari, 1987; Macheboeuf et al. 1993; Malossini et al. 1996; Campo et al. 1999; Chiofalo et al. 2000; Auldust et al. 2002, 2004). This variation influences the technological properties, for example cheese quality and yield (Mariani & Pecorari, 1987; Auldust et al. 2002; Mistry et al. 2002).

Over 75% of Italian milk production is destined for cheesemaking (995 000 tonnes of cheese produced).

Parmigiano-Reggiano represents approximately 15% (111 444 tons of cheese) of Italian cheese production and it is the second national PDO (Product of Designated Origin) cheese in tons produced. Parmigiano-Reggiano is a part-skim, hard-textured, cooked, and long aged cheese (about 2 years of ripening) (Battistotti & Corradini, 1993). It can be produced only in the area of origin (provinces of Parma, Reggio Emilia, Modena, Mantua on the right bank of the river Po and Bologna on the left side of the river Reno). It is made from the milk of cows that are mainly fed with fodder grown in the region of origin, and following strict manufacturing procedures (Council Regulation, 1992; www.parmigiano-reggiano.it). Only raw, unheated milk may be used, the use of additives is strictly forbidden and the diet of the dairy cows is strictly regulated.

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The total number of dairy cows in the Parmigiano-Reggiano district is 336,000, representing 15% of the entire Italian dairy cattle population. A large number of Dutch Friesian cattle were imported during the 1950s and by the 1970s they began replacing local breeds completely. Currently, Italian Friesian cows make up 85% of the cows of Parmigiano-Reggiano herds. About 60% of semen used in Italian Friesian cows herds comes from Holstein-Friesian sires (Maltecca et al. 2002). There are also a substantial number of Italian Brown cows (15%). Finally, 2 native breeds – Reggiana and Bianca Modenese – are relatively insignificant when compared to total herd size.

Due to EU restrictions on milk production (milk quotas) and the introduction of a milk quality payment system for Parmigiano-Reggiano cheese, there is new interest in those cattle breeds that produce milk of high quality.

The differences in milk composition and coagulation properties among the cattle breeds reared in the Parmigiano-Reggiano cheese production area have been reported by Pecorari et al. (1987) and Mariani et al. (2001), both at the level of the individual cow and the herd. There are, however, no studies on the effect of breed on chemical characteristics and dairy-technological properties of milk from the cheese vat (vat milk). Vat milk is the basis for the cheesemaking process and is obtained by mixing of evening milk (partially skimmed by natural creaming) and full-cream milk of the following morning.

The present study is aimed at comparing the basic chemical composition, the main protein fraction distribution, rennet coagulation properties and Parmigiano-Reggiano cheese yield of vat milk from pure breed herds.

Materials and Methods

Experimental design and milk sampling

Thirteen cheesemaking trials were made at 10 different commercial cheese factories producing Parmigiano-Reggiano cheese in the provinces of Parma and Reggio Emilia. The cheesemaking trials involved 34 herds of Italian Brown (IB) cows and 34 herds of Italian Friesian (IF) cows. Size, location (plains or hill-mountains), management practices and feeding were comparable between herds. The average size of IB herds was 20.6 ± 12.2 , IF herds was 19.8 ± 12.3 cows. Twenty two herds of both breeds were located in the plains and their sizes were 30.0 ± 9.3 IB and 30.8 ± 9.8 IF cows. The remaining herds were located in hill-mountains and their sizes were 16.1 ± 10.8 IB and 14.5 ± 9.6 IF cows. The mean values for IB and IF cows were 21.16 ± 5.09 and 26.97 ± 6.15 (kg/d) for milk production per cow; 3.3 ± 0.8 and 3.0 ± 0.6 for lactation number and 191.2 ± 41.7 and 155.3 ± 23.6 for days of milking respectively. The management conditions were comparable between herds of the two breeds: cows were milked two times a day and the housing system was tie-stall. The influences of feeding were not evaluated as feeding of cows producing milk for Parmigiano-Reggiano

cheesemaking is strictly regulated by the Consortium of Parmigiano-Reggiano cheese (http://.parmigiano-reggiano.it/ilconsorzio-regolamento_alimentazione_bovine.cfm). The cheesemaking trials were carried out from March to October during 2003: 4 trials in March, 2 in April, 4 in June, 1 in September, and 2 trials in October.

Cheese was produced by the approved method of the Consortium (council Regulation, 1992). Briefly, milk was processed once a day beginning in the early morning. Evening milk is left in special settling tanks over-night and the fat rises naturally to the surface (natural creaming). The natural creaming process, or gravity separation, is a critical processing step in Parmigiano-Reggiano cheese production, which influences the chemical, physico-chemical, and microbiological characteristics and coagulation properties of the milk (Dellaglio et al. 1969; Bottazzi, 1975; Ma & Barbano, 2000). Following fat separation, the partially skimmed raw milk containing $\sim 2.0\%$ fat is drained from the bottom of the settling tanks and transferred to the cheese vat. Whole milk from the morning milking is added in order to obtain a fat:casein ratio near 1. Once the milk is in the vat (vat milk: part skimmed milk of the evening milking+full cream milk of the morning milking), the cheese-making process begins. Each vat contains ~ 1100 kg milk. The first step is to add the natural whey starter ($2.5\text{--}3.3$ l for every 100 l vat milk). This come from the naturally acidified cheese whey derived from the previous day's cheesemaking and enriches the milk with lactic acid bacteria beneficial to the cheesemaking process (Bottazzi, 1981). The milk is heated to 33°C , and calf rennet is added: 10 ml coagulates 1 l milk at 35°C in 4 mins. The coagulation process begins within about 10 mins. The curd is then broken up into small granules. In the cooking phase the temperature is increased from 33°C to 55°C for about 10–15 mins. During the cooking the curd is agitated continuously. The broken-up curds aggregate and blend together spontaneously through simple decantation when, during the so-called resting period, they deposit at the bottom of the vat. In this step the temperature is $55\text{--}53^\circ\text{C}$ and the process lasts 45–60 mins. The result is a well-consolidated cheese mass that is removed from the vat and placed in special moulds. After a short phase of gradual cooling and drying (2–3 days), the wheels of cheese are placed into saturated brine for a period of 20–25 days. Finally, the cheese enters the ripening phase, a process that lasts about two years.

One vat of IB milk and one vat of IF-milk was used for each cheesemaking trial at each single cheese factory. Each vat contained the daily milk production (evening milking+morning milking of the next day) of at least 2 dairy herds. Due to their lower size, when hill-mountain herds were involved in the trial, the milk produced from a higher number of herds (4–5) was necessary to fill the vat.

Analyses of milk composition, coagulation parameters and rheological properties were carried out twice on milk sampled from the vat before the adding of the natural whey starter. Compositional analyses were carried out

on the cheese whey collected after cheese mass extraction from the vat.

Milk and cheese whey compositional analyses

The following traits were measured in duplicate on the same milk samples: pH with a potentiometer, titratable acidity with 0.25 M-NaOH using the Soxhlet-Henkel method (Anon, 1963) and fat and lactose by infrared analysis (Biggs, 1978) with a Milko-Scan 134 A/B (Foss Electric, DK-3400 Hillerød, Denmark). Total nitrogen (TN) in milk, non-casein nitrogen (NCN) in acid whey at pH 4.6 and non-protein nitrogen (NPN) in milk after treatment with trichloroacetic acid (TCA; 120 g/l), were determined by Kjeldahl method (Aschaffenburg & Drewry, 1959). From these, total protein ($TN \times 6.38$), casein $((TN - NCN) \times 6.38)$, whey protein $((NCN - NPN) \times 6.38)$, and casein number (casein $\times 100$ /total protein) were calculated. The following components were determined: total calcium and soluble calcium in milk and rennet whey, respectively (De Man, 1962); total phosphorus in milk, soluble phosphorus in rennet whey and acid-soluble phosphorus in milk after treatment with TCA (120 g/l) (Allen, 1940); distribution of calcium and phosphorus fractions (White & Davies 1958). Chloride was measured by titration with $AgNO_3$ using the volumetric method of Charpentier-Volhard (Savini, 1946).

Some analytical determinations also concerned cooked whey: total nitrogen, calcium, phosphorus and fat according to the Gerber method.

Analyses of milk coagulation properties

To milk samples (10 ml) 0.2 ml (1:100) rennet solution (1:19000; Chr. Hansen, I-20094 Corsico MI, Italy) was added. The coagulation characteristics, milk clotting time (t), curd firming time (k_{20}) and curd firmness (a_{30}), were measured at 35 °C (McMahon & Brown, 1982) using a Formagraph (Foss Electric). Milk clotting time is the time from the addition of rennet to the onset of gelation. Curd firming time is the time from the onset of gelation till the signal attains a width of 20 mm. Curd firmness is the width of the signal 30 min after the addition of rennet.

Analyses of milk rheological properties

Resistance to compression and resistance to cut of the coagulum were measured 30 min after the beginning of coagulation, using the Gel Tester apparatus (Marine Colloids Inc. Springfield, NJ 07081, USA (Annibaldi, 1973)).

Cheese yield

The two wheels obtained from each cheesemaking process were weighed 24 h after extraction from the cheese vat. Cheese yield was expressed as kg cheese obtained per 100 kg milk from the vat.

Statistical analyses

The effect of breed on the following milk traits was studied: content of protein, calcium, phosphorus and their fractions, chloride content, casein number, casein:fat, pH, titratable acidity, coagulation parameters, rheological properties. Breed differences on cheese moisture content, cheese yield at 24 h, and content of protein, fat, calcium and phosphorus of the cheese whey were also studied. The significance of the differences was tested by analysis of variance, using the general linear model procedure of SPSS (11.5 version, Chicago, IL 60606, USA), according to the following univariate model:

$$Y_{ijk} = \mu + T_i + B_j + e_{ijk}$$

where: Y_{ijk} =dependent variable; μ =overall mean; T_i =effect of trial ($i=1$ to 13); B_j =effect of breed ($j=1, 2$); e_{ijk} =unexplained residual element. The effect of breed was classified in two classes: 1, vat milk samples from IB herds; 2, vat milk samples from IF herds. Linear regression analysis was used to determine simple correlations between the cheese yield and casein content, curd firming time, curd firmness and rheological properties.

Results

Milk composition

The chemical characteristics of the milk sampled in the vat, before addition of the natural whey starter, are shown in Table 1. IB-milk had higher content of all nitrogen fractions: casein (+14.4%; $P \leq 0.0001$), whey protein (+13.0%; $P \leq 0.0001$) and NPN $\times 6.38$ (+12.5%; $P \leq 0.01$), than IF-milk. The casein number was not statistically different between the two breeds. As expected, no differences were observed concerning the milk fat content. Lactose content was higher (+20%; $P \leq 0.05$) in IB-milk.

IB-milk also had higher content of the main milk mineral constituents, e.g. total calcium (+10.54%; $P \leq 0.0001$) and total phosphorus (+6.69%; $P \leq 0.0001$). Concerning the soluble fractions, no differences were observed for the calcium, whereas phosphorus content was significantly higher in IB-milk (+8.63%; $P \leq 0.001$). Concerning the colloidal fractions both calcium (+12.21% $P \leq 0.0001$) and phosphorus (+12.61% $P \leq 0.0001$) were higher in IB-milk. No significant differences were observed between the two milks when the colloidal quotas were reported per 100 g casein (Table 1). This indicated a similar mineral composition of the micelles of both milks.

The milk chloride content was higher in IF-milk (+9.33%; $P \leq 0.01$).

pH, titratable acidity and rennet coagulation parameters

Milk pH, titratable acidity and rennet coagulation parameters are showed in Table 2. Milk pH was not different

Table 1. Least square mean values of chemical composition, nitrogen fractions and mineral salts repartition of the vat milk (IB=Italian Brown; IF=Italian Friesian). 13 comparative cheesemaking trials

		IB	IF	SD	P value†
Total protein (TN × 6.38)	g/kg	34.9	30.7	0.8	****
Casein	g/kg	27.1	23.7	0.6	****
Whey protein	g/kg	6.1	5.4	0.2	****
NPN (× 6.38)	g/kg	1.8	1.6	0.1	**
Casein number	%	77.5	77.1	0.67	NS
Fat	g/kg	28.1	27.1	1.3	NS
Lactose	g/kg	51.0	50.0	0.8	*
Fat: casein		1.04	1.15	0.06	***
Total calcium	mg/kg	1207.6	1131.9	25.5	****
Colloidal Ca	mg/kg	833.2	742.5	28.3	****
Soluble Ca	mg/kg	374.4	389.3	23.5	NS
Soluble Ca %	%	31.0	34.4	3.61	***
Colloidal Ca/Casein	g/100 g casein	3.08	3.14	0.10	NS
Total phosphorus	mg/kg	973.2	880.4	25.0	****
Colloidal P‡	mg/kg	500.0	444.0	16.8	****
Colloidal inorganic P	mg/kg	270.4	240.6	15.5	**
Soluble P	mg/kg	463.2	426.4	21.6	***
Soluble P%	%	47.6	48.4	1.67	NS
Colloidal P/Casein	g/100 g casein	1.89	1.92	0.08	NS
Chloride (Cl ⁻)	mg/kg	962.5	1061.5	63.6	**

† NS = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, **** = $P \leq 0.0001$

‡ Corrected value for the lipide phosphate quota

while titratable acidity value of IB-milk was significantly higher ($P \leq 0.001$) than IF-milk ($+0.18$ °SH/50 ml). Milk clotting time (r) of the two milks was not statistically different. Curd firming time (k_{20}) of IB-milk was significantly lower than IF-milk (-34.3% ; $P \leq 0.001$). A lower numerical value for k_{20} translates into a higher curd firming rate. This implies a higher rate of aggregation of para-casein micelles for IB-milk. The curd firmness (a_{30}), measured 30 min after the addition of rennet, was higher for IB-milk ($+23.53\%$; $P \leq 0.0001$).

Rheological properties

The rheological properties of the coagulum obtained from IB- and IF-vat milk samples are shown in Table 2. Gel tester analyses offer the possibility of estimating the degree of elasticity of the rennet curd, and its resistance to compression and to cut. This provides technological information useful for an indirect evaluation of the strength of contraction of the curd and its capacity for draining (Annibaldi, 1973). IB-milk had higher values for both resistances to compression ($+36.51\%$; $P \leq 0.0001$) and to cut ($+47.99\%$; $P \leq 0.0001$).

Table 2. Least square mean values of pH, titratable acidity, rennet-coagulation parameters and rheological properties of the milk sampled in cheese-vat (IB=Italian Brown; IF=Italian Friesian). 13 comparative cheesemaking trials

		IB	IF	SD	P value†
pH		6.72	6.71	0.03	NS
Titratable acidity‡	°SH/50 ml	3.42	3.24	0.11	***
<i>Coagulation parameters:</i>					
Clotting time, r	min	18.62	18.36	1.33	NS
Curd firming time, k_{20}	min	6.57	10.00	1.55	***
Curd firmness, a_{30}	mm	31.32	24.24	4.05	***
<i>Rheological properties:</i>					
Resistance to compression§	g	32.64	23.91	2.63	****
Resistance to cut§	g	73.46	49.64	7.40	****

† NS = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, **** = $P \leq 0.0001$

‡ Soxhlet-Henkel acidity: ml 0.25 M-NaOH for 50 ml of milk

§ Measure made by Gel Tester 30 minutes after the beginning of rennet-coagulation

Cheese yield

The cheese yield at 24 h, the composition of the cooked whey after cheese mass extraction from the vat and relative percentage of matter loss into cheese-whey are reported in Table 3. The moisture content of cheese after the extraction from the vat was measured in 8 cheese-making trials: 43.93% IB-milk and 43.85% IF-milk ($P > 0.05$). As no difference in the moisture content of cheese was observed between the milks of the two breeds, the cheese yield was not adjusted for this parameter. Cheese yield from IB-milk was markedly higher than IF-milk ($+12.48\%$; $P \leq 0.0001$). This difference corresponds to approximately 1 kg cheese per 100 kg milk in the cheese vat. IB-milk was characterised by higher cheese yield in all the cheesemaking trials, and the differences ranged from a minimum of 0.44 to a maximum of 1.72 kg cheese. The contents of protein and phosphorus were higher in the cheese whey obtained from IB-milk, whereas no differences were observed for the calcium content. IF-vat milk showed higher relative losses of fat and calcium in the cheese whey. However, the higher loss of calcium was related to the higher proportion of soluble calcium observed in the milk of IF-milk (see Table 1).

Discussion

The chemical composition of vat milk of IB-cows was clearly different from that of IF-cows. Casein content of vat milk plays a fundamental role in cheesemaking process, both for the direct effect on the cheese yield and towards rheological properties of the curd. Milk with higher casein content provides curds with higher contraction strength

Table 3. Least square mean values of Parmigiano-Reggiano cheese yield, composition of cooked whey and matter loss into cheese-whey (IB=Italian Brown; IF=Italian Friesian). 13 comparative cheesemaking trials

		IB	IF	SD	P value†
Cheese yield at 24 h‡		8.92	7.93	0.26	****
<i>Cooked whey composition:</i>					
Protein	g/100 g	0.94	0.82	0.03	****
Fat	g/100 g	0.44	0.49	0.06	*
Calcium	mg/100 g	39.21	40.69	2.61	NS
Phosphorus	mg/100 g	47.96	43.83	2.49	***
<i>Matter loss into cheese-whey:</i>					
Protein	%	26.77	26.77	1.00	NS
Fat	%	15.54	18.23	2.05	**
Calcium	%	32.62	35.92	2.13	**
Phosphorus	%	49.29	49.77	1.89	NS

† NS = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, **** = $P \leq 0.0001$

‡ kg of cheese every 100 kg of milk from the vat

and granules of curd are characterised by a better syneresis (Fossa et al. 1994). The higher casein content of IB-milk observed in this study is in agreement with the observations reported in other studies carried out on herd milks in the Parmigiano-Reggiano cheese production area (Mariani et al. 2001). However, the values reported in the present study were slightly higher because of the natural creaming of evening milk, which 'concentrated' casein. Other studies carried out on herd (Campo et al. 1999) and individual (Malossini et al. 1996) milk samples confirm the higher casein content of IB-milk with respect to IF-milk.

The higher contents of total calcium and phosphorus of IB-milk registered in this study agree with the observation of Mariani et al. (2001) on herd milk samples. The difference observed was probably related to the higher casein content of IB-milk. Other studies (Malossini et al. 1996) observed no differences between the two breeds at level of individual milk samples.

Even though the addition of natural whey starter can provoke significant modifications of the vat milk features, the original rennet coagulation parameters represent the major indicator of milk behaviour during the whole cheesemaking process and during ripening. A higher curd firming rate positively affects firmness and, above all, overall rheological features. Others studies, in agreement with the present research, report higher curd firming rate and higher curd firmness for IB- relative to IF-milk, both at the levels of individual milk (Pecorari et al. 1987; Malossini et al. 1996) and herd milk (Mariani et al. 2001). Among the various factors affecting curd firming rate, important roles are played by pH, by titratable acidity, by soluble calcium content (Mehaia & Cheryan, 1983)

Table 4. Simple correlations coefficient between yield parameters (cheese yield and fat loss) and casein content, coagulation parameters and rheological properties of vat milk (26 samples)

	Cheese yield	Fat loss
Casein	0.88**	-0.48**
k ₂₀	-0.70*	0.42*
a ₃₀	0.49**	NS
Resistance to compression	0.61**	-0.51*
Resistance to cut	0.67**	-0.66**

* = $P \leq 0.05$, ** = $P \leq 0.01$

and by the k-casein genetic variants (Mariani & Pecorari, 1987; Pagnacco & Caroli, 1987; Jakob & Puhon, 1992; Ng-Kwai-Hang & Grosclaude, 2003). Milk coagulation properties are strongly correlated to milk acidity parameters (Ikonen et al. 2004), e.g. pH and titratable acidity (Table 2). In general, better rennet-coagulation properties were well correlated with higher values of titratable acidity: IB-milk showed remarkably higher acidity values than IF-milk. Previous studies have reported no differences between the two breeds both for individual milk (Malossini et al. 1996) and herd milk (Mariani et al. 2001). This may be related to modification of salt equilibria between the soluble phase and the micellar system during the overnight storage of the evening milk, e.g. an increase of soluble phosphorus and, consequently, of titratable acidity. In fact, the present study showed an higher value of soluble phosphorus for IB-milk, whereas other studies on herd milk samples observed no differences between the two breeds for the same parameter. A low pH value and a high content of soluble calcium should positively affect the rate of aggregation of para-casein micelles during the secondary phase of rennet-coagulation (Green & Grandison, 1993). In the present study, no differences between the two breeds were observed for either parameters (Tables 1 and 2), confirming other studies (Malossini et al. 1996; Mariani et al. 2001).

The frequency of the B allele at CSN3 locus was not investigated in this study. However, Caroli et al. (2004) have reported a higher frequency of CSN3*B allele in IB-cows compared with IF-cows, 0.65 v. 0.17. This latter study was carried out on 392 IB-cows and 311 IF-cows reared in the Parmigiano-Reggiano cheese production area. The CSN3*B allele is associated with higher casein content with relatively higher k-casein content (Aleandri et al. 1990; Bovenhuis et al. 1992; Ikonen et al. 1999), resulting in smaller micelles (Nielsen et al. 1982; Payens, 1982; Donnelly et al. 1984; Pearce et al. 1986), which in turn leads to improved curd properties (Niki & Arima, 1984; Pearce et al. 1986) and higher cheese yield.

Rheological properties of the coagulum – expressed as resistance-to-compression and resistance-to-cut values – define both the curd firmness and elasticity and are correlated to curd firmness determined by the lacto-dynamographic test. A firmer and more elastic curd can

support the higher physico-mechanical stress applied during the cheesemaking process (curd breaking, stirring, cooking etc.). As a result, a more effective and homogeneous whey drainage during the processing, and sedimentation can occur, with neither elasticity nor cohesion loss over the whole cheese mass (Walstra, 1993; Lucey, 2001). This condition is essential for producing acid-rennet coagulation and long ripened cheeses such as Parmigiano-Reggiano.

The simple correlation coefficients between cheese yield at 24 h and vat milk casein content, curd firming time and rheological properties are shown in Table 4. The basis of the difference is related to the higher casein content, and lower relative fat loss to cheese whey of IB-milk. Fossa et al. (1994), in Parmigiano-Reggiano cheese production, report a higher cheese yield from vat milk characterised by higher casein content. Mistry et al. (2002), comparing Cheddar cheesemaking properties of milk of Brown Swiss and Holstein cows, report an 8% higher cheese yield for Brown Swiss. Because of the greater casein content, the fat:casein value was clearly lower in IF-milk (Table 1) and is likely to have caused an increase in fat loss to whey (Table 3) (Chapman, 1981). However, according to Mistry et al. (2002), Brown Swiss cows' milk shows lower relative fat losses than Friesian cows' milk even if cheese milks are standardised for total solids and fat:casein.

The difference in cheese yield in favour of the IB-breed, has a marked economic relevance for the cheese factory. A farmer's income, however, is made up of both composition and milk yield. The current pricing of milk in Parmigiano-Reggiano cheesemaking is based on the quantity of milk delivered to the cheese factory and on a milk quality payment system. The latter considers the milk fat and casein content, rennet coagulation properties, somatic cell count and several microbiological characteristics. The 'importance' of the milk quality system with respect to the total earnings varies among the cheese factories. In terms of milk yield IF-cows are superior to IB-cows, 8227 and 6435 kg milk, respectively, over 305 days of lactation (Italian Breeders Association, 2003). Despite the introduction of the milk quality payment system in Parmigiano-Reggiano cheese production, the current 'weight' of milk quality characteristics in most cheese factories is not enough to offset the difference in terms of milk production with respect to IF-cows. It would be interesting to study the cheesemaking features of milk from Jersey cows. This breed was recently introduced into a dairy herd in the Parmigiano-Reggiano area (about 500 cows) and its milk is blended with IF-milk prior to cheesemaking. The elevated content of casein and fat of Jersey milk are very promising in terms of cheese yield. However further study are necessary to understand the behaviour of Jersey milk during the whole Parmigiano-Reggiano cheese-making process.

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