ISSN 1330-7142
UDK = 636.2:636.082+637.133.04/.07

GENETIC ASPECTS OF MILK COAGULATION PROPERTIES IN DAIRY CATTLE

M. Cassandro, Chiara Dalvit, E. Zanetti, M. De Marchi, R. Dal Zotto

Review paper

SUMMARY

Authors reviewed the genetic aspects of milk coagulation ability focusing on heritability and genetic correlation values and on the breed and milk protein loci effects on rennet coagulation time and curd firmness. The review discussed milk and cheese yield production all over the world concluding that the per capita retail demand for cheese will increase with a mean annual growth rate of 0.8%. Therefore, in the future, cheese production will continue to be one of the major livestock food products around the world. The development of new payment systems for milk considering the intrinsic value for cheese making ability, could be an important opportunity for select best individual within dairy cattle breeds and to preserve, among dairy cattle breeds, those with high milk coagulation properties. Often these genetic resources, beyond their genetic value, also exercise a positive influence on sustainability of milk production in fragile environments, such as mountain areas, preserving an important cultural value (history, traditions, arts, and literature).

Key-words: dairy cattle, genetic aspects, milk coagulation properties

WORLDWIDE MILK YIELD

The world-wide production of milk in 2006 (Table 1) reached 657 million tons, +2.2% compared to the previous year (Rama, 2007). The projections for 2007 suggest that this rate of growth will probably be maintained. With one advanced annual increase of 4%, the developing countries as China, India, Pakistan, and some South American countries ahead are actually yielding the whole of this increase. In the New Zealand and United States milk yield production increase has been registered while a decreased has been observed in the European Union and Australia. The productive increament of the emergent countries with low production cost has been stimulated by the high prices of the last three years; it has still to be verified which will be the impact of the recent increases of the cereal quotations to produce forages. Asia has replaced Europe in the role of greatest area of milk production, today it supplies 34% of the world-wide product, compared to 30% of 5 years ago. At the base of the production increase, there is a considerable growth of consumptions, supported from the strong economic development and, particularly in India, from the alimentary politics of the Government.
In the Asian area, China has more than doubled its production in the last 5 years, with advanced rates of growth equal to 20% per year; it has been predicted that such increase will slow down, since the production costs are considerably growing in the last years while the price of milk remained constant. In India, the greatest dairy world producer, production continues to increase with a rate of 3% per year, under the push of the crescent demanded of milk products of high added value in the urban areas and of the improvement in the distribution of fluid milk in the rural areas undertaken from the 70's.

WORLDWIDE CHEESE YIELD

According to the Food and Agricultural Organization of the United Nations (2004) over 18 million metric tons of cheese are produced worldwide. The most important producers are United States (30% of world production) followed by Germany, France, and Italy. The biggest exporter, by monetary

PhD. Martino Cassandro, Prof., PhD. Chiara Dalvit, PhD. Enrico Zanetti, PhD. Massimo De March, PhD. Riccardo Dal Zotto - University of Padova, Department of Animal Science, Agripolis, Viale dell'Università, 16, Legnaro, 35020, Padova, Italy

value, is France followed by Germany (although it would be the first one by quantity). Among the top ten exporters, only Ireland, New Zealand, Netherland, and Australia have a cheese-making industry mainly export-oriented. In fact, 95%, 90%, 72%, and 65% of their cheese production, respectively, is sold to foreign markets. On the contrary, only 30% of French production is exported. The United States are a marginal exporter, and most of their cheese manufacture is directed to the domestic market. Schmit and Kaiser (2006) examined US dairy industry using an econometric model: they found that declines in per capita retail demand for fluid milk will persist but at a reduced rate compared with past years. On the other hand, their results indicated that the per capita retail demand for cheese will continue with a mean annual growth rate of 0.8% (Figure 1). These circumstances suggest that cheese production will continue to be, even in the future, one of the major food industries around the world.

Table 1. Principal world areas of milk production of all species 2005-2007

Area	Production (milion of tons)			
	2005	2006	2007	07/05, %
ASIA	**214,9**	**226,2**	**238,1**	**+10,8%**
China	32,4	38,8	45,3	+39,8%
India	95,1	98,4	101,9	+7,2%
Pakistan	29,5	30,4	31,3	+6,1%
Turkey	10,5	10,5	10,4	-1,0%
AFRICA	**31,2**	**31,0**	**31,0**	**-0,6%**
MIDDLE SOUTH AMERICAN	**67,3**	**69,2**	**70,9**	**+5,3%**
NORTH AMERICA	**88,2**	**90,6**	**90,9**	**+3,1%**
Canada	8,1	8,0	7,9	-2,5
United States	80,3	82,5	83,0	+3,4%
EUROPE	**215,9**	**214,5**	**215,4**	**-0,2%**
UE	146,9	144,9	145,1	-1,2%
Russia	31,0	31,6	32,0	+3,2%
Ucraina	13,8	13,3	13,5	-2,2%
OCEANIA	**24,7**	**25,2**	**25,6**	**+3,6%**
Australia	10,1	10,1	10,0	-1,0%
New Zealand	14,5	15,0	15,5	+6,9%
WORLD	**642,2**	**656,6**	**671,6**	**+4,6%**

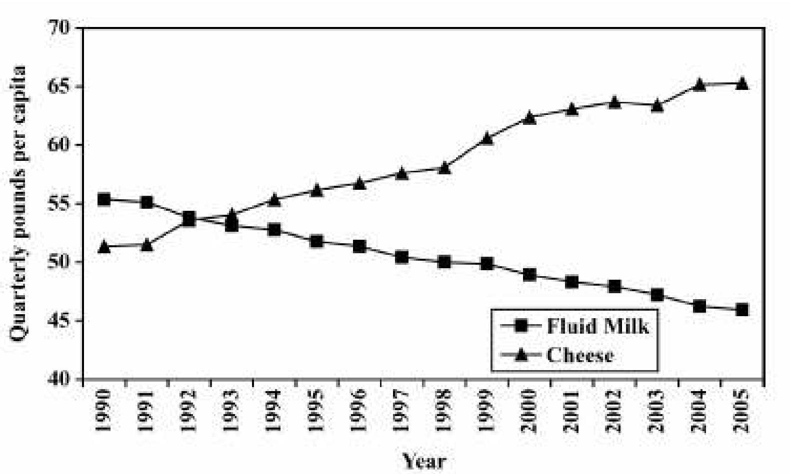

Figure 1. Historical retail fluid milk and cheese demand per capita, 1990-2005

FACTOR AFFECTING DAIRY PRODUCTS DEMAND

Trends of per capita dairy products demand are mainly a result of changes in population demographics and food-spending patterns, not of direct changes in economic variable such as real price or income (Kaiser, 2005). For example, in the United States, from 1995 to 2004 it was estimated that the primary factor contributing to the reduction in per capita fluid milk demand was a decrease in the portion of 5 year of age or younger population followed by increases in real retail prices Kaiser (2005). The same study found out that the most important contributors to growth in per capita cheese demand were a growing Hispanic population and increases in per capita spending on food away from home, followed by the lesser effects of rising real available incomes.

WHAT MILK TO USE FOR CHEESE PRODUCTION?

Milk coagulation properties (MCP) are a fundamental aspect in cheese production, especially in those countries where dairy industry is based on traditional products and is market-oriented. In Italy, more than 70% of the overall milk production (ISTAT, 2005) is used in the manufacture of cheese and 55% of total milk production is processed for PDO (Protected Designation of Origin) cheese like Parmigiano-Reggiano, Grana Padano, Provolone, Asiago, Gorgonzola, Mozzarella, etc. (Cassandro, 2003). France and Italy are the countries with the largest number of locally-made cheese nowadays with 400 products approximately.

Therefore, the evaluation of cheese-making ability of milk plays an important role in cheese production and it can be performed using some MCP as rennet coagulation time (RCT – time in minutes from the addition of rennet to milk to the beginning of coagulation), curd-firming time (K_{20} – time in minutes from the beginning of coagulation to the beginning of coagulation to the moment the diagram is 20 mm), and firmness of the curd (a_{30} – width of the diagram in mm, 30 min after addition of rennet) determined by coagulometer Formagraph (Kübarsepp et al; 2005), as showed in Figure 2. Indeed, favourable conditions of milk reactivity with rennet, curd formation rate and curd strength, as well as curd syneresis, have a positive effect on the entire cheese-making process and consequently on the ripening development of the cheese (Mariani and Battistotti, 1999). Coagulation aptitude is the basic requirement of milk to obtain high quality cheese.

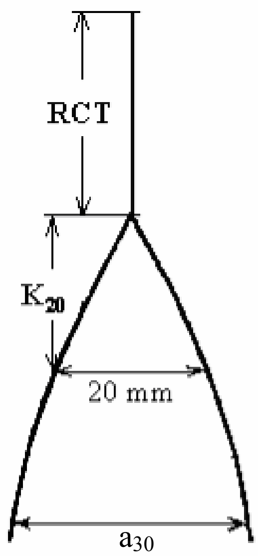

Figure 2. Diagram produced by a Formagraph, and the three milk rennet coagulation parameters (RCT – rennet coagulation time, K_{20} – curd firming time and a_{30} – curd firmness) measured from the diagrams (Kübarsepp et al; 2005)

GENETIC ASPECTS OF MILK COAGULATION ABILITY

Recent studies have shown that genetic improvement of MCP is an approved tool to improve efficiency of cheese production (Ikonen et al., 2000; Ojala et al., 2005). The additive genetic variance of MCP traits was estimated to be about 30-40% (Ikonen et al., 1997; Bittante et al., 2002) of the total variation. However, the lack of suitable equipment for routine determination of MCP has been restricted, until now, the possibility to implement MCP in milk recording system and on genetic evaluation of animals. Alternatively, an indirect selection for traits strongly associated with MCP should be considered. Cassandro et al. (2007), showed at the genetic level, that milk with high casein content, a correct degree of titratable acidity and a moderate content of somatic cells showed a high dairy-technological nature and good aptitude for cheese-making.

Detrimental effects over year on MCP, at the phenotypic level, have been evidenced by some authors (Mariani et al., 1992; Cassandro and Marusi, 1999; Sandri et al., 2001). All these studies reported a negative trend over years on coagulation characteristics of milk yielded in dairy herds located in a traditional area for cheese production. These results were worse in comparison with those reported in the seventies and in the eighties (Annibaldi et al., 1977).

BREED EFFECT ON MILK COAGULATION ABILITY

Breed is an important source of variation for milk quality characteristics and coagulation properties as reported by De Marchi et al. (2007) in a study involved 2 cosmopolitan and high milk yield production cattle breed (Holstein and Brown) and 3 double purpose cattle breed (Simmental, Alpine Grey, and Rendena). De Marchi et al. (2007) reported that milk of the most important dairy breed, Holstein Friesian, showed a fair milk quality for cheese making, while other breeds produced milk characterized by better MCP. A small sized local breed of the Alps, Rendena, showed the best results approving that the risk of extinction of some breeds, and the consequent reduction of biodiversity can cause a loss of economically valuable genetic characteristics, and that this risk has not been fully known and understood yet. The Rendena breed showed the best MCP traits with 13.5 min and 27.0 mm for RCT and a_{30}, respectively. The Holstein Friesian breed had the worst coagulation properties with 18.0 min and 17.5 mm for RCT and a_{30}, respectively. The other three breeds considered in that study, (Brown Swiss, Alpine Grey, and Simmental) showed intermediate coagulation properties.

The positive milk coagulation ability of Rendena milk seemed not to be due to its protein content or other quality analyzed characteristics, as in the case of Brown Swiss; but to other aspects that still have to be investigated. Further researches on these local breeds could lead to a better understanding of the mechanisms involved in the cheese making ability of milk. Moreover, the local breeds are often characterized by robustness, fertility, longevity and adaptability to the mountain environment that, at least in part, can compensate for their lower level of milk production. However, their gap in production, and thus in revenues, compared to Holstein Friesian is increasing and their risk of extinction is increasing.

The development of a payment system for milk taking into account the intrinsic value for cheese making ability could be an important opportunity for the conservation of these endangered genetic resources. Regardless their genetic value, these breeds exert a positive influence on sustainability of milk production in fragile environments. Moreover, they preserve an important cultural value (history, traditions, arts and literature).

MILK PROTEIN LOCI AND MILK COAGUALTION ABILITY

An indirect selection to improve MCP might be to favour alleles in milk protein loci that are associated with better milk coagulation (Ikonen, 2000), as the casein (CN) complex for use in marker-assisted selection (Boettcher et al., 2004).

According to the literature, loci involved in the CN complex showed as α_{s1}-casein (α_{s1}-CN) influences significantly protein content (Aleandri et al., 1986; Ng-Kwai-Hang et al., 1986; Pagnacco and Caroli, 1987) while κ-casein (κ-CN) genotypes have effects on casein content (Mariani et al., 1984; Ng-Kwai-Hang et al., 1984 and 1986), protein content (Ng-Kwai-Hang et al., 1984; Aleandri et al., 1986 and 1990; Ikonen et al. 1999b) and cheese yield (Mariani et al.,1976; Aleandri et al. 1990) as well as on curd firmness (Marzali et al., 1986; Davoli, 1990; Ikonen et al., 1999a). Moreovere, the β-casein (β-CN) genotypes have been found to be associated with fat percentage, fat and protein yield (Ng-Kwai-Hang et al., 1984) and curd firmness (Politis et al, 1988; Ikonen et al., 1999b).

Physical mapping techniques approved a close linkage between the caseins, establishing that the casein loci reside on chromosome 6 within a region ranging from 250 kb (Martin et al., 2002) to less than 200 kb in the order of α_{s1}-CN, β-CN, α_{s2}-CN, and κ-CN (Ferretti et al., 1990; Threadgill and Womack, 1990). Therefore, the allelic effects of these loci are confounded in statistical analyses, even when they are included simultaneously in the model (Ojala et al., 1997). Certain alleles at the casein loci may hence appear together either more or less frequently than expected with a random combination. Consequently, the effects of CN genotypes should be estimated using composite CN genotype instead of separate genotypes, as suggested by Ojala et al. (1997) and approved by Ikonen et al. (1999b).

CONCLUSIONS

The actual circumstances of dairy sector suggest that cheese production will continue to be, even in the future, one of the major food industries in the world. The evaluation of cheese-making ability of milk has started to play an important role in breeding objectives of dairy cattle populations. Cheese production can be increased improving some milk coagulation properties (MCP), as rennet coagulation time and curd firmness. Indeed, favourable conditions of milk reactivity with rennet, curd formation rate and curd strength, as well as curd syneresis, have a positive effect on the entire cheese-making process and subsequently on the ripening development of cheese. Coagulation aptitude is the basic requirement of milk to obtain a high quality cheese. Recent studies have shown that genetic improvement of MCP is feasible confirming that it is possible, using specific breeding objectives, to improve efficiency of cheese production. Moreover, breed factor showed an important effect on MCP traits as the β-κ-casein composite genotypes that have a strong effect on both milk coagulation and milk production traits. The κ-CN locus affected more MCP, whereas the β-CN locus affected more milk production, but the tight relationship found between the two loci, makes the composite genotypes more appropriate when considering their use in selection.
Several studies suggested that it is possible to revise milk quality payment system in order to take into account the "cheese production aptitude" of milk and to reduce the current weight of milk quality characteristics as protein and lipid. This solution improving cheese production per liter of milk will be an interesting way for the development of the European dairy products.
Further investigation is required to confirm these results and to obtain more details about all factors affecting cheese production. However but, at the beginning of the third millennium, it is clear that genetic improvement of dairy cows is possible not only for milk yield, conformation and functional traits but also for cheese yield.

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