Lactose in milk - How can lactose concentration data be beneficial in management and breeding?

P. Løvendahl[1] and M.R. Weisbjerg[2]

[1]Center for Quantitative Genetics and Genomics, Dept. Molecular Biology and Genetics,
Aarhus University, AU-Foulum, DK 8830 Tjele, Denmark
[2]Dept. Animal Science, Aarhus University, AU-Foulum, DK 8830 Tjele, Denmark

E-mail of the corresponding author: Peter.Lovendahl@mbg.au.dk

Abstract

Lactose is a major component of milk dry matter, but it has by tradition not been highly valued. More recently, dairy processors have invented methods to refine lactose and found markets that pay well for refined lactose. However, in Denmark, milk payments are based on kilo fat and kilo protein and a negative price on volume, but without adjustment for lactose content. For herd management, the requirement of individual cows depends on all components in the milk, often summarized as "energy corrected milk, ECM" where the lactose accounts for around 750 kJ of the 3140 kJ/Kg ECM, or 24% of the energy in Holstein milk and 18% in Jersey milk. The 24% and 18% are average fractions that varies between cows and within cow with lactation stage and parity number. Also, results from controlled studies have shown how feeding can affect lactose concentrations in milk. These effects are often hidden because lactose is not measured in milk from test days, despite that the results can be obtained by simply switching on this option on the infrared analyzer instruments.

Feeding rations with higher energy concentration, either with higher concentrate proportion or with forages with higher digestibility, resulted in increases in milk lactose concentrations between 0.05 and 0.10 % units.

There are systematic effects of parity so that older cows with higher yield have less lactose in their milk than first parity cows. During lactation, lactose percentage follow the shape of the yield volume curve, so that peak concentrations are found at 50 to 70 DIM, followed by a steady decline, in parallel between first and later parities. Systematic breed differences are small between Red Danish Cattle and Holstein but Jersey have somewhat lower lactose concentrations than the larger sized cows.

Lactose concentrations are much less variable that fat or protein concentrations, but individual differences were clearly detected with repeatability estimates in the range of 0.70 up to 0.90, within lactation. Estimates of heritability are scarce in literature and results from experimental herds show estimates in a range similar to that of protein concentrations. There is clearly a lack of estimates for heritability, but more importantly estimates of genetic correlations to other production traits or health traits are very few.

In conclusion, there is a need to investigate how lactose from test day samples can benefit management and breeding, so large volumes of data to support this should be obtained from simple expansion of the range of milk components determined in the test day schemes.

Keywords:Lactose, ECM, test day samples, feeding, genetics.

Introduction and background

Lactose is a major component of milk dry matter, but has hitherto not been highly valued. More recently, dairy processors have invented methods to refine lactose and found markets that pay well for refined lactose. This prompted us to revisit the feasibility of analyzing cow test-day samples for lactose content, with a view to utilize the information in feeding, management and genetic selection. Moreover, this should be an easy step as the base data is readily available from already running MIR based analyzers.

Lactose in milk constitutes 4.5 to 5.0% and is less variable that protein and fat content, and constitutes between 18 and 25% of the energy content in milk. Lactose is a disaccharide composed of one glucose and one galactose that can be enzymatically split by lactase. In-vivo lactase is found in the digestive tract of young mammals, but lactase disappears with advancing age in some individuals who then become lactose intolerant. A similar lactase based process is used industrially to make "lactose-free" milk, which is well tolerated.

There is an increasing world market for lactose as a component in pharmaceutical products, in baby milk and in a range of specialty foods. Dry milk powder, especially "infant formula" is required to hold a certain percentage of lactose, which is not met directly if based on Jersey milk. Lately some milk processing inventions has led to factories able at separating and purifying lactose from milk and especially from whey. Purified lactose is sold on the world market, and some European dairy processing companies are now adjusting payments according to lactose content or rather to delivered amounts of lactose, whereas others have not implemented this practice.

Test-day milk samples are collected and analyzed using MIR spectral data which are turned into concentrations of fat, protein, lactose, citric acid, urea, and a range of fatty acids, all depending on which calibration algorithm is used on the given instrument. All calibrations need regular maintenance from operators, and often license agreements add cost for every new analyte requested. In the next step, herd managers must have an idea on how to utilize the information returned, and in a final step genetic evaluations and selection index procedures need to be revised according to genetic parameter estimates. In this study, we aimed at collecting data from a range of published results and some unpublished studies, in order to evaluate the feasibility of adding lactose to the panel of components included in the base panel at milk recording laboratories. To do so we investigated normal biological variation, effects of feeding regimes, and genetic variation, and co-variation with related traits. Hence, the approach is a literature review supplemented with some minor investigations on own data.

Biological variation in milk lactose content

Holstein cows kept at the Danish Cattle Research Centre (DCRC, AU-Foulum, Denmark) milked in AMS are considered representative for high yielding TMR fed cows Denmark and in northern Europe. In their first parity we have observed the yield characteristics shown in table 1, with an average lactose percentage close to 5.0 ranging between 4.49 and 5.44. Lactose is here expressed as the mono-hydrate form, where

the corresponding values for the anhydrous form would be smaller (mean = 4.86%; molar weights 360.3 and 342.3, respectively, see Table 1).

The experimental herd at DCRC also comprise Jersey cows, and cows are kept for the first 3 parities. Milk samples were collected at weekly test sessions covering 48 hours with all samples assayed. This allowed insights to the development over lactation as shown in Figure 1.

Table 1. Yield characteristics of first parity Holstein cows at DCRC, mean and percentile ranges.

	Mean	P_05%	P_95%
Lactose %	4.97	4.49	5.44
Protein %	3.54	2.97	4.19
Fat %	4.20	3.17	5.49
Milk Kg/d	28.3	17.3	39.0

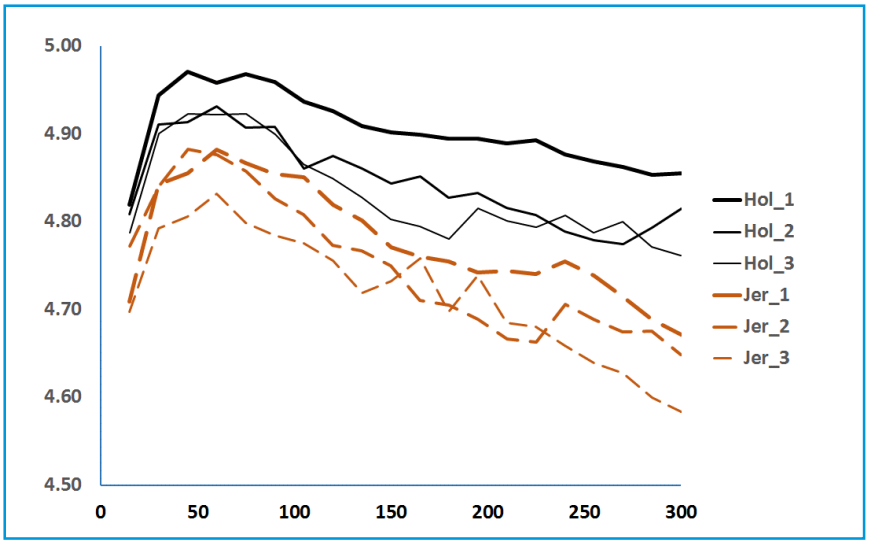


Figure 1. Lactose concentration (%) in Holstein and Jersey milk during 300 days of lactation in the first 3 parities.

The "lactation curves" for lactose percentage clearly follow the shape of those for milk yield, but the changes in level between parities are opposite, so that older cows, although having higher yield also have lower lactose concentration in their milk.

Energy content of milk

Lactose is energy rich and for calculation of Energy Corrected Milk (ECM) Sjaunja *et al* (1990) used the following formula:

1. ECM = Milk(Kg)*(383*Fat% + 242*Protein% + 157*Lactose% + 20.7) / 3140,

   where 3140 is the energy content in KJ, and the other coefficients are energy contents of each component. The 20.7 is covering energy in citric acid and other minor components outside the standard panel of milk components. In case lactose is not available the alternative is Fat and Protein Corrected Milk given by a very similar formula (Sjaunja *et al.*, 1990):

2. FPCM = Milk(Kg)*(383*Fat% + 242*Protein% + 783.2) / 3140,

   where the lactose content is considered constant at 4.86%. Although FPCM is a useful proxy for ECM there will obviously be some deviation between the two calculations, and given the changes in yield and lactose% over lactation these differences will show a systematic pattern (Figure 2) as illustrated with Holstein data from DCRC.

Although the deviations may seem small using only fat and protein corrected milk would systematically underestimate the energy produced by young cows and more so in early than in late lactation.

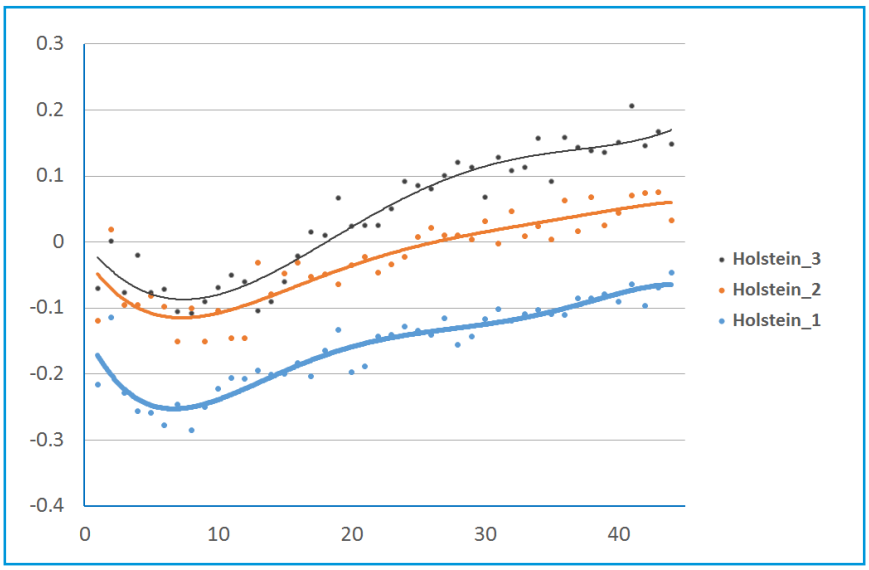


Figure 2. Deviations between FPCM and ECM (FPCM - ECM in Kg/d) yield in Holstein cows during their first 3 lactations at DCRC. X-axis is week of lactation.

Feeding effects

The composition of the feed ration can impact on lactose% as shown by Andersen *et al.* (2003). In the first 16 weeks after parturition a group fed high (75%) concentrates had higher lactose (+0.13% units) than a low (25%) concentrate group. In the same experiment, cows were milked either 2 or 3 times per day, but that had no effect on lactose percentage. Cows on high concentrates were also having larger energy intake and yielding more ECM.

Genetic effects

Genetic variation in lactose% was recently reported for pasture fed Holstein cows in Australia (Haile-Meriam & Pryce, 2017), together with lactose yield and other yield traits. While the heritability for lactose percentage was moderate to high, around 0.30 in mid lactation, the heritability for lactose yield per day was lower, around 0.10 to 0.20. With data from an older experiment, Løvendahl *et al.* (2003) found somewhat higher heritability for lactose%, and found that it changed over lactation, and was slightly higher in second than in first lactation (Figure 3). These parameters were estimated using a random regression model, and it should be noted that changes in heritability followed a similar pattern in first and second parity.

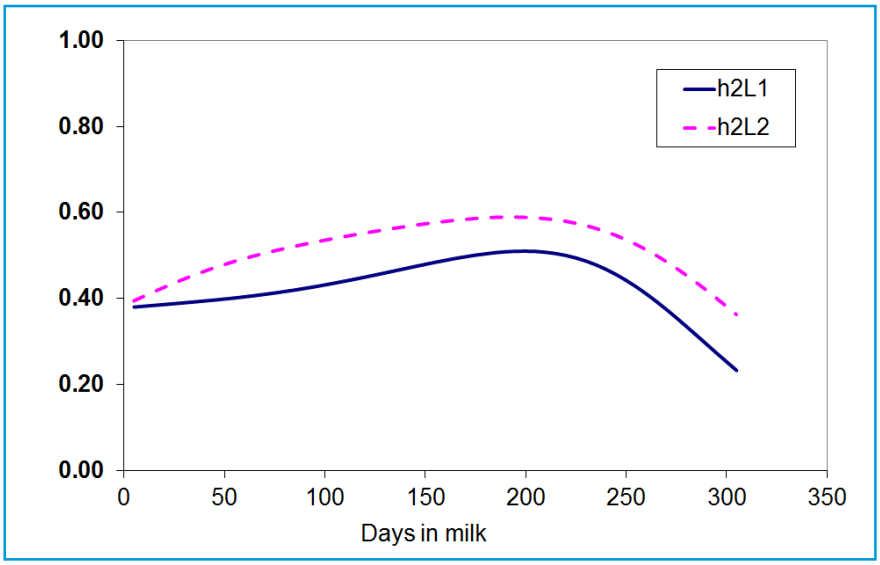
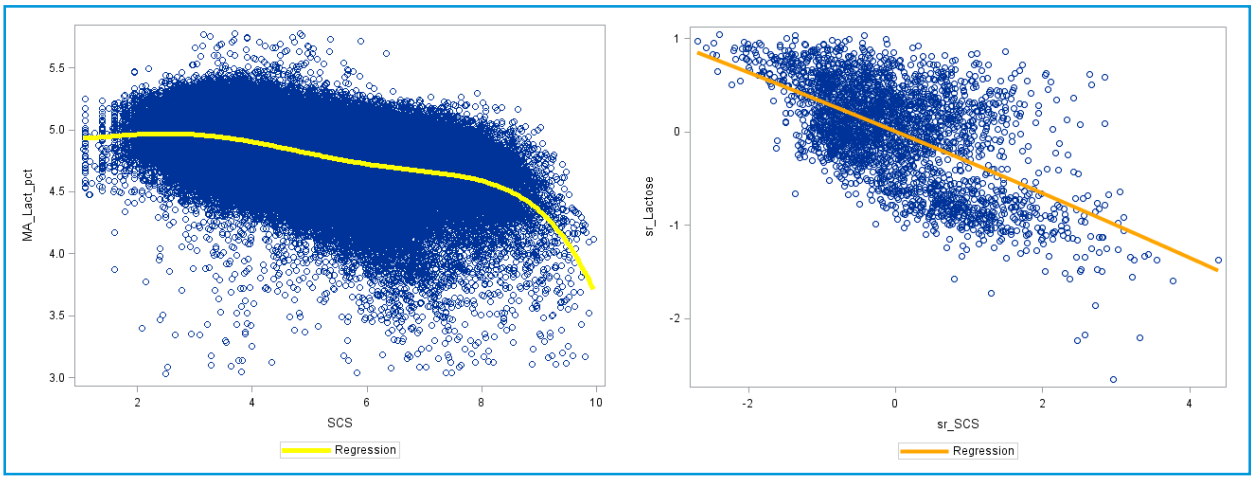


Figure 3. Heritability estimates for lactose percentage in first and second parity cows (from Løvendahl et al*. 2003).*

Correlations between traits

Out of curiosity, we have further investigated the relationships between lactose% and somatic cell score in samples for our experimental herd (DCRC). What we found was a negative correlation (r = -0.44) between lactose% and SCS (Figure 4a), when considering single samples slightly smoothed using a moving average. In a next step extracted random animal solution from linear mixed models, centered around zero, and obtained a stronger and still negative correlation (r = -0.59; Figure 4b).

The relationships between lactose and somatic cell count may be caused by biological events or alternatively by bias in lactose calibration when milk samples contain high amounts of cells, as it is well known that samples with high cell count (i.e. mastitis) also have deviating fat and protein percentage, and often yield is affected too. Thus, the presented relationships need to be further investigated to validate and qualify the findings.



Figures 4a, 4b. Relationship between Somatic Cell Score and lactose% in single milk samples (4a, left) and between random cow-solutions (centered around zero) from a linear mixed model for the same traits.

Conclusion

This study has shown that lactose content of milk varies with age of cow, stage of lactation, breed, feeding level, and that it has sufficient heritability so that genetic selection could be used to change lactose content. The findings of a negative correlation between SCS and lactose percentage indicate that selection for higher lactose content would not harm udder health, or rather it would be somewhat beneficial. This is fortunate because the market for lactose is increasing so that larger production of lactose should be encouraged. A required instrument to this is routine assaying of test-day milk samples for lactose. This is easy to establish in most milk labs if not already running.

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