The Intersection of Dietary and Milk Fatty Acids - How Photoperiod and Variability Affect Production

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Introduction

Diet-induced milk fat depression explains large decreases in milk fat that occur during disrupted rumen fermentation and was the predominant focus of milk fat research for nearly twenty-five years. More recently, research has focused on other dietary and non-nutritional factors that impact milk fat yield. Importantly, these factors have broad application to allow small, but very economically significant increases in milk fat yield and profitability. We have recently characterized the seasonal variation in milk component concentration and yield. It appears that two seasonal timekeepers are present in the cow with changes in milk fat and protein concentration driven by lengthening and shortening days (aligns with solstices) and changes in milk yield driven with the change in day length (aligns with equinoxes). Milk fat is a highly heritable trait and large variation exists between cows within a herd, although there does not appear to be much variation between herds. A number of other factors impact diet-induced milk fat depression including variation in fatty acid profile between corn silage hybrids and interactions with production level of cows. Lastly, variation in patterns of feed intake influence milk component levels and also variation in components between milkings. It is important to consider season, cow, diet, and time of day factors while setting goals, evaluating herd milk production, and designing diets and strategies to maximize milk fat yield.

Annual Rhythms in the Dairy Cow

Rather than simply *responding* to a change in the environment after it occurs, time keeping mechanisms in the hypothalamus allow the animal to *anticipate* yearly environmental changes before they occur. Annual rhythms are present in nearly all studied organisms as a mechanism to perceive and adapt to seasonal environmental changes. For example, migrating birds undergo astonishing changes in metabolism prior to spring and fall migration, including initiation of nocturnal activity and accretion of body fat reserves.

Yearly patterns of milk production have been recognized for over 40 years (Wood, 1970). Producers are familiar with summer declines in milk production, and recovery during the fall. When examining average monthly bulk tank records from the United States Federal Milk Marketing Orders, the presence of an annual rhythm is apparent. These yearly patterns fit a robust cosine function, suggesting that they

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represent a biological rhythm (Salfer et al., 2019). The variation in milk fat concentration due to the annual rhythm is between 0.15% and 0.30%, depending on the region with a lower amplitude in southern regions of the United States.

The presence of yearly production rhythms was confirmed using ten years of dairy herd improvement association (**DHIA**) data from individual herds in Minnesota, Pennsylvania, Texas and Florida (Salfer et al., 2017). Similar to the U.S. milk markets, milk fat and protein concentration peak around January 1 and reach a nadir on July 1 in Minnesota, Pennsylvania, and Texas. Florida, on the other hand, had the greatest fat concentration in November and greatest protein concentration in October. States in the northern U.S. have markedly greater amplitude rhythms of fat and protein concentration. For example, in Pennsylvania and Minnesota the difference between peak and trough for fat concentration was 0.32% and 0.28%, respectively, while Texas was 0.16% and Florida's was 0.08%.

Although fat and protein concentration both peak near the first of the year, the annual rhythm of milk yield peaks between late March and early April, right around the vernal equinox (Salfer et al., 2017). Fat and protein yield peak between late February and early March. Contrary to the rhythms of fat and protein concentration, amplitudes of annual milk yield rhythms are greater in the southern U.S. compared to the north. Fat and protein yield also oscillated more in the southern U.S. than the northern U.S.

Environmental temperature is often blamed for causing the seasonal changes in milk production. Granted it is certainly a factor, our results suggest that an annual rhythm exists independent of temperature (Salfer et al., 2017), with temperature expected to have a separate effect. It is important to note that when cows are placed in heat chambers milk yield decreases and milk fat percent increases, which is not consistent with the decrease in milk fat observed during the summer.

Potential Mechanisms of Seasonality

As discussed above, a primary role of annual rhythms is to coordinate reproduction with resource availability to maximize the likelihood of survival of the offspring. As an important component of reproduction, it is reasonable to expect that lactation is controlled through similar mechanisms. Producing more energy-dense milk with greater concentrations of fat and protein in the winter when energetic demands are greater may increase the likelihood of calf survival.

A consistent environmental factor that impacts the system is day length. It appears that two mechanism may have an impact on lactation with lengthening and shorting days regulating milk fat and protein concentration and the change in day length, that aligns with the equinoxes, regulating milk yield. Management of seasonal rhythms has not been specifically investigated and is complicated by the fact that the endogenous rhythms will be maintained in the absence of controlled lighting. Management of photoperiod for constant long-days is a well-established method to increase milk and milk component yield (Dahl et al., 2012) and its impact on seasonality needs further exploration.

Other Factors Interacting with Milk Fat Yield

Variation in Milk Fat Between and Within Herds

Milk fat is variable between farms because of differences in diet, management practices, and herd genetics among other factors. Significant variation in milk fat composition exists within herds because of differences in stage of lactation, genetics, physiological state, feeding and ruminating behavior, and the interaction of these and other factors.

Interaction of Milk Production Level and Response to Diet

The relationship between milk fat concentration and milk yield is well demonstrated by a 905-cow example herd with low milk fat (herd average = 3.2%). The 25^{th} and 75^{th} percentiles of milk fat concentration were 2.6% and 3.6%, respectively. We have observed a negative relationship between milk yield and milk fat percent in multiple databases, although more work is required to understand the mechanism and implications. Decreased milk fat with increased milk yield may be due to dilution of milk fat in greater yields, but may also be due to some degree of diet-induced milk fat depression (**MFD**).

In several experiments we have observed variation in individual cow response to a MFD induction diet and that high-producing cows were more susceptible to MFD risk factors. For example, Harvatine and Allen (2006) compared saturated (highly saturated prilled free fatty acids [**FA**]; Energy Booster 100) and unsaturated (calcium salts of FA; Megalac R) FA supplements to a no supplemental fat control in low and high producing blocks of cows (milk yield in control treatment 39.4 vs. 47.0 kg/d, respectively). When fed the same control diet in the same barn, the low-producing cows averaged 3.45% milk fat whereas the high-producing cows averaged 3.05%. Additionally, the response to treatment differed with low-producing cows having a non-significant 6% decrease in milk fat when fed the calcium salts of unsaturated FA, whereas the high-producing cows decreased milk fat over 20%. This and more recent studies demonstrate that there is a strong correlation between the level of milk production and diet-induced MFD. The exact mechanism is unclear, but high-producing cows also have higher intakes. Increased intake is expected to increase rumen passage rate, which may modify the microbial population and increase ruminal outflow of *trans* intermediates before complete biohydrogenation has occurred. Additionally, high-producing cows may differ in feeding and ruminating behavior and increased meal size or higher amount of intake after feed delivery may result in rumen acidosis.

Genetics of Milk Fat and Milk Fatty Acid Profile

Milk fat concentration and yield are highly heritable [0.45 and 0.29, respectively; (Welper and Freeman, 1992)] and milk fat is unique in that the genetic variation is due to a limited number of single nucleotide polymorphisms (**SNPs**) with large individual effects (Hayes et al., 2010). The largest effect is a K232A SNP in diacylglycerol acyltransferase [**DGAT1**; (Grisart et al., 2002)] followed by the F279Y SNP in the growth hormone receptor [**GHR**; milk fat allele substitution effect 0.46 percentage units; (Signorelli et al., 2009)]. Wang et al. (2012) identified four quantitative trait loci that explained over 46% of the genetic variation in milk fat concentration including 34% explained by DGAT1 and 12% by GHR. We recently characterized the variation in predicted transmitting ability for fat production between nearly 6,000 herds available in the Dairy Records Management System database. Very little variation was observed between herds, although larger variation is observed between cows within a herd.

Variation in Corn Silage Fatty Acid Profile

Rumen available unsaturated FA are one of the largest risk factors for diet-induced milk fat depression. Nutritionists commonly select feeds based on expected FA concentration and profile, but unexpected variation can lead to issues. Although corn silage is low in dietary fat, its high feeding rate results in it contributing a large amount of unsaturated FA to the diet. We characterized the variation in corn silage FA concentration and profile in test plots in Pennsylvania and South Dakota. Varieties from the 10^{th} to the 90^{th} percentile differed in C18:2 by ~0.6% of dry matter. Fatty acid concentration is the larger contributor, but differences in FA profile also exist. In the future we may select corn silage hybrids that are low in C18:2 by selecting for higher C18:1. High oleic soybeans have similarly been shown to have a lower risk for diet-induced milk fat depression. Genetics are the largest contributor to corn silage FA profile and it is recommended that FA profile is determined for each crop and when diagnosing low milk fat.

Circadian Patterns

Circadian rhythms are daily patterns and the dairy cow has a daily pattern of feed intake and milk synthesis. Dairy producers commonly recognize that morning and evening milking differ in milk yield and composition. Gilbert et al. (1972) reported 1.4 lbs (0.64 kg) greater milk yield at the morning milking, but 0.32 and 0.09 percentage-unit greater milk fat and protein, respectively, at the evening milking in cows milked at 12-h intervals. More recently, Quist et al. (2008) conducted a large survey of the milking-to-milking variation in milk yield and composition on 16 dairy farms. Milk yield and milk fat concentration showed a clear repeated daily pattern over the 5 d sampled in herds that milked twice and thrice daily. We have also observed milk yield and milk composition across the day while milking every 6 h in multiple experiments. Feeding cows in four equal feedings every 6 h increased milk fat and decreased the amplitude of milk fat concentration and yield across the day (Rottman et al., 2014). More recently we have observed that fasting cows for 6 h during the day versus during the night shifts the daily pattern of milk synthesis. These experiments demonstrate that the daily rhythm of milk synthesis is dependent on the timing of intake and highlight the importance of selecting feeding times and frequency on milk synthesis.

Conclusions

Milk fat yield is impacted by many nutritional and non-nutritional factors and their interactions. Diet-induced milk fat depression explains large decreases in milk fat, but does not explain every change in milk fat yield. The season of the year should be considered when setting goals and evaluating herd performance, but it is unclear if we can overcome this pattern through management. We should also consider genetic potential, stage of lactation, and milk yield when evaluating individual cow performance. Lastly, appreciating the impact of feeding behavior on rumen fermentation and milk fat provides additional opportunities to increase milk fat yield through management. The advances in our understanding of the biology and mechanism regulating milk fat synthesis over the past twenty-five years provide many insights, but the interaction of factors makes predictions difficult and requires careful development of strategies to optimize milk fat yield on farm.

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SESSION NOTES