Essentiality of Specific Fatty Acids in Reproductive Performance of High Producing Dairy Cows

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Take Home Messages

- High levels of milk produced by today's dairy cows create a challenge in meeting the animals' energy requirements during early lactation. The resulting negative energy balance impairs reproduction.
- Supplemental fats have been used to increase energy density of the diet with the intent of reducing the magnitude of the early lactation energy imbalance.
- Fats may play a more important role associated with reproduction through the function of essential fatty acids. It may be possible to use fat sources to supply specific essential fatty acids that will enhance reproductive performance of high producing dairy cows.

Introduction

With individual cows establishing production records greater than 27,000 kg per lactation and herds averaging more than 13,600 kg per cow per year, management of the high producing dairy cow has become more and more refined. These levels of milk production lead to new challenges related to animal nutrition, reproduction and health. During the transition period and early lactation, modest energy intake fails to fully support the energy demands of fetal growth; colostrum synthesis and milk production results in a period of negative energy balance. A result of this negative energy balance during transition and early lactation has had an adverse affect on fertility and reproductive performance (Nebel and McGilliard, 1993).

Feeding management strategies used to supply nutrients to high producing dairy cows have therefore changed significantly over the last quarter century in response to the new challenges of higher production. The change in the Dairy

NRC during this same time frame is an example of the industry's response to this change. Consider these advances in dairy cattle nutrition. The industry replaced the crude fiber system with a more accurate and more robust fiber analysis system developed by Dr. Van Soest at Cornell University. The protein system evolved from crude protein to use ruminal degradation characteristics of protein sources that have been used to develop models predicting amino acid supply, a lactating dairy cow's requirements, and the resulting amino acid balance.

With increasing levels of energy required by high producing cows, the use of fats in dairy diets has also evolved. Research has greatly expanded our understanding of lipid digestion and metabolism. From these research findings, recommendations for the use of rumen interactive and rumen inert or by-pass fats have been formulated and are used as standard guidelines. A more in-depth exploration of the role of fatty acids is leading us to a better understanding of the possible roles of unique fatty acids in the reproductive function and fertility of dairy cows.

■ Lipid Nutrition: Sources and Digestion

Dietary fats have been used to increase energy density of the diet. When used to build a dairy ration, basic dietary ingredients combine to form diets containing 2.5 to 3.0% crude fat (Palmquist, 1991). General guidelines for feeding supplemental fats as summarized by Grummer (1996) recommend the use of rumen interactive fats for use as the initial supplemental fat to be used to increase dietary fat to a maximum of 6.0% of diet dry matter. Fat sources used in dairy diets have a variable composition. As shown in Table 1, the fat source chosen affects the fatty acids and the level of saturated and unsaturated fatty acids presented to the ruminal microorganisms.

Table 1. Lipid composition of supplemental fat sources commonly fed to dairy cattle.

Nutritional Parameter	Whole Cottonseed	Whole Soybeans	Tallow	Megalac	Yellow Grease
% Ether Extract	19.3	19.2	99.8	83.0	90.0
C16:0	22.7	10.3	24.5	50.1	22.1
C18:0	2.3	3.8	19.3	4.2	11.5
C18:1	17.0	22.8	40.9	34.1	43.7
C18:2	51.5	51.0	3.2	7.8	14.6
C18:3	0.2	6.8	0.7	0.3	0.9

Adapted from Palmquist, 1991 and NRC, 2001.

The higher the concentration of C16:0 and C18:0, the higher the level of saturated fatty acids and the higher the melting point. As the percentage of C18:1, C18:2 and C18:3 increases, the unsaturated fatty acid content is increased and the melting point of the fat decreases. In addition to the type of fatty acid profile, the way in which a fat source interacts with the rumen environment is also an important consideration.

Rumen interactive sources tend to be cheaper relative to the cost per unit of feed energy provided by commercially manufactured rumen inert fat sources. The use of rumen interactive fats is limited due to the possible impact on rumen fermentation. These fat sources are released into the rumen and “interact” with the ruminal microflora and can disrupt fiber fermentation. It is thought that the rumen bacteria metabolize the unsaturated fatty acids to minimize the adverse effects on the ruminal microbes. Metabolism of unsaturated fatty acids involves the process termed biohydrogenation. In this metabolic process, certain rumen bacteria convert unsaturated fatty acids released from plant oils and other dietary fat sources to a more saturated fatty acid. Therefore, biohydrogenation converts unsaturated fatty acids to saturated fatty acids and changes the profile of fatty acids that flow to the small intestine of ruminants.

In many cases, additional dietary energy benefits the cow. In situations where rumen interactive fats are already included to a maximum level, rumen inert fat sources can be used. Indeed, these rumen inert fats can be used as the first source of supplemental fat. Handling characteristics of rumen inert fats, availability of rumen inert fats, and other intangible characteristics create unique opportunities for the use of these commercially manufactured fat sources. General guidelines involve the addition of rumen inert fats at 0.45 kg per cow per day. So the combined use of rumen interactive and rumen inert fat would increase the concentration of fat in the diet to 8.0% of the diet dry matter. These guidelines address the need to provide the limiting nutrient of energy with the expected outcomes of improved milk production, decreased degree and duration of negative energy balance, and enhanced fertility and reproductive performance.

The inclusion of fat in the diet can alter the fatty acid balance of the cow. As shown in data from the dissertation research of Dr. Amy Mowrey, the increasing levels of whole raw soybeans changed the balance of the circulating fatty acids in early lactation dairy cows (Table 2). By altering the fatty acid balance, the use of dietary fats may impact the reproduction of dairy cows beyond the effect dietary fats can have on energy balance.

Table 2. Changes in Fatty Acid Concentrations of Plasma Fatty Acids in Dairy Cows fed Increasing Levels of Cracked, Raw, Soybeans (Mowrey).

Parameter	Control	1.4 kg/D	2.8 kg/D	4.1 kg/d
C16:0	16.94	14.66	15.67	14.97
C18:0	18.49	18.43	18.30	18.94
C18:1	11.97a	8.96b	9.11a	8.49b
C18:2n6	47.13	52.57	50.98	52.0
Total FA	633.1d	747.1cd	839.6c	860.3c
Sat:Unsat	0.67	0.57	0.60	0.58

▪ Feeding Fats and Reproductive Performance

The benefits of feeding fat on fertility and reproductive function have been variable. Staples and coworkers (1998) and Staples and Thatcher (1999) have provided two excellent reviews of the interaction of fat supplementation and reproductive function. The overall results regarding the affects of fat feeding on fertility and reproductive performance can be best described as variable. A study completed by Scott et al. (1995) measured the effects of a rumen inert fat reproductive performance of dairy cows on 5 commercial dairy farms in Wisconsin. The inert fat increased milk yield of first lactation cows 1.5 kg/d across all farms. Second and greater lactation cows experienced an increased milk yield on only one of the 5 cooperating farms. Reproductive performance was not changed due to the fat supplementation as summarized in Table 3. The reproductive performance of all cows in these high-producing herds is very acceptable. These results point out the need to recognize the important role of reproductive management on the success of breeding programs.

Table 3. The effects of feeding a rumen inert fat on reproductive performance on five commercial dairy farms.[1]

Parameter	Control	Rumen Inert Fat
Days Open (Pregnant Cows)	108.7 days	111.0 days
Days Open (All Cows)	137.9 days	145.8 days
Days to first AI breeding	94.4 days	95.1 days
Conception Rate (1st breeding)	49.3 %	45.7 %
Conception Rate (2nd breeding)	39.2 %	41.6 %

[1] Adapted from Scott et al. (1995).

While these investigators failed to measure a difference in reproductive performance, other scientists have reported both improved and impaired reproductive performance with the addition of dietary fat. Lucy and others (1992) found the addition of fat to the diet tended to increase the days to first service (72 days versus 62 days), decreased first service conception rate (13% versus 49%), and decreased the pregnancy rate. These authors noted that the cows fed the rumen inert fat achieved higher levels of milk yield but had similar energy balances during early lactation due to the increased energy content of the diets containing the added fat. In an earlier study, Lucy et al. (1991) reported that ovarian function and follicular size were affected by energy balance as affected by diet. More recently, Beam and Butler (1997) created a range of energy balances by using different levels of rumen interactive fats. These investigators found the day at which cows reached their most negative energy balance (nadir) was a more critical factor than the severity of negative energy balance.

▪ Fat, Reproduction, and Modes of Action

As Staples and Thatcher reported (1999), numerous studies where supplemental fat improved key reproductive parameters such as decreased days to first service, decreased services per conception, increased conception rate and decreased days open. Many of the studies cited by Staples and Thatcher focused on describing the nutritional value of fat and fat sources rather than the direct and specific objectives of evaluating the effects of fat supplementation on reproductive function. A growing number of studies have begun to focus on the effects of fat supplementation on reproductive tissue function. These projects will be a means of delineating the mode of action and fat source (or fatty acid source) that has the greatest positive impact on function and fertility.

Grummer and Carrol (1988) reviewed the possible roles of dietary lipid on ovarian function. This review described the positive effects of lipid supplementation on lipoproteins. In particular, these authors brought attention to the important role High Density Lipoproteins (HDL) serve as a source of cholesterol. Cholesterol can be used as one of the precursors for steroid hormone synthesis. In fact, progesterone (the hormone responsible for maintaining pregnancy) synthesis was increased when granulosa cells were incubated with lipoprotein cholesterol.

With a similar focus, Williams (1989) has been very involved in the investigation of lipid nutrition and reproduction. In his 1989 study, whole cottonseed was added to the diet to achieve 8% total dietary ether extract. Cows fed the High Lipid diet had higher plasma total cholesterol (1.7 fold increase over control). At day 7 after estrus synchronization, High Lipid treatment cows maintained circulating progesterone at >8.0 ng/ml while control cows averaged less than 2 ng/ml. Talvera et al. (1985) used sunflower seeds as the source of fat. During the animals' estrous cycles, plasma cholesterol decreased with a parallel increase in plasma progesterone suggesting a relationship between these biologically active compounds.

The relationship between dietary fat and changes in reproductive function is not limited to affects on cholesterol and progesterone. Staples and Thatcher (1999) proposed an elegant control feedback system that involves not only progesterone, but also affects prostaglandin synthesis and the role estrogen plays in biological (cellular) function as illustrated in Figure 1. Polyunsaturated fatty acids are proposed to decrease the release of prostaglandins that would augment the establishment of a pregnancy. In addition, the PUFA also decrease the effects of estradiol that enhance the action of prostaglandins. Current research in several laboratories is pursuing the elucidation of the modes of action. These labs are working to not only identify more accurately the mode of action regarding how fat might affect reproduction. Indeed the research is searching to identify the fatty acids that are most effective in causing the desired responses and changes in reproduction.

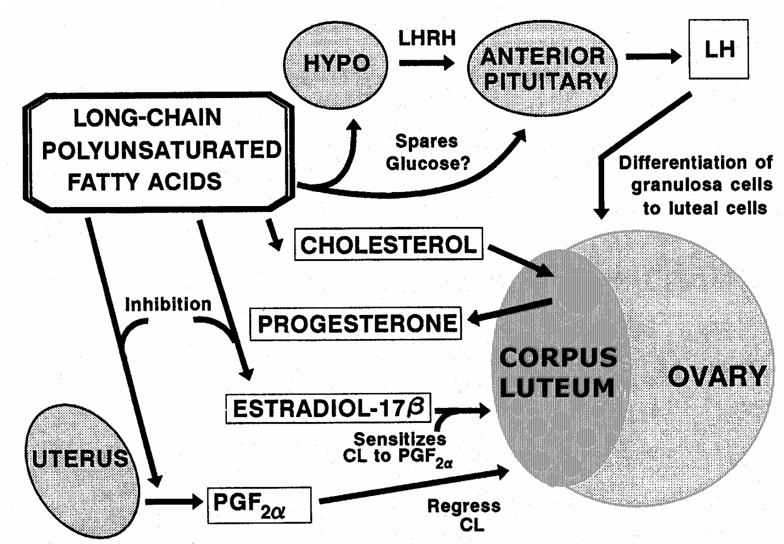

Figure 1. Possible mechanisms for the role of polyunsaturated fatty acids on reproductive function in dairy cows. (Staples and Thatcher, 1999)

▪ References

Bauchart. D. 1993. Lipid absorption and Transport in Ruminants. J. Dairy Sci. 76:3864.

Beam, Stephen W. and W.R. Butler. 1997. Energy Balance and Ovarian Follicle Development Prior to First Ovulation Postpartum in Dairy Cows Receiving Three Levels of Dietary Fat. Bio. Reprod. 56:133.

Drackley, James K. 1999. New perspectives on energy values and supplementation levels of fats. Proceedings of the Western Canadian Dairy Seminar. 11:171.

Grummer, Ric. 1996 Strategies for successful fat supplementation. Proceedings of the Western Canadian Dairy Seminar. 8:117.

Grummer, R.R. and D.J. Carrol. 1988. A review of lipoprotein cholesterol metabolism importance to ovarian function. J. Anim. Sci. 66:3160.

Grummer, R.R. and D.J. Carrol. 1991. Effects of dietary fats on metabolic disorders and reproductive performance of dairy cattle. J. Anim. Sci. 69:3838.

Jenkins, T.C. 1993. Lipid Metabolism in the Rumen. J. Dairy Sci. 76:3851.

Lucy, M.C., C.R. Staples, F.M. Michel, and W.W. Thatcher. 1991. Energy Balance and Size and Number of Ovarian Follicles detected by Ultrasonography in Early Postpartum Dairy Cows. J. Dairy Sci. 74:473.

Nebel, R.L. and M.L. McGilliard. 1993. Interactions of high milk yield and reproductive performance in dairy cows. J. Dairy Sci. 76:3257.

Oldick, B.S., C.R. Staples, W.W. Thatcher, and P. Gyawu. 1997. Abomasal infusion of glucose and fat: effect on digestion, production, and ovarian and uterine function of cows. J. Dairy Sci. 80:1315.

Palmquist, D.L. 1991. Feeding Animal and Plant Fats. Proceeding Alternative Feeds for Dairy and Beef Cattle National Invitational Symposium. St. Louis, MO. Pg. 80.

Palmquist, D.L. and T.C. Jenkins. 1980. Fat in Lactation Rations: Review. J. Dairy Sci.63:1.

Scott, T.A., R.D. Shaver, L. Zepeda, B. Yandell, and T.R. Smith. 1995. Effects of rumen-inert fat on lactation, reproduction, and health of high producing Holstein herds. J. Dairy Sci. 78:2435.

Ryan, D.P., R.A. Spoon, and G.L. Williams. 1992. Ovarian follicular characteristics, embryo recovery, and embryo viability in heifers fed high-fat diets and treated with FSH. J. Anim. Sci. 70:3505.

Staples, C.R., J.M. Burke, and W.W. Thatcher. 1998. Influence of Supplemental Fats on Reproductive Tissues and Performance of Lactating Cows. J. Dairy Sci. 81:856.

Staples, Charles R. and William W. Thatcher. 1999. Fat supplementation may improve fertility of lactating dairy cows. Proceedings of the Southeast Dairy Herd Management Confererence. Macon, GA. Pg.56.

Talvera, F., C.S. Park, and G.L. Williams. 1985. Relationships among dietary lipid intake, serum cholesterol and ovarian function in Holstein heifers. J. Anim. Sci. 60:1045.

Wehrman, M.E. T.H. Welsh, Jr., G.L. Williams. 1991. Diet induced hyperlipidemia in cattle modifies the intracellular cholesterol environment, modulates ovarian follicular dynamics, and hastens the onset of postpartum luteal activity. Bio. Repro. 45:514.

Williams, G.L. 1989. Modulation of luteal activity in postpartum beef cows through changes in dietary lipid. J. Anim. Sci. 67:785.