Mechanisms through which fat supplementation could enhance reproduction in farm animal

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ABSTRACT

Inadequate dietary energy intake and poor body condition can negatively affect reproductive function. Fats in the diet can influence reproduction positively by altering both ovarian follicle and corpus luteum function via improved energy status and by increasing precursors for the synthesis of reproductive hormones such as steroids and prostaglandins. Supplemental lipids have been used to increase energy density of the diet and may also have direct positive effects on reproduction in animal. Several fatty acid sources have been studied as they relate to reproductive function. Common sources include sunflower, safflower, cottonseed, rice bran, soybeans, fishmeal, animal tallow, and calcium salts of fatty acids. This review will examine dietary fat as a reproductive including the role of fatty acid content and minimum effective intake. Although the consumption of neutral lipids by ruminants is limited under natural conditions, the addition of digestible fats to increase caloric content or to positively modify diet physical characteristics is a long-standing practice. More recently, fat supplements have been used in attempts to influence specific metabolic pathways and, ultimately, hormones that directly modulate ovarian cellular processes. Evidence suggests that the consumption of fat by cattle, particularly polyunsaturated plant oils, can positively influence ovarian follicular growth, luteal function, and postpartum reproductive performance independent of caloric effects. Mechanistically, these effects have been attributed to a cascade of events that change rumen fermentation patterns, heighten lipoprotein-cholesterol synthesis, increase secretion of ovarian steroids, modify circulating concentrations of insulin and GH, and enhance the synthesis or accumulation of IGF-I in ovarian cells. Whole oilseeds, oil milling by-products, and some manufactured products are available to exploit these physiological concepts.

Key words: Fat, Reproduction, Farm Animal, Mechanisms
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INTRODUCTION

Adequate nutrition is critical for successful reproductive function. Inadequate dietary energy intake and poor body condition can negatively affect reproductive function. Supplemental lipids have been used to increase the energy density of the diet and avoid negative associative effects [8]. sometimes experienced with cereal grains in high-roughage diets. Supplemental lipids may also have direct positive effects on reproduction in beef cattle independent of the energy contribution. Lipid supplementation has been shown to positively affect reproductive function at

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several important tissues, including the hypothalamus, anterior pituitary, ovary, and uterus. The target tissue and reproductive response seems to be dependent upon the types of fatty acids contained in the fat source. Fat supplementation is a common practice in dairy cattle production, primarily to increase the energy density of the diet. Associated positive and negative effects on reproduction have been reported [16,37]. Due to the extreme differences in DMI and level of milk production, research may not be directly applicable to beef cattle production. The objective of this review is to examine current research findings relating to fat supplementation and reproduction in beef cattle.

Fat Defined
Many different types of supplemental fat have been fed to animals. Some fat sources fed are listed in Table 1. Each fat source is composed of a different mix of individual fatty acids. Rendered fats include animal tallow and yellow grease (recycled restaurant grease) and are composed mainly of oleic acid (~43%). Granular fats are dry fats prepared commercially and are composed mainly of palmitic acid (36-50%). Examples include Energy Booster 100, EnerG-II, and Megalac-R. A variety of vegetable oils can be fed as free oil or in the seed form. The oil seeds contain from 18% oil (such as soybeans) to 40% oil (such as flaxseed). The selection of a vegetable oil will bring with it particular fatty acids. Canola oil is high in oleic acid. Cottonseed, safflower, sunflower, and soybean oils are high in linoleic acid. Flaxseed is high in linolenic acid. Linoleic acid and linolenic acid are essential fatty acids for the cow because neither her body nor her ruminal microorganisms can synthesize them. Fresh temperate grasses contain 1 to 3% fatty acids of which 55 to 65% is linolenic acid. Corn silage lipid contains much more linoleic acid (49%) than linolenic acid (4%) due to the presence of corn grain [31]. Both linoleic and linolenic acid in forages can decrease during storage. As we have moved our dairy cows from pastures to barns and fed them stored forage, their intake of linolenic acid and possibly linoleic acid has likely decreased. The whole oil seed is frequently fed rather than the oil alone. Fish oil is unique that it contains eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), fatty acids found in fish tissue due to their consumption of marine plants.

Table 1. Major fatty acid composition of select dietary fat sources. Fatty acid

Fat source	C14:0 Myristic	C16:0 Palmitic	C16:1 Palmit-oleic	C18:0 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
Tallow	3	25	3	18	43	3.8	<1
Yellow grease	2	21	4	11	44	14	<1
Energy Booster 100 1	3	40	1	41	10	2	<1
Megalac; EnerG-II 1	1	50	<1	4	36	8	<1
Megalac-R1	1	36	<1	4	26	29	3
Canola oil	<1	4	<1	2	63	19	9
Cottonseed oil	1	23	1	3	18	54	1
Flaxseed oil	<1	5	<	3	20	16	55
Rapeseed oil	<1	5	<1	2	54	22	11
Safflower oil	<1	7	<1	2	12	78	<1
Soybean oil	<1	11	<1	4	23	54	8
Sunflower oil	<1	7	<1	5	19	68	1
Menhaden fish oil 2	7	16	8	3	12	1	2
1Commercial preparations considered partially inert in the rumen.							
2Also contains 14% C20:5 and 9% C22:6.							

Digestion and absorption of fats
Metabolism of Fats in the Rumen
Ruminal micro flora hydrolyze triglycerides and phospholipids that contain polyunsaturated fatty acids. Fats of plant or animal origin contain the unsaturated fatty acids palmitoleic (16:1), oleic (C18:1), linoleic (18:2 *n*-6), and α-linolenic (18:3 *n*-3) acids (Table 1), all of which are metabolized in the rumen. Linoleic acid predominates in seed and seed products, and α-linolenic predominates in forages. Fats are hydrolyzed to their polyunsaturated fatty acid constituents and to glycerol. A high proportion of the fatty acids are then partially or completely hydrogenated and much of the glycerol is fermented to propionic acid [7,28]. Estimates of hydrogenation efficiency of linoleic acid range from 70 to 90% [37]. The consumption of large quantities of ruminally active fat (> 5% of total dry matter intake) can markedly reduce fiber digestibility and reduce dry matter intake in ruminants [8]. This occurs due to the selection against microorganisms with cellulolytic capability. However, certain types of fat-containing feedstuffs can be fed in quantities that would contribute fat at levels greater than the 5% limit without such negative effects. For example, whole cottonseeds (approximately 23% oil) can be fed at much higher levels than would be possible if the free oil were mixed throughout the diet. Apparently, this is possible because ruminal metabolism of the oil is

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slowed by the fibrous seed coat, and a portion actually passes through the rumen intact [8]. Due to the lack of reactive double bonds, saturated fatty acids also pass through the rumen undegraded and are considered bypass fats [20]. The effects of animal tallow and other predominantly saturated fats on the metabolism and physiology of the ruminant differ somewhat because of this phenomenon. However, the fatty acid profile of a predominantly saturated fat such as tallow can vary greatly, with concentrations of linoleic acid constituting from 2 to 9% of the total [8]. Table 1 summarizes the fatty acid content of three common fat sources (soybean oil, tallow, and fish oil) used in a study conducted in this laboratory [38].

Ruminal Fermentation
Studies related to effects of fat supplementation on reproductive processes have for the most part been careful to use isoenergetic and isonitrogenous control diets. However, the consumption of reactive fats by ruminants results in effects on fermentation patterns. Therefore, the potential for differences in the efficiency of energy utilization and local energy partitioning cannot be eliminated from consideration. Changes in ruminal volatile fatty acid production occur in response to increments in dietary fat, and the proportion of change is dependent on the degree of saturation of the fatty acids consumed (e.g., polyunsaturated > saturated and highly polyunsaturated) and quantity fed [20]. As already noted, consumption of polyunsaturated fatty acids increases ruminal propionate production and decreases the acetate: propionate ratio. Highly polyunsaturated and saturated fats tend to bypass the rumen unaltered and have fewer effects on ruminal fermentation. Other effects on serum cholesterol and triglycerides are generally similar among the three types of fats, although tallow tends to increase serum triglycerides to a greater extent than the other fats, and fish oil (highly polyunsaturated fatty acids) tends to produce a lesser increase in both total and HDL-cholesterol [38].

Fat Supplementation and Reproductive Function
Metabolic hormone secretion
Dietary fat supplementation causes an array of metabolic effects in cattle. The consumption of polyunsaturated plant oils increases basal serum insulin concentrations in both dairy [30] and beef cows [32,38]. This phenomenon has been observed in cycling cattle and in response to feeding during the postpartum period. Therefore, it is possible that increased serum concentrations of insulin occurring in response to polyunsaturated plant oils play a role in mediating increased follicular growth, either directly through its own receptor or indirectly by modulating granulosa cell IGF-I production. Mean serum concentrations of insulin also increase gradually in response to fats in which either saturated (animal tallow) or highly polyunsaturated fatty acids (fish oil) predominate, with correspondingly modest increases in populations of medium-sized follicles. We speculate that this may be due to the presence of either linoleic acid or palmitoleic acid (16:1) in tallow and fish oil, respectively. All of the fats we have tested increased serum concentrations of GH in beef cattle [32,38]. However, during the postpartum period of beef cows, the effect of fat consumption seemed to be mainly to prevent a postpartum decline in serum GH. Studies conducted during later lactation have demonstrated a similar phenomenon in high-producing dairy cows [15]. Increases in serum GH seem to occur coincident with an increase in the accumulation of follicular fluid IGF-I, but without effects on peripheral circulating IGF-I [15,38]. The basis for this rather confusing observation has not been determined. However, a recent report indicates that moderate doses of porcine somatotropin do not increase growth rate, serum IGF-I, or IGF-I binding proteins in suckling pigs. Growth hormone receptors, while rare, are present in bovine follicles and are abundant in corpora lutea [25]; therefore, mechanisms involving IGF-I as a mediator of local GH effects may or may not be operative. In either case, we have observed increases in follicular fluid IGF-I of fat-supplemented cattle, regardless of type of fat consumed, and a heightened ability of fresh luteal tissue from these animals to secrete IGF-I in vitro [32,38]. In rats, GH has been shown to directly stimulate IGF-I mRNA within granulosa cells and to enhance the production of IGF-I. summarizes the effects of dietary fat supplementation on circulating concentrations of GH and insulin, intra follicular concentrations of IGF-I, and luteal tissue production of IGF-I as reported by various laboratories.

LH Secretion and Follicular Development
Secretion of LH from the pituitary and follicular growth in cattle are regulated partially by the energy status of the animal. Energy provided by fat supplementation increases LH secretion in animals deficient in energy. A mechanism independent from energy by which dietary fatty acids affect LH secretion has not been established [26]. In some studies, LH dynamics were stimulated by fat supplementation but were unchanged or decreased in others [37]. The mechanism by which supplemental fat would stimulate LH release is not known unless a glucose-sparing effect occurs at the mammary gland, providing greater glucose to signal the hypothalamic pituitary control system to secrete more LH [37]. Similarly, fat supplementation may increase glucose production through increased propionate

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production. This increase in glucose may have a positive effect on LH release [14]. Supplemental fat stimulated programmed growth of a preovulatory follicle, increased total number of follicles, and increased the size of preovulatory follicles [26]. Increased size of preovulatory follicles may be due in part to increased concentrations of plasma LH, which stimulates the latter stage of follicular growth. The ovulation of larger follicles may result in the formation of larger corpora lutea with increased steroidogenic capacity and result in greater progesterone production, which has been associated with higher conception rates.

Cholesterol-Progesterone Concentrations

Dietary fat supplementation increases circulating concentrations of cholesterol [37] and progesterone and the lifespan of induced corpora lutea (**CL**) in cattle [39]. Cholesterol serves as a precursor for the synthesis of progesterone by ovarian luteal cells. Progesterone prepares the uterus for implantation of the embryo and also helps maintain pregnancy. Increased concentrations of plasma progesterone have been associated with improved conception rates of lactating ruminants [37]. Increased concentrations of cholesterol from fat supplementation may lead to an increase in progesterone synthesis [37] or reduced rate of clearance from the blood [17]. Cholesterol serves as a precursor for the synthesis of progesterone by ovarian luteal cells. Secretion of progesterone is the main function of the corpus luteum. Progesterone not only prepares the uterus for implantation of the embryo but also helps maintain pregnancy by providing nourishment to the conceptus. The successful establishment and maintenance of pregnancy (before day 16 post AI) requires the maintenance of progesterone secretion through the critical period of the maternal recognition of pregnancy when luteolysis occurs in the non-pregnant animal [23]. Between 25 and 55% of mammalian embryos die in early gestation. Increased concentrations of plasma progesterone have been associated with improved conception rates of lactating ruminants. Similarly, progesterone concentration prior to AI has been associated with greater fertility. In a field study involving 426 lactating dairy cows, blood was sampled on 58d postpartum for multiparous cows and 72 for primiparous cows and then analyzed for progesterone. Cows were bred approximately 3d later in a synchronized estrus scheme. Conception rate increased 1.44% for every 1ng/ml increase in plasam progesterone ($r^2 = 0.11$, [37]). The recovery of embryos 7d after estrus increased as plasma progesterone concentration increased just prior to AI [5]. In either association, dietary fat, which stimulates ovarian cyclicity or corpus luteum function, would contribute to increased fertility. Increased progesterone suggests that luteal function is enhanced by dietary fat. Dynamics of maternal progesterone secretion also appear important for conceptus development and secretion of interferon-τ, which is secreted by the embryo for gestation recognition by the mother. It has been suggested that improved conception rate could be a result of increased concentrations in plasma cholesterol [36], although this hypothesis was not supported by our results. In fact, cows fed formaldehyde-treated flaxseed had lower plasma cholesterol concentration and better conception rate than those fed Megalac® [31]. Other studies have reported no relationship between cholesterol concentrations in blood and reproductive measures [12,36]. The fatty acid profile of the dietary fat may influence the propensity of animals to increase plasma progesterone. Mature ewes were infused intravenously with saline, soybean oil, or olive oil for 5h on d 9 through 13 of an estrous cycle [6]. Serum cholesterol was increased by fat infusates, and olive oil was more effective than soybean oil (127, 141, and 153 mg/dl for saline, soybean oil, and olive oil, respectively). However, soybean oil infusion resulted in greater progesterone response than did infusion of olive oil at 2.5h post infusion. Therefore, the greatest concentration of serum cholesterol did not coincide with the greatest concentration of serum progesterone.

Estradiol Concentrations

Estradiol has stimulatory effect on uterine secretion of $PGF_{2\alpha}$, and can increase the sensitivity of the CL to $PGF_{2\alpha}$ [19] which may enhance regression of the CL. Thus lowerd plasma estradiol may help prevent pre-mature CL regression and early embryonic mortality. Abomasal infusion of tallow or yellow grease reduce concentrations of plasma estradiol on day 15 to 20 of a synchronized estrous cycle compared with cows infused with glucose, a response that also has been observed in beef cows supplemented with lipids [18]. Also, estradiol concentration was reduced in follicular fluid from beef cows fed soybean oil [32]. Although a reduction in follicular estradiol caused by fat feeding might potentially benefit CL lifespan, it may be detrimental to expression of estrus and uterine priming during proestrus.

Prostaglandins synthesis

There are two main pathways (Figure 1) used to synthesize PG: one is used by most dietary fat (e.g. corn and soybean, sources of omega-6 fatty acids) and leads to series 1 and 2 PG while the other one is more specific to fish products and flax (sources of omega-3 fatty acids) and leads to series 3 PG. Thus, depending on the pathway used

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for PG synthesis, the type and role of the resulting PG will differ. PG of series 2 are important at calving; they increase platelet agglutination and blood clot formation, they increase salt retention in kidneys, water retention, and blood pressure. PG of series 2 also cause inflammation, which leads to their role of "bad guys" among the different PG series.

Omega-6 fatty acids	Omega-3 fatty acids

C18:2n6 Linoleic acid   C18:3n3 α-Linoleic acid

↓   ↓

C18:3n6 γ-Linolenic acid   C18:4n3 Stearidonic acid

↓   ↓

C20:3n6 Dihomo-γ-Linolenic acid   C20:4n3 Eicosatetraenoic acid

↓   **Series 1 Prostaglandins**   ↓

C20:4n6 Arachidonic acid   C20:5n3 Eicosapentaenoic acid

cyclooxygenase ↙   prostaglandin synthase

Prostaglandins H_2 **Series 3 Prostaglandins**

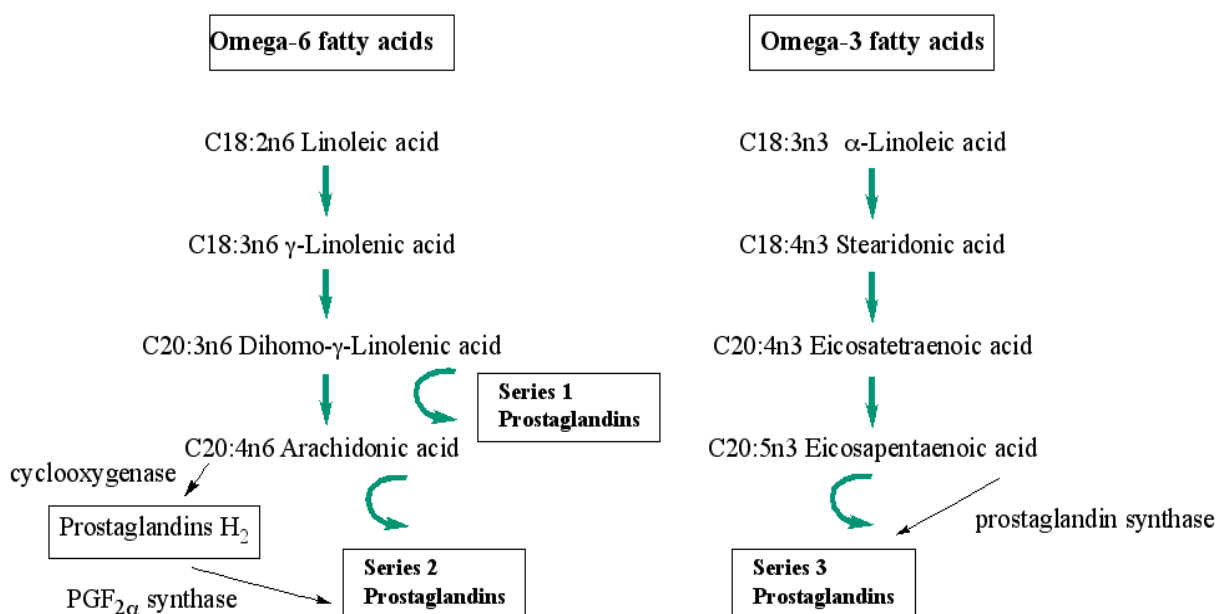$PGF_{2\alpha}$ synthase → **Series 2 Prostaglandins**

Figure 1. Metabolic pathway of series 1,2 and 3 prostaglandins

PG of series 1 improve the immune system of T cells, prevent platelet agglutination and heart attack, contribute to remove the excess of Na and water in kidneys, decrease the inflammatory response and contribute in controlling arthritis and decreasing cholesterol production. PG of the series 3 have a very weak platelet agglutination power and they prevent fabrication of PG of the series 2; they also prevent heart attack, water retention, and inflammation. PG of the series 1 and 3 are thus considered as contrary to those of the series 2. In fact, some immune parameters were affected by the type of dietary fatty acids at the time of embryo implantation. Some polyunsaturated fatty acids (**PUFA**) can serve as a substrate for the synthesis of $PGF_{2\alpha}$. These include cis-linoleic acid (C18:2) that is commonly found in natural fat sources. It can be desaturated and elongated to form arachidonic acid which serves as an immediate precursor for the series 2 PG of which $PGF_{2\alpha}$ is a key member. Key regulatory enzymes for these conversions include Δ six desaturase and cyclooxygenase. These same fatty acids also can inhibit PG synthesis by competitive inhibition with these key enzymes. Linoleic acid has been shown to be an inhibitor of PG synthesis that is produced by the endometrium in response to the presence of a conceptus in order to preserve the integrity of the conceptus. Other fatty acids besides linoleic acid can play inhibitory roles. EPA and docosahexanoic acid (C22:6) have been shown to inhibit cyclooxygenase activity, which is an enzyme involved in the synthesis of $PGF_{2\alpha}$.

Effects of prostaglandins on ovulation
Prostaglandins E2 and F2α are important mediators of the ovulatory process. Their concentration in follicular fluid increases sharply before ovulation. The administration of inhibitors of prostaglandin synthesis such as indomethacin blocks ovulation in rats, rabbits, pigs, sheep, monkeys and humans through the reductions of both PGE2 and PGF2α [35]. When rats were fed diets containing high concentrations of eicosapentaenoic acid and docosahexaenoic acid, the number of corpora lutea found after the first oestrus was reduced. Since the release of GnRH in the rat has been associated with activation of PGE2- dependent pathways [11,22,29,40], eicosapentaenoic and docosahexaenoic acids may have caused a decrease in hypothalamic synthesis of PGE2, which prevented GnRH release and decreased the frequency of ovulations. Experiments have not been designed to examine specifically whether feeding of supplemental fats, such as fish meal or fish oil, interferes with ovulation of the preovulatory follicle in cattle.

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However, after injection of GnRH and PGF2α given 7 days apart, oestrous detection and conception rates to the synchronized service were normal in cows that were fed fish meal [6].

Mechanisms of inhibition of prostaglandin secretion
Dietary PUFAs can decrease PGF2α synthesis by different actions, which include decreasing the availability of precursor arachidonic acid, increasing the concentration of fatty acids that compete with arachidonic acid for processing by PGHS, and inhibiting PGHS. Reduced availability of arachidonic acid in the uterine phospholipid pool for conversion to prostaglandins of the 2 series can occur through a reduction in the synthesis of arachidonic acid or through displacement of existent arachidonic acid from the phospholipid pool by other fatty acids (Fig. 2).
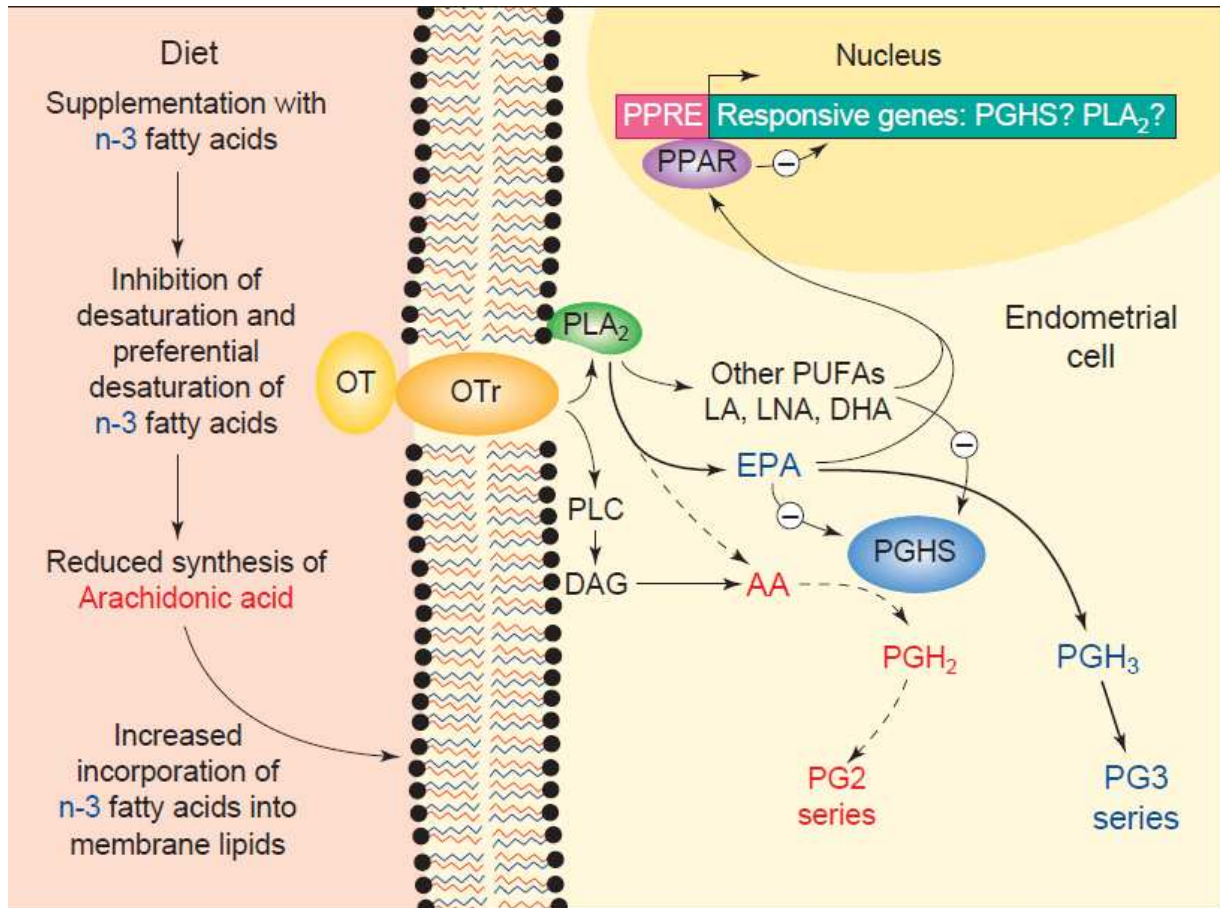

Figure 2. Proposed schematic model of the effect of a diet rich in n-3 fatty acids on the synthesis of eicosanoids
The n-3 fatty acids inhibit desaturase activity and undergo preferential desaturation at the expense of desaturating n-6 fatty acids. This results in increased incorporation of n-3 fatty acids and reduced incorporation of arachidonic acid (AA; C20:4, n-6) into plasma membrane lipids. Decreased availability of arachidonic acid and increased availability of eicosapentaenoic acid (EPA; C20:5, n-3) in the plasma membrane result in decreased synthesis of prostaglandins of the 2 series (indicated by dotted lines) and increased synthesis of eicosanoids of the 3 series. Eicosapentaenoic acid competes with arachidonic acid for processing by prostaglandin H synthetase (PGHS). Eicosapentaenoic acid and other polyunsaturated fatty acids released into the cytoplasm by phospholipase activity, such as linolenic (LNA; C18:3, n-3), linoleic (LA; C18:2, n-6) and docosahexaenoic (DHA; C22:6, n-3), can inhibit PGHS activity. The fatty acids may activate nuclear transcription factors such as the peroxisome proliferator activated receptor (PPAR) to repress transcription of genes encoding phospholipase A2 (PLA2) and PGHS. The PPARs bind to the peroxisome proliferator response elements (PPREs) in the regulatory region of target genes. DAG, diacylglycerol

Effect of fat supplementation on pregnancy rate
Incorporation of lipids in rations for dairy cattle usually increases energy density of ration and improves lactation and reproductive performance [14]. However, when they are supplied in early lactation, frequently there is a reduction in feed intake due to a reduction in dry matter digestibility and to an increase in energy of greater availability, so when lipids are supplied in the early postpartum period, there is little alteration in the energy status of the animal even when a higher energy density ration is consumed [33]. Then, if dietary fat does not alter the energy

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status of dairy cows, reproductive response results more from the supply of some fatty acids, than from the effect of the energy supply per se [37, 39]. There are several studies that report a better reproductive performance in cows fed supplementary lipids. In this respect, Staples et al. [37], showed that lipid consumption exerted a positive effect on reproductive aspects in dairy cows (Table 2). In beef cattle, the same trend has been observed. It is in this context that, de Fries et al. [9] reported that Brahman cows consuming 5.2% lipids in the ration showed a trend towards an increase in pregnancy rate than those cows which consumed only 3.7% lipids in the ration. Ferguson et al. [12] observed a 2.2 times increase in the possibility of pregnancy in lactating cows consuming 0.5 kg lipids per day. In another study, it was demonstrated that grazing cows supplemented with fat, pregnancy rate at first service was 16% higher than in cows which did not receive fat in the ration [4]. Also supplementation with safflower seed, soybeans, or sunflower seed (4.7, 3.8 and 5.1% fat in the ration, respectively) for the last 65 days before calving increased subsequent pregnancy rates (94%, 90% and 91%, respectively) of first-calf beef heifers compared with the control (79 %) that received only 2.4 % fat in the ration. In another study using good quality forage and a higher amount of fat in the ration (6.5%) during 68 days before calving, was unable to improve pregnancy rates relative to a control ration (2.2% fat), this result indicates that when adequate nutrients are available, the effect of supplemental fat may be masked. Grazing Holstein cows which were supplemented for 103 days, as from day 10 post-partum, with two sources of bypass fat Megalac plus 3% (MP; 0.4 kg/day, containing Ca salts of palm fatty acids and Ca salts of methionine hydroxy analogue) and Megapro Gold (MPG; 1.5 kg/day, containing Ca salt of palm fatty acids, extracted rapeseed meal and whey permeate), MPG increased ($P<0.05$) conception rate to first service compared to control group (CG). Conception rate to first service was similar (P=0.14) on MP compared to CG. For pregnancy to second service, CG had a higher ($P<0.05$) conception rate than MP. There were no significant differences between treatments in overall pregnancy rate, services per conception, number of cows served in the first three weeks of the breeding season or the 6- weeks in-calf rate. Comparing the combined fat treatments to CG resulted in a higher ($P<0.05$) conception rate to first service for the fat treatments but no significant difference in overall pregnancy rate [27]. In another full study, Asgari et al [41] that using CSFA with different profiles indicated increase metabolite levels related to reproductive, also using CSFA supplementation in flushing period was effective on reproductive performance of Iranian Afshari ewes.

Table 2. Reproductive performance of beef cows supplemented with fat in the ration. 1First insemination
(Adapted from Thatcher & Staples[37])

Reference	Fat source	Percent inclusion	Pregnancy rate
[34]	Ca-Palm oil	2.6 %	82
[31]	Flaxseed	17%	87
[2]	Flaxseed	9%	481
[2]	Flaxseed	9%	261
[13]	Extruded Linseed	1.7 kgd-1	39
[27]	MegaPro Gold	3.3 lb d-1	54
[21]	Soy + Trans C18:1	1.5%	341
[1]	ByFat ®	1.8%	33
[6]	Fish meal	2.8	41

In another study, Aguilar-Pérez et al[1] observed that pregnancy rate of F1 (Holstein x Zebu) cows grazing under tropical conditions in Mexico, was not affected by supplementation with bypass fat (33.3%), relative to a control group (41.7%) at 90 days postpartum. In conclusion, fat supplementation increased conception rate to first service but did not significantly affect the proportion of cows pregnant at the end of the breeding season, these results suggest that the higher quality of the forage supplied in the different seasons that the trial lasted, may have been a factor that masked the effect of fat supplementation. Juchem et al. [21] evaluated the effect of supplementation before and after parturition with Ca-LCFA of palm oil or with a mixture of linoleic and *trans*-octadecenoic acids and observed that cows fed PUFAs showed a higher pregnancy rate than those supplemented with palm oil at 27 and 41 days (37.9 *vs* 28.6% and 35.5 *vs* 25.8%, respectively) after artificial insemination. Recently, Lopes et al. [24] fed Nellore cows with 0.1 kg cow-1day-1 of PUFAs and observed that pregnancy rate was improved. In this respect, Mattos et al. [26] suggested that the positive effect of fat on fertility may not be due to improvement in energy balance of the cows but rather to the specific effect of some dietary fatty acids on the physiology of the hypothalamus-hypophysis ovary axis and even the uterus. In a review of previous studies in which conjugated linoleic acids (CLA) were supplemented to dairy cows during early lactation, de Veth et al. [10] demonstrated that the probability of pregnancy increases in 26% when CLA are increased in the ration and that the optimum CLA amount is 10.0 g d-1, after which the beneficial effects are reduced. It is possible that the positive effect of lipid supplementation may be due to specific fatty acids [37], and the absorption of unsaturated FA in ruminants is limited

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due microbial bio hydrogenation in the rumen [24]. Some studies have evaluated the possibility that unsaturated FA intake, particularly those of the *n*-6 (linoleic acid) and *n*-3 (α- linolenic, eicosapentaenoic, docosahexaenoic acids) families, may have some influence on reproduction in cows, even when reports in the literature are not always consistent [33]. In this respect, when cows were fed 0.75 kg of linseed rich in α-linolenic acid (*n*-3), or sunflower rich in linoleic acid (*n*-6), pregnancy rate tended to increase in cows of the first treatment [2]. In other studies, no response was observed with linseed [13]. Similarly, feeding *n*-3 fatty acids from fish oil in the form of Ca-LCFA did not improve pregnancy rate postpartum at first service in beef cows when compared to supplementation with beef tallow [21] or with Ca-LCFA from palm oil (Silvestre, quoted by Santos et al[33]), even when pregnancy rate at second service postpartum was higher in cows fed *n*-3 fatty acids (Silvestre, quoted by Santos et al[33]). In grazing F1 (*Bos taurus* x *Bos indicus*) cows, Aranda-Ávila et al [3] observed a 15.4% increase in pregnancy rate when cows were supplemented with corn oil, relative to a control group (54.5 *vs.* 41.7 % respectively) after 35 day supplementation; however, differences were not statistically significant. It is possible that the poor response observed in those studies may be due to an increase in milk production along with a loss of body weight, which occurs in greater or lesser degree in cows during the early postpartum period [34].

CONCLUSION

Fat is recommended to be incorporated into farm animal diets at moderate amounts. Feeding fat to cattle generally improved establishment and maintenance of pregnancy, but benefits to fertility can be negated when weight losses are exacerbated by fat feeding. Potential improvements in fertility of cows caused by fat feeding have generally been associated with enhanced follicle development postpartum, increased diameter of the ovulatory follicle, increased progesterone concentrations during the luteal phase of cycle, altered uterine/ embryo cross-talk by modulating PG synthesis, and improved oocyte and embryo quality. Some of these effects have been more influenced by the type of fatty acid than by feeding per se. Differential responses in vivo to FA feeding suggest that unsaturated FA of the n-6 and n-3 families were most beneficial.

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