The Effects of Late Gestation Supplementation of Rumen Protected Fat on Cow and Calf Serum Fatty Acids, Passive Immunity Transfer and Growth In Beef Calves

Ralph Earl Ricks
Clemson University, ericks@g.clemson.edu

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THE EFFECTS OF LATE GESTATION SUPPLEMENTATION OF RUMEN PROTECTED FAT ON COW AND CALF SERUM FATTY ACIDS, PASSIVE IMMUNITY TRANSFER AND GROWTH IN BEEF CALVES

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Animal and Veterinary Science

by
Ralph Earl Ricks
December 2018

Accepted by
Dr. Nathan M. Long, Committee Chair
Dr. Scott Pratt
Dr. J. Drew Lanham
The primary objective of the cow calf sector of the beef industry is to market live calves after weaning. One component to profitability in this sector is to wean healthy, productive calves with as low of an input as possible. This means not only efficiency of preweaning growth of the calf, but the dam needs to produce a more than adequate supply of milk as it is the primary nutrition of the calf. Production of an animal that can convert the milk supply offered and turn it into pounds of gain efficiently is ideal. The calf, ideally, should be born unassisted and the newborn calf must stand and suckle its dam as soon as possible. Short term, the supply of glucose to the calf from the placenta is removed at birth and must now come from exogenous sources, such as colostrum and gluconeogenesis (Hammon et al., 2013).

The calf must, within the first 24 hours of life, begin building the immune system that will protect it from most pathogens. With few exceptions, mammals possess an immune system that is virtually innate and humoral (Beck et al., 1996; Janeway et al., 2001). The calf is born with an innate immunity to pathogens which serve as both physical and chemical barriers to pathogens. The immune system is both innate and adaptive, it can adapt to changing challenges from pathogens. Exposure can come from infection of a pathogen or immunization. Immunization is exposure to either modified forms that mimic a pathogen or a killed version of the pathogen itself. The innate immune system exists to provide early defense against pathogen attack, and to alert the adaptive immune system to the fact that pathogen invasion has begun. In many cases, an adaptive immune response confers lifelong protective immunity to reinfection with the same pathogen (Janeway et
Adaptive immunity is further subdivided into either humoral or cell-mediated immunity. Humoral immunity is mediated by B-lymphocytes, which respond to antigens to become antibody producing cells and memory cells and provide defense against extracellular microbial infections. In cell mediated immunity, the T-lymphocytes and associated cytokines (proteins made by cells that affect the behavior of other cells) provide defense against intracellular pathogens and tumor cells (Galyean et al. 1999). Antibodies are immunoglobulins made up of several classifications. The immunoglobulin isotypes are: IgM, IgD, IgG, IgA, and IgE (Janeway et al. 2001). The most abundant immunoglobulins found in the plasma are IgG and are the workhorse of the immune system. Immunization occurs actively, either contact with a directly or from being vaccinated. Colostrum has evolved in nature as a nutritional supplement that is fed to the newborn by its mother during a short period after birth. In certain mammals, such as humans, IgG is passed to the fetus through the placenta but in ruminants, via colostrum (Larson et al., 1980). All mammals produce colostrum, but they do not contain the same amount of IgG as in the ruminant. Colostrum contains immunoglobulins for every pathogen the mother had either contracted or been vaccinated against. The bovine transfers large amounts of IgG immunoglobulins from the blood stream across the mammary barrier into colostrum (and milk) by a specific transport mechanism. The passive transfer of immunity to the young is an essential process in mammalian species to provide the neonate protection during the early period in life when its own immune system is being established (Larson et al, 1980). The immunoglobulins from the colostrum are the first step in creating an immune system that will keep the calf healthy.
and able to combat the morbidity that can hinder its ability to turn milk into muscle and therefore profit.

Previous research into supplementation of beef cattle has been primarily concerned with protein and energy and how it relates to Body Condition Score (BCS) of the cow (Alderton et al., 2000; Engel et al., 2008), reproductive performance of the cow (Corah et al., 1975; Bellows & Short, 1978; Marston et al., 1995) and postpartum calf performance (Corah et al., 1975). Fat supplementation in beef cattle has been studied with regard to milk production and energy balance. Supplementation of both fat and specific fatty acids have been directed at beef cows, developing heifers, newly received beef steers and as energy supplementation in feedlot steers on fattening rations. Late gestation supplementation of fat or essential fatty acids to beef cows has primarily focused on cow BCS, reproductive performance and calf performance but lacks research investigations on how it influences the developing calf in utero or the neonatal calf postpartum, a type of developmental programming. Limited research has been performed on rumen protected fatty acid provided during late gestation supplementation in beef cattle. Most research has been performed in dairy cattle, however the importance of an effective neonatal immune system in the beef industry due to the different production goals as to breed differences warrants further studies. The objective of this current study was to determine if late gestation supplementation of rumen protected unsaturated fatty acids (FA): 1) increased unsaturated FA in maternal serum and colostrum during late gestation and 2) increased unsaturated FA in serum of subsequent calves and transfer of IgG in new born calves.
ACKNOWLEDGMENTS

This thesis is the end of a long hard road and is only possible because to the hard work of many people to whom I will be eternally grateful. I owe a debt to Dr. Long that can never be repaid. After nearly three decades of working on beef cattle operations, Dr. Long convinced me that I had the potential to start and finish an advanced degree and along the way, remind me that there is a world of knowledge about beef cattle that I had barely scratched and he rekindled my thirst for that knowledge. Dr. Long has been a friend, mentor, and taskmaster and had the wisdom to know what I needed and when. From 2 a.m. calf deliveries and seemingly endless data collections in the wee hours of the morning to the classroom, in hot or freezing temperatures, Dr. Long has always been either on my left or on my right and most of the time covering my back. I have been lucky to learn from one of the finest teachers I have had the honor to have been associated with and I hope his students, both graduate and undergraduate, recognize their good fortune. I hope I have made him proud of my tenacity at least. I also wish to thank the two students that assisted in daily supplementations and more. Emily Cook and Toni Franken, both of whom are enrolled in veterinarian school, University of Georgia and The Ohio State University respectively, were invaluable in the daily feeding of project cows and helping to weigh daily rations, sort cows and even bring them in every day for supplementation, regardless of how wet, dry, hot or cold and many combinations of both. Working in shifts and sometimes at the same time, they were always there on time without fail and in a cheerful mood which never failed to improve mine. I look forward hearing that they both have earned their DVM and know that they will make fine
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title Page</td>
<td>i</td>
</tr>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iii</td>
</tr>
<tr>
<td>I. Review of Literature</td>
<td>3</td>
</tr>
<tr>
<td>Late gestation supplementation of energy and protein in beef cattle</td>
<td>3</td>
</tr>
<tr>
<td>History of Fatty acid supplementation in beef cattle</td>
<td>4</td>
</tr>
<tr>
<td>Supplementation of Essential Fatty Acids in late gestation in beef cattle</td>
<td>8</td>
</tr>
<tr>
<td>History of Ca salt rumen protected fat</td>
<td>10</td>
</tr>
<tr>
<td>Calcium salt rumen protected fat supplementation in beef cattle</td>
<td>12</td>
</tr>
<tr>
<td>Calcium salt rumen protected fat in late gestation in beef cattle</td>
<td>16</td>
</tr>
<tr>
<td>Soybean Meal Supplementation Late Gestation in Beef cattle</td>
<td>20</td>
</tr>
<tr>
<td>Essential Fatty Acid profile of Soybean Meal, Essentiom &amp; Corn Gluten Feed</td>
<td>21</td>
</tr>
<tr>
<td>Beef cattle immunity</td>
<td>22</td>
</tr>
<tr>
<td>Immunoglobulin G (IgG) in beef cattle</td>
<td>31</td>
</tr>
<tr>
<td>Colostrum in beef cows</td>
<td>33</td>
</tr>
<tr>
<td>Essential Fatty Acids in colostrum</td>
<td>38</td>
</tr>
<tr>
<td>Importance of colostrum to neonatal beef calves</td>
<td>43</td>
</tr>
<tr>
<td>Importance of Essential Fatty Acids to neonatal beef calves</td>
<td>46</td>
</tr>
<tr>
<td>Essential Fatty Acids role in passive immunity transfer</td>
<td>48</td>
</tr>
<tr>
<td>Essential Fatty Acids and rumen bypass fat effects on calf birth weight</td>
<td>51</td>
</tr>
<tr>
<td>Essential Fatty Acids and beef calf growth</td>
<td>52</td>
</tr>
<tr>
<td>Essential Fatty Acids and Beef cow reproduction</td>
<td>55</td>
</tr>
<tr>
<td>Conclusion</td>
<td>59</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>61</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>II.</td>
<td>The effects of supplementing ruminal bypass unsaturated fatty acids during late gestation on cow and calf serum fatty acids in beef cows</td>
</tr>
<tr>
<td></td>
<td>Abstract</td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
</tr>
<tr>
<td></td>
<td>Materials and Methods</td>
</tr>
<tr>
<td></td>
<td>Results</td>
</tr>
<tr>
<td></td>
<td>Discussion</td>
</tr>
<tr>
<td></td>
<td>Literature Cited</td>
</tr>
<tr>
<td>III.</td>
<td>The effects of supplementing ruminal bypass unsaturated fatty acids during late gestation on transfer of passive immunity and growth in calves</td>
</tr>
<tr>
<td></td>
<td>Abstract</td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
</tr>
<tr>
<td></td>
<td>Materials and Methods</td>
</tr>
<tr>
<td></td>
<td>Results</td>
</tr>
<tr>
<td></td>
<td>Discussion</td>
</tr>
<tr>
<td></td>
<td>Literature Cited</td>
</tr>
<tr>
<td>IV.</td>
<td>Impediments to research</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

#### Chapter II

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nutrient profile &amp; fatty acid composition of rumen nondegradable unsaturated fatty acid source</td>
<td>100</td>
</tr>
<tr>
<td>2.</td>
<td>Cow body weight (kg) and BCSs and their changes during the last 90 d of gestation of cows fed an isocaloric supplement containing either 200 mg of ESSENTIOM 5 d a week (EFA) or a supplement with no fat (Control)</td>
<td>101</td>
</tr>
<tr>
<td>3.</td>
<td>Serum total and specific fatty acids (mg/ml) of cows individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk</td>
<td>102</td>
</tr>
<tr>
<td>4.</td>
<td>Colostrum dry matter total and specific fatty acids (FA, mg/g DM) of cows individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk</td>
<td>103</td>
</tr>
<tr>
<td>5.</td>
<td>Serum total and specific fatty acids (FA, mg/ml) of calves at parturition whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk</td>
<td>104</td>
</tr>
<tr>
<td>6.</td>
<td>Serum total and specific fatty acids (mg/ml) of calves at 5 d of age whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk</td>
<td>105</td>
</tr>
</tbody>
</table>
Chapter III

1. Nutrient profile and fatty acid composition of rumen nondegradable unsaturated fatty acid source for both experiments ............................................................. 139

2. Serum IgG in calf serum and colostrum from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen nondegradable fat source (EFA) 5 d/wk.................................................................................................................. 140

3. Calf birth weight from cows during the last 90 d of gestation fed an isocaloric supplement containing either ESSENTIOM 5 d a week (EFA) or a supplement with no fat (Control) ........................................................................................ 141

4. Number of days from parturition to return to ovarian cyclicity for cows that were fed during the last 90 d of gestation fed an isocaloric supplement containing either 200 mg of Essentiom 5 d a week or a supplement with no fat ....................... 142
LIST OF FIGURES

Chapter II

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Serum cholesterol, triglycerides and glucose (mg/dL) of unsuckled calves born to cows individually fed isocaloric supplement containing no bypass fat (CON n = 26) or fed 0.2 kg of an unsaturated rumen nondegradable fat source (RUF n = 20) 5 d/wk. at parturition</td>
<td>106</td>
</tr>
</tbody>
</table>

Chapter III

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Serum cortisol μg/mL of calves from birth to d 4 whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen nondegradable fat source (EFA) 5 d/wk</td>
<td>143</td>
</tr>
<tr>
<td>2. First Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt<em>Parity</em>Day interaction $P = 0.003$</td>
<td>144</td>
</tr>
<tr>
<td>3. Second Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt<em>Parity</em>Day interaction $P = 0.003$</td>
<td>145</td>
</tr>
<tr>
<td>4. Third Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt<em>Parity</em>Day interaction $P = 0.003$</td>
<td>146</td>
</tr>
</tbody>
</table>
CHAPTER 1

Review of Literature

*Late gestation supplementation of energy and protein in beef cattle*

Protein supplementation in beef cattle has been widely studied. Investigating protein supplementation of developing heifers, growing steers and bulls, gestating females at various ages and stage of gestation, post-partum cows, suckling calves and weaned calves. The use of fat as supplements for cattle in both beef and dairy cattle has mainly focused on feeding fats to animals either before or after breeding to try to improve reproductive performance (Hess et al., 2008).

Late gestation supplementation of either protein nonfat energy or fat offers the ability to correct the nutritional plane of beef cows to either maintain proper body condition or to bring her to optimum condition for calving and rebreeding after parturition. Many calving systems are dealing with declining forage quality and DM due to native pastures becoming dormant and therefore, late gestation nutrition becomes critical as high quality forages decline in nutrient content and the cow’s plane of nutrition is decreased. Many cattle rely on hay as the primary source of pre-partum nutrition. One early experiment was designed to determine the effect of level of dietary energy intake during the last 100 days of gestation on reproductive performance of beef heifers and to study the effect of altered level of nutrition during the last 30 days of gestation on the reproductive performance of second-calf cows (Corah et al., 1975).
Marston and Lusby (1995) conducted a two year study to determine the effect of differing amounts of protein and fiber-based energy supplements on intake and digestibility of low quality forage by beef cows during late gestation and early lactation. Radunz et al. in 2012 investigated prepartum energy source on mature gestating cows using hay, corn or dried distillers grain. Engel, Patterson, and Perry (2008) compared the differences in animal and reproductive performance and blood plasma concentrations of GH (Growth Hormone), IGF-I (Insulin Like Growth factor), and NEFA (Non Essential Fatty Acids) in heifers when supplemented with either dried distillers grains or soybean hull pellets. Banta et al., (2006) studied the effects of interval feeding whole sunflower seeds (high in linoleic acids) mid to late gestation four days per week on cow performance and their progeny. All of these studies reported positive influences on cow performance either on increased DMI intake or improved reproductive performance in the dam and that late gestation nutrition can have an effect on offspring performance in the feedlot.

In a novel approach, Linden et al. (2014) focused on how the stage of production influenced intake, digestion and passage rate differed during gestation and lactation on cows. As previously stated, there has been a wide range of late gestation supplementation experiments. Ranging from work done in 1978 by Bellows and Short regarding the effects of feeding cattle from mid to late gestation on birth weight, calving difficulty and post-partum fertility to Meyer et al., (2014) studying the effects of gestational supplementation of the dam on the small intestine of the calf and its resulting gain or loss of feed efficiency in the feedlot when being fed to market weights.
Supplementation with protein and energy pre and post calving have been evaluated on cow body weight, body condition, reproductive performance, and calf weight gains. The conclusion was that feeding greater amounts of supplemental nonfat energy before calving increased body weight gains, body condition, and postpartum pregnancy rates in cows. However, feeding increased levels of energy during a short postpartum supplementation period did not affect weight gains, BCSs, or calf growth however, prepartum supplementation of energy increased pregnancy rate and had greater body weight gains than prepartum supplementation of protein (Marston et al., 1995).

Studies performed on beef cattle as early as 1964 found no difference in performance in cows group-fed either daily, three times per week, or two times per week. It was noted that the cows fed less frequently spent less time anticipating feeding events and more time grazing. Each year there were variations in average weaning weights and pounds of calf weaned per cow, however, when weights were adjusted to a 205 basis, the differences were not significant and indicated that frequency of feeding had no effect (Melton & Riggs, 1964). Huston et al., (1999) concluded that, generally, providing supplement as infrequently as once per week reduced losses in body weight and BCS compared to non-supplemented controls and was as effective as daily supplementation. Forage use improved with increased frequency of supplementation in dormant tallgrass prairie, but the impact on animal performance is not likely observed unless extreme differences in frequency occur (Farmer et al., 2001). Frequency of supplementation was shown to be insignificant again in 2014 by Long et al when groups of heifers fed 3 different supplements 5 days per week had no effect on the results. Cook et al., (2016)
investigated optimal frequency of supplementation of growing beef heifers and observed no difference between supplementation frequencies within a day*time period for pregnant beef heifers that were supplemented 3, 5, or 7 d/wk.

History of Fatty acid supplementation in beef cattle

Fatty acid supplementation began in the early 1800 with the identification of fatty acids by Chevreul, who pioneered a method of separating fatty acids from glycerol. From 1811 to 1825 he pursued the study of fatty acids, isolating and identifying oleic acid in 1815. Chevreul demonstrated that fatty acids are combinations of acids with glycerin and developed a system of nomenclature for fats and derived products (Wisniak, 2002).

Channon, Drummond, and Golding (1924) attempted to determine which fatty acids were passed into milk. They examined Arachis Oil (Peanut Oil), Coconut Oil and Cod-liver Oil added to the diets of cows. Through the analyzation of the fatty acid esters found in the butter fat, investigators expected to determine the method of fatty acid transfer to the milk from the oils used in supplementation. This was prompted by observations of fatty acids in the milk that were found in peanut oil and coconut oil, but were not normally found in milk. Work done by Burr & Burr, in 1929, added the term “essential” to fatty acids when they identified a “deficiency disease” in rats. The symptoms of this “disease” were ameliorated by the feeding of lard to the animals. They next used Chevreul’s methods to isolate the fatty acids in the lard and fed dried amounts of them individually to lab animals and feeding either pure lard or just the fatty acids alone either cured the deficiency or prevented it, while glycerol had no effect on
animals exhibiting the deficiency symptoms (Burr & Burr, 1929). In the late 1990’s investigations began to look less at total fat and more at specific fatty acid supplementation in dairy cattle followed by beef cattle. These investigations looked at ways to alter fatty acid makeup of the food products made for human consumption and at how they affected animal metabolism in the various production processes including reproduction, growth, meat quality and stress (Fluharty et al., 1997; De Fries et al., 1998; Encinias et al., 2004; Kronberg et al., 2011).

As producers and researchers began to increase the supplementation of fatty acids to cattle diets, some practical problems began to appear. Fatty acids exhibit antimicrobial effects on rumen bacteria, which limits the amount of fat that can be fed in a supplement or diet and microbial biohydrogenation of the fatty acids, when rumen bacteria convert unsaturated fatty acids (USFA) to saturated fatty acids (SFA) by adding H, which can interfere with the absorption of certain fatty acids which can influence animal performance or improve the qualities of products for human consumption (Jenkins, 1993) and can alter the rumen microbe environment leading to decreased fiber digestion and reduced DMI.

Henderson, (1973) examined the effects of six fatty acids (oleic, lauric, capric, myristic, palmitic and stearic) at low concentrations on the growth of seven species of rumen bacteria \( (\text{Anaerovibrio lipolytica (strain 5 S), Peptostreptococcus elsdenii (type 2), Bacteroides ruminicola 46/52, Selenomonas ruminantium (strain 17), ButyrivibrioB 835, Ruminococcus 4263/1 and Methanobacterium ruminantium}) \). Four species of bacteria, \( \text{Anaerovibrio lipolytica (strain 5 S), Peptostreptococcus elsdenii (type 2)}, \)
Bacteroides ruminicola46/52, Selenomonas ruminantium (strain 17), growth was unaffected by the addition of oleic acid and one species, Butyrivibrio B 835, growth was stimulated by low concentrations of oleic acid, lauric acid and capric acids while higher concentrations of these same fatty acids were inhibitory. Myristic, palmitic and stearic acids were inhibitory at all concentrations tested. One species, Ruminococcus4263/1, was inhibited by all six of the fatty acids. The most inhibiting of the fatty acids was oleic acid. Henderson concluded that the demonstrated inhibition of growth of these specific rumen bacteria was consistent with the reported effects of lipids on rumen function (Henderson, 1973). Kemp and Lander (1984) looked into what species of rumen bacteria biohydrogenated specific fatty acids. Essentially, these species changed a fatty acid that was fed into a fatty acid that could either benefit or hinder metabolic processes in the animal. They described rumen microbes as falling into two groups: A and B. Group A hydrogenates linoleic acid and a-linolenic acid to trans-octadec-1 1 -enoic acid and related isomers and Group B, hydrogenate many octadecenoic acids, including oleic acid, trans-octadec-1 1 -enoic acid and linoleic acid, to stearic acid (Kemp & Lander, 1984).

De Fries, Neuendorff & Randel (1998) utilized rice bran as a fat source in a ration fed to postpartum Brahman cows to enhance BCSs, follicular populations, and pregnancy rates. Fatty acids found in the rice bran used contained: Oleic, Linoleic, Linolenic, Arachidonic, Malualic, Sterculic and trans-oleate isomers. Calves of rice bran-supplemented cows tended to be heavier and to gain more weight than calves of control cows (De Fries et al., 1998).
Scholljegerdes et al. (2004) hypothesized that supplemental fat high in the form of linoleate or oleate alters unsaturated fatty acid supply to the small intestine with minimal effects on site and extent of digestion in cattle consuming bromegrass hay supplemented with high-linoleate or high-oleate cracked safflower seeds. They found that the variety of safflower seeds that are high in linoleic acid increased intestinal supply and post ruminal disappearance of unsaturated fatty acids. Indicating that the fatty acids apparently available for metabolism are affected by dietary fat source and total flow of unsaturated fatty acid to the duodenum was greatest in cattle fed safflower seeds (Scholljegerdes et al., 2004).

The objective of Kronberg et al. (2011) was to determine if daily supplementation of flaxseed for 85 d to steers finished on grasslands of the northern Great Plains would influence growth and carcass characteristics, fatty acid profile, tenderness, and sensory characteristics of steaks. All in an attempt to produce meat for human consumption that would have good flavor, tenderness and a healthy fatty acid profile. It was concluded that steers grazing on the growing forages of the upper Great Plains, received a daily supplementation of flaxseed for 85 days would exhibit greater growth rates and enhanced n-3 fatty acid profile of the steaks.
Supplementation of Essential Fatty Acids in late gestation in beef cattle

Most studies investigating late gestation supplementation mainly focus either maintenance of BCS during late gestation or post-partum reproduction in mature cows or first calf heifers. Lammoglia et al. (1999) performed two experiments involving prepartum supplementation of fatty acids during gestation of beef cows and the effects on cold tolerance of their calves immediately following birth. Later investigations determined that feeding high-linoleic safflower seed to gestating ewes increases cold tolerance and survival in lambs and that this same fatty acid might be responsible for and increase the thermogenic capacity of BAT (Brown Adipose Tissue) in lambs (Encinias et al., 2004).

Supplements with either high-linoleate cracked safflower seeds or high oleate cracked safflower seeds were used to determine the effects of prepartum energy balance and postpartum lipid supplementation on cow and calf performance in three year old Angus x Gelbvieh beef cows (Lake et al., 2005). The cows were maintained to reach a BCS of 4 ± 0.07 or 6 ± 0.07 at parturition. At 3 days postpartum, cows of both BCSs were randomly allocated to receive hay and a low-fat control supplement or supplements that were either high-linoleate cracked safflower seeds or high oleic acid cracked safflower seeds until 60 days postpartum. Results seem to have more to do with BCS than with supplementation. Cows that had been managed to achieve a BCS 4 at calving maintained BCS whereas those cows with a BCS 6 lost condition. Dietary supplementation of high-linoleate cracked safflower seeds or high oleic acid cracked safflower seeds did not affect cow BW change, BCS change, 12th rib fat, LM area, milk yield, milk energy, milk fat percentage,
milk lactose percentage, first service conception, overall pregnancy rates, or calf performance. BCS at parturition demonstrated little influence on calf birth weight or ADG. First-service conception rates did not differ because of BCS at parturition, but overall pregnancy rate was greater in BCS 6 cows.

The conclusions in a study performed by Dietz et al. (2003) have important ramifications because losses of calves during the early neonatal period have a negative impact on the economic sustainability of the cow/calf operation. Dietz examined the effects of added fat in late-gestation cow diets on neonatal response to cold in two experiments. In experiment 1, pregnant fall-calving heifers received control (1.5% fat), safflower seed (4.0% fat), or whole cottonseed diets (5.0% fat), fed for 47 d prepartum. At calving, calf BW and vigor score, as well as EE, lactose, and IgG in colostrum were not affected by diet (Dietz et al., 2003). Heifers fed the safflower diet tended to have greater colostral solids than heifers fed the control or whole cottonseed diets.

In experiment 2, pregnant spring-calving cows received a control or whole cottonseed supplement fed for 68 d prepartum contained 2.0 and 5.0% fat for control and whole cottonseed diets, respectively. Calf BW, vigor, shivering, dystocia score, time to stand, time to nurse, serum glucose concentrations, and serum IgG were not affected by diet (Dietz et al., 2003). When ambient temperature was ≤ 6°C, calves born to dams fed whole cottonseed had greater BW, tended to stand earlier, and had greater serum IgG concentrations. They concluded that calves from dams fed high-fat diets containing safflower or whole cottonseed respond similarly to cold stress. High-fat dietary supplementation of late-gestation cows may only be beneficial during calving seasons.
with prolonged cold weather and that feeding high-fat diets may improve resistance of neonatal calves to extremely cold calving conditions, but reduced time to standing and increased serum immunoglobulin concentrations were the only positive calf responses observed. The diets were to provide 0.7, 2.0, and 2.6% linoleic acid for control, whole cottonseed, and safflower diets, respectively (Dietz et al., 2003). The major fatty acid of safflower oil is linoleic acid (Matthaus, Özcan & Al-Juhaimi, 2015). Nutrient content of whole cottonseed: Linoleic acid (C18:2) 56.1% (of the total FA), palmitic acid (C16:0) 24.0%, oleic acid (C18:1), 15.2% (Bertrand et al., 2005). Hess, et al (2008) summarized fat supplementation by saying, “Supplementing fat to beef cattle and sheep can be an effective strategy to increase energy density of the animal’s diet. Optimal levels of fat in the diet depend on goals set for the production unit. Limiting supplemental fat to 2% of dietary DM will help prevent negative associative effects for ruminants fed high-forage diets. The energy density of high-forage diets will not be increased if supplemental fat exceeds 4% of DM. Positive effects on reproductive processes in beef cattle fed fat have been attributed to changes in unsaturated fatty acid status rather than changes in energy.” (Hess et al., 2008). Hess goes on to make a statement germane to this research, “Manipulating maternal diet to improve unsaturated fatty acid status of the neonate has practical benefits, especially for neonates exposed to harsh environmental conditions or foreign antigens.” (Hess et al., 2008).

**History of Calcium salt rumen protected fat**

Ruminant diets high in fat have presented problems with depressed fiber digestion. This is a major drawback due to the fact that fiber is the backbone of the production of meat
and milk in ruminant species. As previously stated, high fat diets reducing both DMI and rumen function well-documented by Ward et al. (1957), Henderson (1973), Smith et al. (1978) and Jenkins, & McGuire. (2006). Increased fat in the diet observed concomitant increase of free fatty acids (Wisniak, 2002). As far back as 1929, nutritionists knew that fatty acids were beneficial and essential (Burr & Burr, 1929). However it was later observed that biohydrogenation of the dietary unsaturated fatty acids by the rumen microorganisms, giving rise to less-unsaturated acids and stearic acid and that linolenic acid present in linseed oil was converted in vitro into linoleic acid by the action of sheep-rumen contents (Reiser, 1951). Experiments were performed to protect the dietary fatty acids from biohydrogenation using alfalfa ash mixed with corn oil as part of the ration (Ward et. al., 1957). It has been observed that calcium in the form of either carbonate or chloride was equally effective in alleviating the depressing effect of corn oil upon ration digestibility (Davidson &Woods, 1963). Formaldehyde was observed to prevent biohydrogenation of a variety of fats and even found that protected hydrogenated soybean oil lowered the content of fat and dry matter in milk (Astrup, et al., 1976).

The roots of calcium salt protected fats can be found in the work performed involving alfalfa ash (Ward et. al., 1957) and comparing the efficiency of calcium carbonate, calcium chloride and magnesium carbonate in lessening the effect on digestibility (Davidson &Woods, 1963). The birth of calcium salts as a feed supplement for dairy rations can be traced to 1980 (Block et al., 2005). At that time, research conducted at Ohio State University under the direction of Dr. Donald Palmquist demonstrated conclusively that synthesized calcium salts of unsaturated long-chain fatty acids (LCFAs)
prevented digestibility problems when added to cultures of ruminal microbes and calcium salts help to give rise to rumen-inert fatty acids (Block et al., 2005). When calcium is associated with unsaturated fatty acids, the fat supplement has different physical properties, similar to saturated fatty acids, this is because calcium salts of fatty acids consist of fatty acids associated with a calcium ion instead of a glycerol backbone. At normal rumen pH, more than 60-90% of the calcium salts can remain intact and pass through the rumen inert (Block et al., 2005). The pK (the pH at which 50% of the salt is dissociated) is about 4.5 for calcium salts of LCFAs but varies somewhat with chain length and degree of unsaturation of the fatty acid. Shorter chains and most unsaturated fatty acids have slightly higher pK values, meaning a greater proportion of the calcium soaps of these fatty acids will be dissociated at any given rumen pH (Block et al., 2005).

Research in calcium salt protected fats and fatty acids has been conducted in primarily dairy cattle, but also beef cattle (Hightshoe et al., 1991), dairy goats (Baldin et al., 2013) and even dairy buffalo in India (Savsani et al., 2013; Ramteke et al., 2014). Calcium salt protection allows PUFA’s to reach the duodenum intact and be readily absorbed into the bloodstream where they can then influence the fatty acid make up of meat and milk.

**Calcium salt rumen protected fat supplementation in beef cattle**

As previously stated, the bulk of research with calcium salt rumen protected fat, also known as calcium salts of fatty acids, has been in dairy cattle and a much smaller amount in beef cattle. Where dairy research has concentrated on overall milk production and butterfat concentration in the milk, studies in beef cattle have been mainly on its effects on reproduction in the cow, carcass characteristics and overall efficiency in production
due to increased energy in feedlot systems. Calcium salts of fatty acids are typically more
costly than most conventional feed energy sources and are generally only economically
justified if the benefits elicit a physiological response beyond that associated with energy
alone. (Hightshoe et al., 1991).

Rumen protected fats have been evaluated in growing cattle for numerous reasons. In an
evaluation of Kline barley as a cattle feed grain, calcium salts of fatty acids inclusion in
corn-Kline barley and com-SBM diets on digestibility, ruminal VFA concentrations, and
cattle performance were investigated. Hill and West (1991) cited previous reports that
calcium salt rumen protected fats decreased ADG and feed intake when calcium salts of
fatty acids were fed to feedlot steers. Calcium salts of fatty acids lowered DM
digestibility and increased NDF digestibility and Ca salts of fatty acids increased EE
digestibility. After metabolism trials, they performed 2 feedlot trials to assess whether or
not calcium salts of fatty acids would have the same effect when fed with barley diets.
The first trial compared corn diets; com-barley diets and corn-barley plus protected fat
diets. The second trial compared corn based diets with corn-barley and protected fat diets.
Trial 1 found that corn-barley plus protected fat diets increased feed efficiency and the
second trial led them to conclude that calcium salts of fatty acids may not improve beef
cattle performance, especially when diets contain barley (Hill & West, 1991). The next
step was to determine whether or not calcium salts of long-chain fatty acids would
significantly alter postpartum endocrine characteristics in beef cows when incorporated
into a range supplement. In individually fed multiparous Simmental cows, there was no
change in plasma triglycerides, basal LH was increased in cows receiving calcium salts of
fatty acids; and estradiol-17β serum concentrations lowered in cows receiving calcium salts of fatty acids compared to control cows. Patterns of follicular growth demonstrated that growth of Class 2 follicles into Class 3 and 4 follicles was enhanced in cows receiving the calcium salts of fatty acids supplement. Data indicated that heightened dietary lipid intake leading to a hypercholesterolemic condition is capable of eliciting a unique physiological response in the postpartum cow, it would seem that altered production and (or) clearance of steroid hormones, coupled with enhanced follicular development, resulted in normal luteal function during the first postpartum estrous cycle (Hightshoe et al., 1991).

Three experiments were conducted in 1997 to determine the effects of supplemental fat and CP concentration in diets of newly received steers. They concluded that there is no benefit to increasing the energy density of a receiving diet by addition of calcium salts of fatty acids. In fact, there may be detrimental effects of calcium salts of fatty acids, due to decreased dry matter intake (Fluharty et al., 1997). Feeding ruminally inert fats, such as calcium salts of long-chain fatty acids, may increase essential fatty acid availability for absorption. To determine the effects of supplemental calcium salts of long-chain fatty acids in the diets of pubertal beef heifers prior to breeding, calcium salts of fatty acids were supplemented to determine its effects on growth, reproductive performance, serum metabolites, and hormone concentrations (Lloyd et al., 2002). The addition of calcium salts of long-chain fatty acids to a forage-based diet prior to breeding increased serum cholesterol concentrations and tended to increase calving rate in beef heifers.

Supplementing CSLCFA to the diets of developing heifers prior to breeding may be
advantageous for embryo survival during early pregnancy. However, in the postpartum cow, supplemental CSLCFA may have no significant effect on reproduction, but can be beneficial to maintaining postpartum body condition (Lloyd et al., 2002).

Long et al (2007) were the first to report increased concentrations of cholesterol, triglycerides, high-density lipoprotein and low-density lipoprotein when a rumen-protected fat source was fed to 14 month old Angus and Polled Hereford heifers 60 d before breeding. They fed an 8% calcium salts of fatty acids, 92% corn gluten feed 5 days per week and observed increased serum cholesterol, triglycerides, high-density lipoprotein, low-density lipoprotein and leptin in the heifers and reported an overall trend to increase total conception by 23% (Long et al., 2007).

Using lactating primiparous Nelore cows, 50 to 80 d postpartum, Lopes et al. (2009) tested the hypothesis that supplementation of rumen-protected poly unsaturated fatty acids to beef cows will enhance their reproductive performance. Results indicated that supplementation of rumen-inert PUFA sources (Megalac-E) to beef females is a strategy to increase pregnancy rates, and this can partly be attributed to beneficial post breeding effects of poly unsaturated fatty acids on reproductive function. Based on experiments performed on ovariectomized cattle, they theorized that poly unsaturated fatty acids supplementation may increase reproductive performance of beef cows by directly improving uterine environment and embryo development, perhaps by increasing circulating concentrations of circulating progesterone. These experiments did not explain if this was particular to Bos indicus cattle, nor did it identify breed of recipient cattle used in the trials or the breed of the ovariectomized cattle.
Long et al., (2014), investigated feeding a rumen-protected fat source before and after artificial insemination to observe beef heifer conception rates, overall reproductive efficiency and possible differences in outcomes due to fatty acid source. Heifers were individually fed 1 of 3 isocaloric supplements: (1) control supplement, (2) half the control diet with 0.2 kg of a rumen protected unsaturated fatty acid source or (3) a rumen-protected saturated fatty acid source with all supplements fed 5 days per week. After synchronization for artificial insemination, breeding and pregnancy detection, they observed that heifers BW gain during supplementation was similar between treatment groups. The percentage of heifers cycling tended to be less for treatment 3 cattle compared with treatments 1 and 2. Pregnancy rates by artificial insemination of heifers detected in estrus were similar between treatments. At day 21 and 56, treatment 2 and 3 heifers had greater serum total and specific fatty acids, cholesterol, and triglycerides than did the control heifers. Heifers fed rumen-protected fats (supplements 2 and 3) had increased circulating lipid and leptin, but did not influence reproduction rates (Long et al., 2014).

*Calcium salt rumen protected fat in late gestation in beef cattle*

Late gestation studies using calcium salt protected fats concern either maintenance of BCS or its effects on post-partum reproduction in mature cows or first calf heifers fed either prepartum or postpartum in beef cattle. One such example is multiparous Angus and Hereford x Angus cows ranging from 5 to 7 years of age were used to determine the influence of calcium soaps of fatty acids (CSFA) incorporated in a range supplement on postpartum reproductive characteristics and growth of calves. The cows randomly
received either 125 g/d of CSFA or no CSFA for 105 days, beginning approximately 61 ± 36 days precalving. At the end of the study, body weights at 35 and 50 d post calving were greater in cows fed CSFA than in the cows fed no CSFA. Similar results were observed in BCSs during the same time periods. Concentrations of total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, very-low-density lipoprotein cholesterol, and triglycerides were greater in cows fed CSFA. Percentage of cycling cows (progesterone > 1 ng/mL) at 30 to 90 d postpartum was 38% in CSFA cows and 22% in control cows. The percentage of pregnant cows during the first half of the breeding season was greater in CSFA cows (62.5%) than in control cows (35.5%) (Espinoza et al., 1995). Supplementation in this study was performed both pre and postpartum. Conversely, when rumen protected fats (Ca salts with mainly palmitic and oleic acid) were fed to Holstein cows starting at twelve weeks before expected parturition (and still lactating for approximately four of those weeks), the results were very different. After calving, the cows were fed the same lactation TMR with no differences, making the prepartum CSFA supplementation the main variable in the group of half sib, first lactation, 305-d milk yield > 9,000 kg German Holsteins. This research indicated that cows receiving the CSFA supplement, dry matter intake observed depressed prepartum, milk yield decreased during first 4 wk of lactation and negative postpartum energy balance during this period. During the first 4 weeks of lactation, cows in the CSFA group had a lower lactose content and a decreased lactose yield as a function of greater milk production and yield. There was an increase in milk fat that the authors suspect was a result of triacylglycerols (TAG) in the form of very low density lipoproteins (VLDL)
from the liver transported by chylomicrons (lipoproteins that transport dietary lipids) and utilized by the mammary gland (greater higher plasma TAG in the CSFA supplemented group until 10 d postpartum). Milk protein and fat yield as well as energy corrected milk did not differ, however as the lactation period increased after week 4 and continuing to week 14, the cows fed CSFA had an increased milk fat and milk protein percentage. It is interesting to note that milk fat C14:0 (A saturated fatty acid) was decreased and C16:1 (an unsaturated fatty acid) was greater in the treatment cattle. The authors concluded that feeding a diet containing rumen-protected fat during late lactation and dry period until calving negatively affected dry matter intake, energy balance, and milk yield during subsequent lactation (Duske et al., 2009). Few articles are found concerning late gestation supplementation of calcium salts of fatty acids in beef cattle, sheep or goats.

A 2014 study performed on the effect of supplementing saturated or unsaturated long-chain fatty acids to nulliparous and parous Holstein animals during late gestation evaluated FA profile of colostrum, plasma of newborn calves and on production and absorption of IgG. Three dietary treatments were used: no fat supplementation (Control), 1.7% of dietary DM as mostly free SFA supplement, and 2.0% of dietary DM as Ca salts of FA supplement enriched with essential FA (Megalac-R). Parous but not nulliparous dams tended to give birth to heavier calves if fed fat prepartum. Serum concentrations of IgG tended to be increased in calves born from dams fed fat compared with those not fed fat, and prepartum feeding of SAT tended to improve circulating concentrations of IgG in newborn calves. The IgG concentration in colostrum was greater in parous dams fed fat compared with control dams, whereas that of nulliparous dams was reduced by prepartum
fat supplementation compared with control dams (Garcia et al., 2014). (Feeding oilseeds prepartum to Angus and Hereford heifers did not affect IgG concentration of colostrum (Dietz et al., 2003)). The type of FA fed prepartum tended to affect the total concentration of plasma FA, with a greater concentration of FA in plasma of calves born from dams fed Megalac R. The source of fat supplement fed prepartum did change the FA profile of plasma of newborns. The dietary FA consumed by the dams is reflected in the FA profile in both plasma of newborns and colostrum of dams. Late gestation supplementation is meaningful because the different proportions of essential FA and their derivatives in these biological fluids suggest that the transfer and synthesis of these FA are under tighter regulation in placental than in mammary tissue. When one looks at the offspring, it was found calves born from parous dams supplemented with fat tended to be heavier at birth than those born from control parous dams. Whereas prepartum fat supplementation did not influence the birth weight of calves born to nulliparous dams (Garcia et al., 2014). This parity by dietary fat effect on birth weight may result from heifers utilizing dietary energy for their own growth plus growth of the fetus, whereas mature cows can direct energy to the fetus alone, leading to heavier calves at birth. At birth, serum concentrations of total IgG were decreased and in some cases they could not detect an IgG. Approximately 24 to 30 h after feeding of colostrum serum concentration of total IgG was lower in male calves born from dams not fed fat compared with those born from dams fed CSFA and IgG of female calves did not differ with those born from dams fed CSFA. These sex differences do not agree with our current study that demonstrated a treatment x sex effect with both male and female calves from dams fed
CSFA had greater serum IgG that calves born to control dams and females born to dam that were fed CSFA demonstrated greater serum IgG than male calves born to dams fed CSFA (P =0.0001) . It was concluded that including 1.7% FA as SAT or ESS in low-FA diets (2.0% of dietary DM) during the last 8 wk of gestation can influence the immunoglobulin status of the newborn calf (Garcia et al., 2014).

Soybean Meal Supplementation Late Gestation in Beef cattle

The main concern with SBM supplementation studies is the supply of protein to different classes of cattle. For example, cows receiving either 100 or 150% of NRC recommendations for CP in diets that contained either soybean meal or corn gluten meal/blood meal as the principal supplemental protein source tended to increase ADG in cows (Rusche et al., 1993). Because of increases in estimated daily milk production, daily gain in calves from birth to weaning also improved due to increased dietary protein, but not by source of protein in beef cattle and lactose was the only constituent of milk affected by diet and treatment but had no effect on profiles of LH or progesterone (Rusche et al., 1993). To evaluate specific fatty acids, spring calving Hereford and Hereford x Angus cows that were supplemented to determine effects of level of supplemental energy or protein before and after calving on cow performance (Marston et al., 1995). Over a 120 prepartum supplementation period, cows were supplemented until calving with a 20% CP soybean hull-based supplement or a 40% CP soybean meal-based supplement. Cows were rotated through each supplement treatment to serve as their own control over time. It was concluded that conception rates were improved by feeding supplemental energy prepartum but not postpartum. Additionally, energy supplements
can affect reproduction with minimal effects on BW or condition (Marston et al., 1995). A follow up of this study incorporated ten spring-calving cows from each of the precalving, post calving treatment combinations that calved within a 21-d period in February were selected for evaluation of plasma nonesterified fatty acids (NEFA), glucose, insulin and urea nitrogen. Concentrations of NEFA and glucose in plasma were not influenced by prepartum diets. Insulin in serum was greater for cows fed supplemental energy precalving. Concentrations of glucose and NEFA were not influenced by postpartum supplementation. Concentrations of NEFA were influenced by time after feeding (Marston et al., 1995).

An experiment on late gestation supplementation in Angus heifers, investigated the use of alfalfa leaf meal (22% CP) in beef cattle diets consisting of CP supplied at 100 or 112.5% of the recommended daily intake (Zehnder et al., 2010). Neither supplemental protein source nor amount of protein affected changes in BCS or calving traits. Also, heifers consumed more alfalfa leaf meal supplement than SBM supplement at the expense of hay and corn (Zehnder et al., 2010). However, this project dealt only with protein supplementation but did not address any input of cow or calf nutrition from fatty acids.

*EFA profile of Soybean Meal, Essentiom & Corn Gluten Feed*

Both soybean meal and corn gluten feed are considered protein supplements that contain a fat component and because both were used in this study, their FA profile needs to be considered. Corn gluten feed contains an average of 4.3% crude fat on a DM basis (Myer & Hersom, 2017), whereas soybean meal contains an average of 2% fat DM (Heuzé et
al., 2017) and Essentiom contains 84.5% fat on a DM basis (Church and Dwight Co., Inc., Princeton, NJ).

Soybean meal and Essentiom have several fatty acids in common but these differ in their content. Both have measureable amounts of C14:0, C16:1, C18:0 and C18:3 n-3 but soybean meal is higher in percent comparison in all four of these fatty acids than Essentium (Abu-Ghazaleh et al., 2001). The fatty acids found in Essentiom, but are missing in soybean meal are: C12:0, C16:0, C17:0, C18:1, C18:2n-6 and C20:0. Soybean meal contains 0.41 more g/100g of C14:0, .15 g/100g more of C16:1, .88 g/100g more of C18:0 and 4.91 more g/100g of C18:3 n-3 than Essentiom (Church and Dwight Co., Inc., Princeton, NJ). Soybean meal contains the following fatty acids that are missing in Essentiom: C14:1, C18:1 t 6, C18:1 c 6, C18:1 t 11, C18:1 c 9, C18:1 c 11, C18:2 t 9, t12, C18:2c9, c12, C18:3 n-6 and C20:1 (Church and Dwight Co., Inc., Princeton, NJ).

**Beef cattle immunity**

In terms of immunity in beef cattle, it is important to understand that all multicellular organisms protect themselves against pathogens using sophisticated immune defenses (Beck et al., 1996). Immunity of mammals can be broken down into two major types of response: innate and acquired (Beck et al., 1996).

The science of immunology may have begun with the discovery of vaccination by Edward Jenner in 1796, when he determined that cowpox (*vaccinia*) induced protection against human smallpox. Jenner called his procedure vaccination, or inoculation of healthy individuals with weakened or attenuated strains of disease-causing agents to
provide protection from disease (Janeway et al., 2001). When Jenner introduced vaccination he knew nothing of the infectious agents that cause diseases but findings by Robert Koch proved that infectious diseases are caused by microorganisms. We now recognize four broad categories of disease-causing microorganisms, or pathogens: viruses, bacteria, pathogenic fungi, protozoa and parasites. In 1890, Emil von Behring and Shibasaburo Kitasato discovered that the serum of vaccinated individuals contained substances which they called antibodies that specifically bound to the relevant pathogen (Janeway et al., 2001).

As previously stated there are two major types of response: innate and acquired (Beck et al., 1996). Humoral immune response, occurs during the lifetime of an individual as an adaptation to a pathogen. While the innate immune system employs macrophages and granulocytes to engulf and digest many microorganisms by these phagocytic cells. These cells are immediately available to combat a wide range of pathogens without requiring prior exposure. The innate and humoral immune systems provide an effective defense system. Essentially, the innate immune system exists to provide early defense against a pathogen and to alert the humoral immune system to prolonged pathogen invasion (Janeway et al., 2001).

Both innate immunity and humoral immune responses depend upon the activities of white blood cells, or leukocytes. Innate immunity primarily involves granulocytes and macrophages. Humoral immune responses depend on lymphocytes, which provide the lifelong immunity that can follow exposure to disease or vaccination.
Active components of the bovine immune system are composed of antigens and antibodies. An antigen is any molecule that can bind specifically to an antibody. Their name arises from their ability to generate antibodies. In a broader sense, an antigen is any substance that can be recognized by the humoral immune system. (Antigens in the body of an individual are by convention called self-antigens.) An antibody is a protein that binds specifically to a particular substance’s antigen. Antibodies are produced by plasma cells in response to infection or immunization, and bind to and neutralize pathogens or prepare them for uptake and destruction by phagocytes. Each antibody molecule has a unique structure that enables it to bind specifically to its corresponding antigen, but overall, antibodies have the same overall structure and are known collectively as immunoglobulins (Igs) (Janeway et al., 2001).

To understand and appreciate immunoglobulins, a brief discussion of immunization is appropriate. Immunization is the deliberate provocation of a humoral immune response by introducing antigen into the body. Immunization utilizing an antigen is called active immunization distinguishing it from the transfer of antibodies to an unimmunized individual (Janeway et al., 2001). Antibodies are produced after infection, and are specific for the infecting pathogen. The antigen is a protein on the pathogen (or any other cell).

Interaction with a microorganism initiates a series of events within the body. Many microorganisms that are encountered in daily life of a normal healthy individual do not always cause perceptible disease. Most are detected and destroyed within minutes/hours by innate defense mechanisms that do not require a prolonged period of induction. This is
because they do not rely on the clonal expansion of antigen-specific lymphocytes. Only if an infectious organism can breach these early lines of defense will a humoral immune response ensue, with the generation of antigen-specific effector cells that specifically target the pathogen, and memory cells that can prevent reinfection with the same microorganism (Janeway et al., 2001).

When evaluating humoral immune response, the involvement of B cells by immunoglobulins is imperative. A “B cell”, or B lymphocyte, is one of the two major types of lymphocytes. The antigen receptor on B lymphocytes, called the B-cell receptor, is a cell-surface immunoglobulin. On activation by antigen, B cells differentiate into cells producing antibody molecules of the same antigen specificity as this receptor. Thus antigen-recognition molecules of B cells are immunoglobulins. On the surface of B cells are numerous molecules of membrane immunoglobulins (mIg) of a single specificity that act as the receptor for antigen. Mature B cells are B cells that have acquired surface IgM and IgD and have become able to respond to antigen (Janeway et al., 2001).

Different immunoglobulin isotypes are called IgM, IgD, IgG, IgA, and IgE. IgA is the class of immunoglobulin characterized by heavy chains. IgA antibodies are secreted mainly by mucosal lymphoid tissues. IgD is the class of immunoglobulin characterized by d heavy chains. It appears as surface immunoglobulin on mature naive B cells but its function is unknown. IgE is the class of immunoglobulin characterized by heavy chains. It is involved in allergic reactions. IgG is the class of immunoglobulin characterized by g heavy chains. It is the most abundant class of immunoglobulin found in the plasma. IgM is the class of immunoglobulin characterized by m heavy chains. It is the first
immunoglobulin to appear on the surface of B cells and the first to be secreted (Janeway et al., 2001).

A study in beef cattle, using modified-live bovine virus diarrhea and infectious bovine rhinotracheitis virus vaccines, to investigate the normal rate of decay of maternal antibody and the influence of maternal antibody on responses to a single vaccination at 196 days of age and on response to vaccinations with the same vaccines given twice at 84 and 196 days of age. All calves seroconverted to bovine virus diarrhea vaccine at 84 days of age, even though high levels of maternal antibodies were present. These calves did not seroconvert to infectious bovine rhinotracheitis vaccine at 84 days of age when high levels of maternal antibodies were present. Calves responded well to bovine virus diarrhea and infectious bovine rhinotracheitis vaccines given only once at 196 days of age after passive immunity disappeared. Calves which were revaccinated with infectious bovine rhinotracheitis seroconverted showing a more rapid response than the single vaccinates (Menanteau-Horta et al, 1985). Menanteau-Horta et al. (1985) additionally demonstrated that bovine virus diarrhea titers in unvaccinated animals show that the maternal antibodies decreased steadily from 0 d to 200 days of age. A booster immunization is commonly given after a primary immunization, to increase the titer of antibodies. The titer of an antiserum is a measure of its concentration of specific antibodies (Janeway et al., 2001). The 1985 study shows it may be possible to confer protection through the use of infectious bovine rhinotracheitis and bovine virus diarrhea vaccines at an early age after initial high levels of passive antibody have declined (Menanteau-Horta et al., 1985).
A relationship seems to exist between vitamin E status, stress, and immune response. Rivera et al. (2002) conducted three experiments to determine whether increasing concentrations of vitamin E during the receiving period improved performance and immune response in beef cattle. The increase in circulating antibodies to a foreign antigen noted with supplementation of 1,140 IU/d indicate that vitamin E can enhance humoral immune response. Maximum antibody response was noted after 21 d of supplementation (Rivera et al., 2002). The mammalian immune system of innate and humoral immunity has paid huge dividends. In 1999 it was demonstrated that morbidity rates and treatments per morbid calf were decreased from 37% and 1.14, respectively, for those vaccinated on arrival and 33% and 1.36 for those vaccinated at the sale barn to 27% and 1 for those vaccinated before weaning because of humoral immunity (Galyean et al., 1999). Vaccines may not be effective when given to calves with high levels of maternal antibodies because maternal antibodies interfered with antibody production to a single infectious bovine rhinotracheitis modified live virus vaccination at 84 days of age (Menanteau-Horta et al., 1985). A vaccine can only protect against and prevent disease, when it elicits an immune response. Immunity of a calf is acquired from the mother’s colostrum at birth but the length of neonatal protection is finite. One must also keep in mind how long the maternal antibodies will protect the neonate. Passive immunity decreased to near zero over the first six months of life for both bovine virus diarrhea and infectious bovine rhinotracheitis controls when calves received either a single vaccination with modified-live bovine virus diarrhea and infectious bovine rhinotracheitis virus
vaccines at 196 days of age or given twice at 84 and 196 days of age and the response to these vaccinations was measured (Menanteau-Horta et al., 1985).

In “Basics of Cattle Immunity”, Hairgrove and Hammack (2009) stated that vaccines made from modified live products were usually more efficient at protecting against diseases that infect the insides of cells such as brucellosis or bovine virus diarrhea. Modified live vaccines replicate in the animal and usually do not require boosters. Vaccines made from killed products are usually more efficient at destroying organisms that attack the outside of cells, such as those that cause blackleg or tetanus. Killed products do not replicate, so boosters are usually needed for good protection. Animals must have adequate nutrition for their immune systems to work properly. Environmental stressors such as social behavior and parasites, which may decrease an animal’s natural response to disease and the effectiveness of vaccines.

Downey et al (2013) stated that it is important to strike a balance between having enough passively acquired maternal antibodies to prevent disease and having low enough levels to allow the humoral immune system to respond to the vaccine. Downey used a 2-shot modified live vaccine for bovine viral diarrhea virus type 2 in 1,004 Angus calves in a three year study with fall and spring calving each year born in the spring and fall seasons. They identified and evaluated environmental and management factors that influence passively acquired maternal antibody levels in circulation and, influence the decay rate of maternal antibodies and to evaluate the effects of environmental and management factors on antibody responses to vaccinations. Calves were either weaned at the initial vaccination averaging 139 days of age and the calves weaned at booster vaccination
averaged 128 d of age with age differences accounted for by calves younger calves coming from the later of the two calving season per year (Downey et al., 2013). *Bovine viral diarrhea virus type 2* antibodies were measured in three 21-d intervals via serum samples to quantify antibody levels at initiation and end of vaccination protocol in addition to responses to initial, booster, and overall vaccination protocol. Calves that were weaned at the time of initial vaccination had greater final antibody level, initial response, and overall response to vaccination than animals weaned at booster vaccination. They determined that the level of circulating, passively acquired maternal antibodies present at the time of vaccination had a negative effect on antibody responses to vaccination for the initial response but also the booster response and the overall response. Interestingly, the age at which a calf reached the antibody threshold of maternal antibodies in circulation of < 3.12 titers was dependent on dam age. The level of passively acquired maternal antibodies increased as dam age increased from 2 to 6 years, but then there was no further increase (Downey et al., 2013). Vaccinating beef heifers against *bovine respiratory disease* pathogens decreased forage intake and total DMI during the 2 d following vaccination can be associated with transient metabolic, inflammatory, and acute-phase responses (Rodrigues et al., 2015).

Fatty acids can also effect on the immune system of cattle. Menhaden fish oil was used in a study on the effects of long-chain n-3 fatty acids on, among other things, the immune system (Wistuba et al., 2005). Cattle (Angus crossbred steers) were fed either a corn or wheat middling based supplement, containing 1.5% fish oil. Results of the study suggested that supplementing fish oil to grazing cattle may boost the proliferative
response of lymphocytes and may aid in decreasing morbidity in cattle during the stocker phase of beef production (Wistuba et al., 2005).

In the review by Staples et al., (2008), dietary fats can change the fatty acid profile of tissues and white blood cells in cows fed supplemental linoleic acid. They observed greater concentration of colostrum antibodies and the number of WBC and neutrophils were decreased compared to cows not fed fat (Staples et al., 2008).

Conjugated linoleic acid is naturally present in milk and meat of ruminants due to its production by anaerobic bacteria in the rumen of these animals (Albers et al., 2003). The effects of two different mixtures of the main conjugated linoleic acid (CLA) isomers cis-9, trans-11 CLA and trans-10, cis-12 CLA on human immune function were investigated in 2003 and almost twice as many subjects reached protective antibody levels to hepatitis B when consuming 50% c9, t11 CLA and 50% t10, c12 CLA isomers as compared to subjects consuming the reference substance. This is the first study that suggests that CLA may beneficially affect the initiation of a specific response to a hepatitis B vaccination. The hepatitis B vaccination was used to mimic a primary viral infection capable of inducing both humoral and the cellular responses (Albers et al., 2003).

Calcium salts of safflower oil is a fat supplement rich in linoleic acid. Linoleic acid can decrease the threshold for triggering an immune response that alters innate immunity. Linoleic acid might be suitable for coping with the stressful and highly contaminated postpartum period, but yet calcium salts of fish oil can increase the same threshold (Silvestre et al., 2011). At first thought, this increase might be unfavorable but it may
attenuate immune responses in early pregnancy upon environmental challenges (i.e., mastitis, heat stress) that may benefit embryonic survival (Silvestre et al., 2011).

**Immunoglobulin G (IgG) in beef cattle**

Immunoglobulins (Igs) are essential molecules for the animal humoral immune response and are expressed only in jawed vertebrates, including fish, amphibians, reptiles, birds, and mammals (Sun et al., 2012). Regardless of the form, a typical immunoglobulin molecule contains a heterodimer consisting of two identical heavy chains and two identical light chains (Sun et al., 2012).

Historically immunoglobulins are separated into classes on the basis of their antigenic determinants. The three classes of immunoglobulins in cattle have been identified as immunoglobulin gamma myeloma (IgG), immunoglobulin alpha myeloma (IgA), and immunoglobulin mu-macroglobulin (IgM) (Cohen, 1965; Butler, 1969). IgG is the predominant isotype found in the body. It has the longest serum half-life of all immunoglobulin isotypes. IgG is the most extensively studied class of immunoglobulins. Four IgG subclasses (IgG1, IgG2, IgG3, and IgG4) were identified. (IgG1 > IgG2 > IgG3 > IgG4) IgG antibodies also contribute directly to an immune response, including neutralization of toxins and viruses. IgG is a secondary response immunoglobulin; its function is to neutralize toxins and viruses (Schroeder & Cavacini, 2010).

Bovine IgM can be detected in serum, colostrum, and milk (Butler, 1969). IgM is a primary response immunoglobulin and the first immunoglobulin expressed during B-cell
development (Schroeder & Cavacini, 2010). Bovine IgA occurs as "secretory IgA" in milk and colostrum (Butler, 1969). Secretory immunoglobulin Ig A (SIgA) is essential in protecting mucosal surfaces in the respiratory tract (Phalipon et al., 2002). Investigations revealed species-specific variations from the general pattern, which can often be related to peculiar physiological or genetic traits. At least one such variation has long been recognized in the cow. This concerns the selective accumulation of bovine IgG1 in the colostrum and normal milk (Butler, 1969).

Four livestock species—cattle, sheep, pigs, and horses—express a full range of Ig heavy chains (IgHs) such as IgG, IgD, IgA, IgM, IgE and IgY are heavy chain immunoglobulins. Two poultry species (chickens and ducks) express three IgH’s (Sun et al., 2012).

To determine the effects of maternally supplemented natural- or synthetic-source vitamin E on suckling calf performance and immune response, colostrum from cows and blood from calves was collected 24 h postpartum for analysis of IgG concentration as an indicator of passive transfer and circulating α-tocopherol concentration (Horn et al., 2010). Colostrum IgG concentrations at calving and calf serum IgG concentrations at 24 h of age did not differ due to vitamin E supplementation. Passive transfer of IgG did not differ in calf serum or cow colostrum due to maternal vitamin E supplementation in the study (Horn et al., 2010).
Colostrum in beef cows

The mammalian neonate is unable to collect, chew, or digest solid food, relying entirely on the colostrum of its mother and subsequently on milk for its survival. In addition to providing a complete diet with all the essential nutrients for the neonate during the initial phase of its life, it also provides essential immunological protection in some species. An adequate supply of colostrum, with abundant immunoglobulins, is essential. During the first 48 hours of life the neonate must gain sufficient passive immunity to be able to survive until its own immune system is fully developed. Immunoglobulin antibodies are the main components of the acquired immune system present in colostrum and milk. (Stelwagen et al., 2009).

Immunoglobulins in mammary secretions are both humoral, arising from the bloodstream, and local, arising from production by plasmacytes in the mammary gland. In some species (human, rabbit, etc.), the transfer of maternal immunoglobulins to the bloodstream of the neonate occurs in utero across the placental or yolk sac membrane (Larson et al., 1980). In other species, including ruminants, transfer of maternal immunoglobulins to the neonate occurs exclusively via the colostrum (Larson et al., 1980). Human IgG placental transfer from mother to fetus is possible because the human placenta expedited by an IgG receptor on the placenta. Amniotic fluid contains IgG of maternal origin, and transfer of swallowed IgG into the circulation from the fetal intestine represents another potential pathway of passive immunization. Evidence was found for an Fc receptor on the human fetal intestine, indicating that there is an IgG receptor sight that is Fc mediated, similar to the IgG receptor found in the suckling rat, on the human fetal intestine,
particularly on the microvillus membrane (MVM) from small intestine villi (Israel et al., 1993).

Substantial amounts of immunoglobulins are found in ruminant colostrum, and calves not receiving these immunoglobulins usually died due to debilitating diarrhea, usually *E. coli* (Gay, 1965) as well as viral and bacterial organisms (Larson et al., 1980). Early work showed that calves were born virtually devoid of immunoglobulins, but these soon appeared in the blood of the calf following ingestion of colostrum (Larson et al., 1980). Immunoglobulin antibodies are the main components of the acquired immune system present in colostrum and milk (Stelwagen et al., 2009). The transfer of immunoglobulins to the neonate is highly specialized in ruminants. Bovine colostrum normally contains 50 to 150 mg/ml of immunoglobulins, of which IgG comprises about 85 to 90% of the total (Larson et al., 1980). The bovine transfers large amounts of IgG immunoglobulins, and IgG1 in particular, from the blood stream across the mammary barrier into colostrum. Upon ingestion of the colostrum the immunoglobulins move from the gut lumen across the intestinal barrier into the blood stream of the neonate. The IgG has been the major serum immunoglobulin transferred to the neonate. Bovine IgG is distributed between two subclasses, IgG1 and IgG2. These two subclasses differ slightly in their heavy chains and are about equal concentration in blood (Larson et al., 1980).

Two or three weeks before parturition, massive amounts of immunoglobulins, several hundred grams to over three kg, are transported from the maternal blood across the blood mammary tissue barrier. The immunoglobulins of bovine serum transferred to the lacteal secretions carry a wide array of antibody properties against a multitude of antigens to
which the cow has been exposed (Larson et al., 1980). Prior to Devery-Pocius et al. (1983) there had been no direct studies on the possible relation of age of the bovine dam to the total amount of immunoglobulins secreted in colostrum. Using blood and colostrum samples from 87 dairy cows in five lactation groups and analyzed for Ig G1, G2, M, and A. The cows ranged from first lactation to fifth or more lactations. First lactation cows blood serum contained less IgG1 than older cows and produced less total colostrum containing less total G1, G2, and M. Immunoglobulin G1 comprised over two-thirds of the immunoglobulins in the colostrum of all groups. More IgG1 was found in the colostrum of older cows and had a tendency toward a higher ratio of IgG1 to IgG2. IgG2 and IgM tended to level off in the second lactation while total IgG1 tended to reach a maximum in the third or fourth lactation (almost doubling in the amount when compared to the first lactation cows). Their observations lend further credence to the supposition that the mammary transport system for IgG1 becomes fully developed when the cow reaches maximum capacity for milk production and that the IgG1 transport system may mature following maximum mammary gland development (Devery-Pocius et al., 1983).

When colostrum immunoglobulin absorption is compared with absorption of immunoglobulins that had been extracted from colostrum in the neonatal calf, it was observed a reduction in Ig absorption from Ig present in colostrum that calf plasma immunoglobulin levels were unable to protect the animals against infections (Grongnet et al., 1986). This was proven by washing immunoglobulins from colostrum and then preparing immunoglobulin solutions of differing dry matter, IgG concentrations, similar
ash content, and different Lactose content as well as different antitrypsic activities. The immunoglobulin solutions were formulated to have levels of immunoglobulins similar to complete colostrum. One group of calves were fed an Ig solution conventional milk replacer. The satisfactory levels of ingestion recorded at the first meal of immunoglobulin solution seem to demonstrate that the appetency of the immunoglobulin solutions was not the cause of refusals. The excessively high refusal rates strengthened the notion that the immunoglobulin solutions were harmful to the digestive tract of the calves. Maximum plasma levels of immunoglobulins were found in all the calves at 28 hours after birth. Calves that received an immunoglobulin solution supplemented with milk powder exhibited intermediate levels of Igs compared to calves receiving colostrum. Calves fed the immunoglobulin solutions observed decreased plasma Igs resulting from the composition of the solution. It was concluded that colostrum is a very complex medium that contains not only immunoglobulins but other factors, which allow the immunoglobulins to be absorbed and transported (Grongnet et al., 1986). A positive correlation between peak serum IgG1 concentrations attained by calves and the IgG1 concentration in the colostrum fed was observed in calves fed colostrum higher with Ig concentration developed higher concentrations of serum Ig. (Grongnet et al., 1986). These mechanisms may account for the decreasing apparent efficiency of absorption to serum for IgG1 and IgM when colostrum high in Ig. Mechanisms are saturation of a shared macromolecular transport mechanism across the calf intestinal epithelium or a regulation of the Ig concentrations in calf serum. For example, a loss of Ig from serum once concentrations exceed a threshold level (Besser et al., 1985).
In domestic ruminants, the principal difference between colostrum and milk is the high concentration of immunoglobulins, specifically immunoglobulin G (IgG) (Barrington et al., 2001). The dedicated and specific transfer of a significant mass of immunoglobulin into colostrum distinguishes colostrogenesis as a unique functional state of the mammary gland (Barrington et al., 2001). There is a pronounced decrease in the concentration of IgG1 in blood serum of the dam during the last 2 or 3 weeks before parturition (Brandon et al., 1971). This decrease in blood concentrations is accompanied by an increase in secretion of IgG1 in the colostrum. It is estimated that at least 500 g of IgG1, per week are removed from the blood. In domestic ruminants, transfer begins several weeks prior to parturition and ceases abruptly immediately prior to parturition (Brandon et al., 1971). There is strong evidence suggesting that colostrogenesis is at least partially under control of the lactogenic hormones estrogen, progesterone and prolactin (Barrington et al., 2001).

Meyer et al. (2011) broached the question of nutritional effects on colostrum and Se supply during gestation on yield and nutrient composition of colostrum and milk in first parity ewes. Their study provides an example of not only developmental programming of subsequent offspring by maternal nutrition, but also alteration of milk production by maternal nutrition during. Results indicated that gestational nutrition affected colostrum and milk yield and nutrient content, even when lactational nutrient requirements were met. Long et al. (2009) provides an example of not only developmental programming of offspring by maternal nutrition, but also of alteration of milk production by maternal nutrition during pregnancy (Long et al., 2009).
When the neonatal calf is born, nutrient intake shifts from continuous glucose supply via the placenta to discontinuous colostrum and milk intake with lactose and fat as main energy sources. Because continuous glucose supply by the placenta ceases after birth, the neonate must meet the glucose demand via lactose. Besides establishing a passive immunity, colostrum intake stimulates maturation and function of the neonatal gastrointestinal tract (Hammon et al., 2013).

Zarcula et al. (2010) wanted to establish the influence of breed, parity and food intake on chemical composition of first colostrum in Holstein Friesian and Romanian Black and White cow.. It was observed that fat, proteins, lactose and dry matter increased in cows from second and third lactation compared to those in fourth lactation. Romanian Black and White cows produced colostrum of higher quality compared to the Holstein Friesian cows.

**Essential Fatty Acids in colostrum**

When diets containing fat (0, 3.5%, or 7% of the diet DM as animal fat) was fed to dairy cattle, dietary fat reduced the proportion of short-chain fatty acids in milk fat and increased C18:0 and C18:1 fatty acids This demonstrates that the fatty acid composition of milk triglycerides were altered. Proportions of short-chain and medium-chain fatty acids (C6 to C16) were depressed while long-chain fatty acids (C18 and C18:1) were elevated (DePeters et al., 1987). An explanation for this was suggested by Shaw and Lakshmanan (1957) who proposed decreased synthesis of short-chain fatty acids via...
mammary lipogenesis is compensated for by an increased uptake of longer chain fatty acids from the blood. Brown et al. (1962) suggests that it was then possible that even greater mammary gland uptake of long-chain fatty acids may be realized. Although DePeters et al., did not discuss any effects of either fat supplementation or fatty acid supplementation on colostrum, it is indicated that fatty acid content of milk can be influenced by fat in the maternal diet.

In a second experiment performed by Dietz et al. (2003) beef cows and neonatal calves were fed whole cottonseed (56.3% linoleic acid) to evaluate late gestation of fats and their influence on cold tolerance. They concluded that the high-fat diets did not influence colostral IgG concentrations. Increased serum IgG and IgM concentrations were found in calves that stood and nursed quicker than calves that were slower to stand and nurse and therefore in the present study, the high-fat diets did not influence colostral IgG concentrations (Dietz et al., 2003).

Using an antigenic challenge in suckling calves to determine the effect of maternal lipid supplementation on the immune response, 36 Angus × Gelbvieh beef cows BCS of 4 or 6 at parturition were used to determine the effects of prepartum energy balance and postpartum lipid supplementation on the passive transfer of immunoglobulins in the second part of a 2 part experiment published by Lake et al. (2006). The antibody responses were determined in serum; cell-mediated immunity was assessed by intradermal antigen injection at 60 d of age in calves born to cows that had received a low-fat control supplement or supplements consisting of either cracked, high-linoleate or high-oleate safflower seeds from day 3 postpartum to day 60 of lactation (63 days
postpartum), expecting that maternal prepartum nutritional management and postpartum lipid supplementation of the dam would influence immune response in suckling calves. They noticed a trend for calves suckling control-supplemented cows to have a greater response to antigen compared with calves from linoleate- and oleate-supplemented cows; however, no difference was observed among treatments in cell mediated immune response (Lake et al., 2006). In their conclusions, they speculated that alterations in fatty acid composition of lymphocyte membrane phospholipids might have resulted in decreased antibody production to antigenic challenge in calves suckling linoleate and oleate-supplemented cows. After a great deal of discussion, they finally concluded that the relationship between prepartum nutritional status and transfer of passive immunity should be further studied to elucidate conflicting results in published data (Lake et al., 2006).

With a lack of material available on the EFA composition of colostrum in beef cattle and the effects of late gestation supplementation on beef cattle colostrum, we find ourselves turning to research done on sheep for information. A 2009 study by Long et al. on how maternal obesity can impact postnatal nutrition of offspring used multiparous whiteface ewes that were either classified as obese or control and observed the effects of maternal obesity and high nutrient intake on ovine colostrum nutrient composition. Maternal obesity and over nutrition during gestation decreased the colostrum yield after parturition in the ewe (Wallace et al., 2005). In ewes receiving 60% of their nutritional requirements (RES) and ewes receiving 140% of their nutritional requirements (HIGH) compared with ewes receiving 100% of their requirements (CON), nutritional levels not only affected the
IgG content in the colostrum in both RES and HIGH ewes but did reduce total butterfat, protein, lactose, and solids not fat in the RES and HIGH ewes compared with CON ewes (Swanson et al., 2008) and alterations in the FA profile of the diet results in alterations in the plasma FA for the first 8 d of life in lambs (Noble et al. 1971). Based these conclusions, Long et al. (2009) hypothesized that maternal obesity and high nutrient intake before and throughout gestation will alter the protein content and total and specific FA composition of colostrum in the ewe. The results indicated that colostrum FA composition can alter the lambs circulating plasma FA and provide a mechanism for postnatal effects of maternal obesity and high nutrient intake. Maternal obesity resulted in decreased colostrum protein concentrations in twinning ewes and increased total FA concentrations regardless of birth type (twin versus single). Total FAs were increased in the colostrum of obese ewes compared with control ewes. Obese ewes demonstrated a greater percent of total FA concentrations of 17:0, 18:0, 18:1 t -1 and 18:2 n-6 and an increase in colostrum DM of 10:0, 15:1, 17:0, 17:1, 18:0, 18:1 trans 11, 18:1 n-9, and 18:2 n-6 as compared to control ewes. Obese ewes also tended to demonstrate greater concentrations of colostrum 12:0, CLA, and 20:4 n-6 than control ewes (Long et al., 2009).

It was observed that concentrations of docosahexaenoic acid (22:6-n−3) in ewe colostrum and milk can be enhanced through diet supplementation with fish meal (Or-Rashid et al., 2010). Or-Rashid et al., 2010 performed a study to 1) determine whether a fish-meal-supplemented diet fed to ewes during late gestation and early lactation would increase the proportion of docosahexaenoic acid (22:6n-3) in colostrum and milk and 2) examine the
subsequent effect on plasma fatty acid profile of nursing lambs. The major FA in colostrum or milk of ewes from both groups were myristic (14:0), palmitic (16:0), stearic (18:0), and oleic (9cis-18:1) acids. Predominant FA found in the plasma of the lambs were palmitic (16:0), stearic (18:0), oleic (9cis-18:1), and linoleic (18:2n-6) acids. Fish meal supplementation did not change the average percentages of major SFA in colostrum, such as 10:0, 12:0, 14:0, 16:0, and 18:0. However, 10:0, 12:0, and 18:0 were increased over time (0, 36, and 49 d), whereas 16:0 was decreased over time. The predominant FA found in the plasma of the lambs were palmitic (16:0), stearic (18:0), oleic (9cis-18:1), and linoleic (18:2n-6) acids for both groups. The docosahexaenoic acid status of their suckling lambs can also be further enhanced, and this may contribute to improve neural tissue development and overall performance of suckling lambs. Ewes fed fish meal supplemented diets had greater percentages of EPA (20:5(n-3)), DHA (22:6-n-3), total n-3-PUFA (2.72 vs. 1.93), total CLA (0.83 vs. 0.64), and total VL_n-3-PUFA (>C18, 0.70 vs. 0.38), in colostrum and milk compared with the ewes fed a control diet. Interestingly, the ratio of n-6-PUFA to n-3-PUFA in colostrum and milk was greater in the control group than in the FM-supplemented group (Or-Rashid et al., 2010).

When evaluating the effect of supplementing saturated or unsaturated long-chain fatty acids to nulliparous and parous Holsteins during late gestation on FA profile of colostrum and plasma of newborn calves and on production and absorption of IgG. Among other things, it was found that feeding moderate amounts of saturated or unsaturated long-chain FA during the last 8 weeks of gestation changed the FA profile of colostrum and plasma of neonates to reflect that of the supplements (Garcia et al., 2014a).
Garcia et al. (2014a) recommends that future studies to identify the mechanisms by which prepartum supplementation of fat may modify the efficiency IgG absorption are warranted.

Importance of colostrum to neonatal beef calves

Approximately 50% of mortality that occurs in preweaned calves was directly related to inadequate acquisition of passive immunity (Quigley, 2004). The IgG molecule is a macromolecule able to be transferred across the intestinal wall for the first 24 h of life of the neonate. Since calves are born agammaglobulinemic, having an absence of immunoglobulins in the blood, they have a small window of opportunity to absorb IgG’s from the dam’s colostrum. The IgG absorbed assists in reducing the incidence and severity of numerous gastrointestinal infections, including enteropathogenic *Escherichia coli*, rotavirus and *Cryptosporidium parvum*. The concentration of IgG in calf serum at 24 to 48 h determines whether or not there has been a successful transfer of passive immunity to the neonate. Approximately 50% of mortality that occurs in preweaned calves is directly related to FTP (Quigley, 2004). Dietary IgG may serve as a “first line of defense” against enteric pathogens, including viruses and bacteria. (Quigley, 2004; Waldner & Rosengren, 2009). Nearly 100 years ago, one investigation concluded that a calf deprived of colostrum lacks “something” whose absence permits intestinal bacteria to invade the body and multiply in the various organs (Smith and Little, 1922). This experiment identified the main pathogen involved in the death of 9 of 12 control calves not receiving any colostrum vs. the loss of 3 out of ten calves that did receive colostrum was *Escherichia coli* (Smith and Little, 1922). There are conflicting reports on the effects
of maternal nutrition, on IgG concentrations in both colostrum and the neonatal calf. Blecha et al. (1981) report no significant relationship between concentrations of immunoglobulin in the serum or colostrum of first-calf beef heifers and prenatal crude protein supplementation (Blecha et al., 1981). Later investigation presented data that demonstrated maternal nutritional restriction of beef cows during the last 90 d of gestation did not affect either colostrum IgG or the calves' serum IgG concentration at 24 hours after birth. Calves fed colostrum from restricted cows tended to have lower serum IgG concentration, regardless of whether the calf’s dam was nutrient restricted or not. The investigation, a 2-yr study to examine the effects of nutritional restriction of beef cows in the last 90 d of gestation on neonatal immunity and production, concluded that colostral immunoglobulin concentration was not affected by treatment; colostrum from the restricted cows appeared to be altered in some manner that decreased absorption of immunoglobulins into circulation by the calf (Hough et al., 1990). Colostrum is a source if immune components and contains more protein, nonprotein nitrogen, fat, ash, vitamins, and minerals than does later milk. Colostrum is the primary source of some vitamins that do not cross the placental barrier (Quigley et al., 1998) and are highest in the first colostrum (Morin et al., 1997). Besides establishing a passive immunity, colostrum intake stimulates maturation and function of the neonatal gastrointestinal tract (Hammon et al., 2013). The components of colostrum, other than immunoglobulins, are very important to the uptake of the Ig in colostrum. It has been demonstrated that when colostral IgG is filtered from the milk and fed to calves as an IgG “solution”, calves ingesting complete colostrum had increased levels of IgG, demonstrating that there are
other factors involved (Grongnet et al., 1986). Colostrum also contains hormones, growth factors, cytokines, enzymes, polyamines and nucleotides. Gastrointestinal tract development and function can be strengthened by insulin-like growth factor I. IGF-II, insulin and prolactin as well as glucagon and GH also appear in colostrum (Blum & Hammon, 2000). According to a review by Grosvenor et al. (1993), these “bioactive substances” may function in nutrient transfer and in the regulation of growth and differentiation of various neonatal tissues. It has been demonstrated that prolonged colostrum feeding results in enhanced postnatal development of the gastrointestinal tract with greater villus circumference, area, and height in the small intestine, particularly the duodenum (Bühler et al., 1998). Piglets fed colostrum had greater stomach, jejunum, ileum and liver protein masses than those fed either milk or water. The fractional protein synthesis rates in liver, kidney, spleen and skeletal muscle were also greater in colostrum fed piglets. Increased gastrointestinal growth has been demonstrated in neonatal animals fed colostrum compared to mature milk (Burrin et al., 1992). Bovine milk and colostrum also contains EGF, BTC, IGF-I, IGF-II, TGF-b1, TGF-b2, FGF1 and 2, and PDGF in addition to IGF-I and IGF-II (Gauthier et al., 2006).

Nutrient intake shifts in the neonate from continuous glucose supply via the placenta to discontinuous colostrum and milk intake with lactose and fat as main energy sources. Colostrum does not supply the neonate with glucose directly but increases glucose absorption. Glucose availability in neonatal calves is promoted by perinatal maturation of endogenous glucose production (EGP) and colostrum intake; therefore, more glucose is stored and available for peripheral tissues during the postprandial state (Hammon et al.,
Blood glucose decreases rapidly during the first few hours of life in calves and lambs can also exhibit low blood glucose through the first 24 h of life (Daniels et al., 1974). Daniels et al. (1974) demonstrated that feeding colostrum to calves did not give a uniform rise in blood glucose and that peak blood glucose occurred after the second feeding of colostrum (Daniels et al., 1974).

Challenges to the neonate begin at the onset of parturition as the fetal calf transitions to neonate. Once that transition is complete, the neonate emerges into a world of variable temperature, pathogenic threats and starvation as it is cut off from the dam and it now must rely on its own body to survive. Colostrum has evolved to provide a complete diet with all the essential nutrients for the neonate during the initial phase of its life, as well as providing essential immunological protection (Stelwagen et al., 2009).

Importance of Essential Fatty Acids to neonatal beef calves

Essential fatty acids begin to influence the neonate before it is born, during the last trimester of pregnancy. Feeding supplemental fat during the last trimester to the dam can influence BAT stores (Lammoglia et al., 1999), increase survivability in lambs (Encinias et al., 2004), influences the immunoglobulin status of the newborn calf (Garcia et al., 2014a) and increase weaning weight in calves nursing heifers fed supplemental fat during the last 65 d of pregnancy (Bellows et al., 2001). Leat (1966) demonstrated that at birth, Palmitic acid (16:0), Palmitoleic acid (16:1), Stearic acid (18:0) and Oleic acid (18:1) are the predominant FA found in the serum of the calf. Maternal plasma contains substantial amounts of Linoleic acid (18:2) and α-Linolenic acid (18:3), which are the only two truly
essential fatty acids that must come from the diet, but very small amounts are present in
the plasma lipids of newborn ruminants (Leat, 1966). Even though EFA are important in
the neonate throughout its life, at birth, the neonate’s development is influenced by
EFA’s. In a 1978 study to measure the neonatal EFA content of different farm species
and where they are found was implemented (Payne, 1978). In the fetal calf, the highest
EFA in the brain were 16:0, 18:0, 18:1 ω 9 and 22:6 ω3 (DHA). In fetal calf liver, most
prominent EFA were 16:0, 18:0, 18:1 ω 9, 20:4ω6, 22:5ω3 and 22:6 ω3. Neonatal heart
contained greater amounts of 16:0, 18:0, 18:1 ω 9 and 20:4ω6. The fetal heart contained
higher levels of linoleic and arachidonic acids (Payne, 1978). Linoleic acid has been
identified as being influential in brain development (Sinclair, 1975). 20:4ω6 is essential
for brain and retinal development (Schaiff et al., 2007). EFA intake of the beef neonate is
dependent upon the EFA profile of the dam. Because cows are able to store supplemented
EFA’s in adipose tissue and then mobilize them after parturition this allows their calves
access to higher levels of milk delivered EFA’s (Palmquist and Mattos, 1978) In lambs,
the fatty acid composition of plasma is similar to that of the adult although completely
different at birth (Leat, 1966).

Linoleic acids seems to have a considerable impact on calves postpartum. Long-term
linoleic acid deficiency expresses itself in poor growth, dermatitis, and death as well as
poor reproduction (Burr and Burr 1930). It has been demonstrated that prepartum
supplementation of Linoleic acid in the dam results in greater survivabilities in lambs
(Encinias et al., 2004), as it improves cold tolerance in newborn dairy calves which could
increase calf survival (Lammoglia et al., 1999). Espinoza et al., (1995) determined that a
steady elevated supply of fatty acids in general can increase growth in beef calves.

Neonatal dairy calves that were fed a milk replacer with elevated levels of linoleic acid had an increase in ADG and feed efficiency and tended to have greater mean concentration of serum IGF-1 and IGF-1 (Garcia et al., 2014b). In rats, brown and white fat is the site of storage for the bulk of Linoleic acid as triglycerides (Derry, 1972). Linoleic acid is essential for life of all mammals, functioning as components of membranes and precursors for synthesis of prostaglandins or long chain fatty acids (Palmquist, 2010). In membranes, Linoleic acid provides the eicosatetraenoic acid (ETA) (arachidonic acid, AA, 20:4ω6) needed for membrane synthesis (Palmquist, 2010). Palmquist goes on to state that there is no detailed information on metabolism of linolenic acid in ruminants and such research could prove to be fruitful (Palmquist, 2010).

*Essential Fatty Acids role in passive immunity transfer*

The goal of ruminant colostrum is to provide substances needed to begin development as well as supplying the means necessary to combat pathogenic challenges. Due to the nature of the immune system of generating immunoglobulins specific to pathogens, the newborn immune system is naïve to pathogens. Neonatal calves are born with Ig levels that are very low, even undetectable (Smith & Holm, 1948; Hansen & Phillips, 1949; Garcia et al., 2014a) rendering the neonate defenseless to pathogenic invaders. Fortunately, ruminants have evolved a means to transfer immunoglobulins from dam to offspring, which in other species will cross the placental barrier. Since this transfer of immunity is crucial to the short term survival and long term productivity of the newborn, research on ways to enhance transfer, such as increasing Ig content of colostrum,
increasing efficiency of the transfer or increasing the volume of Ig transferred are warranted. Foley (1978) reviewed methods of preserving excess colostrum and its viability and attempts to artificially augment the ability of calves to attain passive immune support. Work done culturing murine thioglycollate-elicited peritoneal macrophages in the presence of a variety of fatty acids added as complexes with bovine serum albumin hypothesized that it may be possible to modulate the activity of cells of the immune system by dietary lipid manipulation (Calder et al., 1990). Further investigation by De Pablo et al. (2000) concluded that dietary lipid manipulation may affect a great number of immune parameters, such as lymphocyte proliferation, cytokine synthesis, natural killer (NK) cell activity, and phagocytosis. Maternal nutritional restriction on neonatal immunity and production was investigated with dam being restricted during the last 90 d of gestation (Hough et al., 1990). Results determined maternal nutrition did not affect either colostrum IgG concentration for restricted and control cows or the calves' serum IgG concentration; however calves fed colostrum from restricted cows tended to have lower serum IgG concentration (Hough et al., 1990).

A strong interest in conducting research to determine how dietary fatty acids can influence the immune system has been observed. Because of long chain fatty acids (LCFA), primarily in the form of phospholipids, make up a significant component of the cell membrane structure in animals (Staples et al., 2008). Cells dedicated to fight infection in animals contain LCFA in their cell membranes (Staples et al., 2008). When yearling crossbred steers were challenged with concanavalin A after fish oil supplementation during the grazing phase, modulation of immune function was observed.
(Wistuba et al., 2005). An antigen immune challenge on suckling calves was implemented using beef calves from crossbred dams had been supplemented with cracked, high-linoleate safflower seed beginning 1 d postpartum until d 40 of lactation. It was determined that postpartum oilseed supplementation in beef cows decreased antibody production in response to an antigenic challenge in suckling calves (Lake et al., 2006). Since concentrated source Ig is efficiently absorbed by newborn calves, Garcia et al., (2014) attempted to modify the FA profile of colostrum and plasma of newborn calves via supplementation of saturated FA and C18:2n-6. After supplementing nulliparous and parous Holstein cows during late gestation with saturated FA supplement or CSFA for the last 8 wk of gestation, serum concentrations of IgG tended to be increased in calves born from dams fed fat compared with those not fed fat (Garcia et al., 2014a). It was demonstrated that increased calf serum IgG may be caused by supplementing long-chain FA’s prepartum in the saturated and unsaturated forms may influence the FA profile of intestinal absorptive cells (enterocytes). This could affect the transfer of immunoglobulin to plasma of calves. Supplementation of FA during late gestation might change the fluidity of enterocyte membranes, via modification of enterocyte FcRn in the intestine (Garcia et al., 2014a). Two forms of cDNA encoding the bovine homologue of the rat, mouse, and human IgG transporting Fc receptor, bovine FcRn has been isolated, characterized and cloned (Kacskovics et al., 2000). Although IgG absorption by the ruminant is FcRn-independent, FcRn likely has a protective effect on circulating IgG to prevent their premature degradation and clearance from circulation across species. The source of fat supplement fed prepartum altered the FA profile of plasma of newborns
(Garcia et al., 2014a). Including 1.7% FA as SAT or ESS in low-FA diets (2.0% of dietary DM) during the last 8 wk of gestation influenced the immunoglobulin status of the newborn calf (Garcia et al., 2014a). Circulating concentrations of serum IgG were greater in calves born from dams fed saturated fats due to greater apparent efficiency of absorption of IgG from the small intestine (Garcia et al., 2014a). Further studies are warranted to compare suckling between breeds. Immunity in calves, acquired from the dam, after 24 h has both short term and long term influence on the calf. Short term adequate Ig levels protect the neonate from morbidity and mortality. Long term, gestational maternal nutrition can have lifelong effects on the calf (Menanteau-Horta et al., 1985; Galyean et al., 1999). Calves from dams were fed 70% of NEm requirements during the last 40 d of gestation had decreased postweaning vaccination-induced humoral immunity, inflammatory and physiological stress responses (Moriel et al., 2016).

**EFA’s and rumen bypass fat effects on calf birth weight**

A review by Funston et al. (2010) infers that calf birth weights should be increased in cows supplemented with protein and energy due to most fetal growth occurring in the later part of gestation. Effects of variation in nutrient intake during late gestation would have greater effects than in early pregnancy. High gestational feed levels can increase calf birth weights (Bellows and Short, 1978). It has been demonstrated that primiparous cows calving in BCS of 4, 5, or 6, respectively, had calves with progressively heavier birth weights (Spitzer et al., 1995; Renquist et al., 2006). Decreased nutrient intake of beef heifers during early gestation resulted in decreased gestation length and no effect on birth weight (Long et al., 2007). Early gestational undernutrition in multiparous beef
cows resulted in decreased 125d fetal weights and is accompanied by decreased total placentome surface area, decreased allantoic fluid volume and decreased cotyledonary tissue weight (Long et al., 2009). Experimentation on second-calf cows fed 50 % of the recommended level of prepartum energy and had calves that were 3.7 Kg lighter at birth (Corah et al., 1975). Heat stress has been demonstrated to decrease calf birth weight in dairy cattle and beef calves (Collier et al., 1982; Wright et al., 2014). One investigation was executed in 1977 using diets containing polyunsaturated fats, commercially protected tallow and polyunsaturated oil, were fed approximately 1 month prelambing (Palmquist et al., 1977). At the conclusion of the study it was demonstrated that at birth, body weights and linoleic acid in plasma phospholipids of lambs in all treatment groups were identical (Palmquist et al., 1977).

EFA’s and beef calf growth

Late gestation supplementation of EFA’s and protected EFA’s can be beneficial to calf growth and immune system development, both of which result in a healthier calf. Early BW gains in calves can be effected by the nutrition of the dam and occurred throughout weaning and slaughter (Larson et al., 2009). Lactating beef heifers and cows receiving supplemental fat for the last 60 to 75 days of gestation had increased calf weaning weights of their calves (Bellows, 1999). Pre- and postpartum period supplementation of rumen protected fatty acids improved growth and weights of calves at 35, 50, and 90 d of age (Espinoza et al., 1995). Postpartum FA supplementation has observed mixed results on calf performance. Rice bran containing oleic acid, linoleic acid, and linolenic acid as unsaturated fatty acids, and palmitic and stearic acids as saturated fatty acids (Rukmini et
al., 1991). It has been used to supplement multiparous Brahman cows in excellent body condition and calf weight gain tended to be higher in calves nursing rice bran-supplemented dams (De Fries e al., 1998). When rice bran supplementation ended increases in calf weight gain ended as well and investigators attributed the greater gains to an increase in milk energy of their dams (De Fries e al., 1998). High-linoleate safflower seeds; or high-oleate safflower seeds supplemented beginning 3 d postpartum for 90 days in primiparous Angus × Gelbvieh cows resulted in no changes calf weight gains or 205-d adjusted weaning weights after 90 d of supplementation (Bottger et al., 2002). Lake et al. (2005) used three-year-old Angus × Gelbvieh beef cows to determine the effects of prepartum energy balance and postpartum lipid supplementation on cow and calf performance. Cows were fed low-fat control supplement or supplements with either high-linoleate cracked safflower seeds or high oleate cracked safflower seeds from d 3 postpartum to d 60 of lactation and demonstrated that dietary lipid supplementation did not influence calf performance (Lake et al., 2005). Linoleic acid is an essential fatty acid that is required for many physiological processes and prepartum diets containing increased amounts of linoleic acid may be an important factor influencing calf survival (Hess, 2008) and it is reasonable to speculate that these two factors could influence calf performance either separately or together. Garcia et al. (2014) decided to determine whether intake of energy and or differing long-chain FA in late gestation would influence metabolic profile, immune status, health, and growth of calves consuming diets enriched in medium chain FA or EFA (primarily linoleic acid) during the first 2 months of life. Three diets were used on pregnant nulliparous and primiparous Holsteins that were no fat
(CON); a saturated FA (SFA) supplement enriched in stearic acid or unsaturated FA (CSFA - Megalac R) supplement enriched in the essential FA linoleic acid. Newborn calves were fed a milk replacer (MR) with either low linoleic acid (LLA; coconut oil) or high linoleic acid first 30 d. At 30 and 60 d of life (Garcia et al., 2014), concentrations of linoleic acid in plasma were increased in calves born from dams supplemented with essential FA compared with SFA and in calves consuming HLA compared with LLA MR. Prepartum supplementation with SFA improved average daily gain by calves and total n-3 FA concentration was increased in plasma of calves fed HLA compared with LLA MR (1.44 vs. 1.32%) primarily due to increased α-linolenic acid. Increasing mean intake of linoleic acid from approximately 4.6 to 11.0 g/d (a single grain mix (1.0% linoleic acid, DM basis) was offered in ad libitum amounts from 31 to 60 d of age in addition to MR) during the first 60 d of life increased average daily gain without a change in dry matter intake, thus improving feed efficiency (Garcia et al., 2014). The improved ADG and FE apparently were due to the superiority of the HLA MR formulation (i.e., greater intake of linoleic acid). Proportion of total SFA in plasma of calves born from dams fed the SFA supplement was greater and that of linoleic acid tended to be less compared with calves born from dams fed the EFA supplement (CSFA) and may have been due to the deposition of FA by calves in utero that can be mobilized after birth. Concentrations of linoleic acid, C20:2n-6, C20:4n-6, C22:5n-3, and C22:6n-3 in plasma decreased whereas concentrations of C18:3n-6, α-linolenic acid, C20:3n-6, and C22:4n-6 increased in calves at 60 d compared with 30 d of age (Garcia et al., 2014). The authors concluded that the type of energy fed prepartum, specifically the FA profile of the energy
supplement, may influence the metabolism of the newborn calf. Changing formulations of the dam diet toward the end of gestation can influence the metabolic profile and immune status of the newborn calf. It was also observed that there were greater concentrations of insulin and IGF-1 for calves fed HLA MR compared with calves receiving LLA MR (Garcia et al., 2014).

Essential Fatty Acids and Beef cow reproduction

Reproduction in female bovine is the backbone of meat and milk production, without it, neither exist. This explains the predominance of investigations into any supplementation that would result in cows returning to estrus and becoming pregnant more efficiently. A beef or dairy female has 82 days after parturition to become pregnant and stay on a 365 d calving interval. Anything that can be implemented to ensure that this happens be it management, genetics or nutritional is warranted. One example of a management practice that can influence cow reproduction is early weaning of the calf to lessen the demand on the cow prior to breeding initially by removing suckling stimulation. Early weaning of calves is usually not detrimental to the calf (Tipton et al., 2017) and it can improve cow BW, BCS, and reproduction (Shoup et al., 2015). Estrus can be induced in cows by permanently removing calves as early as 25 d of age (Hightshoe et al., 1991). According to Berry et al., (2014) little research has been undertaken on the genetics of reproductive performance in beef cattle. After examining calving dates from 1,632,941 cows, totaling 5,127,232 calving events between the years 2002 and 2010 from 45,480 beef herds, it was concluded that genetic selection for improved reproductive performance in beef
herds is feasible (Berry et al., 2014). Until recently, due to low heritability of reproductive traits genetic selection was deemed difficult at best.

An abundance of nutritional supplementation research in cows and heifers deals with accomplishing that goal. Cows and heifers need to meet maintenance needs and reach acceptable BCS. It has been demonstrated that heifers receiving adequate amounts of feed tend to exhibit estrus by 40 d postpartum than heifers that receive less than 100% of the recommended level of prepartum energy (Corah et al., 1975). Prepartum nutrition is important as well, cows receiving high feed levels before calving experienced shorter postpartum intervals, increased onset of estrus before the breeding season and tended to have a higher fall pregnancy rate (Bellows et al., 1978). Marston et al. (1995) demonstrated that prepartum energy supplementation improved conception rates in cows, but not in the postpartum period and had an 11% greater pregnancy rate than cows supplemented with protein (Marston et al., 1995). Prepartum nutrition observations reported greater BCS at calving resulted in more cows in estrus and pregnant by 40 and 60 d of a breeding season (Spitzer et al., 1995).

There has also been experimentation on effectiveness of different feedstuffs and their abilities to bring cows to an optimum condition. Previous work has investigated various sources of degradable and undegradable protein and their effects on the preproduction of primiparous cows (Alderton et al., 2000). Late gestation supplementation in heifers fed with dried corn distillers grains plus solubles versus a soybean hull supplement in addition to grass hay (Engel et al., 2008) and supplementing beef cows with 3 levels of dried distillers grains, a blend of wheat middlings and cottonseed meal and pelleted
cottonseed (Winterholler et al., 2012). All three reported no influence on reproduction although Engel et al. (2008) did report that a greater percentage of DDGS cows became pregnant compared with SBH cows. Similar investigations were performed on the inclusion of fats as energy sources, both pre and postpartum, and its effects on cyclicity and reproduction. Pregnant crossbred, first-calf heifers receiving three types of oil seeds (safflower, raw soybeans or sunflower) added to a gestational diet had greater pregnancy rates even though fat supplementation was terminated at calving (Bellows et al., 2001). Other observations found that polyunsaturated fatty acids stimulated a greater rate of ovarian follicular growth in cattle when using the polyunsaturated fatty acids found in soybean oil versus the primarily saturated fatty acids in both fish oil and tallow (Thomas et al., 1997). Lipid supplementation early in the postpartum period can alter the fatty acid composition of medial basal hypothalamus, uterine tissue, and serum concentrations of PGF$_{2\alpha}$ metabolites in primiparous beef cows during early lactation. It was observed that the oviduct appeared to be the most sensitive tissue to additional dietary linoleic acid in cattle fed a fat supplement of 95.3% cracked high-linoleate safflower seeds (Scholljegerdes et al., 2007). It should be noted that all of the fats in the above investigations were unprotected against rumen biohydrogenation and degradation.

Simultaneously other investigators were examining rumen-protected fats and fatty acids. When multiparous Angus and Hereford x Angus cows ranging from 5 to 7 yr of age had CSFA added to a range supplement, the percentage of cycling cows at 30 to 90 d postpartum was greater (Espinoza et al., 1995.) Percentage of pregnant cows during the first half of the breeding season increased in CSFA fed cows leading investigators to
conclude that CSFA incorporated in a range supplement during pre- and postpartum period improved reproductive efficiency (Espinoza et al., 1995). Calcium salts of long-chain fatty acids fed for 123 d prior to breeding tended to increase calving rate (Lloyd et al., 2002). When supplemental unsaturated fatty acids are designed to be delivered to the lower gut for absorption, specific fatty acids such as linoleic acid, linolenic acid, EPA and DHA may alter reproductive function and fertility by targeting reproductive tissues (Thatcher et al., 2004). With this in mind, Long et al. (2007) demonstrated that by feeding corn gluten feed supplement containing rumen-protected fat to heifers before breeding increased serum lipids by d 60, resulting in a trend for increased pregnancy rates (Long et al., 2007). Ovariectomized Bos indicus beef cows may have had an increase reproductive performance due to improving uterine environment and embryo development, perhaps by increasing circulating concentrations of P4 when subject to rumen-protected PUFA supplementation (Lopes et al., 2009). An investigation of positive reproductive effects associated with rumen-protected unsaturated fatty acid supplementation (USFA) and a rumen-protected saturated fatty acid (SFA) source demonstrated an appearance of superiority of SFA over USFA. Positive reproductive effects suggests the percentage of heifers cycling tended to be less for USFA fed heifers compared with controls and SFA treatment and a tendency for reduced cycling rates at the start of synchronization in USFA-supplemented heifers coupled with similar AI pregnancy rates (Long et al., 2014).
**Conclusion**

The beef cow provides her new calf with protection against pathogens within 24 h of birth and then she will supply that calf with the bulk of its nutrition until the calf is weaned. The average weaning weight, calving interval, calving percentage and death loss of a herd often is a factor in its annual profitability and survival. Supplementation needs to be strategic in either its timing or makeup (Lemaster et al., 2017). There has been an impressive number of inquiries into the type of supplementation: protein, energy (Marston & Lusby, 1995) and fat (Hess et al., 2008); sources of these nutrients (Engel et al., 2008); amounts of supplementation and the timing of supplementation (Marston et al., 1995; Linden et al., 2014). The dividends expected from supplementation are driven by economics. The return on investment must exceed the cost of the supplement and labor to feed it. Beef cattle are supplemented with two main objectives: to increase milk production and therefore calf weaning weight or increase reproductive performance of the dam. In beef cattle, supplementation has been examined both pre and postpartum. Fat has been used with the intention of capitalizing on the energy density of fat. When it was found that when dietary quantities reached a certain level, the effect was deleterious to ruminants and that was attributed to rumen microbial biohydrogenation of fatty acids. Biohydrogenation of a large amount of fatty acids led to derivatives of fatty acids that then inhibited those very same microbes leading to decreased DMI and milk fat depression (Henderson, 1973; Kemp & Lander, 1984). When methods to protect fatty acids from rumen microbial action were identified, the advantages of delivering intact fatty acids to the duodenum on the ruminant were realized (Scholljegerdes et al., 2004).
Fat supplementation took on a new aspect as protected EFA allow us to increase the flow of saturated and unsaturated EFA’s and when fed during gestation, particularly late gestation, change the uterine/placental environment, modify the fatty acid profile of the calf both pre and post-natal and modify the fatty acid profile of the dam and her milk. EFA supplements in late gestation has been demonstrated to not only increase the EFA profile of the dam and her calf, but also increase the immunoglobulin G (IgG) content of the colostrum and can increase the IgG concentration in calf serum in Holstein calves that have been fed colostrum from late gestation CSFA supplemented dams (Garcia et al., 2014a). Garcia theorized that this increase was possibly due to increased IgG absorption in the calf, because of increased EFA supply. Garcia also demonstrated increased ADG and fed efficiency in Holstein calves whose milk replacer was supplemented with linoleic acid for the first 60 days of life (Garcia et al., 2014b). The EFA intake of the neonatal beef calf is dependent on the EFA profile of its dam. It has been demonstrated that long term EFA can be supplied to the calf thanks to the ability of the dam to store prepartum EFA and then mobilize them allowing higher levels of milk delivered EFA’s preweaning (Palmquist & Mattos, 1978). A steady elevated supply of fatty acids in general can increase growth in calves (Espinoza et al., 1995).

Lastly, fatty acid supplementation satisfies the second most valuable function of supplementation, increased reproductive performance of the cow. There are an ample number of investigations that offer evidence that beef cows pre and/or post-partum supplemented with fatty acids tend to calve sooner than controls. There are mixed results
on return to cyclicity, follicular development and size and hormonal activity (Espinoza et al., 1995; Long et al., 2007 and Long et al., 2014).

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CHAPTER 2

The effects of supplementing ruminal bypass unsaturated fatty acids during late gestation on cow and calf serum fatty acids in beef cows

Abstract: The objective of this study was to determine if supplementation with ruminal protected unsaturated fatty acids (FA) during late gestation increased unsaturated FA in both maternal serum and colostrum and in serum from their newborn beef calves. Angus and Angus crossbred heifers and cows (3-4 years old) all bred to one of two Angus sires were blocked by sire and parity and randomly assigned to either control (1.5 kg of corn gluten feed, CON n = 29) or an isocaloric isonitrogenous supplement containing 200 mg of ESSENTIOM (EFA, n = 29) for the last 90 d of gestation. All supplements were individually fed 5 d/wk. All cows had ad libitum access to the same pastures throughout the study. Maternal blood samples were collected at 90 and 45 d before expected parturition. At parturition, blood and colostrum samples were obtained from each cow. Blood samples were collected from calves at parturition and at 5 d of age. Serum and colostrum FA content were determined. All data were analyzed using PROC MIXED procedure of SAS either as repeated measures or ANOVA depending on parameters. Maternal serum concentrations of C16:0, C18:0 C18:1c9, C18:2, C20:4, and total FA were similar in all cows at start of supplementation but increased (treatment × day interaction $P < 0.01$) in the EFA cows at 45 d before and at parturition compared with CON cows. Colostrum DM was increased ($P = 0.01$) in EFA cows compared with CON cows (30.4 vs. 25.4%, 1.30 SEM). Colostrum concentrations on a DM basis of C18:2, total FA, and total unsaturated FA were increased ($P < 0.05$) in EFA cows compared with CON cows. Serum from calves at birth whose dams were supplemented with EFA had
increased ($P \leq 0.01$) concentrations of C16:0, C18:0, C18:1 t9, C18:2, C20:4 and total FA compared with calves whose dams were supplemented CON. At 5 d of age calves from EFA supplemented dams had increased ($P \leq 0.05$) serum concentrations of C18:0, C18:2, C20:4 and total FA compared with serum from calves whose dams were supplemented CON. The results of this study indicate that supplementation of rumen protected unsaturated FA in late gestation beef cows increased circulating and colostrum unsaturated FA, and this resulted in increased unsaturated and total FA at parturition and at 5 d of age in their calves.

Key words: colostrum fatty acids, ruminal bypass fat, serum fatty acids

INTRODUCTION

Late gestation supplementation of beef cattle is widely practiced, well-studied and has shown short and long-term effects on cows and calves. Late gestation nutrition in beef cows can have long lasting effect on both profitability of the cow/calf enterprise and on the value of the calf produced (Banta et al., 2011; Meyer et al., 2014). Investigations during late gestation have been concerned with weight loss or gain in pre and postpartum cows, changes in cow BCS, calf birth weight and weaning weight, return to post-partum cyclicity and subsequent fertility of the dam (Corah et al, 1975). Studies have looked at prepartum supplementation of protein and energy in many of the different feed byproducts available (Radunz et al, 2012; Summers et al, 2012; Marques et al., 2017). Investigations have demonstrated the consequences of late gestation nutrient restriction and its effects on long term calf growth and productivity and reproductive processes of
the dam (Radunz et al, 2010; Bohnert et al, 2013; Lemaster et al., 2016). There have been many studies on the benefits of prepartum fatty acid supplementation in both cow and calf (Larson et al, 2009; Banta et al, 2011; Bach 2012). These previous studies have used EFA supplied by oilseeds such as safflower or sunflower seeds or high fat oil meals such as cottonseed meal. Oilseeds and oil meals have a high fat content but the EFA are vulnerable to rumen biohydrogenation which can make it difficult to deliver intact EFA to the duodenum of the ruminant for absorption. The objective of this study is to investigate the effects of supplementing rumen protected EFA in late gestation on serum levels of specific fatty acids in the dam prior to parturition and at parturition, colostrum levels of essential fatty acids, and in serum of their calves.

MATERIALS AND METHODS

All procedures were approved by Clemson University Animal Care and Use Committee (AUP # 2013-044)

Animals

Nulliparous, primiparous and multiparous cows were used, all born and reared at Simpson Research Station, Clemson University (range 2 - 4 y, 3.1 ± 0.9 y of age at calving, n = 58), bred to 2 Angus AI sires, one for nulliparous cows and one for the remaining cows. Cows were blocked by age (coming 2 y old n = 21, 3 y old = 14 and 4 y old n = 23) and randomly assigned to one of two treatments for the last 94 ± 3 days of gestation. The control animals (n = 29) were individually penned in 3.5 x 3.5 meter pens and supplemented with corn gluten (19.1% CP, 2.15 Mcal NEm/kg, 2.9% EE on a DM
basis; 90.9%DM) at 1.5 kg per head 5 d per wk and treatment animals (n= 29) were also individually penned and supplemented with an isocaloric and isonitrogenous supplement (1.29 kg of a blend made up of 66.2% corn gluten, 18.2% soybean meal and 15.6% Essentium,) 5 d per wk. This treatment (EFA) provided 200g of a rumen protected fat source that is high in essential unsaturated fatty acids, Table 1. (Essentium, Arm and Hammer Animal Nutrition, Princeton, NJ). Both supplements supplied 260g of CP and 1146g of TDN as fed daily. Of the 29 EFA cows, 11 were coming 2 year olds, 7 were coming 3 year olds and 12 were coming 4 year olds. Of the 29 CON cows, 10 were coming 2 year olds, 12 were coming 3 year olds and 7 were coming 4 year olds.

All cows were maintained as a single group on the same fescue pasture and had access to either adequate forage or high quality ad libidum mixed grass hay (12.9%CP and 1.288Mc/kg NEm) that meet and exceed their requirements. Cow BW and BCS were collected every two weeks and then weekly in the final two weeks before expected parturition. At the beginning of the project, d 45 of treatment and then at parturition, blood samples were collected from each cow via jugular venipuncture into blood collection syringes (~ 10 ml, Starstedt, Newton, NC). Blood samples were allowed to sit at ambient temperature for one hr to clot then refrigerated for 23 hr before being centrifuged at 2000 x g for 20 minutes. Serum was then decanted and stored at -20 C°.

Cows were allowed to calve naturally and two blood samples (~ 6ml each) were collected via jugular venipuncture from the calves, for plasma in Heparinized tubes (Starstedt, Newton, NC) and serum, immediately after parturition and prior to suckling when possible or at no greater than 2 hours after parturition. Plasma samples were held at 4 °C
for no longer than 1.5 hr and then centrifuged at 1500 X g for 25 minutes and then
decanted and stored at -20 °C. Serum samples were handled in a similar manner as the
previous cow samples. Also at parturition, a colostrum sample was obtained from the
cow (~75ml) through hand milking and stored at -20 °C. All cow calf pairs were moved
to a common pasture after parturition. Subsequent blood samples (6 ml) were collected
from the calves daily at 0600 h blood collection syringes until 5 d of age. Blood was
collected and serum was harvested in a similar manner as above. Postpartum, all cow-calf
pairs were fed ad libitum silage (9.9 % CP, and 1.38 Mcal/kg, DM basis)
Serum and Colostrum Fatty Acid Quantification

Serum fatty acid analysis was performed in duplicate 1 ml samples of serum from
all cows and calves and colostrum were lyophilized and transmethylated according to
Park and Goins (1994), and analyzed via gas chromatograph. Colostrum samples were
allowed to thaw at 4°C and then ~ 30 ml were removed and placed in a new previously
weighed 50 ml conical tube. Samples were freeze dried with a weight collected pre and
post freeze drying to calculate colostrum DM. Fatty acid analysis of colostrum, utilized
duplicate ~85 mg samples of lyophilized colostrum. The Park and Goins (1994) method
uses an alkaline catalyst followed by an acidic catalyst to complete the transmethylation
of FFA without rearranging cis/trans double bonds. Each sample of fatty acid methyl
esters (FAME) was analyzed using a Shimadzu 2014 gas chromatograph (GC) equipped
with a Shimadzu AOC-20S automatic sampler. Separations were completed using a 60-
mm capillary column (Agilent, Technologies, Santa Clara, CA). Identification of FA was
achieved by comparing retention times of known standards. An internal standard, methyl
tricosanoic (C23:0) acid, was incorporated into every sample during methylation in order to quantify the sample as a percentage of weight of total FA. The CV based on total FA was 10.4 %.

Serum triglyceride and cholesterol concentrations were determined in maternal samples using previously validated colorimetric assays (Pointe Scientific, Inc., Canton, MI; Long et al., 2014). Serum triglyceride and cholesterol and plasma glucose was determined in samples from all unsuckled calves (n = 46) using above mentioned assays and glucose was analyzed using a previously validated colorimetric assay (Pointe Scientific, Inc. Long and Schafer 2013). All samples for all assays were analyzed in triplicate. The intra-assay and inter-assay CV for cholesterol were 3.4 % and 3.1 %, respectively. The intra-assay and inter-assay CV for triglycerides were 3.3 % and 2.9 %, respectively. The intra-assay and inter-assay CV for glucose were 3.7 % and 4.1 %, respectively.

STATISTICAL ANALYSIS

Maternal BW, BCS, serum total and specific fatty acids during supplementation, and serum cholesterol and triglycerides during supplementation were analyzed using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC) as repeated measures with treatment, time, their interaction, and parity in the model. Covariate structure was Autoregressive 1 as it gave the best-fit statistics. Colostrum DM and fatty acids profile, calf serum FA profile at parturition and five d of age, and serum cholesterol, triglycerides and glucose in unsuckled calves at parturition were analyzed as an ANOVA with treatment, parity, and its interaction in the model. Calf sex was initially included in all calf analysis and was found to be non-significant (P < 0.36) and was removed from the
final model. Data are presented as least squares means ± SEM and were considered
significantly different when $P \leq 0.05$ and a tendency was indicated when $P \leq 0.10$.

RESULTS

Maternal BW and BCS are shown in Table 2. Initial BW and BCS were similar
($P = 0.954$ and 0.71 respectively) among treatment groups. The largest variation in BW
was observed in parity differences ($P < 0.001$) with older cows having greater BW
compared to younger cows. The lack of difference in BW due to treatment continued
throughout the experiment and with BW differences remained similar for treatment and
treatment x parity on day 45 BW and final BW ($P = 0.909$ and 0.961 respectively). The
effects of parity on difference in BW continued to be significant ($P < 0.001$). Final BW
were similar for treatment and treatment x parity ($P = 0.64$ and 0.99 respectively) and
parity was again significantly different ($P < .001$). Parity was responsible for greater
final BW ($P <0.001$), treatment had no effect on final BW ($P = 0.147$) nor was there a
treatment x parity effect ($P = 0.82$). BCS variation followed along the same lines with
treatment and treatment x parity being nonsignificant ($P = 0.71$ and 0.85 respectively)
and parity being significant different ($P < .001$). BCSs at d 45 and final BCS are similar
and reflect the same variations. This lack of differences was expected because all of the
cattle were maintained on the exact same pasture and hay (when necessary) both before
and after parturition.

Serum total and specific fatty acids (mg/ml) of CON and EFA cows over the
treatment period is shown in Table 3. Initially, d 0, serum FA’s were similar ($P < .0001$)
among treatment groups. EFA cows demonstrated a treatment x day interaction for 16:0
(P = 0.0061), 18:0 (P = 0.0006), 18:2 (P < 0.0001), α-Linolenic acid (18:3) (P = 0.0036), 20:4 (P = 0.0002) as well as total fatty acids (P < 0.0001), with EFA cows having increased FA at d. 45 and parturition as compared to CON cows.

Serum cholesterol concentrations of cows are shown in Table 3. As with fatty acids, EFA and CON cows began with similar concentration of cholesterol d 0. Both groups of cows had an increase in serum cholesterol from d 0 to d 45, with EFA cows having a greater increase (trt x day \( P < 0.001 \)). Serum triglycerides are provided in Table 3. Both groups of cows had similar serum triglycerides on d 90, EFA cows had increased serum triglycerides compared to CON cows on d 45 and at parturition (trt x day \( P=0.001 \)).

Cow colostrum DM specific and total fatty acids (mg/g DM) are shown in Table 4. Data shows a treatment effect for percent DM total with EFA cows exhibiting higher DM than CON cows \( (P < 0.01) \). Parity demonstrated no difference in colostrum DM between CON and EFA cows \( (P = 0.79) \), however there was a suckling effect on colostrum DM observed \( (P = 0.0009) \). There was a treatment effect increase in both Linoleic acid (18:2) \( (P < 0.0001) \) and total unsaturated fatty acids in EFA as compared to CON cows. We also observed a tendency for treatment effect for 14:0 \( (P = 0.1) \), 16:1 \( (P = 0.09) \), and 18:1 t 9 \( (P = 0.08) \).

Serum total and specific fatty acids (mg/ml) of calves at parturition (Table 5) demonstrates that calves born to EFA dams had increased serum concentrations of 16:0 \( (P = 0.003) \), 18:0 \( (P = 0.005) \), 18:1 t-9 \( (P = 0.033) \), 18:2 \( (P < 0.001) \) and 20:4 \( (P < 0.001) \). There were no differences in calf serum FA attributable to either parity or
treatment x parity interactions ($P > 0.15$). 18:1 c-9 serum levels indicates a tendency of calves whose dams were individually fed EFA ($P = 0.069$) to be increased as compared to CON dams. EFA calves also had increased serum total fatty acids compared to CON calves ($P = 0.011$).

On d 5 of age, serum FA remained altered due to EFA supplementation of their dams (Table 6). EFA calves had an increase concentration of serum 18:0 ($P = 0.033$), 18:2 ($P < 0.001$), 20:4 ($P = 0.05$) and an increase in total fatty acids ($P = 0.0042$). There was evidence of a tendency for greater serum concentrations of 16:1 ($P = 0.069$) in EFA calves compared to CON calves. Once again we see no differences due to parity and parity x treatment ($P > 0.1$) on d 5.

Figure 1 presents serum plasma glucose, cholesterol and triglyceride concentrations of unsuckled calves from either cows fed EFA or CON. Calves from EFA dams had reduced plasma glucose concentration than did compared to calves from CON cows ($P = 0.04$). Calves from EFA dams had increased serum concentrations of cholesterol ($P = .01$) and triglycerides ($P < 0.02$) than calves from CON dams.

DISCUSSION

Nutritional status of beef cows during gestation has a profound effect on both the fetal and neonatal calf. When referring to maternal nutrition, this not only encompasses energy and protein but includes fatty acids as well. More and more research is demonstrating that exogenous supplies of supplemental essential fatty acids can be advantageous for a variety of reasons. Most investigations have used feedstuffs or
byproducts feed that are high in fatty acid composition but these fatty acids are subject to rumen microbial action whereas supplementation of beef cattle using rumen protected fatty acids has been investigated somewhat less. A great deal of interest in fatty acid supplementation in beef cows has been during the postpartum period and mainly interested in effects on reproduction from an energy standpoint and fatty acids influences on reproductive metabolic processes. This current investigation examined prepartum rumen protected fatty acid supplementation and only its effects on cow BW, cow BCS, serum FA profiles of both cow and calf, colostrum composition and serum cholesterol, triglyceride and glucose of calves.

Cow BW and BCS results indicate that parity has the greatest effect on these variables than either treatment or days on treatment. These results concur with several studies in which parity was the main effect on cow BW and BCS regardless of the treatment (Zehnder et al, 2010; Banta et al, 2011 and Garcia et al, 2014b). This is not surprising given that supplements were isocaloric and isonitrogenous and all cows were on the same pasture. Serum concentrations of EFAs in dams were collected concurrently with BW and BCS data collection to examine EFA profile in maternal circulation. In both CON and EFA cows, serum concentrations of all EFA’s had a net increase as pregnancy progressed to parturition with EFA cows having greater concentrations of EFA’s than CON. Overall, CON cow serum concentration fluctuation mirrored that of EFA cows for d 45 and parturition. The exceptions were 16:1 and 18:3 being marginally higher in CON cows at d 45 than EFA cows but not at parturition. Because 18:2 and 18:3 are truly dietary EFA (and 20:4 which is an end product of 18:3 conversion in most mammals) on
a cellular level. All other EFA are supplied to the ruminant by lipid bilayer of rumen microbes, not necessarily by the diet. Serum 18:2 and 20:4 is greater in EFA cows as compared to CON cows as a result of treatment x day effect ($P < 0.0001$ and $P < 0.001$ respectively) and reflects the 18:2 composition of the supplement. These observed responses are predicted in dairy cows by reason of changes in the FA profile are expected when the diet supplies increased amounts of inert polyunsaturated long-chain FA (Theurer et al, 2009). Cholesterol & Triglycerides increased d 0 to d 45 and then decreased at parturition in EFA and CON cows with EFA cows serum levels much higher than CON, with the exception of d 0 when treatment began for a significant treatment x day influence ($P = 0.0001$) for both cholesterol and triglycerides. The greater concentration of serum cholesterol and triglycerides in EFA cows compared to CON cows at parturition supports Lammoglia et al. (1996) who demonstrated that serum cholesterol and triglycerides were greater in Brahman cows that were supplemented with high fat than in cows that were supplemented with a medium fat or a low fat supplement.

When comparing serum FA of cows to colostrum total and specific fatty acids, 18:2 and total FA mimicked in colostrum what was demonstrated in serum at parturition in both CON and EFA cows. EFA cows total FA are higher in both serum ($P = 0.0003$) and colostrum ($P = 0.02$) and 18:2 was the same with EFA cow data illustrating elevated values in serum ($P < 0.0001$) and colostrum ($P < 0.0001$) higher than CON cows. 18:1 t-9 serum totals reflected a tendency to be higher in EFA cows at parturition ($P = 0.0809$) and replicated this tendency in colostrum as well ($P = 0.08$). The importance of these higher amounts of in 18:2 and 18:1 t-9 at parturition is because the lowest contents of
trans 18:1 and 18:2 isomers are on the day of calving and increase as lactation progresses (Contarini et al, 2014). Even though 16:1 was nearly identical in serum of EFA and CON cows, colostrum 16:1 differences tended to be higher in EFA cows due to treatment ($P = 0.09$). There was a slight tendency for increased 14:0 in EFA cows ($P = 0.1$) due to treatment. Although total colostrum saturated FA (SFA) content was higher in EFA cows, there was no significant difference, unlike unsaturated FA (USFA) in which CON cows were lower ($P = 0.03$). DM percentage of colostrum at parturition was higher in EFA cows ($P = 0.01$) with CON cows at 25.4% DM and EFA cows at 30.4%, for a difference of 5% DM. This data supports Steele et al. (1971) and Long et al. (2009) demonstrating evidence in sheep indicating that circulating FA in the maternal blood could impact FA concentration in milk and therefore colostrum (Steele et al, 1971; Long et al, 2009). Dietz et al. (2003) supports our results with the findings in a study examining the effects of adding fat to late-gestation cow diets on neonatal response to cold. Fall-calving heifers receiving a 47 d prepartum supplement of either a 1.5% fat control diet, a 4.0% fat diet containing safflower seed or a 5.0% fat diet whole cottonseed demonstrated a tendency for the heifers receiving the safflower diet to have greater colostral solids than heifers fed the control or whole cottonseed diets.

Our data disagrees with previous research that found, in dairy cows, parity had the greatest effect on total colostrum FA (Garcia et al 2014), our data provided evidence that in this particular group of beef cows, treatment had the most influence on colostral total FA ($P = 0.02$).
An investigation of data found in Tables 3, 4 and 5 will show in EFA cows and calves that support the work of Garcia et al. (2014) in their statements that in dairy cattle, the FA fed to dams harmonizes with colostrum of the dam and serum of the newborn calf, at least in respect to 16:0, 18:0, 18:1 c-9 and 18:2 (Garcia et al, 2014a), the concentrations of these EFA do not match between cow and calf, but the increases over CON are similar. We also detect similarities between serum EFA profile in EFA cows and their calves with respect to 16:0, 18:0, 18:1 t-9, 18:2 as well as 20:4 that do not necessarily coincide with the content of the supplement. It has been suggested that similar findings indicate a sizeable transfer of EFA across the placenta (Soares, 1986). We are unable to support Garcia et al (2014) as we were unable to demonstrate a significant effect of parity on colostrum FA profile or total colost ral FA. Our CON calf data was predicted in 1966 in regard to 18:1, 18:2 and 20:4 in ruminant offspring (Leat, 1966) and our EFA data demonstrate that these FA can be altered by prepartum supplementation of rumen protected fatty acid supplementation 5 days per week.

At parturition, the neonate must shift from an uninterrupted placental supply of glucose to an intermittent colostrum and milk intake with lactose and fat as main energy sources. Calves tend to be born hypoglycemic and need to establish autogenous glucose production and gluconeogenesis because lactose intake by colostrum and milk may not meet glucose demands (Hammon et al, 2013). Unexpectedly, data from Figure 1 illustrates that CON calves had higher levels of plasma glucose than EFA calves ($P = 0.04$) because of evidence that dairy heifers supplemented with fat during late gestation exhibited increased glucose concentrations in their newborn calves (Lammoglia et al,
There are investigations that provide a variety of theories to explain this difference in glucose levels. Research over half a century ago demonstrated that newborn blood glucose rises after birth during starvation, an excellent example of the neonate establishing gluconeogenesis, and that blood glucose values varied considerably from calf to calf immediately after birth (Goodwin, 1957). Bellows and Lammoglia (2000) observed that, in a study, using primiparous cross bred beef cows, on the effects of severity of dystocia, concentrations of glucose and cortisol in neonatal beef calves, serum glucose was lowest in calves needing no assistance at calving and that blood glucose was highest in calves that required the use of a mechanical calf puller (Bellows and Lammoglia, 2000). In this current study there were only two calves requiring assistance, and neither required a mechanical puller and one calf was from an EFA dam and the other was from a CON dam and therefore this argument does not support our data. Another promising hypothesis for the difference in glucose levels was in 1974 was that in newborn ruminants, glucose has been assumed the primary reducing sugar and energy substrate available to the newborn ruminant but neonatal ruminants may not be dependent upon glucose as their principle energy substrate during the first 24 h of life. Daniels (1974) demonstrated that fructose may play an important role in energy metabolism of the neonatal ruminant during the first few hours since it is relatively high in fetal blood and the first few hours of life and is one of the few studies that collected blood samples immediately after birth from unsuckled neonates (Daniels et al, 1974). Regrettably, no fructose analysis was performed in this current study. A final scenario to explain the unexpected glucose serum differences between EFA and CON calves may be unknown
insulin differences in these calves, with CON calves falling short of the blood insulin levels of the EFA calves. When compared to CON calves, EFA calves are more hypoglycemic at parturition to a very small margin, but not to the degree produced by Comline and Edwards (1968). It has been demonstrated that hypoglycemia can be induced by an oral dose of insulin (Pierce et al., 1964) and it has been demonstrated that insulin accelerates the membrane transport of glucose (Randle et al., 1964). In rebuttal to this concept is evidence from a similar study that demonstrates neither dam diet nor milk replacer (MR) enhanced with linoleic acid, high (HLA) or low (LLA) amounts, affected mean concentration of insulin but does admit that although means were numerically greater and therefore significant, for calves fed HLA compared with LLA MR, HLA calves did have higher levels in insulin, 1.44 vs. 1.28 ng/mL, respectively (Garcia, et al., 2014b). EFA calves might have more insulin at birth, more developed pancreas and delivery system, resulting in lower serum glucose than CON. It must be noted that, although no provision was made to measure calf vigor at parturition, we did notice that when the EFA calves were born, they were on their feet trying to nurse almost faster than data could be collected, displaying a great deal of vigor.

Figure 1 also represents serum cholesterol of unsuckled calves born to cows individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (RUF) 5 d/wk. at parturition. Calf serum CHO mimics dam serum \( (P = 0.0001) \) at parturition and EFA calves higher than CON calves, \( (P = 0.01) \). Cholesterol is important because low cholesterol affects lipid metabolism, hepatic lipid metabolism, steroid biosynthesis, and cell membrane function.
can be expected, which may result in unspecific symptoms of reduced fertility, growth, and health (Gross et al, 2016) and may stimulate an increase in intestinal absorption of lipids (Bitman et al, 1982).

Serum triglyceride concentrations are found in Figure 1. Calf serum triglyceride mimics dam serum (P= 0.001) at parturition where EFA calves have greater serum triglycerides than CON calves (P = 0. 02). There are numerous studies detailing the effects of feeding neonates milk replacers or colostrum on their effects on serum TG, chronicling the rise or fall of serum TG levels and samples were taken and analyzed after feeding so there is little baseline information at day 0 (unsuckled TG levels at birth) available in which to compare our data to establish more credibility of our results (Spanski et al, 1997; Blum et al, 1997). The lowest concentration of triglycerides were observed at birth and was followed by a rapid increase during the first week of postnatal life (Herosimczyk et al, 2013). There is evidence that triglyceride levels usually are dependent on colostrum consumption (Blum et al, 1997). In other species, triglycerides have been demonstrated to be very important when fed to pigs (Swiss et al, 1976) and chicks (Sklan 1979).

To our knowledge, this is the first report demonstrating that supplemental rumen bypass essential fatty acids fed to beef cows during the final 90 days of gestation can effect nulliparous, primiparous and multiparous beef cow EFA profile prepartum and at parturition and colostrum EFA profile. We have also demonstrated that this supplementation can impact serum levels of FA, cholesterol, triglycerides and glucose at birth of their calves as well.
LITERATURE CITED


Payne, E. "Fatty acid composition of tissue phospholipids of the foetal calf and neonatal lamb, deer calf and piglet as compared with the cow, sheep, deer and pig." 1978. British Journal of Nutrition 39, no. 1: 45-52. doi.org/10.1079/BJN19780010.


Table 1. Nutrient profile and fatty acid composition of rumen undegradable unsaturated fatty acid source\(^1\) for both experiments

<table>
<thead>
<tr>
<th>Component</th>
<th>% DM</th>
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<tr>
<td>DM</td>
<td>96.9</td>
</tr>
<tr>
<td>Calcium, % DM</td>
<td>8.8</td>
</tr>
<tr>
<td>Acid Ether Extract, % DM</td>
<td>84.5</td>
</tr>
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</tr>
<tr>
<td>C14:0, % DM</td>
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<td>C16:0, % DM</td>
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<td>C16:1, % DM</td>
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<tr>
<td>C18:0, % DM</td>
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<td>C18:1(t), % DM</td>
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<td>C18:1(c), % DM</td>
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</tr>
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<td>C18:3, % DM</td>
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</tr>
<tr>
<td>Other LCFA(^2), % DM</td>
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</tr>
</tbody>
</table>

\(^1\) Essentium Church & Dwight Co., Inc., Princeton, NJ

\(^2\) LCFA= long chain fatty acid
Table 2. Cow BW (kg) and BCSs and their changes during the last 90 d of gestation of cows fed an isocaloric supplement containing either 200 mg of ESSENTIOM 5 d a week (EFA) or a supplement with no fat (Control)

<table>
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<tr>
<th>trt</th>
<th>Control</th>
<th>EFA</th>
<th>P value</th>
<th>trt</th>
<th>Parity</th>
<th>trt* parity</th>
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<td>12</td>
<td>10</td>
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</tr>
<tr>
<td>parity</td>
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<td>3</td>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial BW</td>
<td>480 ± 12</td>
<td>512 ± 16</td>
<td>479 ± 12</td>
<td>0.954</td>
<td>&lt; 0.001</td>
<td>0.951</td>
</tr>
<tr>
<td></td>
<td>508 ± 12</td>
<td>539 ± 12</td>
<td>496 ± 16</td>
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<tr>
<td>Middle BW</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>0.909</td>
<td>&lt; 0.001</td>
<td>0.961</td>
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<td></td>
<td>556 ± 15</td>
<td>571 ± 12</td>
<td>551 ± 15</td>
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<td>Final BW</td>
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<td>0.648</td>
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<td>0.995</td>
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<tr>
<td>Change in</td>
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<td>598 ± 12</td>
<td>523 ± 12</td>
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<td>BW</td>
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<td>58 ± 3</td>
<td>61 ± 4</td>
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<tr>
<td></td>
<td>58 ± 3</td>
<td>61 ± 3</td>
<td>61 ± 3</td>
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<tr>
<td>Initial BCS</td>
<td>5.6 ± 0.1</td>
<td>5.1 ± 0.2</td>
<td>5.1 ± 0.1</td>
<td>0.710</td>
<td>&lt; 0.001</td>
<td>0.858</td>
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<td>5.6 ± 0.1</td>
<td>5.1 ± 0.1</td>
<td>5.1 ± 0.1</td>
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<tr>
<td>Middle BCS</td>
<td>0.1</td>
<td>5.3 ± 0.2</td>
<td>5.1 ± 0.2</td>
<td>0.821</td>
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<td>5.7 ± 0.1</td>
<td>5.4 ± 0.1</td>
<td>5.6 ± 0.1</td>
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<tr>
<td>Final BCS</td>
<td>0.1</td>
<td>5.1 ± 0.2</td>
<td>5.6 ± 0.1</td>
<td>0.745</td>
<td>0.001</td>
<td>0.825</td>
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<tr>
<td>Change in</td>
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<td>0.5 ± 0.1</td>
<td>0.5 ± 0.1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>BCS</td>
<td>0.1</td>
<td>0.1 ± 0.2</td>
<td>0.0 ± 0.2</td>
<td>0.935</td>
<td>0.005</td>
<td>0.936</td>
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<tr>
<td></td>
<td>0.1 ± 0.1</td>
<td>0.0 ± 0.2</td>
<td>0.5 ± 0.1</td>
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</table>

Data presented LSM ± SEM.
1 Initial BW was collected at initiation of treatment, approximately d 196 of gestation.
2 Wagner et al., 1988.
Table 3. Serum total and specific fatty acids (mg/ml) of cows individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk.

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th></th>
<th></th>
<th>EFA</th>
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<tr>
<td></td>
<td></td>
<td>d 0</td>
<td>d 45</td>
<td>Parturition</td>
<td>d 0</td>
<td>d 45</td>
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<td>SE</td>
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</tr>
<tr>
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<td></td>
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<td>29</td>
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<td>29</td>
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<td></td>
</tr>
<tr>
<td>16:0</td>
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<td>18.71</td>
<td>18.51</td>
<td>19.86</td>
<td>19.99</td>
<td>24.24</td>
<td>25.78</td>
<td>1.08</td>
<td>0.001</td>
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<td>16:1</td>
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<td>2.49</td>
<td>1.90</td>
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<td>1.66</td>
<td>2.47</td>
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<td>24.21</td>
<td>26.12</td>
<td>17.07</td>
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<td>30.67</td>
<td>24.37</td>
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<td>20.01</td>
<td>16.63</td>
<td>19.54</td>
<td>19.49</td>
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<td>22.55</td>
<td>1.00</td>
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<td>18:2</td>
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<td>41.49</td>
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<td>66.67</td>
<td>73.06</td>
<td>3.37</td>
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<td>13.78</td>
<td>8.57</td>
<td>12.84</td>
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<td>10.65</td>
<td>0.68</td>
<td>0.989</td>
<td>&lt;.0001</td>
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<tr>
<td>20:4</td>
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<td>4.77</td>
<td>4.66</td>
<td>4.59</td>
<td>4.69</td>
<td>5.29</td>
<td>6.07</td>
<td>0.25</td>
<td>0.02</td>
<td>0.005</td>
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<tr>
<td>Total FA</td>
<td></td>
<td>151.25</td>
<td>150.94</td>
<td>134.95</td>
<td>144.41</td>
<td>191.00</td>
<td>213.67</td>
<td>9.74</td>
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<td>Cholesterol, mg/dl</td>
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<td>78.2</td>
<td>88.3</td>
<td>79.0</td>
<td>77.7</td>
<td>100.1</td>
<td>95.48</td>
<td>6.66</td>
<td>0.2330</td>
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<tr>
<td>Triglycerides, mg/dl</td>
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<td>26.6</td>
<td>19.6</td>
<td>22.4</td>
<td>33.0</td>
<td>28.8</td>
<td>1.60</td>
<td>0.001</td>
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</table>

Data presented LSM ± SEM.
Table 4. Colostrum dry matter total and specific fatty acids (FA, mg/g DM) of cows individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (RUF) 5 d/wk.

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>EFA</th>
<th>SE</th>
<th>Trt</th>
<th>suckling</th>
<th>parity</th>
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<td>29</td>
<td></td>
<td>1.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry matter, %</td>
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<td>30.4</td>
<td>1.30</td>
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<td>0.0009</td>
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<tr>
<td>16:1</td>
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<td>12.63</td>
<td>2.35</td>
<td>0.09</td>
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<tr>
<td>18:0</td>
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<td>2.01</td>
<td>0.18</td>
<td>0.39</td>
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</tr>
<tr>
<td>18:1 t-9</td>
<td>12.22</td>
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<td>0.32</td>
<td>0.36</td>
<td>0.28</td>
</tr>
<tr>
<td>18:1 c-9</td>
<td>53.89</td>
<td>63.45</td>
<td>6.05</td>
<td>0.28</td>
<td>0.82</td>
<td>0.23</td>
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<tr>
<td>18:2</td>
<td>5.07</td>
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<td>&lt;0.001</td>
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<tr>
<td>Total FA</td>
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<td>283.83</td>
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<td>0.02</td>
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<tr>
<td>Total Saturated FA</td>
<td>109.1</td>
<td>132.38</td>
<td>13.45</td>
<td>0.23</td>
<td>0.72</td>
<td>0.20</td>
</tr>
<tr>
<td>Total Unsaturated FA</td>
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<td>105.94</td>
<td>8.42</td>
<td>0.03</td>
<td>0.94</td>
<td>0.24</td>
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</table>

Data presented LSM ± SEM.
Table 5. Serum total and specific fatty acids (FA, mg/ml) of calves at parturition whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk.

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>EFA</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:0</td>
<td>6.95</td>
<td>11.77</td>
<td>1.1</td>
<td>0.003</td>
</tr>
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<td>0.078</td>
</tr>
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<td>4.13</td>
<td>0.37</td>
<td>0.005</td>
</tr>
<tr>
<td>18:1 t-9</td>
<td>8.26</td>
<td>11.72</td>
<td>1.11</td>
<td>0.033</td>
</tr>
<tr>
<td>18:1 c-9</td>
<td>1.05</td>
<td>1.45</td>
<td>0.15</td>
<td>0.069</td>
</tr>
<tr>
<td>18:2</td>
<td>0.72</td>
<td>2.34</td>
<td>0.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>20:4</td>
<td>0.69</td>
<td>1.57</td>
<td>0.15</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total FA</td>
<td>29.24</td>
<td>43.71</td>
<td>3.84</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Data presented LSM ± SEM. No significant \((P > 0.15)\) parity or treatment * parity interactions.
Table 6. Serum total and specific fatty acids (mg/ml) of calves at 5 d of age whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk.

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>EFA</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
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<td>29</td>
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<td></td>
</tr>
<tr>
<td>16:0</td>
<td>23.79</td>
<td>25.2</td>
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<td>0.44</td>
</tr>
<tr>
<td>16:1</td>
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<td>2.48</td>
<td>1.14</td>
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</tr>
<tr>
<td>18:0</td>
<td>14.27</td>
<td>17.43</td>
<td>1.02</td>
<td>0.033</td>
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<tr>
<td>18:1 t-9</td>
<td>26.04</td>
<td>28.3</td>
<td>1.55</td>
<td>0.307</td>
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<td>2.66</td>
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<tr>
<td>18:2</td>
<td>21.14</td>
<td>32.72</td>
<td>1.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>20:4</td>
<td>3.24</td>
<td>3.8</td>
<td>0.19</td>
<td>0.05</td>
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<tr>
<td>Total FA</td>
<td>113.38</td>
<td>140.89</td>
<td>6.45</td>
<td>0.0042</td>
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</tbody>
</table>

Data presented LSM ± SEM. No significant (P > 0.1) parity or treatment * parity interactions
FIGURES

**Figure 1.** Serum cholesterol, triglycerides and glucose (mg/dl) of unsuckled calves born to cows individually fed isocaloric supplement containing no bypass fat (CON n = 26) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA n=20) 5 d/wk. at parturition.
CHAPTER 3

The effects of supplementing ruminal bypass unsaturated fatty acids during late gestation on transfer of passive immunity and growth in calves

Abstract: The objective of this study was to determine if supplemented ruminal protected unsaturated fatty acids (FA) increased colostrum and serum concentrations of IgG of calves and subsequent calf growth. Commercial Angus and Angus crossbred heifers and cows (n = 48) bred to two Angus sires were blocked by breed and parity then randomly assigned to either control (1.5 kg of corn gluten feed, CON) or an isocaloric isonitrogenous supplement containing 200 mg of ESSENTIOM (Arm & Hammer Animal Nutrition, Princeton, NJ); EFA) for the last 90 d of gestation. All supplements were individually fed 5 d/wk. All females had ad libitum access to the same pastures throughout the study. At parturition colostrum samples were collected from the dam and blood samples were collected from calves and at 24 h of age. Calf BW was collected every month and adjusted for every 30 d of age. Serum and colostrum IgG content were determined by ELISA (Bethel Lab Bethyl TX, USA). All data were analyzed using PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC) either as repeated measures or ANOVA depending on parameters. Dam BW and BCS during late gestation were similar (P > 0.14) between treatments. Colostrum concentrations of IgG were increased (P < 0.01) in EFA cows compared with CON cows (166 ± 13 vs. 102 ± 18 mg/ml, respectively). Calves from EFA dams had tended to have reduced (P = 0.08) birth weight compared with calves from CON dams (30.9 ± 0.6 vs. 32.5.6 ± 0.6 kg, respectively). Serum from calves at 24 h of age whose dams were supplemented with EFA we observed increased (P ≤ 0.01) concentrations of IgG compared with calves
whose dams were supplemented CON (11.4 ± 0.7 vs. 7.6 ± 0.7 mg/ml, respectively). Calf growth demonstrated a treatment x parity x day interaction \((P < 0.01)\). Calves from multiparous EFA had increased BW \((P < 0.05)\) at 90 to 210 d and at 210 d of age compared with calves from CON dams. The results of this study indicate that supplementation of rumen protected unsaturated FA in late gestation beef cows increased colostrum and calf serum IgG and increased calf BW in cows with their second and third calves.

Keywords: late gestation, CSFA supplementation, colostrum, IgG, growth

INTRODUCTION

The goal of the cow/calf industry is to produce revenue by the production and sales of live calves as efficiently as possible and maximize a return on investment. Optimally, the beef calf must be born alive, survive and grow vigorously until weaning to maintain profitability. Pre weaning mortality in calves has been reported as ranging from 8 to 25\% (Raboisson et al., 2016). Researchers have observed a strong relationship between mortality and a failure of passive transfer (FPT) of immunoglobulins (Raboisson et al., 2016). Defense against pathogens begins at birth for the neonatal ruminant when it consumes colostrum which includes many beneficial compounds (Zarcula et al., 2010) not the least of these are immunoglobulins from the dam that provide the calf with its initial immune protection (Quigley & Drewry, 1998). Late gestation supplementation of
protein and energy to beef cattle is widely practiced and well-studied. Late gestation supplementation has been concerned with weight loss or gain in pre and postpartum cows, changes in cow BCS, calf birth weight and weaning weight, and subsequent fertility of the dam (Corah et al., 1975). Late gestation feeding can impact, positively or negatively, calf birth weight and subsequent fertility of the dam (Bellows and Short, 1978). Economically, supplementation can effect both profitability of the cow/calf enterprise and on the value of the calf produced long term (Funston et al., 2010). Few studies have investigated rumen protected fats and fatty acids in beef cattle as a supplementation. This particular study focused on the effects of late gestational rumen protected essential fatty acid supplementation, to nulliparous, primiparous and multiparous cows and its influences on transfer of passive immunity from dam to calf, calf growth from birth to weaning and also postpartum reproduction in the dams.

MATERIALS AND METHODS

All procedures were approved by Clemson University Animal Care and Use Committee (AUP # 2013-044).

Animals

Commercial Angus and Angus crossbred nulliparous, primiparous and multiparous cows born and reared at Simpson Research Station, Clemson University (range 2 -4 years, 3.1 years of age mean and SEM, n = 58), bred to two Angus sires, one for
nulliparous and one for primiparous and multiparous cows. Cows were blocked by BCS and age (2 y old n = 21, 3 y old n = 14 and 4 y old n = 23) and randomly assigned to one of two treatments for the last 94 ± 3 days of gestation. Control animals (n = 28) were individually supplemented with corn gluten pellets (19.1% CP, 2.15 Mcal NEm/kg, 2.9% EE on a DM basis; 90.9% DM) at ~1.5 kg per head 5 days per week. Treatment animals (n = 28; EFA) were individually supplemented with an isocaloric and isonitrogenous supplement of 1.29 kg of a 66.2% CGF pellets, 18.2% soybean meal (2.07 Mcal/kg NEm, 47.5% CP; DM basis, 89.4% DM) and 15.6% Essentium (Essentium, Arm and Hammer Animal Nutrition, Princeton, NJ, Table 1) 5 days per week. This treatment (EFA) provided 200 g of a rumen protected fat source that is high in essential unsaturated fatty acids. Table 1 displays the EFA profile of Essentium. Of the EFA cows (n = 28), the age makeup was: 2 year olds (n = 11), 3 year olds (n = 6) and 4 year olds (n = 11).

All cows were maintained as a single group on the same fescue pasture and had access to either adequate forage or high quality ad libidum mixed grass hay (12.9% CP and 0.584 Mcal/Kg. NEm) in adequate levels to meet requirements (NRC. Nutrient requirements of beef cattle. Seventh edition. Washington, DC: National Academy Press; 2000). Cows were brought up on supplementation days and placed individually in 3.35 X 3.35 m pens then provided their respective treatments.

Cows were allowed to calve naturally and calf birthweight and blood samples (2 - 6 ml samples) were collected via jugular venipuncture immediately after parturition and prior to suckling when possible or at least 4 hours after parturition. Plasma samples were held
at 4C°, centrifuged at 1500 x g for 20 minutes, then decanted into standard storage tubes, labelled and frozen at -80C° for long term storage until analysis. Blood samples for serum sat at ambient temperature for one hour, were refrigerated for 24 hours and then centrifuged at 1500 x g for 20 minutes. Serum was decanted and frozen at -20 C° for long term storage until analysis. Subsequent blood samples were collected from the calves daily until day 5 via jugular venipuncture. Blood was collected and serum was harvested in a similar manner as above. At parturition, a colostrum sample was obtained from the cow (~75ml) through hand milking and frozen at -20° C. All cow calf pairs were moved to a common location after parturition. Bull calves were castrated at day 20 of age and received an anabolic implant (RALGRO, Intervet Inc., Merck /Animal Health, Summit, NJ). Both cows and calves were weighed every 30 days + 7 days until weaning (at < 215 days for all calves and adjusted to a standard day of age (30, 60, 90, 120, 150, 180, 210 days of age) without the age of dam and sex of calf adjustments (Beef Improvement Federation 2010). Starting one month postpartum, a blood sample was collected from every cow via caudal venipuncture twice per week to determine resumption of luteal function postpartum. Postpartum, all cow-calf pairs were fed ad libidum silage (9.9 % CP, and 0.626 Mcal/kg DM). All cows were bred AI using a 5 d CIDR Co-Synch protocol. Cows were bred one service AI to a common sire and then exposed to Angus bulls approximately 10 d later for sixty days.

Hormone and IgG Quantification
Serum cortisol concentrations of the calves from d 0 to d 4 of age were measured in duplicate in using Coat-A-Count cortisol RIA with a sensitivity of 0.5 μg/dL (Siemens Medical Solutions Diagnostics, Los Angeles, CA) that had been previously validated in our lab (Long & Schafer, 2013). The samples had an intra-assay CV of (4.7 %) and an inter-assay CV of (6.4 %). Calf serum at 24 hours of age and d 5 of age and colostrum from the dam at parturition were analyzed for IgG concentration using a commercial available ELISA (Bethel Lab Bethyl TX, USA) previously validated in our lab (Lemaster et al., 2016). Briefly, plasma and colostrum samples were diluted 1:250,000 and 1:500,000 using PBS. The 96 well plate was coated using coating buffer with captured sheep anti-bovine IgG-heavy chain antibody. Plate was then washed blocked using blocking and washing solution (50 mM Tris, 0.14 M NaCL, 0.05 % Tween 20, pH 8.0). Standards and samples were pipetted and incubated at room temperature for 1 h. The plate was washed again then a Conjugate antibody (Sheep anti-Bovine IgG-heavy chain antibody Alkaline Phosphatase conjugated) was diluted 1:75,000 in wash solution and incubated in the dark for 1 h. The plate was washed again and 100 μl of enzyme substrate solution was added to each well and incubated in the dark for 15 min. The reaction was stopped by adding 100 μl of 2 M H2SO4. The sensitivity of this assay was determined to be 0.1 mg/ml. The intra- and inter assay CV was 2.3 and 4.1 % respectively.

STATISTICAL ANALYSIS

Calf serum cortisol concentrations from parturition until d 4 of age and calf BW from d 30 to 210 days of age were analyzed using the PROC MIXED procedure of SAS
(SAS Institute Inc., Cary, NC) as repeated measures with treatment, time, their interaction, and parity in the model. Covariate structure was autoregressive 1 as it gave the best-fit statistics. Calf sex was initially included in the model and found to be nonsignificant ($P < 0.18$) and was removed from the final model. Colostrum and calf serum at d 1 and 5 of age IgG concentrations, calf BW at parturition, Numbers of days for cows to return to ovarian cyclicity and mean calving interval were analyzed as a ANOVA with treatment, parity, calf sex, and their interaction in the model. Pregnancy percentage after the end of the breeding season was analyzed using the GLINMIX procedure of SAS with treatment parity and their interaction in the model statement. Data are presented as least squares means ± SEM and were considered significantly different when $P \leq 0.05$ and a tendency was indicated when $P \leq 0.10$.

RESULTS

Table 2 presents serum IgG in calves on d 1 and d 5 and colostrum IgG concentrations at parturition from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk. At parturition, CON cows had decreased ($P=0.007$) concentrations of colostrum IgG compared to EFA cows. Colostrum tended to increase ($P = 0.10$) as parity increased. Calves born to EFA cows had increased serum IgG compared to calves born to CON cows ($P = 0.0004$) on d 1.

When looking at serum IgG concentrations on day 5, calves born to EFA cows demonstrated increased concentrations of IgG than calves born to CON cows ($P = 0.02$),
however there was no difference due to parity alone \( (P = 0.75) \) or treatment x parity \( (P = 0.66) \).

Calf birth BW are found in Table 3. CON cows tended \( (P = 0.08) \) to have calves with a large BW at parturition than EFA cows. There was also a tendency for parity \( (P = 0.086) \) to influence calf birthweight with EFA cows tending to have decreased birth BW calves compared to CON and 2nd and 3rd calf cows, both EFA & CON, to have calves with a greater birth BW than 1st calf cows.. As expected, bull calves were heavier at parturition compared to heifer calves \( (32.7 \pm 0.7 \text{ vs } 30.6 \pm 30.6 \pm 0.06 \text{ kg}, P = 0.022) \) with no treatment x sex interaction \( (P = 0.080) \).

Serum cortisol of calves from d 0 to d 4 of age are shown in Figure 1. A treatment x day interaction \( (P = 0.002) \) with EFA calves having a significantly reduced serum cortisol concentration compared to Con calves at parturition.

Calf BW for calves born to nulliparous cows for both CON and EFA cows are shown in Figure 2A. No differences were observed in BW in calves born to nulliparous EFA cows compared to calves born to nulliparous CON cows except for day 30 \( (P = 0.003) \). In Figure 2B, primiparous EFA calves are shown to be heavier from 90 to 210 d of age compared to CON calves \( (P = 0.003) \). Table 2C indicates that multiparous EFA calves were heavier than CON calves at 210 d alone \( (P = 0.003) \).

Table 4 reports the number of days from parturition to return to ovarian cyclicity for both CON cows and EFA cows. Evidence demonstrated that return to ovarian cyclicity was
related more to parity of the dam ($P = 0.0004$) than to treatment ($P = 0.82$) on return to ovarian cyclicity.

Table 4 shows the mean calving interval for cows fed an isocaloric supplement containing either 200 mg of ESSENTIOM 5 d a week (EFA) or a supplement with no fat (CON) during the last 90 d of gestation. The EFA nulliparous cows calving the year following treatment calved 8.89 days sooner than CON nulliparous cows (385.86 d. and 394.75 d.) respectively. Primiparous EFA cows gave birth an average of 5 days sooner than CON cows of like parity (367.67d. vs. 372.67d.) respectively. Multiparous EFA cows calved an average of 7.03 days sooner than multiparous CON cows (365.75 d. vs. 372.78 d, respectively). Regardless of parity, EFA cows had a mean calving interval of 373.09 days and CON cows had a mean calving interval of 380.07 days, EFA cows calved 6.97 days sooner than CON cows the following year ($P = 0.04$).

The primiparous EFA cows all became pregnant during the breeding season, Figure 4, following treatment as opposed to CON cows that did have 1 female that failed to breed back ($P = 0.19$).
DISCUSSION

To our knowledge, this is the first report investigating the effects of supplemental rumen bypass essential fatty acids fed to nulliparous, primiparous and multiparous beef cows during the final 90 days of gestation on colostrum IgG concentrations. Also, the effects of supplemental rumen bypass essential fatty acids on IgG levels in calf serum from parturition to 5 days of age and on calf birth BW, calf BW during the pre-weaning period and adjusted weaning weights were examined. This study also investigated the effects of rumen bypass fat supplementation during the prepartum period on dam return to ovarian cyclicity and calving interval on the following breeding and calving period.

IgG concentration results from this experiment were similar to Garcia et al, (2014) in which Holstein cows were supplemented with EFA’s yielded a higher concentration of colostrum IgG than control cows. Conversely, the nulliparous EFA dams on our study demonstrated higher concentrations of IgG whereas Garcia et al. (2014) fat supplemented nulliparous animals observed reduced IgG concentrations. In a calf cold tolerance study, beef heifers fed an isocaloric a safflower-supplemented diet containing 4.0% crude fat experienced no change in colostrum IgG levels in control beef heifers and treatment beef heifers (Dietz et al., 2003). Additionally, Garcia et al. (2014) observed a treatment by parity effect in colostrum IgG levels in multiparous dams. Parity differences may be due to increased concentrations of IgG in the blood of older cows. Serum concentrations of IgG may be material to the amounts of IgG transported to colostrum the mammary
transport system (Devery-Pocius et al., 1983). Gestational nutrition affects colostrum and milk yield and nutrient content, even when lactational nutrient requirements are met (Meyer et al., 2011). Day 0 IgG levels in calves were not analyzed because of sufficient evidence that unsuckled calves have low IgG levels (Smith & Holm, 1948; Hansen & Phillips, 1949; Garcia et al., 2014). In the current study, calves were allowed to suckle which is superior to either bottle feeding or esophageal tube feeding since maximum absorption of IgG is superior in calves that suckle (Stott et al., 1979). Serum IgG concentrations of control calves in the current study ranged from 8.72 mg/ml (± 1.18 mg/ml) for first calf heifers to 7.11 mg/ml (± 1.07 mg/ml) for multiparous cows. This is dangerously close to the minimum of 8 mg/ml, which indicates failure of passive transfer (Perino et al., 1995). Calves born to EFA cows, regardless of parity exceeded 8 mg/ml even accounting for standard error at 24 hours of age. Table 4 shows a decrease in IgG levels by day 5 which is expected; however the decrease in concentration was less for all treatments and parities than the 1.6 mg/ml/d predicted by Waldner & Rosengren (2009).

Increased calf serum IgG may be caused by supplementing long-chain FA’s prepartum in the saturated and unsaturated forms may influence the FA profile of enterocytes that could affect the transfer of immunoglobulin to plasma of calves (Garcia et al., 2014). Strategic supplementation of FA in late gestation might change the fluidity of enterocyte membranes, modifying their endocytic activity in addition to potentially modifying the activity of any neonatal Fc receptor (FcRn) in the intestine (Garcia et al, 2014). FcRn transports IgG from the maternal circulation to the fetal capillaries of the
placental villi (Leach et al., 1996). Although FcRn has been demonstrated that it exists in rats, bovine FcRn has been isolated, characterized and cloned (Kacskovics et al., 2000). Garcia speculates that strategic supplementation of FA in late gestation might change the fluidity of enterocyte membranes, modifying their endocytic activity in addition to potentially modifying the activity of FcRn in the intestine (Garcia et al., 2014). This would increase the efficiency of absorption as well as supplying a greater amount of IgG for absorption by the neonate. Wittum and Perino (1995) point out that 24 hour levels of IgG have lifelong effects, not just during preweaning but also in the feedlot or cow herd. It may be possible to modulate the activity of cells of the immune system, and so an immune response by dietary lipid manipulation.

Evidence on gestational nutrition’s effect on calf birth weight in beef cattle (Corah et al., 1975; Turner et al., 2013 and Riley et al., 2014). Calves from EFA dams tended to have a reduced ($P = 0.08$) birth weight compared to calves from control dams (30.9 ± 0.6 vs 32.5.6 ± 0.6 kg respectively). Garcia et al (2014) reported calves born from parous dams supplemented with fat tended to be heavier at birth than those born from control parous dams but observed no differences in first parity dams. Spitzer et al. (1995) had calf birth weights that increased as cow BCS increased prepartum when cows were fed to increase BCS prior to calving. When cattle are supplemented during late gestation to maintain BCS, higher BCS cattle have heavier calves (Bohnert et al., 2013). While late gestation nutrient restriction reduces calf birth weight (Tudor, 1972, Lemaster at al., 2017). Cases of prepartum nutrient restriction observe lower birthweight is associated with less viable calves at birth and lighter weaning weight (Corah et al., 1975). Previous
studies of prepartum supplementation of rumen protected fats and fatty acids in beef cattle observed unaffected birth weights of subsequent offspring (Encinias et al., 2001; Bellows et al., 2001; Funston, 2004).

Most late gestation studies are determining the influence of a source of calcium salts of fatty acids, on reproductive efficiency during the postpartum period in suckled beef cows maintained under pasture conditions (Espinoza et al., 1995). CSFA’s effects on pubertal beef heifers and postpartum cows and improving reproductive performance of beef heifers have been examined (Lloyd et al., 2002; Long et al., 2007), Conceptus growth is sensitive to direct and indirect effects of maternal dietary intake and needs more investigation (Funston et al., 2010), Dietary fat effect on birthweight may result from heifers utilizing dietary energy for their own growth plus growth of the fetus (Garcia et al. 2014).

In a beef-cow enterprise the most difficult cattle to manage are the nulliparous females (Lalman et al., 2000). During gestation, they are more sensitive to the supply of nutrients due to reduced reserves of energy supplies and must partition nutrients to support maternal and fetal growth (Long et al., 2009). In terms of postnatal growth calves born to both control and treatment dams are very commensurate in BW. However, when the calves were weaned, EFA calves were heavier than control calves.

These growth curves are driven by milk production of the dam is the preeminent influence on weaning weight (Beal et al, 1990; Edwards 2015; Sapkota et al, 2016). Additionally the age of dam at parturition influences milk production (Minyard and
Dinkel, 1965; Rutledge et al., 1971; Baker and Boyd, 2003). The age of the nulliparous cows on the current study was 2 years and for both control and treatment cows, it was their first lactation. This is a very important stage of production (Neville et al., 1974) but below the age projected for maximum milk production at 8 years (Minyard and Dinkel, 1965). Nulliparous dams, regardless of treatment, were at maximum milk production and unable to cope with the demands of the growing calves. While the calves from the nulliparous dams had the potential to demonstrate superior growth characteristics preweaning, their dams, due to age and first lactation, were unable to supply enough milk for the calves to express this potential. A partitioning of nutrients to support maternal growth, milk production and reproduction (Long et al., 2009) may occur. Bellows (1999) suggested that there is a positive-response in calf weaning weights in both lactating heifers and cows when supplemental fat was fed for the last 60 to 75 days of gestation.

Calves born to primiparous and multiparous cows were heavier throughout growth similar to Espinoza et al (1995) 125 g/d vs. 200g/d of the same rumen protected fat source for a shorter period (61 ± 3.9 d precalving vs. 94 ± 3 d precalving). However, only multiparous cows were used in the 1995 investigation (Espinoza et al., 1995). Calves produced by Megalac (Essentiom) supplemented cows were heavier than those produced by controls, which could justify addition of Megalac (Essentiom) to pre- and postpartum cattle diets (Espinoza et al., 1995). Calves born to second parity EFA dams observed weights that exceeded the weights of control calves compared to other parities. This is associated with the largest change in milk production between the ages of 2 and 3 years of age (Minyard and Dinkel, 1965). The narrow range of calf weights throughout the
preweaning growth period suggests that the milk production of the multiparous cows was substantial. CSFA supplementation did give an advantage in milk production its advantages were narrowed by the extraordinary milk production of multiparous cows in general (Johnson et al., 2003).

Speculation based on current evidence suggests that increased weight gain by the EFA calves is a result of increased milk production of the dam (Bellows 1999; Larson et al., 2009; Garcia et al., 2014). It has been demonstrated that fatty acids are crucial for the development of the fetus (Schaiff et al., 2007; Xu et al., 2007; Hanebutt et al., 2008) and that a steady elevated supply of fatty acids can increase growth in calves (Espinoza et al., 1995). Dairy calves fed a milk replacer with elevated levels of linoleic acid grew faster and utilized nutrients more efficiently, tended to have greater mean concentration of IGF-1 and additionally increased levels of insulin (Garcia et al., 2014).

EFA supplementation of the dam ceased at parturition and the calves received no exogenous supplementation of EFA’s. Garcia (2014) proposes that in dairy calves, if calves were consuming dietary linoleic acid in milk replacer, there would be no benefit manifested in performance whereas if calves received sufficient amounts of linoleic acid in utero or from colostrum consumption there may be deposition of FA that can be mobilized after birth. Palmquist and Mattos (1978) concluded that 51 to 75% of absorbed fatty acids may be taken up by the mammary gland depending upon stage of lactation and dietary supply of fatty acids. Consequently, increased exogenously derived fatty acids in milk from cows fed supplemental lipid was not surprising. Low BCS dairy cows rely on
exogenous fatty acids for milk lipid synthesis rather than on adipose tissue reserves suggesting that in cattle receiving more fatty acids than needed for maintenance, accumulate fatty acids in adipose tissue (Pedron et al., 1993) as indicated by exogenously derived fatty acids showing its effects in BCS < 4 because higher BCS cows can either use the exogenous EFA or use what is stored, <4 BCS cows have none stored (Lake et al., 2007). Both control and treatment cows on this study calved with a BCS of > 5 and treatment cows were able to store supplemented EFA’s in adipose tissue (Pedron et al., 1993) and then mobilized the EFA’s after parturition allowing their calves’ access to higher levels of milk delivered EFA’s preweaning leading to heavier weaning weights in the calves born to the EFA dams. This same effect was observed in a previous investigation on prepartum oils seed supplementation that demonstrated a BW improvement in calves from dams that were supplemented with fat during gestation only. This was interpreted their data as indicating a carryover influence of prepartum fat supplementation (Bellows et al., 2001).

The greatest threat to the lifespan of the beef cow is not injury or disease the greatest threat is reproductive failure (Roberts et al., 2015). Profitability is the goal of every brood cow and at the heart of this is reproduction. In a cow calf operation, the generator of capital is the cow, she is the source of income and she does this by either weaning a calf every year to market or she is marketed herself. Reproductive failure means she will become the product rather than producing the product and is culled. There exists a generous number of investigations concerning CSFA’s and fats in general, effects on bovine reproductive processes but however many of these deal with post-partum
applications of CSFA’s as opposed to the current study of prepartum supplementation of calcium salts of fatty acids. In a 2001 two part experiment to examine the effects on reproduction of feeding oil seeds in the gestation diet of crossbred first-calf heifers, it was demonstrated that effects on dam estrous cyclicity were nonsignificant (Bellows et al., 2001) Similar results were observed with no effect of supplementing CSFA on return to cyclicity. The return to cyclicity may be due to parity of the dam, traditionally multiparous cows have a shorter postpartum interval than younger cows (Filley et al., 2000). Reproductive failure occurs more often in cows from 2 to 4 years of age than in 5 to 7 year old cows (Roberts et al., 2015). Studies on mature, multiparous, cows demonstrated that estrous cyclicity was not impacted by supplement level of commodity based feeds (Warner et al., 2011; Winterholler et al., 2012; Shoup et al., 2015). Evidence agrees that fat and fatty acid supplementation do not alter cyclicity status of dams (Filley et al., 2000; Funston 2004; Grant et al., 2003 and Shike et al., 2013).

Effects of prepartum non rumen protected fat supplementation on dam BW, condition scores, estrous cyclicity, and pregnancy percentage were nonsignificant in a 2001 study (Bellows et al., 2001). Conversely, Espinoza previously reported that the inclusion of CSFA in the pre and postpartum diet improved reproductive efficiency in multiparous Angus and Hereford x Angus cows (Espinoza et al., 1995). The current study observed increased reproductive efficiency following breeding season, at pregnancy detection and subsequent calving the next calving season. Prepartum CSFA supplementation tended to not only decreased calving interval the following year for all parities but increased reproductive performance. Although our data demonstrates parity
differences only on return to cyclicity, EFA cows had a shorter calving interval and a higher overall pregnancy rate and bears further investigation.

Calcium salts of fatty acids supplemented to beef cows in late gestation can increase the passive transfer of IgG from dam to offspring and thus give beef calves an improvement in their immune system that can result in less mortality and morbidity. This expanded volume of IgG can be particularly advantageous in younger cattle and in harsher weather conditions at calving. Post calving, CSFA’s can impact calf weaning weight by allowing both cow and calf to draw upon reserves of EFA’s that were stored during gestation to furnish an elevated supply of EFA’s after supplementation has ended. While this prepartum supplementation of CSFA did not significantly shorten the dam’s return to cyclicity, there is evidence that calcium salts of fatty acids supplemented cows did conceive earlier as the calving interval to the following year’s calf was shorter in calcium salts of fatty acids supplemented cows than in control cows. These are advantages that should be considered in the management of first calf heifers to increase the likely hood that they will not be removed from the beef herd for reproductive reasons and lose associated development costs of these cows and further investigation into late gestation lipid supplementation is needed (Bellows et al., 2001; Long et al., 2014).


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Payne, E. 1978. "Fatty acid composition of tissue phospholipids of the fetal calf and neonatal lamb, deer calf and piglet as compared with the cow, sheep, deer and pig." British Journal of Nutrition 39, no. 1: 45-52 doi.org/10.1079/BJN19780010.


doi.org/10.3168/jds.2016-11213

doi.org/10.2527/jas1971.333563x.


### Table 1. Nutrient profile and fatty acid composition of rumen undegradable unsaturated fatty acid source¹ for both experiments.

<table>
<thead>
<tr>
<th>Component</th>
<th>Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>96.8</td>
</tr>
<tr>
<td>Calcium, % DM</td>
<td>8.9</td>
</tr>
<tr>
<td>Acid Ether Extract, % DM</td>
<td>84.4</td>
</tr>
<tr>
<td>C12:0, % DM</td>
<td>0.0</td>
</tr>
<tr>
<td>C14:0, % DM</td>
<td>0.0</td>
</tr>
<tr>
<td>C16:0, % DM</td>
<td>21.8</td>
</tr>
<tr>
<td>C16:1, % DM</td>
<td>0.0</td>
</tr>
<tr>
<td>C18:0, % DM</td>
<td>3.1</td>
</tr>
<tr>
<td>C18:1 t, % DM</td>
<td>0.0</td>
</tr>
<tr>
<td>C18:1 c, % DM</td>
<td>27.6</td>
</tr>
<tr>
<td>C18:2, % DM</td>
<td>26.9</td>
</tr>
<tr>
<td>C18:3, % DM</td>
<td>4.0</td>
</tr>
<tr>
<td>Other LCFA², % DM</td>
<td>1.1</td>
</tr>
</tbody>
</table>

¹ Essentiom (Church and Dwight Co., Princeton, N.J.)

² Long chain fatty acids
**Table 2.** Serum IgG in calf serum and colostrum from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk.

<table>
<thead>
<tr>
<th>trt</th>
<th>Control</th>
<th>Essentiom</th>
<th>P value</th>
<th>trt</th>
<th>Parity</th>
<th>trt*parity</th>
</tr>
</thead>
<tbody>
<tr>
<td>parity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colostrum IgG, mg/ml</td>
<td>1</td>
<td>91.75 ± 25.35</td>
<td>1</td>
<td>126.19 ± 19.18</td>
<td>0.007</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>94.37 ± 29.45</td>
<td>2</td>
<td>199.89 ± 27.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>121.34 ± 19.57</td>
<td>3</td>
<td>171.07 ± 17.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum IgG d 1, mg/ml</td>
<td>1</td>
<td>19.18</td>
<td>1</td>
<td>11.05 ± 1.09</td>
<td>&lt;0.001</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>27.03</td>
<td>2</td>
<td>13.58 ± 1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17.86</td>
<td>3</td>
<td>9.45 ± 1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum IgG d 5, mg/ml</td>
<td>bull</td>
<td>3.76 ± 1.45</td>
<td>bull</td>
<td>8.27 ± 1.35</td>
<td>0.02</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>heifer</td>
<td>5.82 ± 1.69</td>
<td>heifer</td>
<td>7.51 ± 1.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.63 ± 1.32</td>
<td></td>
<td>8.49 ± 1.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum IgG d 5, mg/ml</td>
<td>bull</td>
<td>6.80 ± 1.27</td>
<td>bull</td>
<td>6.89 ± 1.30</td>
<td>0.65</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>heifer</td>
<td>3.33 ± 1.18</td>
<td>heifer</td>
<td>9.28 ± 1.13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Calf birth weight from cows during the last 90 d of gestation fed an isocaloric supplement containing either ESSENTIOM 5 d a week (EFA) or a supplement with no fat (Control).

<table>
<thead>
<tr>
<th>Parity</th>
<th>Control</th>
<th></th>
<th>EFA</th>
<th></th>
<th>P value</th>
<th>Trt</th>
<th>Parity</th>
<th>Trt x Parity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.2</td>
<td></td>
<td>29.8</td>
<td></td>
<td>0.0803</td>
<td>0.0868</td>
<td></td>
<td>0.798</td>
</tr>
<tr>
<td>2</td>
<td>32.2</td>
<td>±1.0</td>
<td>30.3</td>
<td>±1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>33.4</td>
<td>±1.2</td>
<td>32.6</td>
<td>±1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±1.0</td>
<td>±1.2</td>
<td>±1.0</td>
<td>±1.0</td>
<td>±1.3</td>
<td>±0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Return to cyclicity, calving interval and pregnancy percentage for cows during the last 90 days of gestation fed an isocaloric supplement containing Essentiom 5 d a week (EFA) or a supplement with no fat (CON).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>Essentiom</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Days to cyclicity</td>
<td>76 ± 5</td>
<td>65 ± 6</td>
<td>57 ± 4</td>
</tr>
<tr>
<td>Calving interval, d</td>
<td>395 ± 9</td>
<td>373 ± 9</td>
<td>373 ± 8</td>
</tr>
<tr>
<td>Pregnancy,%</td>
<td>40 ± 15</td>
<td>86 ± 18</td>
<td>69 ± 13</td>
</tr>
</tbody>
</table>

Data presented LSM ± SEM
Figure 1. Serum cortisol μg/ml of calves from birth to d 4 whose dams were individually fed isocaloric supplement containing no bypass fat (CON) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA) 5 d/wk (trt*day $P = 0.002$) a, b denotes a significant difference at that day.
Figure 2. 1st Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt*Parity*Day interaction $P = 0.003$
Figure 3. 2nd Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt*Parity*Day interaction $P = 0.003$
Figure 4. 3rd Parity Calf BW by maternal parity from dams that were individually fed during the last 90 d of gestation an isocaloric supplement containing no bypass fat (CON, open circles) or fed 0.2 kg of an unsaturated rumen undegradable fat source (EFA, closed boxes) 5 d/wk. Trt*Parity*Day interaction $P = 0.003$
CHAPTER 4

Impediments to Research

In research we try to control as much as we can when it comes to variability, but we cannot control the environment. As we see in Bellows et al. project, the environment, in this case rainfall, effected the forages that were a vital aspect to the project. Forages were also an important part of this project. Unfortunately, the pastures which sustained the cattle were, more than likely unable to respond favorably in the event weather extremes. If we had experienced more rainfall than expected the predominantly toxic fescue pastures lacked the soil conditions to respond with a greater quantity or quality of growth. The prepartum pastures suffer from textbook symptoms of poor soil pH and levels of N-P-K as is evidenced by poor regrowth and a high amount of weeds. Postpartum, cow/calf pairs were maintained on similar toxic fescue dominated mixed grass pastures but were fed decent quality silage in a finite amount per day. Paddocks available for the cultivation of cool season annual forages were not planted and therefore not available. The effects of poor soil fertility and the forages available to the cattle the full potential for cow and calf performance will be forever unknown. Ideally, the cows selected for this study would have summered on non-toxic perennial warm season grasses prior to the study that has been properly limed and fertilized and then had the same dormant or semi-dormant forages available during late gestation and would have entered the last trimester of gestation in the best shape possible. After parturition, we may have seen different results if the cow/calf pairs had ample high quality cool season grazing available.
High quality pastures do not happen by accident. Carrying capacity of pastures is influenced by growth and subsequent regrowth of grass and this can only occur if soil fertility is maintained at optimum levels. Increased fertility, increased weed control and an increased use of summer perennials and winter annuals can increase the carrying capacity of the land and decrease purchased feed and decrease the labor needed to feed it.

As a land grant university, we are supposed to be teaching the next generation the proper ways to increase the productivity of the land and our animals. We perform research for the same reasons. We teach this in the classroom and disseminate that same information to our producers through extension, and we must demonstrate it on the research farms. By “practicing what we preach”, we can at least offer all parties some of the tools they need to have a reasonable chance to be successful producers. Accuracy of research depends on the elimination of as many variables as possible with the exception of our hypothesis. This means removing as many impediments to this accuracy as possible.