Effects of Feeding Supplemental Fat to Beef Cows on Cold Tolerance in Newborn Calves

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(ABSTRACT)

Two experiments were conducted to investigate the effects of added fat in late gestation cow and heifer diets on thermogenic and neonatal metabolic responses. In Experiment 1, the effects of source of fat in late gestation diets on serum glucose and thermogenic response during short-term cold stress were examined in fall-born neonatal beef calves. Pregnant fall-calving heifers (n = 15) were randomly assigned to three dietary treatments: Control (CON, n=5), Safflower seed (SAF, n=5), or Cottonseed (COT, n=5) supplement. Hay-based isonitrogenous and isocaloric diets met NRC requirements while containing 1.53%, 4.0% and 5.0% fat for CON, SAF and COT diets, respectively. Diets were fed for 47.5 ± 5.4 d before calving. Heifers were weighed weekly and at parturition. At parturition, colostrum samples were taken from the dam, calves weighed, and vigor scores recorded. Calves remained with their dams for 5 h to nurse. At 5.5 h of age, calves were fitted with an indwelling jugular catheter. At 6.5 h of age, calves were placed in a 5°C cold room for 90 min. Shivering scores (1= no shivering, 2 = slight shivering 3 = muscle shivering, 4 = severe muscle shivering), rectal temperatures and blood samples were taken every 15 min. Colostrum samples were analyzed for fat, solids, protein, lactose and IgG concentrations. BW and BCS of heifers at calving, and birth weights and vigor scores of calves were unaffected by diet ($P > .5$). Mean fat, lactose and IgG concentrations in colostrum were not different ($P > .3$) among treatments. SAF tended to increase colostral solids ($P = .11$) and protein ($P = .13$) compared to COT or CON. During cold stress, calf body temperature increased in a quadratic fashion ($P < .03$). Mean glucose levels tended ($P = .12$) to be greater and shivering scores were non-significantly increased in CON compared to SAF or COT calves. Glucose concentrations averaged 74.4, 51.9, and 60.0 ± 7.3 mg/dl, whereas shivering score averaged 2.14, 1.69, and 1.68 ± .24 in CON, SAF and COT calves,

respectively. Shivering scores increased in all groups during cold exposure in a linear fashion ($P < .001$). Vigor scores increased in a linear fashion throughout cold exposure for all groups ($P < .04$). Cortisol concentrations decreased in a cubic fashion throughout cold exposure for all groups ($P < .02$). Cortisol concentrations averaged 28.62, 37.7, and 35.65 $\pm$ 3.58 ng/ml in CON, SAF and COT calves, respectively. We conclude that calves from dams fed high fat diets containing safflower seeds or cottonseed respond similarly to cold stress, but these responses are not necessarily consistent with greater cold resistance.

In Experiment two, pregnant spring-calving cows (n = 75) were randomly assigned to two dietary treatments: Control (CON, n=35) and Cottonseed (COT, n=40). Hay-based isonitrogenous and isocaloric diets met NRC requirements while containing 2.0% and 5.0% fat for CON and COT diets, respectively. Diets were fed for 60 ± 5 d before calving. At parturition, calves were weighed, ambient temperature was recorded and dystocia score was recorded. At 30 min of age, rectal temperature one was recorded and shivering scores (1= no shivering, 2 = slight shivering 3 = muscle shivering, 4 = severe muscle shivering) were recorded. At 180 min postpartum, two blood samples were drawn from each calf to determine blood glucose and cortisol concentrations. At 36 $\pm$ 4 h postpartum, two blood samples were again drawn from each calf to determine blood glucose and IgG concentrations. Calf birth weight, calf sex, vigor score, shivering score, time to stand, dystocia score, and serum IgG concentrations were unaffected ($P > .5$) by diet. Shivering score was affected by ambient temperature ($P < .003$) and time of calving ($P < .006$). Calf birth weights were unaffected by diet, calf sex, and the diet x calf sex interaction ($P > .2$). Mean time to nurse was non-significantly longer (101.2 vs 70.1 min), respectively, for COT calves compared to CON calves. At 30 min ($P < .05$) rectal temperatures were higher in male than female calves from dams on the COT diet (39.3 vs 39.1°C). Whereas rectal temperatures were lower in male calves than female calves from dams on the CON diet (39.1 vs 39.3°C; diet x calf/sex, $P < .05$). The same relationship among rectal temperatures was observed at 180 min (diet x calf/sex, $P < .05$). Changes in body temperature between 30 and 180 min were affected by diet ($P < .05$) as body temperatures for COT calves increased more from 30 min to 180 min than CON calves. Body temperature at 30 min was affected by time of calving ($P < .01$). Body temperature

at 180 min was affected by ambient temperature at calving ($P < .03$) and there was a tendency for body temperature at 180 min to be affected by time of calving ($P < .09$). Serum glucose concentrations at time 180 min were unaffected by diet ($P > .3$). Serum glucose concentrations at time 36 $\pm$ 4 h tended to be affected by sex ($P < .07$). With glucose levels higher in females (127 mg/dl) than in males (119 mg/dl). Differences in serum glucose at time 180 min and 36 $\pm$ 4 h were not affected by diet, sex, or diet x sex interaction ($P > .7$). Serum glucose at 36 $\pm$ 4 h was affected by ambient temperature at calving ($P < .04$). Mean serum cortisol concentrations tended to be higher (47.4 ng/ml vs 36.5 ng/ml) for COT calves compared to CON calves ($P < .09$). Differences in serum cortisol levels were unaffected by sex or diet x sex interaction ($P > .5$). When ambient temperature or time of calving were included as covariates, calf weight, calf vigor and serum IgG were unaffected by ambient temperature or time of calving ($P > .05$).

Dedication

First and foremost I would like to thank Kelly, my loving wife, for supporting me, both financially and personally, throughout my very long academic career. Without her by my side I would not be in graduate school and would not have had the opportunity to pursue my education. It is to her that I owe most of my thanks and all of my gratitude. I dedicate this work to her.

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Introduction

Adequate cold tolerance in the newborn calf is crucial for the calf to be able to survive its first few hours of life. The first hours after parturition are the most metabolically demanding for the neonate. Considerable economic losses are incurred by the beef industry each year due to perinatal calf mortality (Carstens et al., 1987). Total neonatal mortality has been estimated to be approximately 9% (Cundiff et al., 1982), with 6.9% of this mortality attributable to cold stress (Bellows et al., 1987). Beef calves born during cold and wet conditions have increased mortality and morbidity rates (Azzam et al., 1993). Fifty percent of calf losses occur within 24 h postpartum (Kroger et al., 1967). Calves born to heifers fed protein-restricted diets had 11.4% lower heat production than calves born to control heifers (Carstens et al., 1987). Corah et al. (1975) and Warrington et al. (1985) demonstrated that prepartum nutritional restriction adversely affected calf mortality. Alexander (1962a,b) suggested that one manifestation of prepartum nutritional stress that may relate to calf mortality is an altered thermogenic ability in the neonate. Koritnik et al. (1981) demonstrated that prepartum dietary restriction in ewes reduced liver weight per body mass in newborn lambs. The relationship between proportional weights of metabolically active organs and heat production has been well established (Koong et al., 1985). Poor prepartum nutrition may alter a neonate's thermogenic ability, thus compromising its resistance to environmental stress.

Supplementing the dam with dietary fat can increase the survivability of the calf while simultaneously increasing future conception rates of the dam. It has been shown that calves from dams supplemented with safflower seeds have increased serum glucose concentrations, increased serum cholesterol levels, increased serum cortisol levels and higher rectal temperatures during prolonged cold exposure compared to calves from dams not supplemented with fat (Lammoglia et al., 1999). Feeding supplemental fat during late gestation provides increased glucose concentrations in the newborn calf. This results in favorable responses in body temperature in cold-stressed newborns (Lammoglia et al., 1999). The increase in glucose availability suggests a potential positive effect on heat generation in neonates during sustained periods of cold stress.

Percent linoleic acid in the fat supplement appears to be a very important factor in the neonates' ability to thermoregulate. Linoleic acid is the major fuel for heat production in brown adipose tissue (BAT), (Lammoglia et al., 1999a). In addition to shivering thermogenesis, BAT thermogenesis, or nonshivering thermogenesis, is used by the neonate to maintain core body temperature during the first few hours of life (Nedergaard et al., 1983; Lammoglia et al., 1999b). A large percentage of the composition of BAT is linoleic acid, an essential fatty acid. Safflower seeds contain 37% oil with 79.1% linoleic acid. Animals fed diets containing high concentrations of linoleic acid resulted in animals with BAT containing higher concentrations of linoleic acid, increased BAT activity, and increased BAT thermogenesis (Nedergaard et al., 1983).

In Virginia, whole cottonseeds are a readily available high fat by-product and are moderate in cost. The fatty acid composition of safflower seed and cottonseed varies only slightly and percent linoleic acid is similar. Whole cottonseeds contain approximately 56.3% linoleic acid. Therefore, whole cottonseed may be a useful supplement for heifers and cows in late gestation.

Review of Literature

Cattle have evolved in a variety of climates and have adapted to a wide range of environmental conditions. The range in ambient temperature over which the newborn calf is able to maintain homeothermy is much narrower than that of growing or adult cattle. However, the newborn calf is more cold tolerant than the newborn of other domestic species (NRC, 1981). During parturition, the newborn calf encounters drastic temperature changes as it moves from the controlled uterine environment to the ambient environment. The combination of a large surface area to body mass ratio, evaporation of amniotic fluid from the body and respiratory tract, and low resistance to cooling predispose the neonate to tremendous rates of thermolysis during the early neonatal period (Carstens, 1994). To maintain thermal balance, the newborn calf must adapt to extrauterine life quickly by generating large quantities of heat. Calves born unassisted that immediately respire usually are able to maintain homeothermy through shivering thermogenesis (muscle tissue) and non-shivering thermogenesis (brown adipose tissue) (Alexander, 1979 and Alexander et al., 1975).

Adverse climatic conditions during the early neonatal period disrupt thermal balance and may result in hypothermia or death. There have been numerous reports which demonstrate that calf mortality increases during inclement weather, (Bellows, et al., 1987 and Young et al., 1986). More recently, Azzam et al. (1993) established the relationship between climatic conditions (ambient temperature and precipitation) and mortality rates in *Bos taurus* calves. Calf mortality was shown to increase progressively as ambient temperature decreased or as precipitation amount on the day of calving increased. The stress of maintaining homeothermy during severe cold exposure for extended periods may interact with other etiologic factors associated with neonatal calf mortality and morbidity through depletion of energy reserves, induction of physical weakness, and delayed absorption of immunoglobulins. The physical, physiological, and biochemical processes associated with normal thermoregulation in the neonate, and the pre-natal and post-natal factors that enhance or impair cold tolerance and intake of colostrum in the newborn calf are important in understanding the ability of the neonate to maintain homeothermy.

Physiology of the Fetal Period

The fetus undergoes marked changes in shape and form during prenatal growth and development. The prenatal development of calves may be divided into three main periods; ovum, embryonic and fetal (Hafez, 1987). The ovum period begins at ovulation and culminates with the initial attachment of the blastocyst but is prior to the establishment of an intraembryonic circulation.

General tissue and body growth

The embryonic period extends from day 15 to day 45 gestation in the cow. In this period, rapid growth and differentiation occur during which the major tissues, organs, and systems are established and the major features of external body form are recognizable. The order of tissue growth follows a sequential trend determined by physiological importance, starting with the central nervous system and progressing to bones, muscles, and adipose tissue (Hafez, 1987). The fetal period extends from about day 45 in cattle until parturition. Growth and changes in the form of the fetus characterize this period.

The fetus receives a continuous supply of glucose from its dam through the placenta. Glucose is the major metabolic fuel for the fetus (Hafez, 1987). Towards the end of gestation,

the normal fetus accumulates glycogen in its liver and skeletal muscles to assist it in overcoming the transitional period after birth until efficient suckling is established (Hafez, 1987). The growth rates of the fetus and its component organs and tissues vary during different stages of intrauterine life. During early fetal development, the cephalic region grows rapidly. Later in gestation, cephalic growth slows. At birth, the head and limbs are relatively more developed than the muscles. The rate of fetal growth depends primarily on the feed supply and the ability of the fetus to use the feed. Species, breed, and strain differences in fetal size are due to differences in the rate of cell division, which is determined genetically. There is close association between the feed supply to the fetus, the rate of cell division and thus, the rate of growth. The relative size of the fetus changes during gestation, with the largest increase in weight occurring during the last trimester of gestation. In cattle, over one half of the increase in fetal weight occurs during the last two months of gestation (Hafez, 1987).

Maternal nutrition exerts an important influence on fetal growth. Undernutrition of the cow and ewe during late gestation leads to production of stunted lambs and calves (Hafez, 1987), even though an adequate level of nutrition was present during early gestation. A feeding program opposite of this results in normal-sized calves and lambs.

Adipose tissue development

Two types of adipose tissue, white and brown, exist in neonatal ruminants. The primary function of white adipose tissue is storage and release of fatty acids for use as an energy source. Brown adipose tissue (BAT), the second type, is commonly distinguished form white adipose tissue based on color and the multiocular distribution of lipid within the cell (Carstens, 1994). Due to the lower lipid concentration and greater concentration of mitochondria and blood vessels in BAT, the color is typically darker than white adipose tissue. The unique morphological feature of BAT is its high density of mitochondria. In the newborn animal, brown adipose tissue functions primarily to produce heat via nonshivering thermogenesis.

Brown adipocytes from newborn calves are characterized by multiocular lipid droplets with one large central lipid locule dominating (Carstens, 1994). Anatomically, the distribution of BAT appears to be similar for lambs, kids, and calves, with the predominant location of BAT being the perirenal site (Alexander et al., 1975 and Vatnick et al., 1987). This was confirmed by

Casteilla et al. (1989), who examined the mRNA expression of a BAT unique uncoupling protein (UCP), in perirenal, pericardiac, peritoneal, mesenteric, intermuscular, and subcutaneous adipose tissue deposits in newborn lambs and calves. Uncoupling protein mRNA was expressed in all adipose tissues except subcutaneous tissue. Expression was highest in perirenal adipose tissue, followed by pericardiac and intermuscular tissue (≈ 50% of perirenal) and peritoneal tissue (≈ 15% of perirenal). Trace amounts of UCP mRNA were expressed in mesenteric adipose tissue. The quantity of BAT in neonatal crossbred Friesen calves has been estimated to be approximately 1.5% of body weight (Alexander et al., 1975). Total body fat, including both brown and white adipose tissue, has been reported to be only 2%, 2.8%, and 3.1% for 2-day-old Simmental, Charolais, and Hereford calves, respectively (Buckley et al., 1990). Therefore, in calves, only small amounts of white adipose tissue are present at birth, restricted mainly to subcutaneous deposits.

Full recruitment of functional brown adipocytes must occur during fetal development to enable newborn calves the ability to exhibit maximal nonshivering thermogenesis during the early postnatal period. Alexander (1978) found that detectable quantities of perirenal adipose tissue first appeared in ovine fetuses at 70 days of gestation. Allometric growth of dissectible perirenal adipose tissue relative to fetal weight occurred from 70 to 120 days of gestation (100 mg/kg of fetal weight/day). Thereafter, the growth of perirenal adipose tissue was isometric until parturition (6 mg/kg/day). Lipid locules were first identified in perirenal adipocytes on day 70 of gestation and, by day 80 to 90, mitochondria began to proliferate and take on morphologic features of brown adipocytes. Rapid accumulation of lipid occurred during allometric growth of perirenal adipose tissue, whereas, during the isometric growth period, approximately the last 30 days, adipocytes increased rapidly in mitochondrial density and developed sympathetic innervation (Gemmell and Alexander, 1978).

Although rapid growth of perirenal adipose tissue in lambs occurs from 70 to 120 days of gestation, it is apparent that the development of major morphological and biochemical features critical to functional BAT does not occur until late gestation. This was confirmed by Casteilla et al. (1989) who characterized prenatal ontogenic changes in bovine fetal UCP from perirenal adipose tissue deposits. Expression of UCP mRNA was not detected until day 211 of gestation,

and in small quantities thereafter until day 259, when levels increased dramatically (Casteilla et al., 1989). A 10-fold increase in expression of UCP mRNA was reported between day 266 of gestation and birth.

Giralt et al. (1989) examined prenatal development of BAT iodothyronine 5'-deiodinase activity in bovine fetal perirenal tissue and found that the activity of this enzyme first appeared in fetal perirenal tissue at two months of gestation. Iodothyronine 5'-deiodinase is an enzyme involved with intracellular conversion of thyroxine (T_4) to triiodothyronine (T_3). Thereafter, iodothyronine 5'-deiodinase activity increased rapidly, peaking at seven months of gestational age and subsequently declining in activity until birth. Giralt et al. (1989) noted that the activity of iodothyronine 5'-deiodinase peaked at approximately the same time that the expression of UCP mRNA was first detected. Giralt et al. (1989) hypothesized that endogenous BAT conversion of T_4 to T_3 may be involved in prenatal induction of UCP expression. Therefore, prenatal recruitment of brown adipocytes apparently involves rapid hypertrophic and hyperplastic growth during mid gestation, and mitochondrial proliferation and UCP expression during late gestation. Casteilla et al. (1987) reported that most of the growth of BAT in cattle occurred in the last 28 days of gestation.

Colostrum production

The first stage transfer of immunoglobulin (Ig) from the cow to the calf involves the secretion and concentration of maternal Ig in the colostrum, which occurs during the late fetal period (Besser and Gay, 1994). Ig is concentrated in the colostrum by an active, selective, receptor mediated transfer of IgG_1 from the blood of the dam across the mammary gland secretory epithelium (Bourne, 1977). As a result of this active transport, IgG_1 is the predominant colostral Ig, whereas IgM, IgA, and IgG_2 are present in lower concentrations.

The transfer of IgG_1 to colostrum begins several weeks prior and continues up to the time of parturition (Besser and Gay, 1994). The IgG_1 diffuses across the vascular endothelium, is bound by specific IgG_1-F_C receptors on the basal membrane of the mammary gland secretory epithelium, is taken up by micropinocytotic vesicles that traverse the epithelial cell, and is secreted into the colostrum (Bourne, 1977). This process results in colostral IgG_1 concentrations 5 to 10 times higher than maternal serum concentrations and the transfer of up to several hundred

grams of IgG_1 to the colostrum. The transfer is large enough that it is associated with a measurable decrease in the concentration of IgG_1 in the maternal serum during this period (Besser and Gay, 1994).

Parturition

The fetal bovine undergoes a tremendous transition from intrauterine to extrauterine life at parturition. Progesterone withdrawal is a key factor in the initiation of parturition. When a fetus reaches a critical size and stage of maturation, significant endocrine alterations take place that prepare the fetus and the uterus for parturition. In sheep and cattle, active labor is induced by enhanced cortisol production by the fetus, which begins to rise about 15 days prior to parturition, with a marked increase beginning 2 to 3 days before delivery (Hafez, 1987). The elevation in plasma glucocorticoids is produced by an increased fetal adrenal sensitivity to ACTH. Elevated fetal cortisol concentrations direct placental steroidogenesis towards estrogens and away from progesterone by increasing the activity of 17 alpha-hydroxylase, 17-20 desmolase, and aromatase enzymes (Breazile, et al., 1988). Although other endocrine alterations also occur, fetal cortisol has the effect of preparing the fetus for transition to extrauterine life by stimulating lung, gastrointestinal, and brain maturation, surfactant production, and liver glycogen stores for use as energy upon cessation of placental blood flow (Hafez, 1987). Cortisol production increases postpartum so that within a few minutes after birth, plasma cortisol concentrations may be double that observed during parturition (Comline et al., 1974).

In the cow, a rise in estrogen production occurs about 3 to 4 weeks prepartum. High concentrations of progesterone during pregnancy inhibit impulse transmission through the myometrium. A decrease in progesterone enhances the contractile activity of the uterus, marking the onset of labor (Breazile et al., 1988). The prepartum decrease in placental progesterone production and an increased estrogen production stimulate the uterine endometrium to produce prostaglandins in increasing concentrations.

Prostaglandins play a key role in parturition (Hafez, 1987). Progesterone, through inhibition of phospholipase A_2, inhibits the production of uterine prostaglandins during pregnancy. The increased production of prostaglandins enhances uterine contractions by increasing myometrial intracellular calcium ion concentrations (Breazile et al., 1988). Uterine

tissue and the placenta produce relaxin, a polypeptide hormone (Breazile et al., 1988). The effect of relaxin is to inhibit myometrial contractions during pregnancy, in synergy with progesterone. A few days prior to parturition, relaxin results in a relaxation of the cervix and pelvic ligaments. Relaxin also has the effect of increasing the number of oxytocin receptors in the myometrium, increasing the uterine sensitivity to this hormone. Oxytocin secretion by the hypothalamo-neurohypophyseal system is enhanced by rhythmic contractions of the uterus and cervical and vaginal dilation, all of which initiate afferent input to the spinal cord. Upon neural transmission to the hypothalamus, oxytocin-producing cells are excited. Oxytocin acts to increase ACTH secretion, enhances milk let down, and acts on the uterus to aid in the sustaining of uterine activity and strength of uterine contraction (Breazile et al., 1988).

Parturition is divided into three stages. Stage one begins with the initial uterine contractions and ends with cervical dilation. In the cow, this stage generally lasts for from 2 to 4 hours. Stage two is characterized by abdominal contractions, fetal entry into the birth canal, rupture of the allantoic sac, and expulsion of the fetus. This stage should normally be completed within 2 hours after the appearance of fetal membranes. Stage three includes the period of uterine involution and expulsion of placental membranes. This should be accomplished within 12 hours after the end of stage two (Putnam, 1982).

Factors affecting dystocia

Dystocia represents a serious distress for the fetus, not only through the possibility of trauma, but also through varying degrees of metabolic and respiratory acidosis resulting from hypoxia (Breazile, et al., 1988). Increased calving difficulty results in less vigorous calves as measured by interval from calving to standing (Odde, 1988). Dystocia, the most common cause of perinatal calf mortality (PCM), is directly responsible for over 50% of calf deaths (Koger et al., 1967). Additionally, dystocia causes indirect losses by increasing the risk of calves developing infectious diseases, the second most common cause of calf mortality (Bellows et al., 1987). Dystocia can be attributed to calf birth weight, sex of calf, area of the pelvic opening, and the age of the dam (Bellows et al., 1987). As a result of dystocia, cows produce fewer antibodies in their colostrum and are slower to clean their calves than cows not experiencing dystocia

(Odde, 1988). Early intervention during difficult calving can reduce the incidence of dystocia and its effects (Bellows et al., 1987).

Postpartum

Because intrauterine transfer of maternal immunoglobulins across the placenta to the fetus does not occur in cattle, calves are born with very low serum Ig levels and absorption of colostral antibodies after birth is essential to provide passive immunity during the neonatal period. High serum Ig concentrations after colostrum ingestion are associated with decreased morbidity and mortality from many calfhood diseases, including septicemia, diarrhea and respiratory disease. Also, lymphocytes and other cells from the maternal colostrum are absorbed into the calf's circulation and can impact the development of the immune system of the calf. Although all major Ig classes are present in the maternal colostrum, and all are capable of being absorbed by the intestine of the newborn calf, IgG_1 is the predominant Ig in colostrum and subsequently in the serum of a colostrum fed calf (Besser and Gay, 1994).

Absorption of Ig

The transfer of colostral Ig from the colostrum to the body fluids of the calf is the result of a transient, nonselective macromolecular transport mechanism across the small intestinal absorptive epithelium (Bush and Staley, 1980). The mechanism involves uptake by apical tubules and micropinocytotic vesicles, transfer to supranuclear protein-filled vesicles, and secretion at the basement membrane. The uptake is nonselective in that other Ig classes, as well as non-Ig macromolecules in the colostrum, are transferred across the intestinal epithelium with approximately equal efficiency. The absorbed Ig molecules enter the bloodstream with the intestinal lymph via the thoracic duct (Bush and Staley, 1980).

The ability of the newborn calf to absorb colostral Ig decreases rapidly following birth (Stott et al., 1979). By nine hours of age, an average calf absorbs only about half of the Ig it would have from a feeding eight hours earlier. This process is known as "gut closure" and is essentially complete by the time the calf is 24 hours of age (Stott et al., 1979). It is imperative that the neonate receives adequate amounts of high quality colostrum prior to "gut closure". The time it takes for the neonatal calf to stand and nurse, therefore, is an important measurable

parameter that must be considered. Closure is minimally affected by whether the calf is fed or starved and by stresses such as dystocia or cold environmental temperatures (Stott et al., 1979).

Nutrients supplied by colostrum

Dramatic changes occur at parturition in both the neonate's supply, and demand, for nutrients. The fetal ruminant is provided with high levels of carbohydrates and low levels of fat in utero. The neonatal ruminant is provided with colostrum, which is high is fat and low in carbohydrate (Girard, 1982). Prior to the intake of colostrum, the neonatal ruminant depends solely on mobilization of tissue glycogen and lipids to provide energy substrates for basal metabolism and thermogenesis in shivering muscle tissue and in BAT. To mobilize these energy substrates, numerous physiologic mechanisms are orchestrated, involving the sympathetic nervous system and pancreatic, adrenal, and thyroid glands (Carstens, 1994). Because protein catabolism is minimal during the early postnatal period, the major source of energy substrates for thermogenesis in neonatal ruminants is glycogen and lipid (Mellor and Cockburn, 1986).

In neonatal lambs, the predominant sources of glycogen are liver and muscle tissue. Glycogen concentrations in liver are approximately 70 mg/g and in muscle, 40 mg/g of wet tissue weight (Mellor and Cockburn, 1986), although not all of this glycogen is available for use during the early postnatal period. Approximately 90% of liver glycogen and only 60% of muscle glycogen can be mobilized within the first 18 hours of birth in neonatal lambs (Mellor and Murray, 1985). The total quantity of lipid, predominantly BAT, in neonatal lambs (Mellor and Cockburn, 1986) and calves (Buckley et al., 1990) is approximately 2.5% of body weight, and only half of it is available to supply nonesterified free fatty acids and glycerol in neonatal lambs (Mellor and Cockburn, 1986).

Marked increases in plasma concentrations of glucose and nonesterified free fatty acids, as well as lactate and glycerol, during cold exposure in neonatal lambs (Alexander et al., 1972 and Alexander et al., 1968) and calves (Godfrey et al., 1991 and Okamoto et al., 1986) have been reported. The cold-induced increases in these energy substrates apparently involve stimulation by the sympathetic nervous system, given that similar increases have been reported during NE infusion under thermoneutral conditions in lambs (Alexander et al., 1968) and calves (Mostyn et al., 1993). The elevation in nonesterified free fatty acid and glycerol concentrations in response

to cold exposure reflects increased rates of lipolysis. Free fatty acids are used as an energy substrate for thermogenesis in muscle tissue as well as BAT. Cold-induced increases in glucose concentrations in the neonate are the result of hepatic glycogenolysis and gluconeogenesis. Although the fetal liver is unable to synthesize glucose from gluconeogenic precursors, the capacity for hepatic gluconeogenesis increases rapidly following parturition. This increase in capacity for hepatic gluconeogenesis is through the induction of key gluconeogenic enzymes brought about by an increase in plasma glucagon and a decrease in plasma insulin (Girard, 1986). In addition, Godfrey et al. (1991) and Stanko et al. (1991) found an increase in concentration of blood lipids in calves exposed to cold environments when compared to calves exposed to warm environments. This further suggests that blood lipids are involved in cold thermogenesis.

Thermoregulation in the Newborn Calf

Thermal loss

The ability of the newborn calf to maintain normal core body temperature during the early neonatal period is a direct function of its ability to produce enough heat to balance the loss of heat by evaporative and nonevaporative routes, and to minimize nonevaporative heat losses. Nonevaporative heat loss involves the flow of heat across temperature gradients from the sources of metabolic heat in the animal to the environment by radiation, convection, and conduction (Blaxter, 1989). Evaporative heat loss in the neonate occurs as water vaporizes from the skin and respiratory tract surfaces. Heat loss by evaporation increases rapidly as ambient temperature increases to and exceeds body temperature. This is an important means by which animals are able to avoid hyperthermia during heat stress. However, in dry, cold environmental conditions, evaporative heat losses are minimal and are relatively independent of changes in ambient temperatures. Gonzalez-Jimenez, et al. (1962) found similar heat losses (344 kcal/m^2/day) in neonatal calves at 3 and 23°C. The exception to this is during the immediate postnatal period when amniotic fluid is evaporated from the skin and respiratory tract of the neonate. Vermorel et al. (1989) found an immediate decline in rectal temperature during the early postnatal period due to evaporation of amniotic fluid. Thompson and Clough (1970) found that evaporative heat losses in Ayrshire calves averaged 180 kcal/m^2/hour during the first hour and 78 kcal/m^2/hour

from 1 to 6 hours of life. These high rates of evaporative heat loss during the first several hours exceeded heat production by the calf and, as a result, rectal temperature declined from 39.5°C at birth to 38.8°C at 2 hours and to 38.3°C at 6 hours of age.

Body size effects

The principal factor that determines an animal's resting, thermoneutral metabolism, is body size. Light weight neonates have a lower summit metabolic rate per unit of surface area and as a consequence light weight neonates will be less cold tolerant than heavy weight neonates (Carstens et al., 1987). Okamoto et al. (1986) found that the time required to reduce rectal temperature to 35°C in a cold-water immersion system was prolonged by increased body weight. This resulted in a 67-minute differential in the time required to induce hypothermia between the lightest and heaviest calves. Furthermore, summit metabolism per unit of surface area was 33% higher in the heaviest calf (55 kg) versus the lightest calf (32 kg). Therefore, research suggests that light weight neonates will have a more difficult time maintaining thermal balance during cold stress because of a lower cold-induced thermogenic rate per unit of skin surface area than heavier neonates. This phenomenon may partially explain the higher incidences of neonatal mortality that have been reported in lighter pigs (Alexander, 1975), lambs (Alexander et al., 1968), and calves (Azzam et al., 1993 and Morris et al., 1986).

Insulation effects

The insulative nature of the external hair coat and the ability of cutaneous tissues to resist nonevaporative heat losses during cold exposure are of critical importance in maintaining homeothermy. The rate of nonevaporative heat loss is referred to as thermal conductivity and its reciprocal is an assessment of total thermal insulation or resistance to cooling. Total thermal insulation for 2-day-old Ayrshire calves expressed as temperature gradient per unit of surface area per unit of heat flow was 16.4 (°C/ m^2/day)/Mcal (Gonzalez-Jimenez et al., 1962). A higher thermal insulation enhances cold tolerance by decreasing LCT as well as the rate of nonevaporative heat loss per 1°C, which results in the occurrence of summit metabolism at a lower ambient temperature. Total thermal insulation describes the resistance of cutaneous tissue to conductive heat loss from the body core to the skin surface, whereas external insulation describes the thermal resistance of the hair coat and air interface to radiative, convective, and

conductive heat losses from skin surface to the environment (Webster, 1974). Tissue insulation in neonatal calves is low at birth but increases with age, as demonstrated by Rawson et al. (1989), who found that tissue insulation in cold-exposed Holstein calves increased by 37% during the first 14 days of life. In cold-exposed Ayrshire calves, tissue insulation increased from 3 to 5.1 (°C/ m^2/day)/Mcal over the first 20 days of life (Gonzalez-Jimenez et al., 1962).

Although enhanced tissue insulation is critical for improving cold tolerance in neonates, external insulation plays a larger role in determining the total thermal insulation of the neonatal calf. When exposed to dry, cold, still-air environmental conditions, external insulation, as a proportion of total thermal insulation, in neonatal calves, ranges from 65% to 75% (Rawson, 1989). External insulation is a function of the thermal resistance of both the hair coat and the air interface. It can be enhanced by piloerection of the hair coat and impaired by air movement or precipitation. Cold-induced piloerection in Ayrshire calves increased hair coat depth from 12.2 to 23.2 mm, which increased the insulative value of the hair coat from 5.5 to 7.7 (°C/ m^2/day)/Mcal (Gonzalez-Jimenez et al., 1962). Insulation of the air interface of 6 (°C/ m^2/day)/Mcal in this experiment (dry, still-air environment) was independent of changes in ambient temperature. Therefore, a neonate's total thermal resistance to heat loss is a function of the physical properties of skin and hair coat and the ability to induce vasoconstriction of cutaneous blood vessels and piloerection of the hair coat.

Weather effects

The relationship between metabolic heat production and effective ambient temperature (EAT) provides a basis for assessing and animal's thermoregulatory ability. Effective ambient temperature is used to describe the overall environmental impact on heat exchange from an animal based upon a variety of climatic conditions, including humidity, wind, precipitation, and radiant energy, as well as ambient temperature (NRC, 1981). The thermoneutral zone (TNZ) is a limited range in EAT over which an animal's metabolic heat production is minimal and independent of changes in EAT. The lower border of the TNZ is called the lower critical temperature (LCT) and is defined as the EAT below which an animal must increase its metabolic heat production to maintain thermal balance. The LCT of an animal is determined by the animal's ability to resist heat loss and the animal's resting, thermoneutral heat production

through metabolism. An increase in thermal insulation or an increase in thermoneutral metabolic rate decreases LCT, improving cold tolerance in an animal (Carstens, 1994). In lambs, estimates of LCT were 37 and 32°C for light (2 kg) and heavy (5 kg) birth weight neonates immediately after birth while still wet with amniotic fluid, and 31 and 22°C, respectively, when lambs were more than 1 day of age (Alexander, 1979). Adult cattle are more cold tolerant as demonstrated by LCT estimates of O°C for 1-month-old calves and -36°C for finishing steers gaining 0.8 kg/day (Webster, 1974). At the lower border of the cold zone is the cold lethal limit. This is the ambient temperature below which the calf is unable to generate sufficient heat to offset heat losses required to maintain thermal balance, and at which hypothermia begins. Prolonged periods of exposure below the cold lethal limit will result in death. The cold lethal limit also can be defined as the ambient temperature below which heat loss exceeds the calf's summit or maximal metabolism (Carstens, 1994).

Neonatal calves are remarkably cold tolerant in a dry, still-air environment (Rawson et al., 1989b). The thermal demand of an outdoor cold environment, however, is a function of wind and precipitation as well as ambient temperature. Holmes and McLean (1975) examined the effects of cold, wind, and precipitation on thermal balance in Jersey and Friesan calves from 7 to 60 days of age. Calves in a cold environment (5°C) that were exposed to wind, simulated rain, or a combination of wind and rain had total thermal insulative values that were reduced by 8, 11, and 29%, respectively, compared with calves in a cold, dry, still-air environment. The additive effect of wind and precipitation in reducing thermal resistance to heat loss was also demonstrated in neonatal lambs (Alexander, 1962c). Calculations of LCT according to the National Research Council method (NRC, 1981) revealed that the effect of wind or rain alone increased LCT by 2 to 3°C. The effect of wind and rain in combination increased LCT by 7°C above the LCT of calves in a dry, still-air environment.

Thermogenesis in the Neonatal Ruminant

The ability of the newborn calf to avoid hypothermia depends on immediate activation of thermogenic mechanisms at birth, when the demand for heat production is typically highest. Cold induced thermogenesis is brought about when incoming cold sensations, as perceived by multiple thermoreceptors in the skin, spinal cord, and hypothalamus, reach a threshold level

(Jessen, 1990). The rate of cold induced thermogenesis increases in a linear fashion as ambient temperature decreases below LCT, until the animal's summit metabolism is reached. The sources of cold induced thermogenesis in neonatal ruminants are shivering thermogenesis in skeletal muscle tissue and nonshivering thermogenesis in BAT.

Shivering thermogenesis

Shivering consists of involuntary, periodic contractions of skeletal muscle. Heat is produced during contraction of muscle bundles in skeletal tissue that has increased in tone, as well as in skeletal tissue exhibiting overt tremors (Alexander, 1979). Shivering of skeletal muscle is advantageous for animals attempting to maintain thermal balance during cold exposure because heat can be generated from skeletal muscle without the need for physical movement that can increase convective heat loss. However, thermogenesis of contracting skeletal muscle during physical activity also can be a significant source of heat in the newborn calf (Vermorel, 1989). Vermorel et al. (1989) measured heat production in neonatal calves from 4 to 21 hours of age and observed that heat production was increased by approximately 100% when standing for the first time for 10 minutes. Heat production was increased by an additional 40% later, when calves were stronger and stood for 30 minutes or more.

Nonshivering thermogenesis

The principal site of cold induced nonshivering thermogenesis in animals is BAT (Alexander, 1979). BAT is a specialized organ found in cold-adapted animals, hibernators, and most newborn mammals. In domestic species, BAT has been clearly identified in neonatal lambs (Gemmell, 1972), kids (Thompson, 1970), and calves (Alexander, 1975), but not in pigs (Alexander et al., 1975). The capacity for BAT thermogenesis is attributed to a unique 32,000 M_r uncoupling protein (UCP) located in the inner mitochondrial membrane (Himms-Hagen, 1990). The UCP in BAT mitochondria allows mitochondrial respiration to be uncoupled from oxidative phosphorylation (synthesis of adenosine triphosphate, ATP) thereby using the energy generated by mitochondrial respiration in BAT to produce heat rather than ATP. In the mitochondria of skeletal muscle (no UCP present), mitochondrial respiration is coupled to oxidative phosphorylation and the production of ATP. Heat is produced in muscle tissue only

when ATP is used, ATP is used during muscle contraction, thus generating more adenosine diphosphate (ADP) to further induce mitochondrial respiration (Carstens 1994).

Similar to shivering muscle tissue, the ability of BAT to generate heat depends on the rate of substrate (glucose or fatty acid) oxidation in the mitochondria. In muscle, the principle factor controlling the rate of substrate oxidation is the rate at which ATP is utilized to provide ADP for oxidative phosphorylation (Carstens, 1994). Resynthesis of ATP by oxidative phosphorylation reduces the proton gradient, thereby inducing an acceleration of the electron transport system and mitochondrial respiration. Muscle tissue mitochondria have a large capacity for both electron transport and oxidative phosphorylation. BAT, in contrast, has a large capacity for electron transport, but a low capacity for oxidative phosphorylation (Himms-Hagen, 1990). In BAT, heat is generated when the proton gradient is dissipated by increased operation of UCP, which subsequently induces an acceleration of the electron transport system and mitochondrial respiration. The concentration of UCP in BAT is now widely accepted as a key biochemical marker of the thermogenic capacity of this tissue (Himms-Hagen, 1990).

Control of nonshivering thermogenesis

BAT is extensively vascularized, and brown adipocytes, as well as blood vessels, are highly innervated by the sympathetic nervous system (Alexander, 1980). The release of norepinephrine (NE) during cold exposure in neonatal ruminants stimulates increased blood flow to BAT, as well as thermogenesis in BAT (Alelxander et al., 1975). Although BAT accounts for only 1.5 to 2% of body weight in newborn lambs, it can account for 22% of cardiac output and 40% of maximal thermogenesis during cold exposure (Alexander and Williams, 1968). Alexander and Williams (1968) using various pharmacologic agents, to block shivering or nonshivering thermogenesis during summit metabolism determined the relative contributions of shivering and nonshivering thermogenesis to summit metabolism in neonatal lambs. Approximately 40% of the thermogenic response during summit metabolism was attributed to nonshivering thermogenesis, with the remaining of about 60% being attributed to shivering thermogenesis. The magnitude of summit metabolism in neonatal calves was assessed in three experiments using a temperature controlled water-immersion system to induce cold exposure.

The average summit metabolic rate in these experiments was 114 cal/kg/minute, 3.5-fold greater than the average thermoneutral metabolic rate (Alexander and Williams, 1968).

Norepinephrine stimulation of BAT thermogenesis is mediated by the activation of adenylate cyclase through binding of β-adrenergic receptors. Increased adenylate cyclase activity stimulates cyclic-adenosine monophosphate (c-AMP) to activate hormone-sensitive lipase, which then activates lipolysis to provide free fatty acids for mitochondrial respiration. Free fatty acids also have been shown to stimulate UCP activity (Himms-Hagen, 1990). Additional control of BAT thermogenesis is provided by purine nucleotides. Guanosine diphosphate (GDP) and adenosine diphosphate (ADP) bind to UCP and inhibit proton conductance through UCP.

Through binding of both α_1- and β-adrenergic receptors, NE also stimulates the synthesis of iodothyronine 5'-deiodinase (Himms-Hagen, 1990). This enzyme is involved with the intracellular conversion of thyroxine (T_4) to triiodothyronine (T_3). Endogenous production of T_3 plays an important role in enhancing the synthesis of UCP (Himms-Hagen,1990). Increased metabolic responses to NE stimulation under thermoneutral conditions have been used in neonatal lambs and calves as an in vivo measure of the thermogenic potential of BAT. In crossbred Friesian (Alexander et al., 1975a) and purebred Angus neonates (Carstens et al.,1993) NE infusion elevated thermogenic rates by a factor of 2.3 and 2.1, respectively, over preinfusion rates. Similar thermogenic responses to NE, 2-2.4 fold increases in thermogenic rates, have been reported in neonatal lambs (Alexander and Williams, 1968).

In addition to its role in acute activation of BAT thermogenesis, NE is involved in long term modulation of BAT growth and development during cold stress. Stimulation of the sympathetic nervous system induced by chronic cold exposure markedly enhanced differentiation and proliferation of brown adipocyte precursor cells and endothelial cells that form new capillaries (Carstens, 1994). NE release during sympathetic stimulation plays a critical role in both the activation of BAT thermogenesis during acute periods of cold exposure and in the recruitment and proliferation of BAT during sustained periods of cold exposure (Geloen, 1988).

Several other hormones have been shown to modulate BAT function, including thyroid hormones, glucagon, and glucocorticoids. Thyroid hormones have long been recognized for their role in regulating cold thermogenesis in animals (Carstens, 1994). However, although thyroid hormones are critical for normal BAT function, excess levels of thyroid hormones apparently suppress the thermogenic response of BAT (Abelenda and Puerta, 1992). Glucocorticoids are essential for cold thermogenesis, and marked increases in glucocorticoids have been reported in response to cold exposure in neonatal lambs (Basset and Alexander, 1971) and calves (Godfrey et al., 1991). Glucocorticoids, however, likely play an indirect role in supporting cold thermogenesis through mobilization of lipid and glycogen to supply energy substrates for cold thermogenesis (Himms-Hagen, 1990). Plasma concentrations of glucagon have been shown to increase dramatically during the early postnatal period. Work done in rats has demonstrated that glucagon enhances cold tolerance by stimulating BAT thermogenic activity (Billington, 1991).

Effects of age on thermogenesis

The demand for cold-induced thermogenesis is reduced with advancing age. Slee et al. (1990) examined cold tolerance in neonatal lambs. Cold tolerance, measured as the time required to induce hypothermia (35°C) in a cold-water immersion system, was similar for 12-hour-old and 14-day-old lambs. However, summit metabolic rates of 14-day-old lambs were as much as 32% lower than summit metabolic rates of 12-hour-old lambs. Alexander and Williams (1968) demonstrated a similar reduction in summit metabolism during the first 3 to 4 weeks of age in neonatal lambs. This decline in summit metabolism during the first month of age has been attributed to a substantial decrease in nonshivering thermogenesis (Alexander and Williams, 1968). A decline in nonshivering thermogenesis with advancing neonatal age also has been demonstrated in calves (Alexander et al., 1975). Alexander and Williams (1968) determined that shivering thermogenesis contributed 60% of the maximal cold thermogenic response in newborn lambs, whereas it contributed 95% at 30 days of age. Conversely, nonshivering thermogenesis contributed 40% of summit metabolism at birth, but only 5% at 30 days of age. This demonstrates that nonshivering thermogenesis plays a much less important role in maintaining thermal balance in older neonates.

This decline in nonshivering thermogenesis coincides with rapid morphologic changes in BAT and the apparent conversion of brown adipocytes to white adipocytes, as demonstrated in calves (Alexander et al., 1975) and lambs (Gemmell et al., 1972). Vernon (1977) found that most of the perirenal adipocytes in neonatal lambs had lost the morphologic characteristics of BAT by 9 days of age. He hypothesized that the brown adipocytes had differentiated into white adipocytes, given that total DNA content and adipocyte number were unaffected by age. Although recent studies have shown that the postnatal disappearance of morphologically identifiable BAT in neonatal ruminants is associated with decreases in key biochemical characteristics of BAT, including a decrease in thermogenic activity of brown adipocyte mitochondria, (Casteilla et al., 1987 and Vatnick et al., 1987) a reduction in the expression of UCP mRNA, (Casteilla et al., 1987) and a decrease in activity of iodothyronine 5'-deiodinase enzymes, (Wu et al., 1991) direct evidence for cellular conversion of brown to white adipocytes remains to be determined.

Cold exposure during the early postnatal period delays the disappearance of BAT. Ter Meulen and Molnar (1975) examined the effects of ambient temperature on postnatal changes in perirenal adipose tissue from neonatal calves. In contrast to calves maintained in a warm environment, perirenal adipose tissue from calves kept in cold ambient temperatures (2°C) still possessed morphologic features of brown adipocytes at 25 days of age. By 50 days of age, all perirenal adipocytes were morphologically classified as white adipocytes, irrespective of previous temperature exposure. In neonatal lambs, cold exposure during the early postnatal period retarded the decline in summit metabolism and the involution of BAT, and increased the rate of nonshivering thermogenesis compared with lambs of similar ages not previously exposed to cold ambient temperatures (Alexander and Williams, 1968). Symonds and Lomax (1992) reported that 8-day-old lambs reared in a cold (15°C) environment since birth possessed BAT that was 54% more active thermogenically than lambs reared in a warm (25°C) environment.

Casteilla et al. (1987) observed that the expression of UCP mRNA in perirenal adipose tissue, although highly expressed at birth, was barely detectable in 2-day-old neonatal calves born in the fall. However, UCP mRNA was highly expressed in 15 and 38-day-old neonates born in the winter. Prenatal exposure of the dam or postnatal exposure of the neonate to colder

ambient temperatures during the winter months, or a combination of prenatal and postnatal cold exposure, may contribute to the higher expression of UCP mRNA in the older winter born calves. Postnatal cold exposure enhances cold tolerance of the neonate by delaying the normal decline in nonshivering thermogenic capabilities with age.

Environment During Prenatal Period and Neonatal Survival

Exposure of pregnant ewes to cold as a result of winter shearing has been shown to increase subsequent lamb birth weight per ewe and lamb survival rate (Thompson et al., 1982), whereas exposure to hot ambient temperatures reduces lamb birth weight and lamb survival rate (Shelton and Huston, 1968). It was first thought that winter shearing enhanced lamb birth weight and lamb survival rate through improved fetal nutrition because shearing is known to increase feed intake. However, in subsequent studies, it was shown that maternal exposure to cold increased lamb birth weight independent of changes in prepartum feed intake (Thompson et al., 1982). Thompson et al. (1982) suggested that maternal mobilization of glucose induced by acute cold exposure during late gestation increased glucose supply to the fetus, which stimulated fetal secretion of insulin, thereby promoting fetal growth. An increase in birth weight due to maternal cold exposure would be expected to enhance cold tolerance and survivability of the neonate.

Additionally, studies have demonstrated that maternal cold exposure may also improve survival of newborn lambs by enhancing nonshivering thermogenesis, independent of differences in birth weight (Symonds et al., 1992). Stott and Slee (1985) found that lambs born to shorn ewes that were exposed to cold (6°C) for the last 14 days of gestation exhibited significantly higher NE-induced thermogenic rates than lambs from unshorn ewes exposed to warm temperatures (26°C). Also, Symonds et al. (1992) found that lambs from cold-exposed ewes were 15% heavier at birth, and possessed 21% more perirenal brown adipose tissue that was also 40% more thermogenically active than lambs from unshorn control ewes. Newborn lambs from cold-exposed ewes were clearly more cold tolerant, given that thermogenic rates were 16% greater in a warm (28°C) environment and 40% greater in a cold (14°C) environment relative to lambs from control ewes. Symonds et al. (1992) also observed that four of the seven newborn lambs from control ewes exhibited shivering during cold exposure, whereas none of the lambs

from cold-exposed ewes shivered during cold exposure. This indicates that lambs from control ewes relied more heavily on shivering thermogenesis to maintain thermal balance.

Results presented by Stevens et al. (1990) demonstrated that fetal glucose infusion stimulates BAT growth more than fetal growth, suggesting that pregnant ewes are able to adapt metabolically to cold ambient temperatures by repartitioning the use of nutrients to promote fetal growth, and the recruitment and proliferation of brown adipocytes to enhance cold tolerance of the newborn lamb. This phenomenon has not been investigated in pregnant cows, although a Canadian study (Jordan et al., 1977) reported heavier calf birth weights from cows maintained outdoors (-20 to –7°C) during late gestation compared to cows housed in an enclosed, insulated barn (5 to 8°C). Indirect evidence to support the postulate that prepartum temperature exposure of the dam may influence calf birth weights was derived from a genotype-by-environment study that simultaneously compared Hereford cows of Montana and Florida origins in both Montana and Florida environments over an 11-year period (Burns et al., 1979). Averaged over both Hereford lines, calves born to cows in Montana in a colder ambient environment were 22% heavier than calves born to cows in Florida.

Influence of Prenatal Nutrition on Neonatal Survival

The inability of the neonate to maximize thermogenesis in response to cold stress during the early postnatal period may be one of the manifestations of prepartum protein or energy malnutrition. Malnutrition of the dam during late gestation has been shown to adversely affect neonatal calf survival (Corah et al., 1975). Alexander (1978) fed high-energy and low-energy diets to pregnant ewes beginning on day 90 of gestation. Prepartum energy restriction reduced the proportional weight of perirenal adipose tissue by 17% in single and 24% in twin fetuses at 125 days of gestation. A reduction in the quantity of fetal perirenal adipose tissue strongly suggests that nonshivering thermogenic capabilities would have been impaired by maternal malnutrition in this study, given that little white adipose tissue is present in perirenal adipose tissue deposits (Gemmell and Alexander, 1978). Additionally, feeding a protein-restricted diet to pregnant rats during late gestation reduced BAT weights in newborn pups by 41 to 53% (Tyzbir et al., 1982) and decreased the thermogenic activity of BAT by 38% (Tyler and Ramsey, 1991), even though birth weights were unaffected.

Several studies have examined the effects of prepartum protein (Carstens et al., 1987) and energy (Ridder et al., 1991) restriction of the dam on subsequent thermoneutral thermogenic rates of calves at birth. Prepartum protein restriction during the last trimester reduced thermoneutral thermogenic rates by 12%, without affecting birth weights, resulting in an estimated increase in LCT of 3°C. Comparing these studies, it appears that prepartum energy restriction had less effect on reducing thermoneutral thermogenic rates than prepartum protein restriction, although the level of energy restriction imposed by Ridder et al. (1991) had greater effects on maternal body weight gain and condition score, and calf birth weights.

Maternal malnutrition also adversely affects the availability of energy substrates required by the neonate for cold thermogenesis. Mellor and Murray (1985) found that nutritional restriction of pregnant ewes reduced total body lipid in fetal lambs, of gestational age 142 days, from 2.04 to 1.74% of fetal weight, even though muscle and liver glycogen concentrations were unaffected. Alexander (1962) found that total body lipid, but not muscle or liver glycogen, stores were lower in lambs born to nutritionally restricted ewes. Alexander (1962) starved newborn lambs born to ewes previously fed high-energy or low-energy diets during late gestation to assess their survival time and energy substrate utilization. Lamb survival time was extended from 43 to 68 hours in a thermoneutral environment (23°C), and from 26 to 39 hours in a cold environment (9°C) in lambs whose dams were fed the high-energy diet during late gestation. The potential impact of nutritional restriction of the fetus in-utero is to impair cold tolerance of the neonate by reducing body substrate reserves available for cold thermogenesis and reducing nonshivering thermogenic capabilities. Additionally, maternal malnutrition has been associated with weak labor (Corah et al., 1975), reduced calf vigor, increased incidence of dystocia, and decreased colostrum production (Warrington, 1985). All of these factors may contribute to an increased rate of mortality and morbidity in newborn calves.

Feeding rats diets containing high concentrations of linoleic acid resulted in fetuses with BAT containing higher concentrations of linoleic acid (Derry, 1972), pups with increased BAT activity (Schwartz et al., 1983), and increased BAT thermogenesis (Nedergaard et al., 1983). Lammoglia et al. (1999b) found that calves born to heifers receiving a high fat diet containing safflower seeds had glucose concentrations higher than calves born to heifers receiving no added

fat. This difference may indicate that muscle and liver glycogen content may also have been higher.

Cows supplemented with fat prepartum have been reported to have higher blood concentrations of cholesterol than cows that received no supplemental fat (Hawkins et al., 1995). Lammoglia et al. (1999b) reported that calves born to heifers fed high fat diets containing elevated levels of linoleic acid were able to maintain body temperatures during cold exposure for a longer period of time than calves from heifers receiving no added fat. This was attributed to shivering thermogenesis associated with higher concentrations of plasma glucose or nonshivering thermogenesis associated with increased concentrations of linoleic acid in BAT and increased BAT thermogenic activity. Long-chain fatty acid supplementation increases proprionate, decreases acetate production, and increases gluconeogenesis in the liver of cows supplemented with fatty acids (Carstens, 1994).

Glucocorticoids play an indirect role in supporting cold thermogenesis through lipid and glycogen mobilization to provide energy substrates for thermogenesis (Himms-Hagen, 1990). Increased blood glucose and NEFA concentrations in calves exposed to cold environments have been reported (Godfrey et al., 1991), indicating possible associations of these metabolites with thermogenesis. Elevated cortisol concentrations in cold environments have been reported to be involved in thermogenesis by providing substrates from lipid and glycogen stores, and BAT (Bassett and Alexander, 1971; Bell and Thompson, 1979). Lammoglia et al. (1999b) concluded that blood glucose concentrations play an important role in thermogenesis in the neonatal calf. Feeding cows or heifers supplemental fat high in linoleic acid for approximately 60 days prior to parturition may increase the ability of the neonatal calf to survive prolonged cold exposure by increasing plasma glucose concentrations and increasing substrate availability for cold thermogenesis.

The last 60 days of gestation appear to be a critical period of BAT development as well as a crucial period when dam cold exposure may effect the calf's thermogenic capability. This could allow researchers to influence neonatal survival by manipulating late gestation diets. Therefore, we designed the first experiment to determine if feeding whole cottonseed to beef females in late gestation will result in similar blood profiles and thermogenic response in calves

during short term cold stress as calves from dams being fed safflower seeds. The relationship between birth weight and heat production will also be examined, since small calves are less tolerant of cold stress (Young et al., 1986). The second experiment will examine if there is enhanced survivability in neonatal calves from dams being fed whole cottonseed.

Materials and Methods

Experiment 1

Two trials were conducted, one during the fall of 1999 at the Virginia Tech Beef Cattle Center and one during the spring of 2000 at the Bland County Correctional Facility. In Experiment 1, ten Angus, five Hereford and two Charolais pregnant heifers from the Virginia Tech Beef Cattle Center were randomly assigned to one of three dietary treatments. All three diets were fed as Total Mixed Rations (TMR). Treatment group one received a control diet (TMR-C) consisting of hay, soybean meal, molasses and cracked corn. Diet one contained 1.5% crude dietary fat (n=5), Table 1. Animals in this group received 33 lbs/head/day or 165 lbs of TMR-C daily. Two heifers originally assigned to TMR-C treatment were removed from the experiment. One heifer failed to calve while the other heifer's calf died as a result of injuries unrelated to the experiment. These heifers were replaced by two heifers that calved at a later date than other heifers in the experiment. However, responses from these two heifers were not different from other heifers in the TMR-C treatment so their data was included in the statistical analysis. Treatment group two received a safflower diet (TMR-S) consisting of hay, soybean meal, cracked corn and safflower seed. Diet two contained 4.0% crude dietary fat (n=5). Animals in this group received 32 lbs/head/day or 160 lbs of TMR-S daily. Treatment group three received a cottonseed diet (TMR-CS) consisting of hay, soybean meal, cracked corn and whole cottonseed. Diet three contained 5.0% crude dietary fat (n=5). Animals in this group received 32 lbs/head/day or 160 lbs of TMR-CS daily. Each day, for all treatment groups, rejected feed was weighed and recorded to determine the precise amount of feed consumed.

Safflower (*Carthamus tinctorius*) seed containing 37% oil with a composition of 79.1% linoleic, 6.2% palmitic, 2.1% stearic, and 10.3% oleic fatty acid was used as the supplemental fat source in diet two**.** Whole cottonseed containing 24% oil with a composition of 56.3% linoleic, 23.35% palmitic, 2.1% stearic, and 16.95% oleic fatty acid was used as the supplemental fat

source in diet three. Gestating heifers were fed their respective diets for 47.5 $\pm$ 5.4 days prior to expected parturition and continued to receive that diet until parturition. Heifers calved from August 25, 1999 through November 2, 1999. All diets were formulated to be isonitrogenous and isocaloric, Table 2. All diets were formulated to meet NRC requirements for gestating heifers (NRC, 1996). All diets were supplemented with free choice trace mineral salt, and all animals had ad libitum access to water.

Heifers were observed for signs of parturition every 2 h and were observed continuously once parturition started. Within 1 h after calving, the cow/calf pair was removed from the treatment group and placed in a maternity pen. Colostrum samples were taken from the dam while restrained in a cattle head chute. Colostrum samples were kept at -20°C until assayed for IgG concentrations, milk fat, protein, lactose and solids. Calves were weighed and then returned and allowed to suckle their dam. The calf remained with its dam for approximately 5 h. At 5.5 h of age (birth = 0) and 60 minutes before cold exposure, an indwelling catheter (Angiocath; 20 G X 4.5 in) was inserted into the jugular vein using aseptic procedures. An 18 in extension was connected to the catheter to allow blood collection without disturbing the calves.

At 6.5 h of age, and 60 min after catheter insertion, calves were maintained away from the dam in a 5°C cold room for 90 min. All fluid had evaporated, and the calves were dry when placed in the cold room. Rectal temperatures (mercury thermometer; Jorvet, New Hyde Park, NY) and 10-mL blood samples were taken at 0, 15, 30, 45, 60, 75, and 90 min while the calf was restrained in a metabolism crate within the cold room. Handling the calves in this manner allowed researchers to safely restrain the calves and also protect the calves and researchers from injury. A thermostatically controlled refrigeration unit and air circulation fan cooled the room. Calves were protected from air currents generated by the fan by a canvas partition. Temperature variations during the experimental period were less than 3°C.

The experiment at the Virginia Tech Beef Cattle Center began on July 28, 1999. At that time cows began to receive their respective diets. Data collection from calves from dams in this study began on August 25, 1999. The approximate mean environmental temperature in Montgomery County Virginia during the time of the experiment was 21°C. The cool room being used in this experiment is located in the basement floor of Litton Reaves Hall, Virginia Tech,

room number 78. Moving calves into a cool room of approximately 5°C from a 21°C outdoors environment should mimic a cold shock large enough to induce shivering thermogenesis and a BAT nonshivering thermogenesis response in the neonate.

After collection, blood was placed into test tubes. Blood was processed to yield serum, which was kept at –20°C until glucose and cortisol concentrations were determined. Plasma cortisol (kit TKC05; DPC, Los Angeles, CA) concentrations were determined using RIA procedure (Laredo et al., 1994). Spectrophotometric techniques were used to determine glucose concentrations (kit 315; Sigma, St. Louis, MO), (Williams et al., 1987). Colostrum IgG (Bovine Vet Rid kit; Bethyl, Montgomery, TX) concentrations were determined using RID procedure (Besser and Gay, 1994). Intra-assay and inter-assay variation were less than 2% for all assays. Oxytetracycline (LA-200) was administered to each calf at the end of the sampling period as directed by a veterinarian. Calves were then returned to the Virginia Tech Beef Cattle Center and placed with their dams.

Experiment 2

Ninety eight cows at the Bland County Correctional Facility were randomly assigned to one of two treatment groups. Treatment group one received a control diet consisting of hay, whole corn, and SBM. Diet one contained 2% (n=51; low fat; CON) crude dietary fat, Table 4. Treatment group two received a diet consisting of hay, whole corn and whole cottonseed. Diet two contained 5% (n=47; high fat; COT) crude dietary fat. Gestating cows were fed their respective diets 60.5 $\pm$ 11.5 days prior to expected parturition and continued to receive that diet until parturition. All diets were formulated to be isonitrogenous and isocaloric, Table 5. All diets were formulated to meet NRC requirements for gestating cows (NRC, 1996). All diets were supplemented with free choice trace mineral salt, and all animals had ad libitum access to water.

Ambient temperature, precipitation, calf weight, and dystocia scores were recorded at parturition. Thirty minutes postpartum, rectal temperature (mercury thermometer; Jorvet, New Hyde Park, NY) was measured, and calf vigor score and calf shivering score were recorded. The amount of time required for calves to stand and to nurse were also recorded. A journal was

also kept during this time to record precipitation and daily high and low temperatures in the vicinity of the experiment.

At 180 min postpartum, two 10-mL blood samples were drawn from 35 calves from CON dams and 40 calves from COT dams. Rectal temperature was also measured for each calf at this time. At 36 $\pm$ 4 hours postpartum, two 10-mL blood samples were again drawn from the same calves sampled at 180 min.

Blood collection tubes containing Sodium Flouride were used to prevent glucose metabolism by red blood cells for samples collected at 180 min and 36 $\pm$ 4 h. Blood collection tubes containing no additives were used for determination of cortisol at time 180 min postpartum, and IgG concentrations at 36 $\pm$ 4 h postpartum. After collection, blood was placed into test tubes. Blood was processed to yield serum, which was kept at –20°C until glucose, cortisol, and IgG concentrations were determined using procedures indicated in Experiment 1. Intra-assay and inter-assay variation were less than 2% for all assays.

The experiment at the Bland County Correctional Facility began on January 17, 2000. At that time cows began to receive their respective diets. Data collection from calves from cows in this study began on March 6, 2000. The approximate mean environmental temperature in Bland County Virginia during this time of year is normally 7°C, whereas the uterine environment is approximately 38°C. The ambient mean temperature was expected to provide a cold shock large enough to initiate shivering thermogenesis and BAT nonshivering thermogenesis in the neonate.

Statistical Analysis

In Experiment 1, calf birth weights and heifer colostrum parameters were analyzed using GLM procedures for analysis of variance. Calf body temperature, shivering and vigor score, serum glucose, serum cortisol and heifer body weight data were analyzed by statistics for repeated measures with effects of diet, calf sex, and their interactions included. Similar statistical analyses were conducted in Experiment 2. Calf birth weight, shivering and vigor score, minutes to nurse and stand, serum cortisol and IgG, heifer dystocia score and ambient temperature were analyzed using GLM procedures for analysis of variance. Calf body temperature at 30 and 180 min, and serum glucose at 180 min and 36 $\pm$ 4 h were analyzed by statistics for repeated measures with effects of diet, calf sex, and their interactions included.

Data was analyzed using ambient temperature at time of calving and time of calving as covariates. Mean separation was accomplished using the PDIFF option (SAS, 1994).

Results

Experiment 1

Heifer and calf calving data for CON, SAF, and COT diet calves are summarized in Table 3. Body weight and body condition score of heifers at calving were unaffected by diet ($P > .5$). Vigor scores were not different at birth ($P > .05$). Calf birth weights were unaffected ($P > .5$) by diet, calf sex, or the diet x calf sex interaction. Mean fat, lactose and IgG concentrations in colostrum were not different ($P > .3$) among treatments. However, SAF tended to increase colostral solids ($P = .11$) and protein ($P = .13$) compared to COT or CON (Table 4).

Body temperature in calves for all treatments decreased throughout cold exposure resulting in a 0.5 °C drop in body temperature ($P < .03$). Calf body temperature changed during cold exposure in a quadratic fashion due to a slight increase in body temperature at 75 min of cold exposure in all groups. Dietary treatment did not alter body temperature response to cold stress.

Shivering score averaged 2.14, 1.69, and 1.68 ± .24 in CON, SAF and COT calves, respectively. During cold stress calf shivering scores increased in all treatment groups ($P < .001$). Shivering scores increased throughout cold exposure in a linear fashion. Vigor scores of calves in all groups increased in a linear fashion throughout cold exposure ($P < .04$). Dietary treatment did not alter vigor or shivering score response to cold stress.

Mean serum glucose levels tended ($P = .12$) to be greater in CON compared to SAF or COT calves (Figure 1). Glucose concentrations averaged 74.4, 51.9, and 60.0 ± 7.3 mg/dl for CON, SAF, and COT, respectively. In addition, mean glucose concentrations increased in a linear fashion for all calves in all treatments throughout cold exposure ($P < .004$). Mean glucose concentrations in calves from CON dams averaged 22.5 and 14.4 mg/dl higher compared to SAF and COT calves, respectively, throughout the cold exposure sample period.

Serum cortisol concentrations were unaffected by diet ($P > .3$). However, cortisol concentrations were affected by time of cold exposure for all groups ($P < .02$). Serum cortisol concentrations decreased in a cubic fashion throughout cold exposure (Figure 2). There was

tendency for a treatment x time interaction for decreased cortisol levels in all groups (P = .14). Cortisol concentrations averaged 28.6, 37.7, and 35.6 ± 3.6 ng/ml in CON, SAF and COT, respectively. In general, cortisol concentrations were elevated when the calf was placed in the cold room, followed by a continuous decrease in concentrations throughout 90 min of cold exposure.

Experiment 2

At birth, calf birth weight, vigor score, shivering score, time to stand, and dystocia score (Table 6) were unaffected by diet (P > .5). Body weight and body condition score of cows at calving were unaffected by diet (P > .05). Calf birth weights were unaffected (P > .2) by diet, calf sex, or diet x calf sex interaction. Mean time to nurse was non-significantly (P > .2) longer (101.2 ± 19 vs 70.1 ± 21.3 min) for COT calves than CON calves, respectively.

Calf weight, calf vigor and serum IgG were unaffected by ambient temperature or time of calving (P > .05). However, shivering score decreased as ambient temperature increased (P < .003) and when calves were born during warmer periods of the day (P < .006). Body temperature at 30 min was affected by time of calving (P < .01). Body temperature at 180 min was affected by ambient temperature at calving (P < .03) and there was a tendency for body temperature at 180 min to be affected by time of calving (P < .09).

The interaction of diet x calf sex at 30 min (P < .05) resulted from higher rectal temperatures in male than female calves from dams on the COT diet (39.3 ± .18 vs 39.1 ± .18°C), whereas body temperatures were lower in male compared to female calves from dams on the CON diet (39.1 ± .21 vs 39.3 ± .19°C), Figure 3 and Table 8. A similar diet x calf sex interaction was observed at 180 min (P < .05) as rectal temperatures were elevated in male compared to female calves from dams fed COT diet (39.2 ± .17 vs 38.9 ± .18°C), whereas rectal temperature was depressed in male compared to female calves from dams fed CON diet (38.9 ± .2 vs 39.3 ± .17 °C), Figure 4. Changes in body temperatures from 30 to 180 min were affected by diet (P < .05) as body temperatures for COT calves decreased more from 30 to 180 min than CON calves.

Serum glucose at 36 ± 4 h was affected by ambient temperature at calving (P < .04). Serum glucose concentrations at time 180 min were unaffected by diet (P > .3). However, serum

glucose concentrations at time 36 ± 4 h tended to be influenced by sex (P = .07) with serum glucose levels greater in females (127 ± 3.1 mg/dl) than males (119 ± 3.3 mg/dl) at 36 ± 4 h. Differences in serum glucose at time 180 min and 36 ± 4 h were not affected by diet, sex, or diet x sex interaction (P > .7). Serum glucose concentrations increased by almost two-fold from 180 min to 36 ± 4 h in both treatments (P < .001).

Mean serum cortisol concentrations tended to be greater (P = .08) in COT calves compared to CON calves (47.4 ± 4.3 vs 36.5 ± 4.6 ng/ml). Serum cortisol concentrations tended to be affected by diet (P > .08). Differences in serum cortisol levels were unaffected by sex or diet x sex interaction (P > .5). Means of metabolic, immunologic, and physiologic traits for cottonseed and control diet calves are summarized in Table 8.

Discussion

In Experiment 1, body weight and body condition score of heifers at calving were unaffected by diet. Williams (1989) reported that cows fed high-lipid diets from parturition to d 100 after calving did not differ in body condition scores or body weight. Similarly, Lammoglia et al. (1999a) found no difference in body condition or body weight of cows fed high-lipid diets prepartum. Calf birth weights were not affected by dietary treatment. These results contradict findings by Lammoglia et al. (1999b) who reported higher birth weights in calves from dams that received a high fat diet during the last 53 d of gestation. However, these results agree with findings reported by Lammoglia et al. (1999a) who suggested that these effects on birth weight are not consistent.

During the cold challenge, rectal temperatures of calves from CON, SAF, and COT declined, but prepartum dietary treatment did not affect response to cold. The controlled-temperature room used in Experiment 1 was kept at a constant 5°C. Results presented by Lammoglia et al. (1999b) demonstrated that rectal temperatures in calves increased during the first 30 min of cold exposure in a 0°C cold room and then decreased steadily for the remainder of the cold exposure period. The magnitude of this decline was similar to the body temperature drop in the present experiment. The duration of cold exposure in Lammoglia et al. (1999b) was 140 min compared to 90 min in the present experiment. We chose 90 min because we felt this would be enough time to enable us to graph changes in serum glucose and cortisol

concentrations, and rectal temperatures. In addition, the amount of shivering increased while calf vigor was depressed during cold exposure. The effects on body temperature, shivering score, and vigor score indicate that length of time of cold exposure of calves was sufficient to initiate cold-induced thermogenesis.

Jessen (1990) showed that thermoreceptors present in the hypothalamus, skin, and spinal cord perceive cold and stimulate thermogenesis and increased body temperatures. In our study, body temperature in most calves increased between 60 and 75 min. This increase may indicate calves were using additional resources and mechanisms to thermoregulate.

In Experiment 1, glucose concentrations in calves from the CON diet heifers exceeded those of calves from the SAF diet and COT diet heifers. A possible explanation may be that more energy was available to CON heifers during the treatment period. CON heifers received diets containing higher TDN than either SAF or COT heifers. Diet composition differences encountered were not planned. The CON, SAF, and COT diets were formulated to have similar DM, CP, and TDN, but chemical analyses found this was not attained. The resulting elevation of TDN in the CON diet above calculated levels may have altered the response of the calves to the cold challenge. The elevated glucose levels indicate that muscle and liver glycogen content may have been higher in the CON diet calves.

Glucose concentrations increased during cold exposure. This indicates that calves were mobilizing additional substrates for thermogenesis as glucose is essential for thermoregulation (Jessen, 1990). The diet x time interaction of serum cortisol indicates that over time cortisol concentrations decreased steadily for all groups. This may have been due to acclimation of the environment by the cold exposed calves.

In Experiment 2, changes in rectal temperatures of calves over time were affected by diet. Calves from COT fed dams decreased body temperature with age while CON calves maintained body temperature. Diet induced differences in calf body temperature may be a result of altered levels of shivering and nonshivering thermogenesis or ambient temperature at time of birth.

Blood glucose concentrations appear to play an important role in thermogenesis in the neonatal calf (Godfrey et al., 1991). Godfrey et al. (1991) reported an increase in both NEFA and blood glucose concentrations in cold exposed calves. This indicates that possible

associations exist between these metabolites and thermogenesis. Serum glucose at 36 ± 4 h was affected by ambient temperature at time of calving. As ambient temperature decreased serum glucose concentration increased. Calves born during warm environmental conditions may have had more glycogen stores available for use as energy at 36 ± 4 h. Increased glucose levels would mean more substrate was available for shivering thermogenesis (Godfrey et al., 1991). Serum glucose concentrations almost doubled from 180 min to 36 ± 4 h in both dietary treatment groups. This was expected as the calf consumed colostrum between those sample periods. The neonates liver also begins gluconeogenesis and glycogenolysis during this period of time and thus begins to produce its own glucose (Godfrey et al. 1991).

Alternatively, the higher fat intake by COT compared to CON cows may have increased concentrations of linoleic acid in BAT and increased BAT thermogenic activity in bull calves born to COT diet cows. Concentrations of linoleic acid in BAT were not measured in calves from these experiments. However, the feeding regime may have influenced the composition of BAT. Changes in fatty acid composition of BAT increases BAT thermogenic activity (Schwartz et al., 1983) resulting in greater heat production from nonshivering thermogenesis (Nedergaard et al., 1983).

In contrast, in both dietary treatment groups, at both time 30 and 180 min, heifer calves from COT diet cows had lower rectal temperatures than heifer calves from CON diet calves. Average ambient temperatures during calving for bull and heifer calves, for both dietary treatment groups, were numerically different. In addition, mean ambient temperature during calving for heifers in the COT diet group was greater than mean ambient temperature during calving for heifers in the CON diet group. Warmer ambient temperatures may be responsible for the lack of cold-induced thermogenesis and may explain the lower body temperatures of the heifers in the COT diet compared to heifers in the CON diet. Calf shivering scores were affected by ambient temperature at time of calving and time of calving. Ambient temperatures were above normal during the time of the experiment and are reflected in the lack of shivering noted in the calves.

Body temperatures of calves at 30 min were affected by time of calving and body temperatures of calves at 180 min were affected by ambient temperature at time of calving.

Calves born during warm environmental conditions have higher rectal temperatures than calves born during cold environmental conditions (Godfrey et al., 1991). Prevailing environmental temperatures may affect fat-supplement-induced response (Lammoglia et al., 1999a).

Himms-Hagen (1990) reported that glucocorticoids play an indirect role in supporting cold thermogenesis through lipid and glycogen mobilization to provide energy substrates for thermogenesis. Bassett and Alexander (1971) reported that elevated cortisol concentrations in cold environments appear to be in involved in thermogenesis by providing substrates from lipid and glycogen stores and BAT. In the present experiment, increased serum cortisol concentrations in COT calves may have affected substrate mobilization.

Data collection for Experiment 1 began during late summer. During this time daytime environmental temperatures ranged from 7.2 to 31.1°C. Mean daily temperatures during the last 90 d of gestation in Experiment 1, for July, August, and September 1999, were 27.2, 23.8, and 16.7°C, respectively. Data collection for Experiment 2 began during early spring. During this time daytime environmental temperatures ranged from –4.9 to 25.5°C. Although Experiment 2 was conducted during late winter, average environmental temperatures were warmer than predicted for this time of year. Mean daily temperatures for January, February, and March for the past 10 years have been reported by the National Weather Service to be 4.9, 3.3, and 6.6°C, respectively. In Experiment 2, average ambient temperatures for calves born in the COT and CON diets were 11.27 and 10.52°C, respectively. Mean daily temperatures during the last 90 d of gestation in Experiment 2, for January, February, and March 2000, were 10.5, 7.2, and 8.8°C, respectively. The warm ambient temperatures and lack of any significant precipitation during the data collection period allowed for a clean, dry, environment for calving. Calf survival is influenced by environmental factors such as ambient temperature, wind, and precipitation (Azzam et al., 1993). Precipitation has greater effects on mortality at lower temperatures. This is expected because the amount of precipitation affects the insulating ability of the hair coat (Azzam et al., 1993). Bellows et al. (1987) attributed 6.9% of the mortality in 620 normal calves to exposure (chilling). Stanko et al. (1991) reported a study on weak calf syndrome where this condition seemed to be associated with weather stress and that an increased frequency of deaths from this syndrome occurred during periods of cold, wet weather. Azzam et al. (1993) reported

that the amount of precipitation and the average ambient temperature on the day of birth interact and affect mortality and morbidity.

Studies have demonstrated that maternal cold exposure may improve survival of newborn lambs by enhancing nonshivering thermogenesis, independent of differences in birth weight (Symonds et al., 1992). Stott and Slee (1985) found that lambs born to shorn ewes that were exposed to cold (6°C) for the last 14 days of gestation exhibited significantly higher NE-induced thermogenic rates than lambs from unshorn ewes exposed to warm temperatures (26°C). Also, Symonds et al. (1992) found that lambs from cold-exposed ewes were 15% heavier at birth, and possessed 21% more perirenal brown adipose tissue that was also 40% more thermogenically active than lambs from control ewes. Stevens et al. (1990) demonstrated that pregnant ewes are able to adapt metabolically to cold ambient temperatures by repartitioning the use of nutrients to promote fetal growth, and the recruitment and proliferation of brown adipocytes to enhance cold tolerance of the newborn lamb. In the present experiment, ambient temperatures may not have been sufficiently cold enough to initiate the desired cold-induced thermogenesis as well as altering fat-supplement-induced response.

Conclusions

We conclude that calves born to dams fed high fat diets containing safflower seeds or cottonseed respond similarly to cold stress, but these responses are not necessarily consistent with greater cold resistance. The similarity in responses warranted the use of cottonseed in field trials. Calves from heifers receiving CON diets containing higher than predicted TDN may have had higher muscle and liver glycogen content than either SAF or COT calves. Bull calves may have had more substrate available for shivering and nonshivering thermogenesis possibly due to the alteration of the chemical composition of BAT. Feeding whole cottonseed during late gestation may improve cold tolerance in newborn calves and result in improved calf survival. However, under the conditions in our experiment this was not determined. Elevated serum cortisol concentrations may have effected substrate mobilization in calves from COT dams. Warmer mean ambient temperatures during calving may have accounted for the body temperature differences reported between heifer calves. The effects of supplemental fat may have been altered due to the warm ambient temperatures encountered during the last 90 d of gestation.

Summary

Whole cottonseed is a by-product readily available to Virginia beef cattle producers at a competitive price. Experiment 1 was designed to determine if feeding whole cottonseed would have similar beneficial effects on the neonatal calf as that of feeding safflower seed. Experiment 2 was designed to determine if cows supplemented with whole cottonseed would produce calves with increased survivability and livability, an increased resistance to cold stress and heavier birth weights than those calves of dams that were not supplemented with whole cottonseed.

The cattle used in Experiment 1 and Experiment 2 were from well-managed beef cattle farms. Dams in these herds were supplied with adequate nutrition and mineral supplementation. The calving environment was clean, dry, and calving pastures were rotated yearly. Veterinary care was routine and prepartum and postpartum vaccinations were part of the regime. These herds were used in the present experiments because they were available to me and the facilities on both farms were excellent. However, these are not typical of many of the farms found in Virginia. It may have been better to conduct this experiment on a cattle farm that did not have such a well-managed herd. It is in herds such as this that feeding supplemental fat during late gestation may have its greatest effect.

If I were to conduct Experiment 2 again I would design a 2x2 factorial arrangement using two groups of cows receiving high fat diets and two groups receiving low fat diets. The four groups would be assigned to treatments based on nutritional status and body condition. Animals considered to be in poor condition would be assigned to a low and a high fat diet. The same would be done for animals considered to be in good condition. This would allow us to make comparisons between groups receiving the same diets but differing in overall condition.

Vita

Richard E. Dietz

I received my Bachelor of Science in Animal Science from West Virginia University in 1992. I received my Bachelor of Science in Biology from Virginia Tech in 2000 and my Masters in Animal Science from Virginia Tech in 2000.

Table 1. Design and subgroup numbers for Experiment 1

Gestation diet[a]	Calculated % fat[b]	Actual % fat[c]	Calf Sex		Total number
			Male	Female	
Control	2.02%	1.53%	2	3	5
Safflower seed	4.99%	4.00%	2	3	5
Cottonseed	4.99%	5.00%	1	4	5

[a]Diets were formulated to be isocaloric, isonitrogenous and meet NRC requirements for gestating heifers.
[b]% fat on DM basis as calculated from proximate analysis of ingredients.
[c]% fat on DM basis as determined from proximate analysis of samples from total mixed ration.

Table 2. Diet composition (DM basis) for Experiment 1

Item	Diet[a]		
	CON	SAF	COT
Ingredient, % of total diet (dry matter basis)			
Corn grain, cracked	8.2	68.4	52.6
SBM	10.2	12.6	5.3
Barley	53.1	_	_
Mollasses, liquid	28.5	_	_
Safflower seeds	_	19.0	_
Cottonseed	_	_	42.1
Analysis, calculated %[b]			
Dry Matter	89.0	89.0	89.0
Crude Protein	10.8	10.9	10.9
Total Digestible Nutrients	67.0	67.0	67.0
Fat	2.0	5.0	5.0
Analysis, actual %[b]			
Dry Matter	88.8	89.7	90.7
Crude Protein	10.4	9.5	10.5
Total Digestible Nutrients	67.1	64.2	63.3
Fat	1.5	4.0	5.0

[a]Total mixed ration diet formulations for control (CON), safflower (SAF), and cottonseed (COT) treatments. Water and mineral supplements fed ad libitum.

[b]CP, TDN, and fat are expressed on a DM basis.

Table 3. Means (± SE) of calving data for control, safflower, and cottonseed diet calves for Experiment 1

Diet[a]	Heifer weight[b] (Kg)	Heifer BCS[c]	Calf birth weight (Kg)	Calving ease[d]	Vigor Score[e]	Shivering Score[f]	Calving AT[g] °C
CON	544.6 ± 124	5.4 ± .3	37 ± 1.7	1.2 ± .03	1.48 ± .05	2.14 ± .1	12.32 ± 1.8
SAF	576.3 ± 71.6	5.2 ± .2	35.3 ± 1.5	1.2 + .03	1.68 ± .04	1.68 + .1	20.88 ± 2.5
COT	563.9 ± 87.7	5.6 ± .4	37.3 ± 1.6	1.0 ± .01	1.71 ± .06	1.68 ± .1	20.22 ± 2.4

[a]Control (CON), Safflower (SAF), and Cottonseed (COT) diets.

[b]Mean heifer weight at time of calving.

[c]Mean body condition score (BCS) of heifers at time of calving, 1=emaciated to 9=obese.

[d]Calving ease score for heifers at time of calving are 1=unassisted 2=assisted after at least one hour of labor, easy pull 3=assisted after at least one hour of labor, difficult pull.

[e]Vigor scores for calves during cold exposure are 1=alert, vigorous, active 2=alert, calm, able to stand 3=not alert, quiet, lethargic, unable to stand.

[f]Shiver scores for calves during cold exposure are 1=no shivering 2=slight localized shivering 3=moderate body shivering 4=severe overall body shivering.

[g]Ambient temperature at time of calving.

Table 4. Means (± SE)of colostrum data for control, safflower, and cottonseed diet calves for Experiment 1

Diet[a]	Fat (mg/dl)	Lactose (mg/dl)	Solids (mg/dl)	Protein (mg/dl)	IgG (mg/dl)
CON	6.95 ± .4	3.04 ± .3	20.35 + 1.7	15.05 ± 1.1	8472 ± 427.2
SAF	4.31 ± .3	2.93 ± .2	26.18 ± 1.9	21.01 + 1.4	9600 ± 465.5
COT	5.45 ± .3	3.08 ± .3	18.94 ± 1.4	13.46 ± .8	8260 ± 402.1

[a]Control (CON), Safflower (SAF), and Cottonseed (COT) diets.

Table 5. Design and subgroup numbers for Experiment 2

Gestation diet[a]	% fat[b]	Calf Sex		Total number
		Male	Female	
Control	2.0%	15	20	35
Cottonseed	5.0%	21	19	40

[a]Diets were formulated to be isocaloric, isonitrogenous and met NRC requirements for gestating cows.
[b]% fat on DM basis as calculated from proximate analysis of ingredients.

Table 6. Diet composition (DM basis) for Experiment 2

Item	Diet[a]	
	Control	Cottonseed
Ingredient, % of total diet (dry matter basis)		
Hay	76.3	77.9
Corn grain, cracked	18.9	4.9
SBM	3.9	_
Mineral	0.9	1.0
Cottonseed	_	16.2
Analysis, calculated %[b]		
Dry Matter	81.3	81.7
Crude Protein	11.4	11.6
Total Digestible Nutrients	59.2	59.0
Fat	2.0	5.0

[a]Diet formulations for control (CON) and cottonseed (COT) treatments. Water and mineral supplements fed ad libitum.

[b]CP, TDN, and fat are expressed on a DM basis.

Table 7. Mean (± SE) birth weights, physical characteristics, rectal temperatures and ambient temperatures at calving for cottonseed and control diet calves for Experiment 2

Diet[a]	Birth Weight (Kg)	Vigor Score[b]	Shivering Score[c]	Time to Stand[d] (min)	Time to Nurse[e] (min)	BT at 30 minutes[f] (°C)	BT at 180 minutes[g] (°C)	AT at calving[h] (°C)
COT	38.34 ± 1.6	1.07 ± .05	1.32 ± .1	43.05 ± 6.4	101.2 ± 19.0	39.23 ± .13[i]	39.09 ± .12[j]	11.27 ± 2.3
CON	38.66 ± 1.8	1.08 ± .05	1.4 ± .1	42.31 ± 7.2	70.06 ± 21.3	39.19 ± .14	39.18 ± .13	10.52 ± 2.5

[a]Cottonseed (COT) and Control (CON) diets.

[b]Vigor scores for calves during cold exposure are 1=alert, vigorous, active 2=alert, calm, able to stand 3=not alert, quiet, lethargic, unable to stand.

[c]Shiver scores for calves during cold exposure are 1=no shivering 2=slight localized shivering 3=moderate body shivering 4=severe overall body shivering.

[d]Time from parturition until calf stands.

[e]Time from parturition until calf nurses dam.

[f]Rectal temperature of calf at 30 minutes postpartum.

[g]Rectal temperature of calf at 180 minutes postpartum.

[h]Ambient temperature at time of calving.

[i,j]Row means without common superscript letters differ (effect of time $P < .04$).

Table 8. Means (± SE) of metabolic, immunologic, and physiologic traits for cottonseed and control diet calves by sex for Experiment 2

	Cottonseed Diet		Control Diet	
	Bulls (n=21)	Heifers (n=19)	Bulls (n=15)	Heifers (n=20)
Glucose 1 (mg/dl)[a]	59.21 ± 3.5	65.83 ± 3.7	64.11 ± 3.7	70.12 ± 3.8
Glucose 2 (mg/dl)[b]	117.71 ± 3.0	124.55 ± 3.2	121.04 ± 3.2	130.54 ± 3.3
IgG (mg/dl)[c]	3906.66 ± 238.3	3823.12 ± 263.2	3863.33 ± 257.1	3575.8 ± 214.4
BT 30 (°C)[d,h]	39.33 ± .13	39.12 ± .13	39.03 ± .14	39.31 ± .13
BT 180 (°C)[e,h]	39.16 ± .12	39.01 ± .1	39.02 ± .13	39.3 ± .13
Mean AT(°C)[f]	10.04 ± 1.6	12.62 ± 1.7	8.4 ± 1.1	12.11 ± 1.6
Mean BW (kg)[g]	39.37 ± .08	37.02 ± .06	39.46 ± .09	38.03 ± .07

[a]Mean serum glucose concentrations in calves at 180 minutes postpartum.
[b]Mean serum glucose concentrations in calves at 36 ± 4 hours postpartum.
[c]Mean serum IgG concentrations in calves at 36 ± 4 hours postpartum.
[d]Mean rectal temperatures of calves at 30 minutes postpartum.
[e]Mean rectal temperatures of calves at 180 minutes postpartum.
[f]Mean ambient temperature at time of calving
[g]Mean birth weight of calves at parturition.
[h]Diet x sex interaction ($P < .05$).

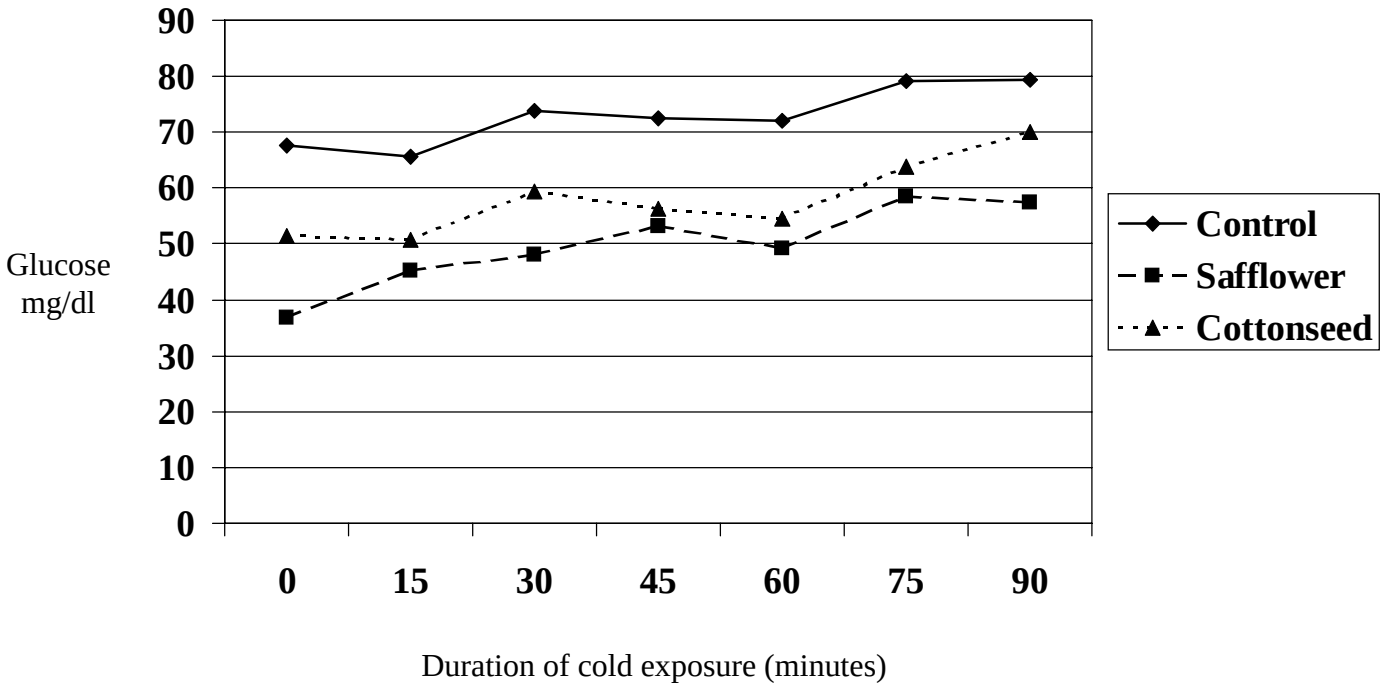

Figure 1. Serum glucose concentration during cold stress for CON, SAF, and COT calves for Experiment 1. No effect of time, diet, calf sex, diet x calf sex ($P > .05$). Standard errors were .8, .9, .7 for CON, SAF, COT, respectively.

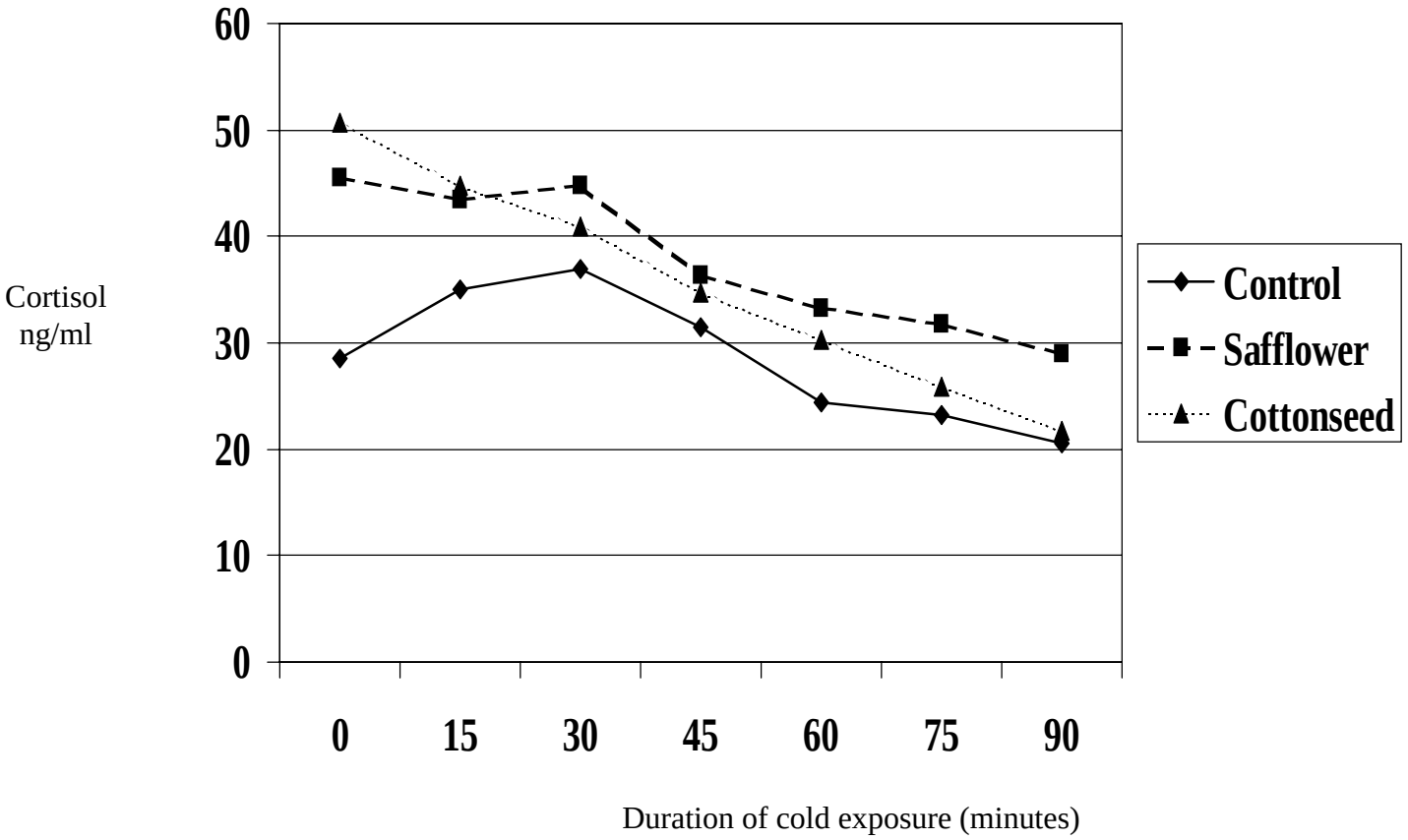

Figure 2. Serum cortisol concentrations during cold stress for CON, SAF, and COT calves for Experiment 1. No effect of time, diet, calf sex, diet x calf sex (P > .05). Standard errors were .6, .8, .9 for CON, SAF, COT, respectively.

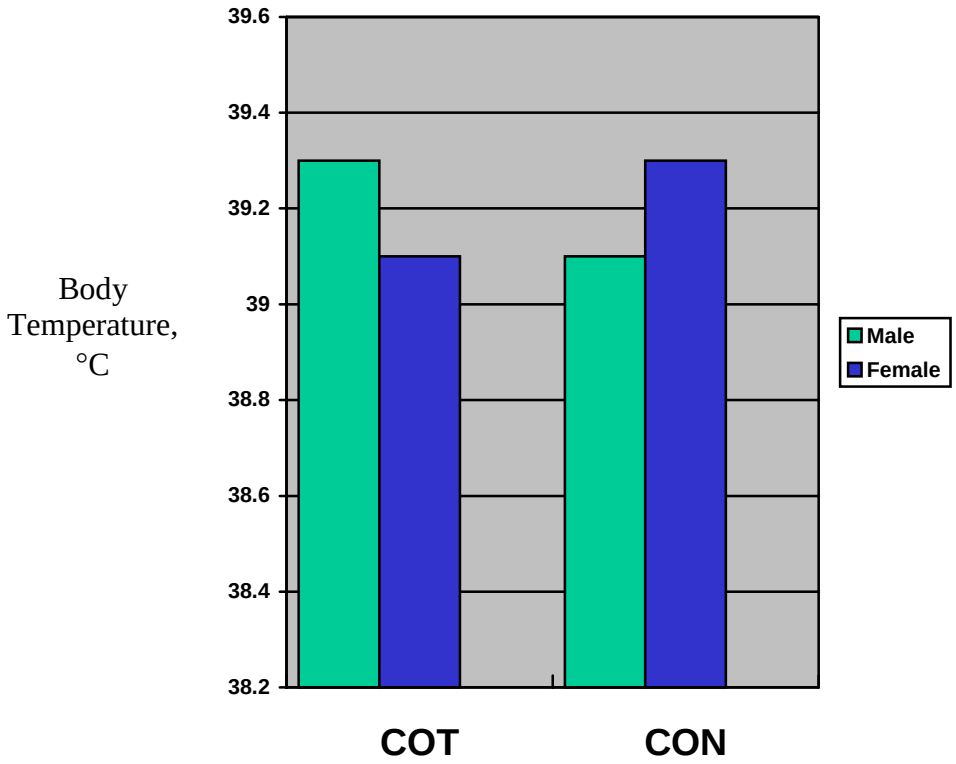

Figure 3. Mean calf body temperature at 30 minutes postpartum for Experiment 2. Standard errors were .18 and .18 for Cottonseed diet bull and heifer calves, and .21 and .19 for Control diet bull and heifer calves, respectively. Effect of diet x calf sex ($P < .04$).

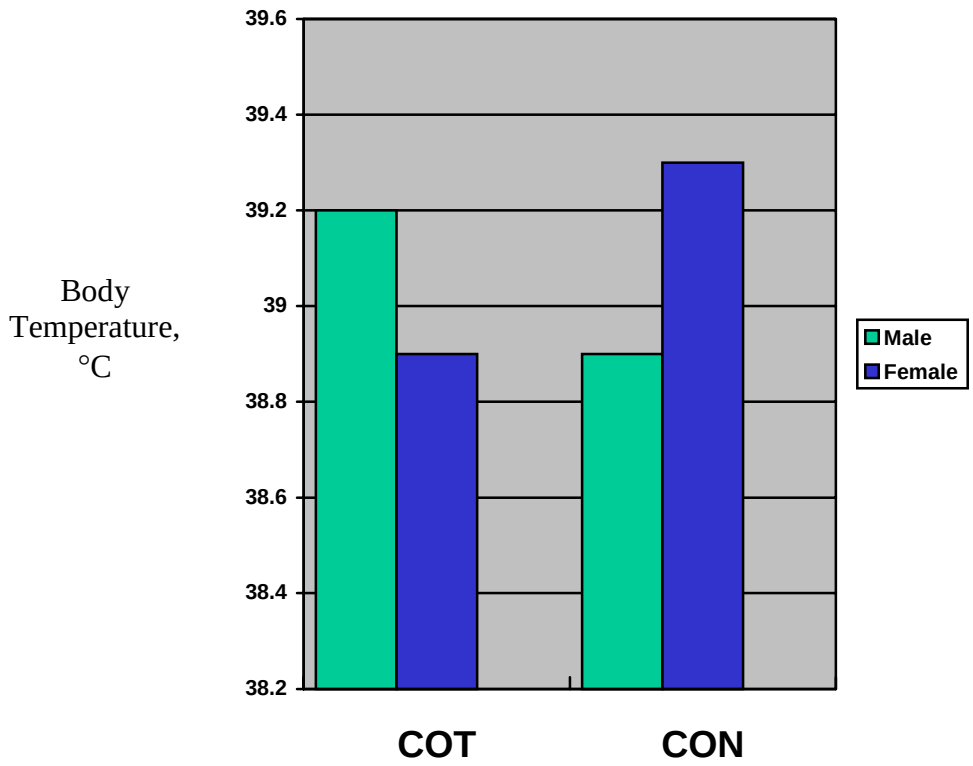

Figure 4. Mean body temperature at 180 minutes postpartum for Experiment 2. Standard errors were .17 and .18 for Cottonseed diet bull and heifer calves, and .20 and .17 for Control diet bull and heifer calves, respectively. Effect of diet x calf sex ($P < .04$).

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