USE OF SOYBEAN HULLS IN DRYLOT BEEF COW-CALF DIETS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

One hundred and twenty-one Red Angus beef cows were used to evaluate the effects of soybean hull inclusion in drylot beef cow diets. Cows were stratified by age, body weight (BW), and body condition score (BCS), and randomly assigned to treatment (n = 4 pens per treatment). Treatments included a control diet (CON) and soybean hull diet (SBH). Beef cow BW, BCS, ultrasound backfat (BF) measurements, colostrum quality, and milk production were evaluated. Beef calf performance was evaluated based on birth weight, weaning weight, ADG, and ultrasound measurements of BF, rump fat, and ribeye area at weaning. Dam BW, BCS, and BF measurements were not affected ($P \geq 0.12$) by treatment. Additionally, calf birth and weaning weights were unaffected ($P = 0.30$). The present study demonstrated that soybean hulls can be included in beef cow diets at 26% of dietary DM without altering cow and calf outcomes.

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thought, you moved from Wisconsin to North Dakota for a girl, you are a true blessing. I look forward to all of what life has to offer us as we start our next adventure!

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LIST OF ABBREVIATIONS

ADF ....Acid detergent fiber

ADG..Average daily gain

BCS ....Body condition score

BF ....Back fat

BW ....Body weight

°C ....Degree Celsius

Ca ....Calcium

cm..Centimeter

CON ....Control diet

CP...Crude protein

d..Day

DM ....Dry matter

DMI...Dry matter intake

g..Gram(s)

h..Head

kg..Kilogram(s)

mDGS ....Modified distillers' grains plus solubles

mm ....Millimeter

n..Number

NASEM ....National Academics of Science Engineering and Medicine

NDF ....Neutral detergent fiber

NEFA ....Non-esterified fatty acid

NDSU..North Dakota State University

NE ....Net energy

NRC ....National Research Council

P ....Phosphorus

SAS ....Statistical Analysis Software

SBH ....Soybean hull diet

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

The annual soybean crop covered over 6.9 million acres in the state of North Dakota with averaged production of 35.5 bushels per acre in the 2018 season (U.S. Department of Agriculture-National Agricultural Statistics Service, 2019). North Dakota produced approximately 332,937 metric tons of soybeans in 2018 (North Dakota Soybean Council, 2019). Several nationally and internationally distributed products including soybean meal, soy oils, and soybean hulls are created through a crushing and oil extraction process (Blasi et al., 2000; American Soybean Association, 2001; Ipharraguerre and Clark, 2003). Soybean hulls used in cattle diets can be distributed as whole, ground, or pelleted forms (Blasi et al., 2000; American Soybean Association, 2001; Ipharraguerre and Clark, 2003; Barmore, 2012).

The highly digestible fiber content of soybean hulls is what allows soybean hulls to be a relatively safe byproduct in ruminant diets, when used to replace portions of grains or forages (Anderson et al., 1988; Löest et al., 2001; Ferreira et al., 2011). Previous research suggested soybean hulls can replace portions of corn grain ≤ 30% (DM basis) and forages ≤ 25% (DM basis; Ipharraguerre and Clark, 2003). Soybean hulls contain approximately 46.4% neutral detergent fiber (NDF), 12.4% crude protein (CP), and 63% total digestible nutrients (TDN; Blasi, 2000; Zelinsky et al., 2006; NASEM, 2016). Common forages replaced by soybean hulls are alfalfa hay, alfalfa silage, and corn silage (Ipharraguerre and Clark, 2003).

Howlett et al. (2003) and Smith et al. (2017a) have demonstrated that the high digestible fiber content of soybean hulls improved fiber digestibility of steers when fed at 30% dietary dry matter. Engel et al. (2008) observed no differences in beef cow performance when supplemented soybean hulls during late gestation. Smith et al. (2017b) supported data proposed by Engel et al.

(2008) and reported soybean hull supplementation of cows with limit-fed hay diets during late gestation did not influence cow or calf performance. Other work demonstrated that when included in the diet, soybean hulls do not negatively impact conception rates of beef cows (Morrison et al., 1999; Howlett et al., 2003; Banta et al., 2008; Engel et al., 2008). Additionally, milk composition is not impacted by soybean hull supplementation when fed at 14 to 25% DM basis (Ipharraguerre and Clark, 2003). Furthermore, Banta et al. (2008) reported no differences in postpartum growth and development of calves at weaning with dams fed soybean hulls.

The objective of this thesis is to expand on previous research involving the use of soybean hulls as a replacement feed source in beef cattle diets during periods of limited forage availability by evaluating beef cattle performance during gestation and lactation. Our hypothesis is that soybean hulls, when included in drylot beef cow diets, will not impact cow or calf performance.

Literature Review

Grazing versus Drylot-Raised Beef Cow-Calf Systems

General Information. Beef production can be broken into multiple segments, including cow-calf, backgrounding, and finishing operations (Gleason and White, 2019). Cow-calf operations produce beef calves that once weaned can be used as replacement heifers or as feeder calves in drylot or grazing systems (Fairbairn, 2017). After weaning, calves often enter a backgrounding system to assist in calf growth by feeding greater concentrations of forage before entering into the feedlot (Comerford et al., 2005; Gleason and White, 2019). Feedlots often purchase and/or receive calves to finish for slaughter by feeding greater concentrations of grain to produce high quality beef (Comerford et al., 2005; Gleason and White, 2019).

There are advantages and disadvantages to raising beef cattle on pasture or in a drylot setting. Availability of resources such as location, land, forage production, and facilities will determine the type of production system used (ZoBell et al., 1999). Previous research demonstrated both aspects of grazing and drylot systems to be successful in beef production (Anderson et al., 2013). In the northern Great Plains, grazing systems place cows on pasture, although, grazed forage may not meet the nutritional needs of cattle during certain periods of the year (Johnson et al., 1998; Cline et al., 2009). This is caused by variability in forage nutritive value that can occur annually as climate and precipitation patterns change (Thomas and Durham, 1964; Moore, 1970, Johnson et al., 1998; Vallentine, 2006; Cline et al., 2009; Lalman, 2018). Energy requirements of beef cattle vary by stage of production, energetic expenditure, and forage energy intake (Caton and Dhuyvetter, 1997; T. McCollum III, 1997). Forage intake is influenced by quality, such as protein content, and forage availability (McCollum III, 1997; Lalman, 2018). To prevent forage quality and quantity deficiencies, nutrient supplementation, such as protein, energy, vitamins, and minerals are often provided to grazing cattle, especially during late-fall and winter (Johnson et al., 1998). Supplementation programs for grazing cattle are used to improve production when nutrients are not supplied by forages to meet nutrient requirements for production goals of beef cattle (Caton and Dhuyvetter, 1997; Lalman, 2018). Baumann et al. (2004) suggests supplementing soybean hulls for cows on forage-based diets can be a suitable energy supplement, as soybean hulls are high in calcium, fiber, and crude protein when compared with forages such as native prairie hay and corn silage.

Further research has been conducted on the use of soybean hulls in finishing beef cattle diets (Hibberd, 1986; Anderson et al., 1988; Ludden et al., 1995; Mueller et al., 2011), but limited research pertaining to drylot beef cows and the use of soybean hulls has been conducted

(Engel et al., 2008; Smith et al., 2017a, b). Mueller et al. (2011) concluded soybean hulls can serve as a potential replacement for dry rolled corn in oat silage-based diets for feedlot cattle. Engel et al. (2008) evaluated performance of beef heifers in a drylot when fed 26% dietary dry matter of soybean hulls during late gestation. Similar BW and BCS were observed in heifers fed soybean hulls versus dried distillers' grains plus solubles (**DDGS**; Engel et al., 2008). In addition, similar calving ease and calf performance were reported for both soybean hull and DDGS diets (Engel et al., 2008). Although soybean hulls supplemented up to 30% dietary dry matter does not affect cattle performance, previous research suggested limits to including soybean hulls in beef cattle diets.

Ludden et al. (1995) reported a decreased risk of metabolic upset with soybean hulls fed at lower inclusion rates (≤ 60% dietary dry matter) whereas Löest et al. (2001) reported an increased risk when soybean hulls were included at 91.6% dietary dry matter. Löest et al. (2001) fed three diets (corn, roughage, and pelleted soybean hulls) to heifers for 98-d to observe growth performance and digestion. Löest et al. (2001) reported beef heifers presented signs of reduced efficiency when fed soybean hull diets. Differences reported in performance are likely caused by changes in gastrointestinal tract fill. This could indicate that the rate at which soybean hulls are included in cattle diets is important, especially for digestion and passage rate.

Several authors reported no differences in cow or heifer performance when fed soybean hulls at inclusion rates between 0 to 60% under feedlot or drylot conditions (Ludden et al., 1995; Engel et al., 2008; Mueller et al., 2011; Smith et al., 2017a, b). Therefore, precautions should be taken when using greater inclusion rates (> 60% DM basis) of soybean hulls in beef cattle diets due to the potential cause of metabolic upsets, such as risk of bloat, and decreased dietary consumption (Löest et al., 2001; Ipharraguerre and Clark, 2003).

Grazing Systems. Cow-calf pairs grazing pasture is a standard practice within the beef industry. Continuous and rotational grazing are two main management practices. Continuous grazing is the simplest grazing system. Although, this continuous grazing can cause overgrazing which reduces forage availability and cattle performance (Vallentine, 2006) if pastures are not managed properly. Changes in season can also affect forage nutrient quality (Johnson et al., 1998; Cline et al., 2010) which is why rotational grazing systems are used to overcome forage availability issues (Vallentine, 2006). Rotational grazing systems are used to increase forage productivity by alternating grazing pressures by using of two or more pastures, this allows time for forages to regrow and prevents a temporal decrease in cattle performance (Moore, 1970; Vallentine, 2006). Rotational grazing provides forage access, but also improves nutrient content to increase forage yield during the growing season (Moechnig, 2010). Rotational grazing will be the main system used in comparison to drylot practices for this literature review.

Management of pastures, such as extended grazing time, and pasture plant species composition are often influenced by regional climate conditions for rotational grazing systems (Moore, 1970; Comerford et al., 2014). The northern Great Plains rangelands consist of mixed season grasses containing both warm and cool seasoned grasses. Predominant vegetation in the northern Great Plains is cool season grasses due to climatic conditions consisting of warm summers and cold winters (Cline et al., 2009; Sedivec et al., 2009). Cool season grasses, such as *Pascopyrum (Wheatgrass)*, *Thinopyrum intermediate (Intermediate Wheatgrass)*, *Bromus inermis (Smooth Brome)*, and *Agropyron cristatum (Crested Wheatgrass)* have an initial growth during spring with a second growth during late summer or early fall (Sedivec et al., 2007). Whereas warm season grasses, such as *Andropogon gerardii (Big Bluestem)*, *Schizachyrium scoparium (Little Bluestem)*, *Panicum virgatum (Switchgrass)*, and *Sorghastrum nutans*

(Indiangrass) grow best during late spring to early fall (Sedivec et al., 2009). Rangeland consisting of mixed season grasses contain both warm and cool season grasses. Overall, grazing management can maximize the quality and quantity of grasses grown throughout the year (Vallentine, 2006; Ball et al., 2007).

Drylot Systems. Producers can house cow-calf operations in either semi- or year-round drylots. Rasby (2016) recommended semi-confinement systems as they are a mix of drylot and pasture-based systems. This is similar to the suggestions provided by Thomas and Durham (1964) and Lardy et al. (2017) for cattle to be placed into a drylot during winter seasons. Year-round drylot systems provide cow-calf pairs with feed, water, and bedding in a pen (Lardy et al., 2017). Drylot systems offer producers an alternative approach to raising cattle.

Although drylot systems may be beneficial, careful consideration is necessary for creating enough space per cow-calf pair based on herd size. Producers can sort cows based on age, weight, and BCS during early gestation/lactation (Lardy et al., 2017). Whereas post calving season, cow-calf pairs can be assigned to a pen based on calf birth date, sex, and sire breed (Deutscher and Slyter, 1978). Pen space is typically divided among cow-calf pairs to provide an equivalent amount of space (Anderson et al., 2013) per pen. Previous research on drylot facilities suggests a minimum of 7.4 square meters per pair and a maximum of 112 square meters per pair (Anderson et al., 2013; Gunn et al., 2014). In addition, adequate bunk space is crucial in a drylot setting. For cow-calf systems, Anderson et al. (2013) recommends at least 0.6 m of bunk space per cow. Creep feeding is another management practice used in cow-calf operations and can provide an advantage to producers who plan to background calves before the finishing phase of production (Lardy et al., 2017).

Controlling nutritional inputs of ruminant diets are important for efficient beef cattle production (Hess et al., 2005). Drylot diets can be balanced to meet NASEM (2016) requirements, although, diet composition may vary each year (Lardy et al., 2017) based on availability of ingredients. Dietary ingredients can vary in producer preference, cost, quantity and quality for drylot systems. As feed continues to be one of the main expenses for beef cattle operations, byproducts, such as soybean hulls, could be a way to reduce these input costs (Ludden et al., 1995; Löest et al., 2001; Mueller at al., 2011).

Nutritional Requirements for Beef Cattle

General Information. Beef cattle require energy for both maintenance and production (i.e., growth, reproduction, etc.). Energy requirements for maintenance in beef cattle are defined by the amount of energy intake resulting in no net loss or gain of energy from tissues (NRC, 1996; NASEM, 2016). Energy requirements necessary for beef cattle production are defined by the amount of energy applied to calf development, reproductive performance, and carcass quality (NRC, 1996; NASEM, 2016). Management of energy reserves in beef cattle is essential for economic success and will vary based on BW, breed, sex, age, season, temperature, physiological state, and previous nutrition (NRC, 1996; NASEM, 2016).

Reproductive Performance. Reproductive efficiency is a key factor in cow-calf operations. Reproductive efficiency is defined as the ability of the cow to resume estrous and achieve optimal reproduction within a short period of time following parturition (Hess et al., 2005). Optimal reproductive performance is influenced by genetic potential as well as nutritional and metabolic demands during early lactation (Mulliniks and Beard, 2018).

The relationship between the nutritional status of the dam, and the ability to conceive are related to energy intake and BCS during postpartum periods of anestrus (Rutter and Randel, 1984; Rusche et al., 1993; Hess et al., 2005). Body condition scores are a common measurement used to determine nutritional status by evaluating the plane of nutrition (over or under fed) for beef cows (Ndlovu et al., 2007; Dahlen et al., 2015). Body condition scores are an estimate of energy reserves within the body and impact reproductive performance (Rutter and Randel, 1984; Vizcarra et al.,1998; Engel et al., 2008; Dahlen et al., 2015). By maintaining BCS of beef cattle during pregnancy and at calving, cows are able to return to estrous sooner (Rutter and Randel, 1984; Dahlen et al., 2015; Engel et al., 2008).

Previous research demonstrated that the use of soybean hulls does not affect dam BW or BCS during late gestation (Engel et al., 2008; Smith et al., 2017b). Consistent reproductive efficiency has been reported in beef cows fed soybean hulls (up to 30% dietary dry matter) compared with cows fed corn-based or roughage-based diets (Morrison et al., 1999; Howlett et al., 2003; Banta et al., 2008; Engel et al., 2008).

Early Gestation and Lactation. Early lactation for beef cattle is a constant period of negative energy expense for the dam (Jorritsma et al., 2003; Engel et al., 2008). Metabolic and nutritional status of the dam during lactation will influence milk production, suckling calf growth, and fetal development (Clutter and Nielsen, 1987; Funston et al., 2010; Radunz et al., 2012; Mulliniks and Beard, 2018; Kennedy et al., 2019). Beef cattle energy requirements during lactation are based on insufficient data, therefore nutritional balance is estimated based on net energy (NE_m) and net protein.

Milk production in dairy cattle is easier to measure than beef cattle (Ipharraguerre and Clark, 2003; NASEM, 2016). This is because producers are able to milk dairy cattle at least twice a day versus producers who leave beef cattle in pasture-based environments (NASEM, 2016). Milk production in beef cattle has not been adequately assessed and effects of age, breed, and stage of lactation are poorly understood (NASEM, 2016). Total milk production values are predicted from NE_m and net protein requirements (NASEM, 2016). As important as it is to meet prepartum energy requirements, there is a greater importance of nutrition on milk yield during lactation (Lalman et al., 2000). Below in Tables 1.1 and 1.2 are the estimated values of Net Energy (Mcal/d) and Net Protein required during lactation. For example, 5 kg/d of milk produced at week 9 of lactation requires 3.58 Mcal/d of energy and 170 g/d of protein whereas 14 kg/d of milk produced at week 9 requires 10.03 Mcal/d of energy and 475 g/d of protein.

Table 1.1. Net Energy (NE_m, Mcal/d) required for milk production[1]

	Milk Yield, kg/d[2]			
Week of Lactation	5[3]	8[3]	11[3]	14[3]
3	2.42	3.87	5.32	6.77
6	3.40	5.44	7.48	9.52
9	3.58	5.73	7.88	10.03
12	3.36	5.37	7.39	9.40
15	2.95	4.72	6.49	8.26
18	2.49	3.98	5.47	6.96
21	2.04	3.26	4.48	5.71
24	1.64	2.62	3.60	4.58
27	1.29	2.07	2.85	3.62
30	1.01	1.46	2.19	2.83

[1]Adapted from NASEM (2016) assuming milk contains 4.0% fat, 3.4% protein, 8.3% solids, and 0.72 Mcal/kg.
[2]Peak milk yield of 5, 8, 11, and 14 kg/d estimated at week 9 of lactation.
[3]Equation used to calculate NE_m (Mcal/d) requirements throughout lactation: FFL = Yen/NEma.

Table 1.2. Net Protein (g/d) required for milk production[1]

	Milk Yield, kg/d[2]			
Week of Lactation	5[3]	8[3]	11[3]	14[3]
3	115	183	252	321
6	161	258	354	451
9	170	272	373	475
12	159	254	350	445
15	140	223	307	391
18	118	188	259	330
21	97	154	212	270
24	68	124	170	217
27	61	98	135	172
30	48	77	105	134

[1]Adapted from NASEM (2016) assuming milk contains 3.4% protein.
[2]Peak milk yield of 5, 8, 11, and 14 kg/d estimated at week 9 of lactation.
[3]Equation used to estimate Net Protein (g/d) requirements throughout lactation: TotalMPI = TotalY/0.65.

Mid- and Late Gestation. Each gestational stage has a different effect on the development of the fetus (Funston et al., 2010; NASEM, 2016), which is why adequate nutrition of the dam is crucial. Maternal nutrition will influence organ and tissue development of the fetus during each phase of gestation (Funston et al., 2010). Previous research indicated a change within maternal nutrition can affect the development and long-term performance of offspring such as muscle development, birth weight, and body composition (Clutter and Nielsen, 1987; Funston et al., 2010; Radunz et al., 2012; NASEM, 2016; Kennedy et al., 2019). During later stages of gestation, net energy and protein requirements are still estimated based on NASEM (2016). Below in Table 1.3 are the estimated values of Net Energy (Mcal/d) and Net Protein (g/d) required during mid- and late-gestational stages.

Table 1.3. Net Protein (g/d) and Net Energy (NE_m, Mcal/d) required by the gravid uterus during gestational stages[1]

Days of Gestation	Available Net Protein, g/d[2]	Net Energy Maintenance (NE_m)[3]
130	9.1	0.327
160	17.5	0.634
190	32.2	1.166
220	56	2.027
250	95.2	3.333
280	156.1	5.174

[1]Adapted from NASEM 2016 for gravid uterine tissues based on average calf birth weight of 38.5 kg.
[2]Equation used to estimate Net Protein (g/d) requirements during days of gestation: MPy = Ypn/0.65.
[3]Equation used to estimate Net Energy (Mcal/d) requirements during days of gestation: NEy = $[CBW \times (0.05855 - 0.0000996 \times DP) \times e^{(0.03233 \times DP - 0.0000275 \times DP^2)}]/1{,}000$.

Maternal Nutrition Effects on Calf Development and Performance. Fetal growth and development are dependent on maternal nutrition (Radunz et al., 2012). Nutrient restriction during early or late gestation can affect placental and/or fetal organ system development (Funston et al., 2010). During early-gestation, physiological changes occur between maternal and fetal tissue within the uterine environment (Reynolds and Redmer, 1995; Duarte et al., 2014). Muscle fiber formation will occur during mid-gestation (Duarte et al., 2014) and can be sensitive to dam nutritional deficiency (Zhu et al., 2004). Maternal nutrition impacts fetal growth and development during each gestational stage.

Poor maternal nutrition during late gestation will decrease calf performance as fetal development is heavily impacted by the nutrient status of the dam (Robinson et al., 1977; Funston et al., 2010; Randuz et al., 2012; Wang et al., 2015). Maternal nutrient deficiencies during calf development can result in long-term negative effects in the calf (Radunz et al., 2012). Disturbances in calf development such as reduced postnatal growth and insulin sensitivity, postpartum, are associated with low protein in maternal nutrition (Radunz et al 2012). Wang

(2015) suggests under or overnutrition of the dam will alter placental hormone concentrations, affecting fetal growth, postnatal growth, and adipose deposition of the calf.

Postpartum development and weaning weight of calves are greatly influenced by maternal nutrition delivered through milk (Knapp and Black, 1941; Boggs et al., 1980; Frecking and Marshall, 1992; Funston et al., 2010; Radunz et al., 2012). Previous research indicated an increase of energy intake by the dam will increase milk production (Lalman et al., 2000). Colostrum intake can influence feedlot health based on the supply of passive immunity provided to the calf by the dam (Funston et al., 2010; Dunn et al., 2016). By meeting NASEM (2016) requirements during pregnancy, we are able to foster a successful cow-calf operation.

The energy value of soybean hulls is 74 to 80% of that of corn grain (Ludden et al., 1995). Several authors reported soybean hull supplementation (up to 30% dietary dry matter) did not negatively affect digestion or performance of dairy cows (Nakamura and Owen, 1989; Sarwar et al., 1992; Ipharraguerre et al., 2002a). Weidner and Grant (1994b) reported soybean hulls fed at an inclusion rate of 7% in forage-based diets did not impact dairy cow performance. In addition to Weidner and Grant (1994b), several authors supported the idea (Firkins and Eastridge, 1992; Stone, 1996) of soybean hulls replacing portions of forage-based diets will not affect cow performance, dry matter intake, or milk production. These authors have also reported no differences in milk composition when dairy cows were fed soybean hulls at 0 to 25% DM basis. Banta et al. (2008) reported no differences in calf weaning weight when dams were fed soybean hulls. Furthermore, Faulkner et al. (1994) observed no differences in calf carcass measurements when calves were creep fed soybean hulls at 1.0 kg/d DM.

Soybean Hull Production and Management

General Information. Soybean hulls are a byproduct of soybean processing (Blasi et al., 2000) and can be used as a dietary fiber source in ruminant diets (Löest et al., 2001; Ferreira et al., 2011; Mueller et al., 2011). The nutritive value of soybean hulls is similar to corn when used in low inclusion rates (up to 30% dietary dry matter) in high forage diets (Anderson et al., 1988; Ferreira et al., 2011; Mueller et al., 2011). Furthermore, Jenkins et al. (2014) recommends feeding energy dense by-products such as soybean hulls as an alternative feed when crop residues are unavailable.

Soybean Crushing Process. The soybean crushing process is divided into three steps which are demonstrated in Figure 1.1. The steps of this process are: **(1) Soybean Preparation** – Raw soybeans enter into the facility and are stripped of impurities and dried to approximately 10% moisture (Blasi et al., 2000; American Soybean Association, 2001; Ipharraguerre and Clark, 2003). Soybeans are then cracked and flaked to dehull a majority of the soybean hulls which are then separated with the use of a sifter (Blasi et al., 2000; American Soybean Association, 2001; Ipharraguerre and Clark, 2003). Once soybean hulls have been separated from the soybean, the soybean will continue onto steps 2 and 3 of the crushing process (American Soybean Association, 2001; Ipharraguerre and Clark, 2003). **(2) Extraction** – Oils are extracted from the soybean(s) by using an organic solvent, hexane (Blasi et al., 2000). The extracted oil will be purified and is then ready for production or shipping, to be used by diverse industries. Remaining soybeans are washed to remove hexane remnants before entering step 3 (Blasi et al., 2000). **(3) By-Product Production** – Soybeans are now used to create by products such as soybean meal and soy oil. At this point it is possible for any remaining soybean hulls to be removed and be toasted and mixed into soybean meal products, other soy protein products, or recycled for future use (Blasi et al., 2000). Soybean hulls can be used as is and made into byproduct forms such as whole, ground, or pelleted forms to be used by diverse industries (Blasi et al., 2000).

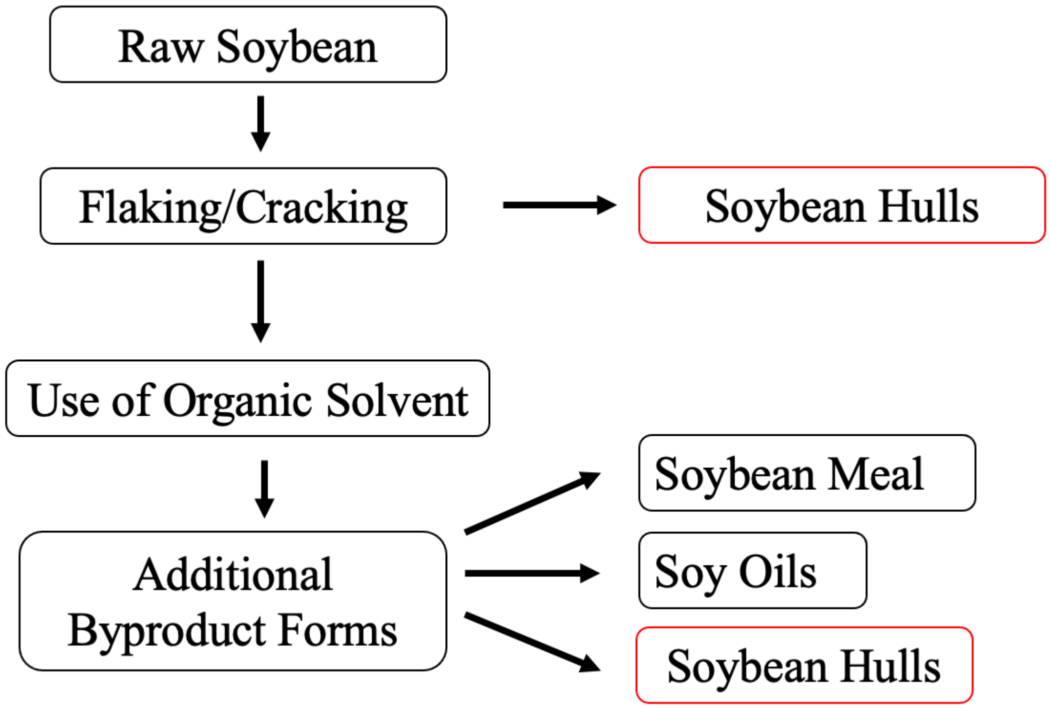

Figure 1.1. Flow diagram outlining soybean crushing process and extraction of hull from soybean**.** Red boxes indicate soybean hull extraction points. Adapted from Blasi (2000).

Soybean Hull Nutrition

Soybean Hulls versus Other Feed Ingredients. Soybean hulls can provide similar, and even greater nutritional values such as CP, acid detergent and neutral detergent fiber to that of corn and corn silage (Boyles, 1999; Jenkins et al., 2014; NASEM, 2016). Blasi et al. (2000) explained that pelleted soybean hulls are highly digestible and considered a source of readily available energy, as well as fiber, due to their structural carbohydrates. Soybean hulls have greater amounts of readily digestible fiber that result in greater energy values compared with most feed ingredients that are similar in acid detergent and neutral detergent fiber values. Soybean hulls are high in calcium (Ca) while phosphorus (P) values remain low, allowing for a natural 2:1 ratio (Zelinsky, 2006). Complete nutrient profiles for common feedstuff and soybean hulls are provided in Table 1.4 and 1.5.

Structural carbohydrates are one of the major energy sources by providing fiber to stimulate rumination and reticuloruminal motility (Fahey and Berger, 1988; NASEM, 2016) with rumen microbes. The rate at which starch is digested is heavily influenced by the diet, rate of consumption, and source of starch provided (Huntington, 1997). Starch-based feeds, such as cereal grains, are considered non-fibrous or non-neutral detergent fiber (non-NDF) carbohydrates (Fahey and Berger, 1988; NASEM, 2016). These cereal grains contain starch deposits within the endosperm with a protein matrix can affect digestion rate (Merchen, 1988; NASEM, 2016). The ability of the ruminant to regurgitate and rechew feed during the process of rumination, reduces grain particle size and allows for greater surface area which is necessary for microbial digestion (Huntington, 1997; Hoffman, 1988; Merchen, 1988; NASEM, 2016). Extensive starch digestion can lead to metabolic upsets such as acidosis if diets are not monitored appropriately (Russell et al., 1992; NASEM, 2016). Similar to cereal grain inclusion rates, soybean hulls can also cause potential risk of metabolic upset if not balanced properly (Löest et al. 2001), especially when fed at greater inclusion rates (≥ 91.6%) within the diet.

Compared with grains, the high amounts of structural carbohydrates found within soybean hulls can decrease risk of ruminal acidosis and allow for a quicker passage rate (Grant, 1991; Ludden, 1995; Parish, 2007). Löest et al. (2001) and other work (Nakamura and Owen, 1989; Weidner and Grant, 1994b) suggest the small particle size of soybean hulls is what allows for rapid ruminal passage rates. Nakamura and Owen (1989) proposed the rate of passage of soybean hulls is approximately 8% faster when soybean hulls are constituted as the major ingredient of the diet. This would suggest that feeding soybean hulls at greater inclusion rates, such as 91.6%, causes soybean hull particles in the rumen to be flushed into the lower digestive tract too rapidly which would decrease rumination (Löest et al., 2001; Ipharraguerre and Clark, 2003). The rumen is the primary pregastric site of fiber digestion through the use of anaerobic fermentation (Merchen, 1988; NASEM, 2016). The fiber mat within the rumen works to entangle the fiber particles within the soybean hull. Neutral detergent fiber assists in stimulating rumination, regurgitation, salivation, and rechewing of feed in order to decrease particle size necessary for digestion (Parish, 2007; NASEM, 2016). Rumen microorganisms will then attach to the surface area of the newly entangled fiber particles and increase the digestion rate of the soybean hulls (Parish, 2007). As a highly digestible fiber byproduct, soybean hulls contain greater concentrations of neutral detergent fibers (NDF) and provide cattle with dietary energy (Blasi et al., 2000; Boyles, 1999; NASEM, 2016). Previous research suggested no differences in cattle performance when fed soybean hulls compared with grains and/or forages (Anderson et al., 1988; Engel et al., 2008; Ferreira et al., 2011; Mueller et al., 2011; Smith et al., 2017a, b). Therefore, soybean hulls are considered a relatively safe by-product in ruminant diets, when fed at inclusion rates of ≤ 60% for grains or forage substitutions (Anderson et al., 1988; Löest et al., 2001; Ferreira et al., 2011).

Soybean Hull Feed Management

Feed Distribution. Soybean hulls can be distributed in a number of forms, but management practices of these byproduct types are important for proper storage and disbursement. Unlike pelleted soybean hulls, whole or ground soybean hulls have a greater chance of feed loss, due to environmental influence during disbursement (Blasi et al., 2000). Feed shrink is commonly referred to as the amount of feed loss from point of purchase to consumption via transportation, handling, disbursement, and/or mixing (Barmore, 2012) of soybean byproducts into cattle feed. Lack of management practices could disrupt soybean byproduct distribution. In addition, whole and ground soybean hulls are able to hold more moisture and cause difficulty in distributing the byproduct form (Blasi et al., 2000; Barmore, 2012). Whereas pelleted soybean hulls hold less moisture and provide opportunity to store in bins because of the increased bulk density compared with un-pelleted soybean hulls (Blasi et al., 2000; Barmore, 2012). This study uses pelleted soybean hulls based on the bulk per ton expense.

Table 1.4. Nutrient composition of soybean hulls and other concentrate feeds

	Nutrient Content (% DM)							Energy Content (Mcal/kg)	
Item	**CP**	**ADF**	**NDF**	**TDN**	**Ca**	**P**	**Starch**	**NE_m**	**NE_g**
Soybean Hull	12.37 ± 2.15	46.40 ± 4.84	46.40 ± 4.84	62.6 ± 4.16	0.60 ± 0.09	0.15 ± 0.08	1.10 ± 1.22	1.4	0.82
Grains									
Barley	12.78 ± 2.83	7.09 ± 2.11	18.29 ± 3.96	84.1 ± 2.13	0.08 ± 0.05	0.38 ± 0.07	56.74 ± 4.54	2.06	1.49
Corn Dry Rolled	8.79 ± 0.97	3.56 ± 0.88	9.72 ± 1.83	87.6 ± 1.83	0.03 ± 0.06	0.29 ± 0.05	72.07 ± 3.18	2.17	1.52
DDGS	30.79 ± 2.67	16.17 ± 3.15	33.66 ± 2.67	89.0 ± 4.48	0.05 ± 0.04	0.86 ± 0.11	5.58 ± 2.43	2.21	1.52
mDGS	29.08 ± 2.45	14.81 ± 3.06	28.73 ± 3.67	93.0 ± 5.71	0.08 ± 0.05	0.94 ± 0.14	3.36 ± 1.07	2.33	1.62
Millet	11.27 ± 2.04	13.88 ± 5.13	21.61 ± 6.33	76.2 ± 7.07	0.68 ± 0.78	0.30 ± 0.07	49.24 ± 9.92	1.83	1.20
Oat	12.55 ± 1.89	13.30 ± 4.77	26.65 ± 8.62	83.0 ± 4.23	0.10 ± 0.05	0.38 ± 0.09	44.09 ± 7.94	2.03	1.37
Sorghum	11.64 ± 1.83	4.57 ± 1.81	7.20 ± 3.58	86.0 ± 1.86	0.06 ± 0.05	0.34 ± 0.05	71.16 ± 5.55	2.12	1.45
Triticale	12.13 ± 2.20	4.49 ± 1.05	14.10 ± 2.61	82.7 ± 1.23	0.07 ± 0.06	0.36 ± 0.06	61.04 ± 4.39	2.02	1.37
Wheat	13.79 ± 2.46	4.15 ± 1.46	12.36 ± 2.92	86.8 ± 1.83	0.08 ± 0.06	0.36 ± 0.07	62.42 ± 5.10	2.15	1.47

Information adapted from NASEM (2016).

Table 1.5. Nutrient composition of soybean hulls and other roughages

	Nutrient Content (% DM)							**Energy Content (Mcal/kg)**	
Item	**CP**	**ADF**	**NDF**	**TDN**	**Ca**	**P**	**Starch**	**NE_m**	**NE_g**
Soybean Hull	12.37 ± 2.15	46.40 ± 4.84	46.40 ± 4.84	62.6 ± 4.16	0.60 ± 0.09	0.15 ± 0.08	1.10 ± 1.12	1.4	0.82
Roughages									
Alfalfa Hay	19.81 ± 3.18	33.25 ± 5.91	41.73 ± 8.53	55.2 ± 5.86	1.47 ± 0.26	0.26 ± 0.05	2.97 ± 1.37	1.15	0.59
Barley Hay	10.95 ± 3.84	33.88 ± 6.47	56.88 ± 8.59	60.2 ± 5.21	0.37 ± 0.18	0.24 ± 0.08	5.66 ± 5.52	1.31	0.74
Bromegrass Hay	8.34 ± 2.33	40.29 ± 3.74	65.92 ± 4.64	52.0 ± 4.29	0.55 ± 0.10	0.18 ± 0.05	2.64 ± 0.35	1.04	0.49
Fescue Hay	9.22 ± 3.02	40.30 ± 4.40	64.99 ± 4.12	58.3 ± 2.52	0.48 ± 0.18	0.22 ± 0.08	--	1.25	0.68
Meadow Hay	8.79 ± 2.64	35.79 ± 3.31	60.85 ± 4.57	52.9 ± 4.31	0.50 ± 0.16	0.18 ± 0.05	--	1.07	0.51
Millet Forage Hay	9.53 ± 3.29	37.69 ± 5.26	62.48 ± 6.02	52.5 ± 4.90	0.50 ± 0.19	0.21 ± 0.06	2.91 ± 2.06	1.06	0.50
Native Prairie Hay	6.76 ± 2.02	41.45 ± 3.93	66.58 ± 4.82	48.4 ± 4.77	0.49 ± 0.13	0.13 ± 0.05	--	0.91	0.37
Oat Hay	8.73 ± 2.56	37.08 ± 4.66	59.13 ± 6.40	59.9 ± 4.22	0.29 ± 0.13	0.21 ± 0.06	3.97 ± 2.57	1.31	0.73
Sundangrass Hay	8.33 ± 2.62	41.1 ± 4.11	65.83 ± 4.00	54.5 ± 2.80	0.44 ± 0.09	0.20 ± 0.05	1.60 ± 1.39	1.12	0.57
Timothy Hay	9.44 ± 3.19	38.04 ± 2.74	63.81 ± 3.90	57.0 ± 0.00	0.42 ± 0.12	0.21 ± 0.07	--	1.21	0.64
Triticale Hay	11.58 ± 4.34	36.69 ± 6.34	57.73 ± 8.30	58.5 ± 4.42	0.31 ± 0.12	0.25 ± 0.08	5.06 ± 6.38	1.26	0.69
Wheat Hay	11.11 ± 3.93	35.89 ± 6.14	57.89 ± 7.90	58.8 ± 4.51	0.32 ± 0.15	0.21 ± 0.07	4.68 ± 4.74	1.27	0.70
Barley Silage	12.05 ± 2.98	34.73 ± 5.06	54.77 ± 7.17	60.6 ± 4.58	0.41 ± 0.15	0.30 ± 0.06	9.17 ± 8.16	1.33	0.75
Corn Silage	8.24 ± 1.06	25.46 ± 3.84	42.98 ± 5.48	67.7 ± 2.40	0.24 ± 0.05	0.23 ± 0.02	32.58 ± 6.96	1.56	0.96
Wheat Silage	12.67 ± 3.13	36.59 ± 4.40	56.54 ± 6.21	59.1 ± 3.73	0.33 ± 0.17	0.11 ± 0.06	6.62 ± 6.82	1.28	0.71

Information adapted from NASEM (2016).

Previous Research with Soybean Hulls in Beef Cattle Diets. There are many benefits to using soybean hulls as a partial forage replacement in beef cow diets. Soybean hulls can be used as an energy source in ruminant diets (Anderson et al., 1988) because unlike many crop residues which are low in digestibility, soybean hulls are typically greater in nutritional value and are considered energy dense (Jenkins et al., 2014). Previous research suggested a direct correlation between dry matter intake (DMI) and average daily gain (ADG) which affects feed efficiency (Russel et al., 2016). Russel et al. (2016) reported an increase in beef cow ADG when fed increased inclusion rates of soybean hulls. In addition, Anderson et al. (1988) supports Russel et al. (2016) findings and suggests that soybean hulls have the ability to support and/or increase daily gains in beef heifers similar to that of corn. Low inclusion rates of soybean hulls may increase feed efficiency whereas high inclusion rates will decrease feed efficiency (Ludden et al., 1995; Ferreira et al., 2011; Russel et al., 2016; Smith et al., 2017a).

Soybean hull-based diets produce greater digestibility than DDGS diets (Smith et al., 2017a). This is brought on by the digestible fiber provided by the hull (Löest et al., 2001). Previous work demonstrated that soybean hulls can be utilized in mid- to late-gestation as a partial forage replacement without impacting cow or calf performance (Smith et al., 2017b). Supplementing soybean hulls and DDGS have also provided similar effects on body weight and condition scores in heifers when limit-fed (Engel et al., 2008). Between calving and breeding there was no weight change in the primiparous cows when fed soybean hulls at 26% of the diet (Engel et al., 2008). Engel et al. (2008) reported similar calf performance with dams fed either soybean hull or DDGS diets.

Beef Cattle Performance

Herd Health. Herd health is partially dependent upon herd health programs. Management of healthy calves is based on maintaining a vaccination protocol, administration of effective vaccinations, and limiting disease exposure (Stoltenow and Lardy, 1999; Comerford et al., 2014). In addition to a vaccination protocol, minimizing stress is essential for cow-calf pairs to reach peak performance (Stolenow and Lardy, 1999; Bourg, 2012; Comerford et al., 2014). Providing clean environments for cow-calf pairs can reduce environmental stressors and potential diseases (Bourg, 2012). Adequate nutrition can support the immune system, reproductive performance, and growth of cow-calf pairs (Bourg, 2012; Lardy et al., 2017).

Vaccine protocols increase the immunity of a herd. Management protocols for vaccination of calves through a preweaning program can prevent common diseases (Stolenow and Lardy, 1999) responsible for economic loss in the cattle industry (Engelken, 1997). Preweaning health programs are used to reduce diseases within a herd (Stoltenow and Lardy, 1999) and are best discussed with a local veterinarian (Engelken, 1997; Wenzel, 2015; Lardy et al., 2017). For example, respiratory diseases are estimated to be responsible for 8% of pre-weaned calf death rates (Engelken, 1997). Vaccinations used for initial immunity against these common diseases are given at 2 to 3 months of age and boostered near weaning (Bagley, 2001; Wenzel, 2015). Vaccines allow the immune system to build resistance against disease-causing antigens. Some of the most common respiratory diseases to protect against would include infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), parainfluenza 3 (PI3), and bovine respiratory syncytial virus (BRSV) (Comerford et al., 2014). Clostridial disease is also common to vaccinate against (Bagley, 2001). Implementing a preweaning health program into a herd is important for prevention of transmissible diseases.

Management practices are key to reducing stress and disease-causing pathogens. Providing a clean environment for cow-calf pairs can reduce environmental and disease-causing stressors (Bourg, 2012; Lardy et al., 2017). As weaning approaches, there are multiple management strategies to reduce stress implemented through sorting, hauling, and unfamiliar surroundings (Bourg, 2012). The additional stress of weaning is why preweaning health programs are important. By preconditioning calves, producers are reducing stress and potential sickness that may come in the following weeks (Lalman and Ward, 2005).

Meeting nutritional requirements throughout an entire production cycle is essential to ensure production efficiency of a herd (Morrison et al., 1999; Funston et al., 2010). Maternal nutrition pre- and postpartum influences calf growth until weaning (Perry et al., 1991; Beaty et al., 1994; Spitzer et al., 1995; Stalker et al., 2006). In addition to fetal and postnatal growth and development, maternal nutrition can affect the mammary gland and colostrum yield (Funston et al., 2010; Dunn et al., 2016). Nutritional status can influence weight, health, growth, reproduction, carcass weight, and carcass quality of a herd (Funston et al., 2010; Bourg, 2012).

Reproduction and Artificial Insemination. In addition to maternal nutritional and health status, a reproductive protocol is recommended to ensure pregnancy. Reproductive efficiency is an essential asset of cow-calf operations (Rusche et al., 1993). There are several management strategies for beef cattle reproduction. These strategies include synchronizing estrous and ovulation cycles, sire selection, and artificial insemination (Lamb et al., 2009; Romano, 2014). The use of these reproductive techniques can decrease estrus detection, increase reproductive efficiency within a herd, and decrease length of calving seasons (Lamb et al., 2009).

Reproductive techniques such as artificial insemination (**AI**), estrous synchronization, and fixed-time AI are used by producers to improve productivity and profitability of their operation (Rodgers et al., 2012; Dahlen et al., 2014; Mercadante et al., 2015). Artificial insemination has become beneficial to cattle producers because of its ability to improve production traits, increase genetic potential, sire selection, and reduce disease in their herd (Mercadante et al., 2015). By using an AI protocol with estrous synchronization, producers are able to shorten calving seasons.

Beef cattle have a 21-d estrous cycle that can be manipulated via exogenous hormones to bring females into heat (Odde, 1989). The technique used to manipulate estrous cycles of beef cattle with the use of these hormones is called synchronization (Lamb et al., 2009). The inability to synchronize estrous and ovulation cycles, reduces pregnancy rates (Lamb et al., 2009). Recent developments in reproductive management have demonstrated effective synchronization and decreased periods of estrus detection (Lamb et al., 2009). Beef cows managed in confinement allow for quicker and more efficient estrus detection and synchronization compared with cows raised on pasture (Lardy et al., 2017). Overall, synchronizing estrous cycles of beef cows within a herd will increase conception rates and shorten breeding seasons (Odde, 1989; Lamb et al., 2009).

Sire selection is a crucial aspect of reproductive success. With the use of AI, producers lose the ability of traditional bull selection (Dahlen et al., 2015). The use of AI has the ability to present genetically superior sires into a herd (Lamb et al., 2009; Dahlen et al., 2015). Advances to AI technology can also lower breeding costs for producers (Lamb et al., 2009). Managing beef cows on pasture and performing AI programs can be quite difficult because of the labor needed to enhance efficiency (Odde, 1989). Therefore, confinement systems are more beneficial to producers for heat detection and breeding protocols (Lardy et al., 2017).

Milk Quality. Stage of lactation is affected by several factors including calving, calving season, nutritional status (Rodrigues et al., 2014), genetics and environment (Sullivan, 2009). Maternal nutrition can influence both in utero programming and colostrum quality through nutrients, immunoglobulins, and growth factor supply (Funston et al., 2010; Hammer et al., 2011; Kennedy et al., 2019). After parturition, colostrum provides calves with passive immunity from the dam, proteins, fats, lactose, amino acids, energy, and vitamins and minerals (Quigley and Drewry, 1998; Georgiev, 2008; Dunn et al., 2016). For instance, protein concentration in colostrum has a strong relationship with IgG absorption in postnatal calves (Quigley and Drewry, 1998). In dairy cattle, energy balance is often indicated through milk protein and the milk protein:fat ratio (Konigsson et al., 2008).

In comparison to milk composition, colostrum will contain greater concentrations of nutrients to provide passive immunization to the calf (Georgiev, 2008). Previous research suggests that colostrum quality is more similar to that of milk composition at 3-d postpartum (Georgiev, 2005; Georgiev, 2008). Milk composition (milk protein, fat, solid contents) is influenced by stage of lactation and diet (Rodrigues et al., 2014). Milk containing greater fat and protein content has been associated with pre-weaning weight gain in calves (Rodrigues et al., 2014).

Milk Production. Nutritional status of the dam influences milk production (Swanson et al., 2008; Brown et al., 2002). Early post-partum calf development is dependent upon maternal nutrition to provide the necessary nutrients through milk. In addition to early development, maternal nutrition and milk production are a critical component of preweaning calf growth (Brown et al., 2002). Previous research indicated milk production influences 60 to 66% of calf weaning weight difference (Boggs et al., 1980; Rodrigues et al., 2014). Milk production is the main factor influencing calf weaning weight (Knapp and Black, 1941; Boggs et al., 1980).

Measuring milk production in beef cattle is difficult as they are not routinely milked like dairy cattle; but it can be assessed by calf weaning weights, milk samples collected by hand or machine, teat cannulation post oxytocin injection, or the weigh-suckle-weigh technique (NASEM, 2016). Weigh-suckle-weigh is a primary technique used to measure milk produced by the dam in beef cattle (Benson et al., 1999). Calves are separated from their dam for a period of time, weighed, and allowed to suckle. This technique can be used from d 50 to 180 postpartum (Williams et al., 1979; Boggs et al., 1980; Beal and Notter, 1990; Radunz et al., 2010) with a variety of separation intervals between the dam and calf within a 24-hour period (Le Du et al., 1978). Separation intervals may vary from 2 hours to 24 hours (Williams et al., 1979; Boggs et al., 1980; Beal and Notter, 1990; Radunz et al., 2010). Modified procedures can include more than one separation prior to milk production determination (Williams et al., 1979; Beal and Notter, 1990; Benson et al., 1999; Radunz et al., 2010). Milk yield is measured as the difference in calf weight before and after suckling (Beal and Notter, 1990; Sullivan et al., 2009).

Blood Metabolites

General Information. Blood metabolites are influenced by feed intake and indicate the energy and/or protein status of cattle (Bowden, 1971; Noya et al., 2020). Relationships between blood metabolites and hormones play a large role in gestational stages and lactation (Bowden, 1971; Konigsson et al., 2008) as metabolic hormones influence nutrient supply during milk synthesis (Lake et al., 2006). Metabolites such as non-esterified fatty acids (**NEFA**) and ketone bodies, and blood glucose have a role in the synthesis and secretion of milk fat (Bowden, 1971).

Non-esterified fatty acids are released from lipid stores to be used as an alternative energy source for the cow or assist the udder to provide milk triglycerides (Konigsson et al., 2008).

Non-esterified Fatty Acids. Metabolites such as NEFA are classified as blood lipids in conjunction with glycerides, cholesterol esters, free cholesterol, phospholipids, cerebrosides, and short-chain fatty acids (Bowden, 1971). Non-esterified fatty acids are considered a metabolic fuel that are created during lipolysis and are used to measure the nutritional status of beef cattle based on lipid mobilization (Adewuyi et al., 2005; Ndlovu et al., 2007; Konigsson et al., 2008). As adipose tissues become mobilized, NEFAs are released into the blood plasma to support the metabolic needs of cattle (Bowden, 1971).

During early pregnancy and lactation, NEFA concentrations are increased, likely because of beef cattle experiencing a period of negative energy balance associated with high energy requirements related to milk production and insufficient feed intake postpartum (Konigsson et al., 2008). Previous studies have reported negative energy balance in cattle is related to the interval to first ovulation during the first 3 weeks of lactation (Beam and Butler, 1999; Butler, 2000; Konigsson et al., 2008). The greatest concentrations in plasma are seen during peak lactation, likely caused by the mammary gland using NEFA to provide milk triglycerides or act as an alternative energy source for the dam (Bowden, 1971; Hart et al., 1978; Konigsson et al., 2008).

Glucose. Previous research suggests energy and protein intake will influence glucose concentrations of cattle (Vizcarra et al., 1998; Rodríguez-Sánchez et al., 2018). The metabolic pathway of gluconeogenesis takes place in the liver and is responsible for glucose synthesis (Vizcarra et al., 1998; Brockman and Laarveld, 1986). Blood glucose concentration is regulated by metabolism (Brockman and Laarveld, 1986) and with several hormones such as insulin.

Circulating blood glucose concentrations will fluctuate during pregnancy in ruminants (Brockman and Laarveld, 1986; Grattan, 2015). During lactation, glucose production is promoted at the expense of low insulin concentrations to provide nutrient supply to the mammary glands and uterus for milk production and fetal development (Brockman and Laarveld, 1986). Glucose concentrations are considered the main source of energy for lactating cows (Rodríguez-Sánchez et al., 2018) because a greater demand for glucose occurs during peak milk production during lactation (Vizcarra et al., 1998). As weaning age approaches and calves reduce milk intake, a shift in blood glucose concentration will occur to reduce milk production (Flint, 1995; Rodríguez-Sánchez et al., 2018).

Conclusion

Traditionally, producers raise beef cattle on pasture but in recent years, drylot beef cattle operations have become an alternative. Managing cow-calf operations in a drylot system requires a greater demand for labor and equipment but decreases energy expenditure in cattle by meeting nutritional requirements daily. To continue improving beef cattle operations, nutritional status of beef cows can be evaluated with many techniques, by assessing BW and BCS, blood metabolite concentration analysis, and milk quality and production. Furthermore, evaluating the use of different feed sources in drylot beef cattle diets has become a popular topic when assessing nutritional requirements of cattle. Although, scientific literature suggests the use of alternative feed sources in drylot operations, alternative feed sources have only been assessed for limited durations throughout beef cow production cycles.

There is a lack of data in scientific literature regarding soybean hulls as a forage replacement for drylot managed cow-calf operations throughout an entire production cycle. Investigating soybean hulls as a partial forage replacement will undoubtedly add to current literature and assist producers in determination of feed ingredients used for beef cattle. Determining performance of beef cows fed either soybean hull-based diets or corn/corn silage-based diets under drylot management throughout an entire production cycle will further aid in understanding forage replacements. Research is needed to confirm whether or not soybean hulls are a good substitute for traditional forages in drylot managed beef cattle.

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CHAPTER 2. USE OF SOYBEAN HULLS IN DRYLOT BEEF COW-CALF DIETS

Abstract

One-hundred twenty-one Red Angus beef cows were used to evaluate the effects of soybean hull inclusion in beef cow diets. Cows were stratified by age, body weight (**BW**), and body condition score (**BCS**) and were randomly assigned to treatment (n = 4 pens per treatment). Diets were formulated to meet the nutritional requirements of beef cows for early gestation, mid-gestation, late gestation, and lactation. Dietary treatments included 1) control diet [**CON**; corn silage, modified distillers' grains plus solubles (mDGS), and wheat straw], and 2) soybean hull diet [**SBH**; 26 to 27% soybean hulls (DM basis) replacing portions of corn silage, mDGS, and wheat straw]. Beef cow BW, BCS, average daily gain (**ADG**), and back fat (**BF**) were evaluated. Blood and colostrum samples were collected on a subset of randomly selected cows from each pen. Weigh-suckle-weigh technique was used to evaluate milk production. Calf birth weight, weaning weight, and ADG were evaluated. At weaning, calves were ultrasounded for BF, rump fat, and ribeye area. Dam BW, BCS, BF, and ADG were not affected ($P \geq 0.12$) by treatment. Non-esterified fatty acids (**NEFA**; $P > 0.40$) and glucose ($P > 0.44$) concentrations were not affected by treatment. Colostrum fat, somatic cell count, urea nitrogen, and other solids were not altered ($P \geq 0.13$) by dietary treatment, however, colostrum protein was greater ($P \geq 0.09$) in CON cows. Milk production at d 60 was greater ($P = 0.03$) for SBH cows compared with CON, but no differences were observed at d 120 ($P = 0.55$). Calf birth and weaning weights were unaffected by maternal treatment ($P = 0.30$). Ribeye area measurements were greater ($P = 0.05$) in SBH calves (14.6 vs. 13.7 ± 0.76 cm^2), but BF and rump fat thickness of offspring were not affected ($P \geq 0.58$) by maternal dietary treatment. The present study demonstrates that soybean hulls can be included in beef cow diets at 26 to 27% of dietary DM. Our data and previous

research indicate that an alternate energy source with highly digestible fiber, such as soybean hulls, can be effectively fed to drylot beef cows during gestation without negative impacts on cow or calf outcomes.

Key words: beef cow, calves, colostrum, drylot, performance, soybean hulls

Introduction

Maternal nutrition during pregnancy impacts offspring development and performance (Reynolds and Caton, 2012; Reynolds and Vonnahme, 2016). Radunz et al. (2012) indicated source of energy in cow diets affects fetal growth, especially during late gestation. Soybean hulls are a highly digestible fiber source that may more efficiently provide energy to pregnant beef cows than starch-based feeds because of their readily digestible fiber provided (Hibberd, 1986; Anderson et al., 1988). This concept is supported by other work where the highly digestible fiber of soybean hulls improved fiber digestibility in steers (Howlett et al., 2003). Further, several authors indicated that soybean hulls can be used as a supplement in drylot beef cow diets (Ludden et al., 1995; Engel et al., 2008; Smith et al., 2017b). Engel et al. (2008) reported no impacts on cow or calf performance when cows were fed soybean hulls at 26% dietary DM during late gestation.

While previous research evaluated short-term use of soybean hulls in beef cow diets, research has not evaluated the impacts of feeding soybean hulls to pregnant beef cows throughout gestation. Therefore, our study evaluated soybean hulls replacing portions of corn silage, modified distillers' grains plus solubles (mDGS), and wheat straw in drylot beef cow diets during an entire production cycle. We hypothesized beef cow and calf performance would not be affected by soybean hull inclusion in drylot beef cow diets when fed for a production cycle. Specific objectives of this study were 1) To evaluate body weight (BW), body condition score

(BCS), back fat (BF), and blood metabolites of beef cows fed soybean hulls under drylot management throughout a production cycle; and 2) To evaluate dam colostrum quality and milk production, and calf performance resulting when cows were fed soybean hulls under drylot management.

Materials and Methods

Ethics Approval

Experimental protocols were approved by the North Dakota State University Institutional Animal Care and Use Committee.

Study Area

Weather data, including temperature and precipitation are reported from an NDAWN station approximately 1 km from the study location and are presented in Table 2.1 (NDAWN, 2020). During winter months (October to April), wheat straw bedding was provided for the wellbeing of the cows.

Table 2.1. Average weather data for study location[1]

	Month[2]														
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Temperature, °C															
Current Study	17.6	21.1	18.1	14.5	2.6	-4.2	-10.7	-12.5	-9.8	-2.9	2.3	10.7	20.0	22.1	20.5
20-year average	17.9	21.1	19.6	14.6	7.0	-1.6	-10.1	-11.6	-10.7	-2.9	5.2	12.4	17.9	21.1	19.6
Rainfall, cm															
Current Study	6.1	10.5	9.0	23.5	10.2	0.2	1.6	1.4	0.2	1.3	2.4	3.8	1.8	15.2	3.1
20-year average	8.6	8.5	6.8	5.2	4.3	1.3	2.7	1.5	1.0	2.2	2.9	7.1	8.6	8.5	6.8
Snowfall, cm															
Current Study	0.0	0.0	0.0	0.0	76.7	5.6	53.3	14.2	4.3	14.2	15.7	0.0	0.0	0.0	0.0
20-year average	0.0	0.0	0.0	0.0	8.6	9.6	25.9	19.6	16.7	15.5	10.6	0.7	0.0	0.0	0.0

[1]Revised from NOAA.
[2]Month: Jan = January.

This research was conducted at the Carrington Research Extension Center located at approximately 44.5112° N, -99.1250° W in Carrington, North Dakota (USDA NRCS WSS, 2019). Drylot pen surfaces consisted of clay soil and concrete aprons. Pen space was determined per cow-calf pair which consisted of 109 m^2 of pen space per pair. Additionally, bunk space was 0.98 m of bunk space per cow-calf pair.

Animals and Dietary Treatments

One hundred and twenty-one red angus cow-calf pairs were used to evaluate the effects of soybean hulls in drylot cow-calf diets. Gestational phases evaluated for the entirety of this study were early-gestation (d 0 to 111), mid-gestation (d 112 to 202), late gestation (d 203 to 296), and lactation (d359 to 455). Before breeding, cow-calf pairs were stratified by age (4.52 ± 0.85 years), BW (650.1 ± 30.8 kg), and BCS (5.40 ± 0.10). Cow-calf pairs were divided into eight pens (n = 4 pens per treatment; 6 pens of multiparous cows and 2 pens of primiparous heifers). At mid-gestation, open cows were replaced with bred heifers following culling of open cows.

Cows were provided one of two treatments (Table 2.2) for the entirety of the study and included 1) control diet (**CON**; included corn silage, modified distillers' grains plus solubles mDGS, and wheat straw), and 2) soybean hull diet [**SBH**; diet included soybean hull inclusion at 26 to 27% (DM basis), replacing portions of corn silage, mDGS, and wheat straw]. Diets were formulated to meet nutritional requirements during early gestation, mid-gestation, late gestation, and lactation (NASEM, 2016). Diets were mixed in a truck mounted mixer (Ford Oswalt Mix Four Auger; Dodge City, Kansas) and limit-fed once daily at 0800-h, 7 d/week. Throughout mid-gestation, late gestation, and lactation, cows were provided on average 2 round wheat straw bales per week in an open ring (with slanted feeding stations) round bale feeder. Previous research has suggested forage waste can be influenced by bale feeder design (Buskirk et al., 2003; Moore and Sexten, 2015). Sexten (2011) reported an estimated 39% waste of grass-hay when using an open ring (with slanted feeding stations) round bale feeder. Similar estimates of tall-fescue hay waste were reported when fed with an open ring (with slanted feeding stations) round bale feeder by Moore and Sexten (2015). In the current study, straw intake was not measured during any gestational period but estimated straw consumption was 3.2 kg/cow daily, assuming 50% waste. Greater estimated waste in the current study could indicate the lower nutritional value of wheat straw in addition to the type of round bale feeder used. Salt blocks were provided in each pen (American Stockman White Salt Block; 41013ST).

Table 2.2. Dietary ingredient profile and dietary analysis of diets fed during gestational phases of beef cattle for a production cycle

	Gestational Phase[1]							
	Early-Gestation		Mid-Gestation		Late-Gestation		Lactation	
	CON	SBH	CON	SBH	CON	SBH	CON	SBH
Ingredients, % DM								
Soybean hull	--	26.0	--	27.0	--	27.0	--	26.0
mDGS[2]	22.5	14.0	21.0	14.0	14.0	9.0	22.5	15.0
Straw	--	--	--	--	29.5	18.0	20.0	15.0
Corn[4]	--	--	--	--	--	--	25.0	22.0
Corn Silage[3]	75.4	58.0	75.8	56.0	54.0	43.4	--	--
Grass Hay[4]	--	--	--	--	--	--	30.4	20.0
Supplement[5]	2.15	2.0	3.2	3.0	2.5	2.6	2.15	2.0
Analysis, % DM[6]								
Dry Matter, %	37.9	45.0	32.7	36.8	40.3	48.2	60.2	61.1
Crude Protein, %	12.4	12.7	14.6	13.5	12.7	12.0	14.2	13.7
Acid Detergent Fiber, %	26.5	32.6	28.0	31.9	27.9	32.3	27.2	33.3
Neutral Detergent Fiber, %	47.4	53.3	51.7	55.5	53.1	54.8	50.5	55.8
NE_m, Mcal/kg[7,8]	1.7	1.6	1.7	1.6	1.5	1.4	1.6	1.6
Ca, %	0.3	0.4	1.2	1.0	0.4	0.5	0.9	0.6
P, %	0.5	0.3	0.3	0.4	0.4	0.3	0.5	0.4

[1]Treatments: CON, control diet; SBH, soybean hulls at 26 to 27% dietary dry matter.
[2]mDGS = modified distillers' grains plus solubles.
[3]Original diet contained corn silage but silage was limited, so beet pulp was substituted on 1:1 basis during mid-gestation.
[4]Original diet contained corn silage but silage was limited, so a combination of grass hay and corn grain was substituted on a 1:1 basis during lactation.
[5]Supplement consisted of 14.0% Crude protein; 1.00% Crude fat; 8.00% Crude fiber; 9.90% Ca; 0.10% P; 5.94% NaCl; 0.10% K; 550 ppm Cu; 13.5 ppm Se; 1,595 ppm Zn; 34,019 IU/kg Vitamin A; 3,402 IU/kg Vitamin D3; and 34 IU/kg Vitamin E.
[6]Average values from laboratory nutritional analysis.
[7]NE_m = Net Energy maintenance.
[8]Calculated value from NASEM, (2016).

Dam Performance

Body weights and BCS were collected on two consecutive days at the initiation and conclusion of each gestational phase before feed delivery. Intermediate BW and BCS were collected approximately every 28-d on all cows to monitor average pen weight. Body condition scores were based on a 1 to 9 scale (with 1 = emaciated and 9 = obese; Westendorf et al., 1988; Eversole et al., 2009) to evaluate average pen BCS. For consistency purposes, the same BCS evaluator was used throughout the study. Furthermore, BF measurements were collected at the initiation of early-gestation, mid-gestation, late gestation, lactation and the conclusion of the study using a 5.0-MHz transducer, Aloka 500V (Aloka America, Wallingford, CT). Backfat thickness was measured and recorded in millimeters for the purpose of this study.

Cows and replacement heifers were synchronized via the Co-Synch and controlled internal release drug (CIDR) fixed time artificial insemination (AI) protocol (Lamb et al., 2009). Cattle received an intramuscular injection of 100 μg gonadotropin releasing hormone (GnRH; 2-mL Factrel; Zoetis Inc., Florham Park, NJ) and a CIDR insert (Zoetis Inc) containing 1.38g progesterone. After d 7, CIDRs were removed, and cattle received an injection of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$; Lutalyse HighCon – 2mL dose; Zoetis Inc.) on d 0. Heifer AI occurred from 52 to 56-h after $PGF_{2\alpha}$, whereas cows were bred from 60 to 66-h after $PGF_{2\alpha}$. Cows were then exposed to cleanup bulls approximately 7-d after the artificial insemination procedure for an additional 45 d. Bulls used in this study were considered reproductively sound by passing a breeding soundness exam (Dahlen et al., 2014).

Pregnancy in 2019 was determined by transrectal ultrasonography 33-d following AI. Confirmed pregnancy required presence of an embryo. Final pregnancy confirmation of fetal age was determined by measurement of fetal crown rump length (mm) using transrectal ultrasonography 98-d following AI. Pregnancy in 2020 was determined by transrectal ultrasonography 61-d following AI. Final pregnancy confirmation of fetal age was determined by measurement of fetal crown rump length (mm) using a transrectal ultrasonography 86-d following AI.

Blood Metabolites

Blood samples were taken by jugular venipuncture for analysis of non-esterified fatty acids (NEFA) and glucose from a subset of 48 randomly selected cows (n = 5 to 8 cows per pen). To monitor concentrations, blood was collected using a 10-mL blood collection tube (BD Vacutainer Serum) at the initiation of early-gestation, mid-gestation, late gestation, lactation and the conclusion of the study. Blood samples were placed into an insulated cooler and allowed to clot before serum harvesting.

Calving

Record keeping of calves consisted of birth weight, sex, and calving ease. Birth weight was recorded within ±12 hours postpartum. Bull calves were banded using an elastrator. Calving ease was scored on a 1 to 5 scale. Difficulty or ease was recorded as: 1) no strain, 2) accumulation of minor struggle, 3) accumulation of difficulty - assistance required, 4) necessary caesarian section, and 5) abnormal (Randle and Berger, 2013).

Colostrum Quality and Milk Production

A subset of 42 cows (n = 4 to 8 per pen) were used to evaluate colostrum quality within 24 h of birth. To analyze colostrum quality, cows were hand milked from 2 of 4 quarters (3 to 4 strips per teat). Colostrum samples were placed into vials containing preservatives and refrigerated up to 10-d before laboratory analysis of fat, protein, somatic cell count (**SCC**), urea nitrogen (**UN**) and other solids.

Weigh-suckle-weigh was used to evaluate milk production from a subset of 48 cow-calf pairs (n = 4 to 7 per pen) and measured at 60 and 120 postpartum by a modified procedure (Williams et al., 1979; Benson et al., 1999; and Radunz et al., 2010). Cow-calf pairs were stratified by calf birth date to accommodate for the range in calf age: Group 1 (n = 25) consisted of pairs with calving dates between March 3 to March 22, 2020; and Group 2 (n = 23) consisted of late calving dates between March 23 to May 16, 2020. Briefly, an initial 2-h separation occurred at 0530 h (sunrise). Pairs were brought together, and calves were allowed to nurse their dam dry. Pairs were re-separated for 6 h. Following the second separation, calves were weighed, allowed to nurse, and reweighed immediately as suckling ceased (approximately 20 minutes). Milk production was determined by multiplying weight gain by 4 to estimate 24-h production.

Calf Performance

Calf performance was evaluated based on birth weight, weaning weight, and ADG. Calf ADG was measured from approximately d 30 after birth to d 131 at weaning. Calves were ultrasounded at the conclusion of the study to assess BF, rump fat, and ribeye area differences using a 5.0-MHz transducer, Aloka 500V ultrasound machine by an experienced technician (Corometrics Medical Systems, Wallingford, CT; Black et al., 2015).

Laboratory Analysis

Diet samples were collected once every two weeks and dried to determine dry matter (**DM**) using a forced air oven (55°C; Sheldon Manufacturing, Inc., Cornelius, OR) for 48 h, stored at room temperature, and ground to pass a 1-mm screen (Thomas-Wiley Laboratory Mill, Model 4). Dry matter, ash, crude protein (**CP**), calcium, and phosphorus were determined using AOAC (2010) procedures (934.01, 942.05, 2001.11, 968.08, and 965.17, respectively). Neutral detergent and acid detergent fibers were determined using Goering and Van Soest (1970) procedures modified by Ankom Technologies (ANKOM Model A200 Fiber Analyzer; ANKOM Technology, Macedon, NY).

Vacutainer tubes were placed into a centrifuge (Allegra X-30R Centrifuge; Beckman Coulter) and spun for thirty minutes at 2,200 × g and 4°C to obtain serum. Serum samples were frozen until further analysis. Non-esterified fatty acid analysis was performed using a Fujifilm HR Series NEFA-HR 2 (Fujifilm Wako Code No. 999-3491) in the Nutrition Lab located at North Dakota State University. Glucose analysis was performed using a Synergy H1 Microplate Reader (Biotek, Winooski, VT).

Colostrum was analyzed by the Stearns DHIA Laboratories (Sauk Centre, MN). Sample analysis was conducted using a 4,000/5,000 Combi-Foss Analyzer to determine colostrum fat, protein and SCC concentrations, and a Skalar analyzer determined UN. Calf ultrasound measurements of BF, rump fat thickness, and ribeye area were analyzed by the Centralized Ultrasound Processing Laboratory (Ames, IA).

Statistical Analysis

Data were analyzed as a completely randomized design using the MIXED procedure of SAS (9.4, SAS Inst. Inc., Cary, NC). The (Kenward roger) approximation was used for all analyses to determine the denominator degrees of freedom for the tests of fixed effects. Pen was the experimental unit for all statistical analyses, and significance was set at $P \leq 0.05$ and tendencies were determined if $P > 0.05$ and $P < 0.10$. All results are reported as least square means and PDIFF was used for mean separation. The covariance structure for each model was chosen based on the smallest Akaike information criterion.

Dam BW, BCS, BF, and reproductive performance were analyzed for effects of treatment. Because cows were culled from the herd, each period was analyzed independently.

Serum samples were analyzed only on cows that remained in the herd for the duration of the project (i.e.. early-gestation to lactation). Serum metabolites were analyzed as repeated measures in time for effects of treatment, period and a treatment × period interaction. Colostrum samples were analyzed only on cows with calves that remained in the herd for the entire lactation period. Composition of colostrum (i.e.. colostrum fat and protein, SCC, UN, and other solids) and milk production were analyzed for effect of treatment. Milk production data was analyzed separately for each sampling timepoint. Calf birth weights, 30-d weights (weights at the start of lactation), weaning weights, and ultrasound measures were analyzed for effect of treatment.

Results and Discussion

Intake

Dry matter intake for CON and SBH dams was not measured for the entirety of this study but were adjusted for early-gestation (average = 8.7 vs. 9.0 ± 0.65 kg/cow daily, respectively), mid-gestation (average = 4.9 vs. 5.1 ± 0.65 kg/cow daily, respectively), late gestation (average = 5.3 vs. 6.2 ± 1.13 kg/cow daily, respectively), and lactation (average = 9.6 vs. 9.7 ± 0.80 kg/cow daily, respectively). Dietary intake was not impacted ($P \geq 0.97$) by treatment and were formulated to have similar dietary energy (NE_m) and CP to meet NASEM (2016) requirements. Formulated NE_m supply was similar ($P = 0.67$) for early-gestation (13.16 vs. 12.90 ± 0.97 Mcal/d), mid-gestation (7.12 vs. 7.26 ± 0.97 Mcal/d), late gestation (7.72 vs. 8.94 ± 1.68 Mcal/d), and lactation (15.21 vs. 15.04 ± 1.18 Mcal/d) when adjusted for actual intake. Formulated CP was similar ($P = 0.66$) for early-gestation (average = 1.12 vs. 1.15 ± 0.08 kg/d, respectively), mid-gestation (average = 0.72 vs. 0.69 ± 0.08 kg/d, respectively), late gestation (average = 0.67 vs. 0.74 ± 0.15 kg/d, respectively) and lactation (average = 1.07 vs. 1.33 ± 0.10 kg/d, respectively) when adjusted for actual intake.

Energy of maintenance and metabolizable protein are essential for maintaining physiological functions such as respiration, circulation, and digestion, as well as production characteristics such as growth, milk production, and reproduction in cattle (Hilton, 2014). Energy intake and level of protein influences cattle performance when fed forage-based diets (Cappellozza et al., 2014.). Energy requirements can vary by stage of production, energetic expenditure, and forage intake (Caton and Dhuyvetter, 1997; Cappellozza et al., 2014). Previous research (Morrison et al., 1999; Freetly et al., 2000) reported energy fed during late gestation can maintain BW and BCS in beef cows while supporting fetal development. This could further indicate the use of an alternative energy source with highly digestible fiber, such as soybean hulls, can be fed to beef cattle during gestation.

Dam Performance

There were no differences ($P \geq 0.32$; refer to the Appendix) between initial BW (649.5 vs. 652.0 ± 31.5kg), BCS (5.4 vs. 5.4 ± 0.1), or BF (5.7 vs. 6.5 ± 0.7mm) for CON versus SBH dams. During mid- and late gestation, no differences ($P \geq 0.12$) in BW (653.3 vs. 671.3 ± 26.5kg), BCS (5.8 vs. 5.9 ± 0.1), BF (3.3 vs. 3.5 ± 0.3mm), or ADG (0.6 vs. 0.7 ± 0.1kg) between CON and SBH dams were observed. There were no differences ($P \geq 0.25$) in BW (618.1 vs. 628.3 ± 22.7kg), BCS (5.3 vs. 5.4 ± 0.1), BF (3.8 vs. 4.5 ± 0.4mm), or ADG (± 0.1kg) for CON versus SBH. Overall, no differences ($P \geq 0.12$) for CON or SBH cow BW, BCS, BF, or ADG were found between treatments for any of the four study segments. Dam performance, such as ADG for those fed SBH were similar to data reported by Ferreira et al. (2011), Mueller et al. (2011), and Russel et al. (2016) when feeding soybean hulls to beef cattle. Previous work (Engel et al., 2008; Smith et al., 2017b) that fed various inclusion rates of soybean hulls agree with the present study in that supplementing soybean hulls into the diet of drylot beef cows did not impact dam performance during mid- to late-gestation. Engel et al. (2008) fed soybean hulls 26% (DM basis) to beef cows during late gestation and reported no effects on cow body weight from calving to weaning. Similarly, Banta et al. (2008) reported no differences in dam weight at time of weaning when feeding a soybean hull-based supplement at 1.56 kg/head daily (DM basis; 45.6% soybean hulls, 54.4% soybean meal).

Reproductive performance during 2019 and 2020 were similar between CON and SBH treatments ($P \geq 0.49$; refer to the Appendix). Conception rate to artificial insemination and final pregnancy rates during lactation were unaffected by treatment ($P = 0.10$). Final pregnancy rates in 2019 were 89.6 and 94.2% for CON and SBH, respectively. During 2020, final pregnancy rates were 91.5 and 84.8% for CON and SBH, respectively. Data of the current study agrees with Morrison et al. (1999) as there were no effects of soybean hull inclusion observed in postpartum cow reproductive performance. Previous research (Howlett et al., 2003) reported consistent reproductive efficiency with dams supplemented soybean hulls (30% DM basis) compared with a corn-based diet. Furthermore, Banta et al. (2008) found no differences between cows supplemented soybean hulls or not. Therefore, our data combined with other data (Morrison et al., 1999; Howlett et al., 2003; Banta et al., 2008; Engel et al., 2008) appears to indicate that when included in the diet, soybean hulls do not negatively impact conception rate.

Blood Metabolites

Non-esterified fatty acid concentrations were not affected by a treatment by phase interaction ($P = 0.17$; Figure 2.1). Concentrations of NEFA tended to be greater ($P = 0.06$) for SBH cows compared with CON at the start of lactation. Overall, no differences ($P \geq 0.40$) were observed between treatments for NEFA concentrations. Concentrations of NEFA for CON and SBH were [518.9 vs. 449.9 ± 53.89 µmol/L (start of study); 395.2 vs. 432.2 ± 36.30 µmol/L (early-gestation); 389.6 vs. 410.7 ± 36.74 µmol/L (mid-gestation); 526.4 vs. 535.6 ± 46.34 µmol/L (late gestation); 635.1 vs. 826.4 ± 70.47 µmol/L (start of lactation); 348.2 vs. 367.5 ± 43.56 µmol/L (end of study), respectively]. Phases 1 to 6 in Figure 2.1 below indicate the start of the study (Phase 1), followed by early-gestation (Phase 2), mid-gestation (Phase 3), late-gestation (Phase 4), lactation (Phase 5), and the conclusion of the study (Phase 6).

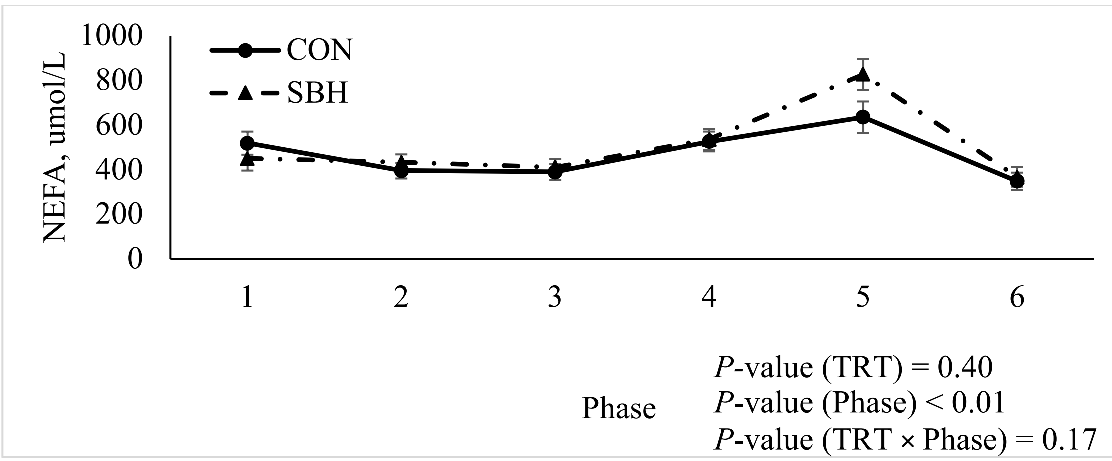

Figure 2.1. Effects of soybean hull inclusion on non-esterified fatty acid concentration from dams fed in confinement during an entire production cycle.

Similarity between circulating NEFA concentrations could be expected due to similar NE_m fed between treatments throughout the study. The role of NEFA concentrations in beef cattle is related to energy balance (Engel et al., 2008; Radunz et al., 2010; Mueller et al., 2011) and the mobilization of lipid stores (Lucy et al., 1991). Increased NEFA concentrations are often seen during metabolic changes in the dam, such as the transition between calving and lactation (Engel et al., 2008) when negative energy balance occurs. Similar to Engel et al. (2008), concentrations of NEFA increased postpartum and gradually declined. This pattern demonstrates the role of NEFA concentrations in beef cattle and its relation to energy balance (Engel et al., 2008; Mueller et al., 2011) pre- and postpartum. In contrast to Radunz et al. (2012), no differences were observed for circulating NEFA concentrations during lactation when diets contained hay at the end of the current study.

Glucose concentrations did not differ ($P \geq 0.44$; Figure 2.2) between treatments. Concentrations of glucose for CON and SBH were [72.0 vs. 68.1 ± 1.98 mg/dL (early-gestation), 69.7 vs. 70.6 ± 2.74 mg/dL (mid-gestation), 62.0 vs. 65.2 ± 1.71 mg/dL (late gestation), 65.2 vs. 66.0 ± 2.76 mg/dL (start of lactation), respectively]. Additionally, circulating glucose concentrations for CON and SBH were not affected by a treatment by phase interaction (P = 0.12). Phases 1 to 6 in Figure 2.2 below indicate the start of the study (Phase 1), followed by early-gestation (Phase 2), mid-gestation (Phase 3), late-gestation (Phase 4), lactation (Phase 5), and the conclusion of the study (Phase 6).

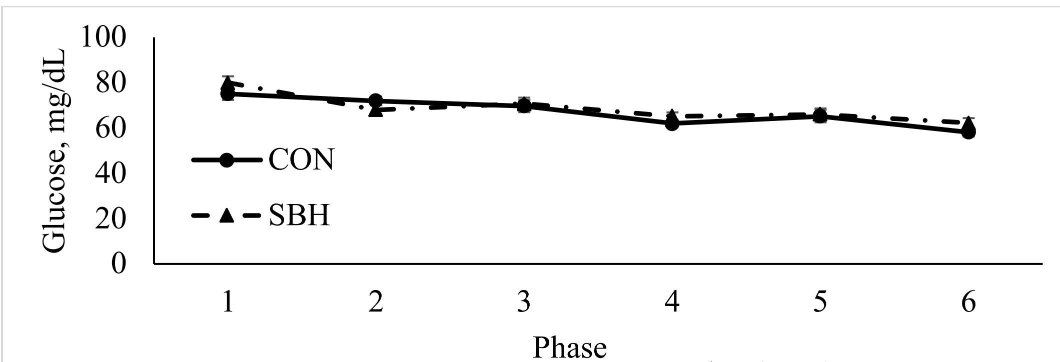

Figure 2.2. Effects of soybean hull inclusion on glucose concentration from dams fed in confinement during an entire production cycle.

No differences in glucose concentrations from the current study are similar to reports by Mueller et al. (2011) with steers fed soybean hulls or oat silage-based diets. Similarly, Ranathunga et al. (2009) reported no treatment effect on plasma glucose when Holstein cows were fed soybean hull inclusion at 20, 23, and 26% of the diet. Maintaining glucose concentrations could be expected due to similar NE_m fed to cows throughout the study. Furthermore, it is possible that both dietary treatments supplied similar amounts of gluconeogenic precursors for cows to maintain circulating glucose concentrations throughout gestation (Mueller et al., 2011). Maintaining glucose concentrations is possible as dams metabolically adjust through gluconeogenesis, which provides approximately 70% of the total glucose needed by the cow (Nafikov and Beitz, 2007). Additionally, Radunz et al. (2012) reported no differences between glucose concentrations with dams supplemented corn or hay diets. A similar effect was observed at the conclusion of the present study when limited corn silage resulted in corn grain and hay substitution.

Colostrum Quality and Milk Production

Colostrum fat, somatic cell count, urea nitrogen, and other solid content were not altered ($P \geq 0.13$; Table 2.3) by dietary treatment. Colostrum protein content tended to be greater (P = 0.09) in CON compared with SBH (11.8 vs. 9.3 ± 0.96%, respectively). Total colostrum volume was not measured in the current study. Therefore, if total colostrum yield was different between treatments, is possible that total fat, protein, SCC, UN, and other solids could vary.

Table 2.3. Impacts of soybean hull inclusion in beef cow diets on colostrum quality

	Treatments[1]			
	CON	SBH	SEM[2]	*P*-value
Colostrum Analysis[3]				
Fat, %	4.1	4.4	0.53	0.61
Protein, %	11.6	9.3	0.96	0.09
Somatic Cell Count, cells $\times 10^3$/mL[4]	2,616	4,165	710.7	0.13
Urea Nitrogen, mg/dL[4]	2.6	4.3	1.20	0.31
Other[4]	4.9	4.7	0.15	0.29

[1]Treatments: CON, control diet; SBH, soybean hulls at 26 to 27% dietary dry matter.
[2] n = 4 pens per treatment.
[3]Colostrum samples were collected within 24 h of birth.
[4]Other includes additional solids such as lactose and ash.

Greater colostrum protein concentrations in CON dams could be caused by an increased secretion of immunoglobulins (Ig); however, Ig was not measured in the current study to confirm nor deny that CON cows were more immunologically stressed than SBH cows. Previous research suggests in comparison to milk, colostrum is greater in proteins, including Ig, immediately after parturition (Quigley and Drewry 1998; Georgiev, 2008; Hammer et al., 2011).

Wagner et al. (1965) evaluated the effect of soybean hulls on milk fat quality in Holstein cows and concluded soybean hulls fed at 30% of the diet can maintain milk fat quality when dietary forages are scarce. In other work, Ranathunga et al. (2009) supported this theory by reporting no differences in milk fat, protein, or other solids when Holstein cows were fed soybean hulls at inclusion rates of 20, 23, and 26% of the diet. Previous research (Nakamura and Owen, 1989; Sarwar et al., 1992; Ipharraguerre et al., 2002; Ranathunga et al., 2009) discussed the ability for milk fat and yield increase when soybean hull inclusion rates are greater than 30% in cow diets. Our data, combined with other data (Wagner et al., 1965; Ranathunga et al., 2009) appears to indicate that when included in the diet, soybean hulls do not negatively impact colostrum quality.

Milk production at d 60 of lactation was greater ($P = 0.03$; Table 2.4) for cows fed SBH compared with CON (16.0 vs. 11.8 kg/d respectively). Previous research suggests a greater relationship between milk production and calf weight gain (Clutter and Nielsen, 1987; Beal and Notter, 1990; Meyer et al., 1994) until d 60 of lactation before decreasing (Neville, 1962). Milk production at d 60 in the current study is greater than reported by Edwards et al. (2017) with Angus-crossed cows and milk production ranging from 6.8 to 12.7 kg/d on d 58 of lactation. This could indicate the use of an alternative energy source with highly digestible fiber, such as soybean hulls, can be fed to beef cattle during late gestation and early lactation. Previous research suggests peak milk production in cattle is observed between 45 to 100 d during lactation (Freetly and Cundiff, 1998; Litherland, 2018). Jenkins and Ferrell (1992) reported a linear increase in milk production based on increased energy intake by the dam prior to peak lactation.

Radunz et al. (2010) suggests when dams are fed adequate dietary energy sources during late gestation, milk production is not altered.

Table 2.4. Impacts of soybean hull inclusion in beef cow diets on milk production

	Treatments[1]			
	CON	SBH	SEM[2]	*P*-value
Milk Production, kg/d[3]				
60 d post-calving	11.8	16.0	1.32	0.03
120 d post-calving	8.8	9.8	1.12	0.55

[1]Treatments: CON, control diet; SBH, soybean hulls at 26 to 27% dietary dry matter.
[2] n = 4 pens per treatment.
[3]To determine milk production during lactation, weigh-suckle-weigh was used at 60- and 120-days post-calving.

Later in lactation, no differences ($P = 0.55$) were observed at d 120 (8.8 vs. 9.8 ± 1.1 kg/d respectively). Milk production at d 120 in the current study fell between observed milk production ranges (6.0 to 11.0 kg/d) at d 129 reported by Edwards et al. (2017). Ranathunga et al. (2009) observed no differences in milk production of lactating dairy cows when fed soybean hulls at 20, 23, and 26% of the diet compared with dairy cows fed a starch-based diet. Bauman et al. (2004) reported a decrease in calf milk intake from early lactation (13.1 ± 1.1 kg) to d 112 (7.7 ± 1.1 kg) when dams were fed soybean hulls at 24% (DM basis), although these reports were lower than the current study. As weaning age approaches, reduced milk intake by the calf and maternal production of milk occur (Drewry et al., 1959; Boggs et al., 1980; Holloway et al., 1982; Abselsamei et al., 2005). Other work supports the idea that as calves approach weaning age, milk consumption will decrease with access to grain and/or forages (Knapp and Black, 1941; Holloway et al., 1982). Similarly, several authors reported a decrease in milk production occurred after dams reached a mid-lactation period (Wagner et al., 1965; Boggs et al., 1980; Holloway et al., 1982; Abselsamei et al., 2005). Therefore, our study appears to indicate that soybean hulls do not negatively impact cow milk production throughout lactation.

Calf Performance

Calf birth weights were unaffected ($P \geq 0.54$) by CON and SBH treatments (35.7 vs. 36.9 ± 2.7; Table 2.5). Fetal development is heavily impacted by the nutrient status of the dam (Robinson et al., 1977; Reynolds and Caton, 2012; Reynolds and Vonnahme, 2016) especially during late gestation as key nutrients are transferred from the dam to the fetus (Underwood and Sherman, 2006; Funston et al., 2010). In contrast, to the current study, previous research (Banta et al., 2008) reported heavier birth weights when dams were supplemented soybean hull-based supplements than those that were not. Heavier birth weights reported by Banta et al. (2008) could have resulted from a greater inclusion rate of soybean meal/soybean hull supplement (54.4% soybean meal and 45.6% soybean hulls) in the diet during late gestation. Furthermore, greater concentrations of soybean hulls could lead to increased NE_m and CP concentrations to support fetal development for those with dams supplemented soybean hulls versus those that were not.

Table 2.5. Effects of soybean hull inclusion on beef calf performance resulting from dams fed in drylot during a production cycle

	Treatment[1]			
	CON	SBH	SEM[2]	*P*-value
Calf Performance				
Birth Weight, kg	36	37	2.7	0.54
30-d BW, kg[3]	79	84	2.1	0.11
Weaning Weight, kg[4]	171	180	6.0	0.30
ADG, kg[5]	1.0	1.0	0.05	0.58

[1]Treatment: CON, control diet; SBH, soybean hulls at 26 to 27% dietary dry matter.
[2]n = 4 pens per treatment.
[3]30-d BW = weight at start of lactation.
[4]Weaning weight was collected at the conclusion of study.
[5]ADG = average daily gain; calculated for 95 d of lactation.

Body weights observed at approximately 30-d postpartum were not different ($P = 0.11$) for either CON or SBH calves (78.5 vs. 83.9 ± 2.1 kg, respectively). Preweaning calf growth rate is dependent upon dam nutritional status, milk production, and genetic potential (Frecking and

Marshall, 1992; Radunz et al., 2012; Rodrigues et al., 2014). Previous research (Lampkin and Lampkin, 1960; Neville, 1962; Holmes et al. 1968) indicated a correlation (r = 0.5 to 0.80) between calf weight and milk production under drylot conditions. Greater milk yield influencing calf weight can be caused by a demand for more milk from the calf or a greater capacity to consume milk quantity (Rutledge et al., 1971). Although, the correlation between milk intake and calf weight was not analyzed in this study. After 3 months of age, it is predicted that the calf gains one-half of its energy from nonmilk sources (Sims et al., 1975; Boggs et al., 1980). At weaning, calf weight is approximately 60% dependent upon dam milk production (Neville, 1962; Rutledge et al., 1971; Boggs et al., 1980).

Calf weaning weight was not affected ($P = 0.30$) by treatment (170.7 vs. 180.2 ± 6.0 kg for CON and SBH, respectively). In previous research, Banta et al. (2008) reported no differences ($P = 0.94$) between calf weaning weight when dams were fed soybean hulls. In addition to weaning weight, there were no differences ($P \geq 0.58$) in ADG for calves in the current study. This is because postpartum development and weaning weight are greatly influenced by maternal nutrition delivered through milk (Knapp and Black, 1941; Boggs et al., 1980; Freking and Marshall, 1992; Funston et al., 2010; Radunz et al., 2012). This could suggest that prepartum dams in the current study were fed equal dietary energy and protein concentrations. Providing CON and SBH dams with equal energy and protein concentrations was the goal for the diets developed in this project.

There were no differences ($P \geq 0.58$; Table 2.6) in BF (0.2 vs. 0.2 ± 0.02 cm), or rump fat thickness (0.1 vs. 0.2 ± 0.03 cm, respectively) for calves from dams fed either CON or SBH. Faulkner et al. (1994) reported no differences for adjusted fat thickness, internal fat, or longissimus muscle area at slaughter in calves creep-fed corn and/or soybeans hulls (limited intake 1.0 kg/d DM; or ad libitum DM intake).

Table 2.6. Effects of soybean hull inclusion on beef calf ultrasound measurements resulting from dams fed in drylot during a production cycle

	Treatment[1]			
	CON	SBH	SEM[2]	*P*-value
Ultrasound Measurements				
Rump fat, cm	0.1	0.2	0.01	0.74
Back fat, cm	0.2	0.2	0.01	0.58
Ribeye area, cm^2	13.7	14.6	0.34	0.05

[1]Treatment: CON, control diet; SBH, soybean hulls at 26 to 27% dietary dry matter.
[2]n = 4 pens per treatment.

Ribeye area for SBH calves was greater ($P = 0.05$) than CON (14.6 vs. 13.7 ± 0.8 cm^2, respectively). Previous research (Radunz et al., 2012) has suggested heavier birth weights can be associated with greater muscle measurements, although no differences in calf birth weights were found in the present study. The reason for the differences in calf ribeye area is unknown; however, it is possible that milk production at d 60 for SBH dams is related to the greater ribeye area in SBH calves at weaning.

Conclusion

In conclusion, we fail to reject our hypothesis that soybean hulls can be included in beef cow diets at 26 to 27% of dietary dry matter without altering cow or calf performance. No differences in dam performance could likely be caused by meeting energy and protein demands throughout gestation with the use of soybean hulls. Jointly the present and previous data appear to indicate that soybean hulls can be used effectively in beef cow diets. More research is necessary to measure dam performance during an entire production cycle with various soybean hull inclusion rates to define the use of soybean hulls in drylot beef cow diets. In addition, further research is needed to determine the influence of maternal dietary inclusion of soybean hulls on postpartum calf development and performance.

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APPENDIX. EFFECTS OF SOYBEAN HULL INCLUSION ON PERFORMANCE AND CONCEPTION RATE OF BEEF COWS FED IN CONFINEMENT DURING LACTATION, MID-GESTATION, AND LATE GESTATION

	Treatment[1]			
	CON	SBH	SEM[2]	*P*-value[3]
Early-Gestation[4]				
Initial BW, kg[5]	650	652	31.5	0.96
Final BW, kg	610	613	28.2	0.94
Initial BCS[5]	5.4	5.4	0.11	0.98
Final BCS	5.3	5.2	0.15	0.84
Initial BF, mm	5.7	6.4	0.46	0.32
Final BF, mm	5.7	6.5	0.74	0.46
ADG, kg	-0.4	-0.4	0.04	0.90
Conception Rate[8]				
AI, %	68.8	71.4	5.78	0.76
Final, %	89.6	94.2	4.39	0.48
Mid-Gestation[6]				
Final BW, kg	633	646	27.2	0.75
Final BCS	5.9	6.1	0.11	0.15
Final BF, mm	3.3	3.5	0.26	0.50
ADG, kg	0.6	0.7	0.06	0.50
Late-Gestation				
Final BW, kg	673	696	25.8	0.55
Final BCS	5.6	5.6	0.09	0.90
Final BF, mm[7]	.	.	.	.
ADG, kg	0.5	0.60	0.05	0.12
Lactation[8]				
Final BW, kg[9]	618	628	22.7	0.76
Final BCS[9]	5.3	5.4	0.06	0.31
Final BF, mm	3.8	4.5	0.38	0.25
ADG, kg	0.1	0.1	0.05	0.56
Conception Rate[8]				
AI, %	66.3	62.3	2.71	0.34
Final, %	91.5	84.8	2.48	0.10

[1] Treatment: CON, control diet; SBH, soybean hull diet.
[2] n = 4 pens per treatment.
[3] *P*-value less than 0.05 considered significantly different.
[4] Lactation Analysis and Conception Rates of 2019. Conception rates to artificial insemination and final pregnancy rate determined via ultrasound.
[5] Initial body weights and condition scores were collected at the beginning of study.
[6] Replacement of open cows with replacement heifers completed at weaning. Replacement heifers were previously managed on control and soybean hull rations.
[7] Final BF measurements during Late gestation were unavailable due to machine malfunction and below freezing temperatures.
[8] Lactation Analysis and Conception Rates of 2020. Conception rates to artificial insemination and final pregnancy rate determined via ultrasound.
[9] Final body weights and body condition scores were collected at the conclusion of study.