THE INFLUENCE OF DAM AGE AND HEIFER POST-WEANING VOLUNTARY FEED INTAKE ON SUBSEQUENT PRODUCTION, REPRODUCTION AND LIFETIME PRODUCTIVITY OF ANGUS BEEF FEMALES

by

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DEDICATION

To mom and dad,
Thank you for teaching me that I can do more than I think I can,
instilling my love of farming and agriculture,
and your unending love and support always.

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ABSTRACT

Limited research has been done to evaluate the impacts of dam age or post-weaning voluntary feed intake and its impact on subsequent performance and longevity in the beef herds, specifically female offspring. Therefore, the objectives of this research were to investigate how dam age and post-weaning voluntary feed intake influences lifetime productivity of commercial Angus females. First-calf heifers and mature cows were used to conduct three studies. Results indicate that classification of replacement heifers based on intake as a heifer had little to no impact on subsequent productivity as a mature female, while dam age had a greater influence overall. Productivity as a measure of total pounds of calf weaned through 5 yrs indicated that cows from dams that were 8-yr old or older weaned more total pounds of calf than cows from 3-yr old dams. Results indicated that heifers classified as low intake heifers, had greater mature BW at breeding and greater BCS than cows that were classified as average or high intake as heifers. However, DMI expressed as g/kg of BW displayed no differences with respect to cow age. Milk production was influenced by post-weaning intake for 2 and 5-yr old cows. The dam age study, indicated that dam age will affect future outcomes of replacement heifers. Cow BW at weaning displayed significance for dam age with cows born from 5- and 8-yr old and older dams having greater BW than cows born from 2-yr old. Cow yearling weight was significant for dam age with cows from 5-, 6/7-, and 8-years and older dams having greater yearling weights than cows from 2- and 3-yr old dams. The probability of remaining in the herd at 5-yr old varied across dam age groups with cows from 2-yr old and 5-yr old dams having greater probability to remain in the herd than the other age groups. Therefore, our research suggests that selection of replacement heifers based on post-weaning voluntary feed intake at 45 d post-weaning is not a strong indicator of lifetime productivity. Instead, cow age has a greater impact on lifetime productivity than heifer post-weaning voluntary feed intake.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

Feed Intake and Efficiency in Cow/Calf Production

Lifetime productivity, measured as the total weight of calves weaned during a cow's lifetime, is one of the most important components of efficiency in beef cow-calf production because it is a function of survival and reproductive performance of cows and of survival and growth rate of their offspring (Cundiff et al., 1992). Additionally, cows that remain in a herd longer reduce the cost of replacements on a yearly basis. These traits are a function of fertility, maternal ability and survival of the cows as well as of prenatal and postnatal survival and preweaning growth of their offspring.

Herd life may also be defined as the age at which a cow dies or is culled because she is unable to wean another live calf due to unsoundness or infertility. Cows that die in a herd have no economic value, whereas cows in good condition that are culled because of low fertility may have a relatively high salvage value. For a herd to be profitable, the cows should remain in the herd long enough to pay for their maintenance cost. Data from Boyer and colleagues (2020) indicated that in order for replacement females to cover their developmental costs and maintenance expenses, they must have at least six calves. Data from Clark and coworkers (2005) reported slightly lower numbers, suggesting 3 to 5 calves should be produced in order for a replacement heifer to repay her development costs. The number of cows remaining in production beyond this breakeven age must compensate for those cows that are culled before that age (Snelling et al., 1995). Greater longevity also allows producers to be more selective when choosing replacement females, although this may increase generation interval. Longevity traits reflect the performance of a cow over her total herd life and can only be measured after the cow has been culled. An alternative measure of herd life is the use of stayability traits. Stayability, as a measure of herd life, is defined as the probability of surviving to a specific age when given the opportunity to reach that age (Hudson and Van Vleck, 1981).

To remain profitable in the beef industry, it is important for producers to balance production costs against revenue generated within a system that typically sees drastic fluctuations in feed prices, sale prices of cattle and market availability for finished cattle (Chewning et al, 1990). Feed costs represent about two-thirds of the cost associated with maintaining a beef cow (Anderson et al., 2005) and are the largest determinant of profitability for beef producers (Miller et al, 2001). Therefore, livestock production systems must utilize forage resources in order to obtain optimal animal performance (Wyffels et al, 2019). It is also important to remember that interactions between individual animal and environment play a critical role in overall productivity of each animal (Grayson et al., 2008). Reducing inputs associated with developing replacement heifers can help reduce cost of production. However, there is much debate regarding raising replacement beef heifers due to input costs and the time that it takes to get them to achieve an ideal weight and size for breeding.

The objective of this review is to provide current literature available regarding the relationship between postweaning voluntary feed intake and its impacts on lifetime productivity of beef females. Therefore, feed efficiency, dam age, cow body size, pounds of calf weaned, milk yield, and reproductive efficiency will be discussed. Based on currently available data, we hypothesize that heifer postweaning voluntary feed intake may impact overall lifetime productivity.

Factors Affecting Feed Intake

A considerable amount of individual animal variation exists regarding feed intake (Herd et al., 2003) and maintenance requirements (Johnson et al., 2003). Herd and Arthur (2009) identified several physiological processes that impact residual feed intake (RFI) across species, specifically digestion of feed, activity level, thermoregulation and metabolism. In order to maximize individual animal growth and overall productivity we need to ensure that individual animal type is able be successful within the environment in which they are placed. In low quality forage scenarios, ruminants with greater rumino-reticular capacity are more efficient (Van Soest, 1996) presumably due to the potential for greater intake and/or retention time. Heifer development programs should consider a synergistic combination of nutrition, genetics and environment in order to allow females to be the most productive over a lifetime. Therefore, it is important to consider potential metrics in beef heifer selection to improve lifetime productivity.

When feed requirements of the United States beef industry were evaluated, the breeding cowherd required more than half of the total feed requirements compared to feedlot cattle (Carstens and Tedeschi, 2006) indicating that these producers have the potential to improve profitability through improved feed efficiency and reduction in feed costs (Ahola and Hill, 2012). Additionally, biological mechanisms, such as stage of production impact feed intake (Loyd et al., 2011, Sprinkle et al., 2020). Moreover, numerous factors may influence regulation of satiety in growing cattle, including composition of the diet and feed quality. In addition, Carstens and Tedeschi (2006), reported that ADG and metabolic BW are responsible for 60% of the total phenotypic variation in feed intake. In order to ensure adequate growth and productivity post-weaning, it is important to ensure that diet composition and quality are formulated in a way that allow growing heifers to consume adequate intake to meet production standards necessary to meet body size and weight requirements needed to allow for first breeding at 15 months of age.

Research by Minson (1990) reported that dry matter intake (DMI) in lactating cows fed primarily forages increased by 30% during the lactation phase. These factors directly impact the number of animals that can be grazed in a specific location and that stage of production has a substantial impact on voluntary feed intake (Beck et al., 2016). Interestingly, Carstens and Tedeschi (2006) reported that ADG and metabolic BW are responsible for 60% of the total phenotypic variation in feed intake. This suggests that heifers that have greater ADG during the post-weaning phase have greater feed intake. Additionally, these data suggest that heavier cattle consume more feed, which is most likely due to their increased reticulo-rumen capacity. However, this may also suggest that heavier cattle may also consume less feed when expressed on a g/kg BW basis. Although not specifically based on feed intake, Clanton et al., (1983) determined that timing of heifer ADG post-weaning did not impact age at puberty, calf production the following year or other production parameters. Clanton and coworkers (1983) also suggested that heifer rate of gain may not have long-term impacts on subsequent production. Data from Stewart and Martin (1983) reported that smaller framed cows remained in the herd longer than larger framed Angus cows, therefore producing more calves over their lifetime.

Techniques Used to Measure Feed Intake

Recent technological developments have enabled real-time collection of behavior patterns (Theurer et al., 2013) and feed intake on an individual animal basis (Lancaster et al., 2009; Kayser and Hill, 2013). The GrowSafe System (Airdrie, Alberta) collects the exact location, time and duration each time an animal visits the feed bunk. Previous research that focused on measuring feed efficiency assumed that cows 1) consume 2 - 2.5% of their body weight daily, 2) have used individual feed bunks, 3) and/or fecal markers to estimate cow intake (Davis et al., 1983, Kirkpatrick et al., 1985; Kress et al., 2001). However, with current technology utilizing automated feeders and individual electronic identification (EID) tags, we now have the ability to collect accurate individual feed intake data, including intake behavior (visits per day, intake per visit, daily intake, and time spent at feeders) that we have not previously been capable of collecting (Mendes et al., 2011). This technology is currently being used to collect precise intake data used to assess and report (RFI) classifications (GrowSafe); however, this equipment is expensive, there is no way to limit access to cattle for limit feeding, and the process is labor intensive and time consuming. Similar technology is currently being used on arid western rangelands to monitor and record individual animal supplement intake and intake behavior (C-Lock; Rapid City, SD). By utilizing individual animal intake systems we have the ability to collect individual intake data from weaning, analyze across intake classifications and determine efficiency and productivity from weaning through maturity. More specifically, through the C-Lock system, we have the ability to measure individual intake within pasture and between multiple feeds available through their ability to limit feed intake based on EID.

Measures of Feed Efficiency

Several studies have shown that there is considerable variation in feed efficiency within and across breeds (Archer et al., 1999; Herd and Bishop, 2000; Renand and Krauss, 2002). There are numerous avenues for measuring feed efficiency in growing cattle. The most common method in determining feed efficiency is gross efficiency or a feed conversion ratio (FCR). In other words, this is the ratio between gain output and feed input expressed as gain to feed (G:F) or feed to gain (F:G; Archer et al., 1999; Retallick, 2017). Feed conversion ratio is a moderately heritable trait (0.31 to 0.37) that can be useful in evaluating the effects of overall management practices in growing and finishing cattle. Feed conversion ratio is strongly correlated with growth traits, specifically leading to an increase in genetic merit for growth and mature size of breeding females (Herd and Bishop, 2000; Retallick, 2012). However, FCR does not consider maintenance requirements of individual animals (Archer et al., 1999). In addition, it is also known to be negatively correlated with postweaning ADG, yearling BW and cow mature size (Herd and Bishop, 2000).

Another measure of feed efficiency in cattle is RFI, which is defined as the difference between an animal's actual intake and predicted intake. This number is based on animal actual gain, metabolic body weight and overall body composition. Residual feed intake measures variation in feed intake that is independent of BW or growth rate (Crews, 2005) and is computed as the difference between the actual daily feed intake of an animal and its predicted daily feed intake for a given level of maintenance or production (Basarab et al., 2003). An animal that eats more also tends to be larger and gain more weight. The predicted daily feed intake value is calculated by regressing daily DMI on ADG and mid-metabolic BW (MBW; BW at test midpoint $^{0.75}$; Black et al., 2013).

A third measure of feed efficiency is residual average daily gain (RADG). Residual average daily gain is defined as the difference between the actual gain and predicted gain based on an individual animal's DMI, BW and overall body composition or fat cover (Northcutt, 2010). Unlike RFI, higher ADG values are more desirable when selecting cattle based on RADG, as cattle with greater numbers can be expected to gain more weight on the same amount of feed. RADG could be beneficial to producers as they focus on growth of cattle that gain faster on the same or lower amounts of feed. However, increased rate of gain could lead to increased mature weights of growing animals, therefore increasing input costs and decreasing feed efficiencies.

Post-weaning Heifers

Growth and Productivity. Limited research has been done to evaluate the impacts of postweaning voluntary feed intake and its impact on subsequent performance and longevity of female offspring in cow-calf herds. Development and selection of replacement beef heifers is a key factor to improving overall herd productivity and profitability since feed cost represents about two-thirds of the cost of production for majority of beef cattle production systems (Anderson et al., 2005). Therefore, feed efficiency should be a major area of focus in livestock breeding programs (Kennedy et al., 1993) and selection of replacement heifers. In order to maintain a stable herd size and create opportunity for improving overall herd genetics, replacement heifers are necessary (Bagley, 1993). The most common period to manipulate heifer growth and development is between weaning and the first breeding season (Whittier, 1995; Funston et al., 2012). Numerous researchers have determined that feed intake is a heritable trait in beef cattle (Koch et al., 1963; Fan et al., 1995; Nkrumah et al., 2007; Elzo et al., 2009; Mao et al., 2013; Retallick et al., 2017), with heritability values in growing cattle ranging from 0.20 to

0.48, respectively. However, there is much debate regarding raising replacement beef heifers due to input costs and time that it takes to grow them to an ideal weight and size for breeding.

Current NRC (2016) models indicate that older animals generally consume more feed per unit of BW than younger animals due to the difference in age relative to mature body weight composition. It is well understood that increase in cow size leads to an increase in overall capacity, maintenance requirements, and therefore, an increase in feed inputs. Furthermore, feed intake will be influenced by stage of production, environmental factors, and the overall size of the rumino-reticulum (Church, 1979). Smaller framed cows may have reduced feed intake on a daily basis compared to their large-framed counterparts, but due to an increased longevity in the herd, this will also lead to an increase in the amount of feed consumed throughout their lifetime.

Heifers that consume more feed prior to having their first calf are more likely to be larger as a mature animal, barring extreme nutritional or environmental stressors (Webster, 1983). Physiologically, heifers that are larger in frame and capacity should have greater rumino-reticular capacity than smaller framed heifers; greater size leads to greater DMI (NASEM, 2016). Specifically, the capacity of the gut determines the capacity for digestion in herbivores (Demment and Van Soest, 1985). The increase in rumino-reticular volume allows for greater retention rates and digestion of forages that are typically high in fiber and low in quality. This can be extremely important for grazing cattle in the Western United States, where cattle are highly dependent on low-quality forages during the fall and winter months.

Intake and Efficiency. Shike et al. (2015) evaluated postweaning heifer intake, RFI classification and residual gain on Angus and Simmental × Angus heifers over a 5-yr period. Results based on heifer intake classification indicated that a greater percentage of females from the medium or high intake group were retained in the herd longer compared to the low intake heifers. This suggests that cows in the medium and high intake groups may have a greater reticulo-rumen capacity to consume more feed on a daily basis compared to their low intake counterparts. This is in contrast to the selection of smaller framed cattle for herd longevity that was suggested by Stewart and Martin (1983). Additionally, as expected, cows that were classified as high intake had calves that were heavier at birth than calves from dams that were classified as medium or low intake. However, there was no impact of heifer intake classification on milk production following calving. These data suggest that intake classification as a heifer may have limited impact on overall herd longevity and subsequent calf performance.

Parsons and colleagues (2021b) reported that BCS, calf birth weight, and longevity were not influenced by heifer RFI intake classification. As would be expected, birth weight of calves born to first calf heifers were lighter than those calves born to second- and third-parity females. These data suggest that parity may play a larger role in calf growth and production than RFI classification.

Cassady and colleagues (2016) indicated that heifers that consumed less feed than the herd average had a 7% reduction in mature cow BW, regardless of forage quality. This suggests that feed intake during heifer development does have an impact on mature cow BW. In addition, cows that consumed more feed as heifers had the greatest DMI as cows, regardless of feed quality. Also, cows that consumed more forage/feed as heifers consumed greater than 17% more forage compared to animals that were classified as low or moderate intake heifers. These data suggest that reticulo-rumen capacity may have a larger role in herd total feed intake than forage quality.

Lifetime Productivity Metrics in Cow/Calf Production Systems

Beef cow efficiency is a complex, multi-trait variable that's dependent on individual production systems, environment and operation goals (Greiner, 2009). These measures are likely different for each producer and may change from year to year. Several of the major factors that can be used to determine cow efficiency include cow body size, reproductive efficiency, milk yield, pounds of calf weaned and structure/soundness.

Dam Age

A recent study by Beard et al. (2019) investigated the impacts of dam age on heifer progeny performance and longevity from 1,059 Husker red cows that ranged from 2 to 11 yrs of age. Data indicated that heifer calves born to younger (2 to 3 yrs old) cows had lighter birth weights and 205-d weights than those born to moderate (4 to 6 yrs old) and old (≥ 7 yrs old) cows. Although there were significant differences between the birth weights and 205-d weights, the results indicate a 2 kg spread in birth weight and 8 kg spread in 205-d weights. This would suggest that dam age may not have a large biological significance in heifer growth performance. However, these slight weight differences did not lead to differences in pre-breeding BW or weight at pregnancy diagnosis (Beard et al., 2019). As expected, they also determined that female offspring born to moderate aged and old cows had a greater percentage of heifers that reached puberty before breeding compared with heifers born to young cows. However, this did not lead to a difference in pregnancy rates or those calving in the first 21-d. Interestingly, they did determine that calf crop from progeny within dam age was different among all groups with young dams having more calves (3.1 ± 0.7) than moderate (2.8 ± 0.7) and old (2.2 ± 0.8). However, this in part, may be due to the number of cows in the young category compared with the moderate and old cows, which was not reported. Overall, their data suggests that dam age has minimal effects on heifer progeny growth and reproductive performance. with heifer progeny from moderate and older dams having increased performance prior to first calving. However, young dams had increased calf crops and increased productivity compared to older animals.

Additional research out of Nebraska by da Silva and coworkers (2016) evaluated the effects of dam age on female calf productivity through the second breeding season. Their data indicated that as dam age increased, heifer adjusted 205-d BW increased until 7 to 8 yrs of age. In addition, pre-breeding BW were greater in heifer calves born to older dams than younger dams. Data also indicated a tendency for dam age to influence the percentage of heifers that were pre-pubertal prior to breeding season with heifers born to older dams having greater cyclicity rates than heifers born to younger dams. The ability of the females to rebreed in a timely manner is one of the biggest determinants of a female remaining in the herd.

Fuerst-Waltl et al. (2004) reported that as dam age increased, offspring culling rate increased, indicating that dam age may negatively impact longevity of female offspring, and therefore decreasing overall productivity. In addition, Tanida and colleagues (1983) reported the number of calves weaned in Hereford cows was 3.46 calves and 3.66 for Angus cows over 30 yrs and 23 yrs, respectively. Meanwhile, Stewart and Martin (1983), reported total number of weaned calves to be 6.4 over a 12-yr period, respectively. In other words, females that are able to rebreed sooner, maintain a pregnancy from year to year and wean a good calf will remain in the herd longer, which in turn allows for her to produce a greater number of calves over her lifetime.

Cow Body Size

Cow body size has been shown to influence calf weaning weight (WW) and feed intake, and as a result, cow efficiency (Dinkel and Brown, 1978, Scasta et al., 2015, Beck et al., 2016). Data from Ziegler and coworkers (2020) using crossbred mature beef cows, determined that cow BCS at calving pre-breeding and weaning was positively correlated with greater cow BW. In addition, for every 100-kg increase in cow BW, calf birth weight was increased at birth and adjusted 205-d weights. In addition, BW of heifer progeny post-weaning was increased with every additional 100-kg increase in dam BW. Parsons and colleagues (2021a) reported that cow BW of lactating and non-lactating females were greater in older cows than younger cows, however there was no differences in DMI (g/kg BW) suggesting that intake may be confounded by age and size.

Pounds of Calf Weaned

Total weight of calves weaned during a cow's lifetime is an important factor of the cow-calf segment as it is a factor that accounts for the survival and reproductive performance of the dam, as well as the survival and growth rate of their offspring (Burns et al, 2010). In other words, weaned calf production per replacement heifer over a lifetime is considered a comprehensive measure of fertility or calving rate, mothering ability, weaning weight and cow survival or longevity (Tanida et al., 1988; Nunez-Dominguez et al., 1991).

Using crossbred purebred cows, Cundiff and coworkers (1992) reported that weaning weight per cow exposed increased as cow age increased from 2 to 5-yrs of age, peaked from 5 to 9-yrs of age and declined from 9 to 12-yrs of age. Stewart and Martin (1983) reported total calf weigh weaned for 113 Angus cows over 12-yr was 1283 kg respectively. Total pounds of calf weaned is important as this is the main form of income for cow-calf producers.

Milk Yield

Lubritz et al., (1989) reported that milk production in beef cow plateaus between 6 and 10 years of age. Neville (1974) reported that milk production increased linearly until age 6, while Rutledge and colleagues (1971) reported 8 yrs of age. Buskirk et al., (1995) reported that increased postweaning ADG (0.6 vs 0.4 kg/d) was beneficial to milk and overall productivity of traditionally weaned heifers. Heifers with decreased milk yield utilize greater feed energy per unit of calf weaning weight, contributing to a reduction on lifetime calf weaning BW (Freking and Marshal, 1992), but may have led to increased longevity in the herd.

Jeffery and colleagues (1971) analyzed milk yield in Aberdeen, Angus, Galloway, Hereford and hybrid breeds. In this study, age of dam and milk yield correlations were low (0.32), but production tended to increase within increasing age through the first three lactations before leveling off, which is less than previously reported data. This may suggest that breed also plays a pivotal role in milk production, especially in younger beef females.

Ferrell and Jenkins (1985) determined that a cow with genetic potential for high milk production will be more efficient when high-quality forages are available but fail to maintain milk production and body condition when low-quality forages are more readily available within their environment. This can be problematic in the Western United States, where forages are low-quality for the majority of the year. Ultimately, this could lead to reduced milk yield in those beef females in the West and potentially reduce calf WW.

Reproductive Efficiency

There is much debate regarding the benefits and disadvantages of raising replacement heifers due to the input costs and time it takes to get them to ideal size, weight etc. Research states that heifers should be approximately 65% of their mature body weight at first breeding and 85% at first calving (Patterson et al., 1992). Management of replacement heifers should focus on ensuring that they reach puberty so they able to calve at 2-yr of age. Calving at 24 months of age allows for maximum lifetime productivity (Patterson et al., 1992). Heifers that calve at 2-yr of age will produce more calves during their lifetime compared to those that calve at ≥ 3-year-old cows (Pope, 1967; Donaldson, 1968; Pinney et al., 1972; Bernard et al., 1973; Carter and Cox, 1973; Cundiff et al., 1974; Chapman et al., 1978; Núñez-Dominquez et al, 1985).

Schubach et al., (2019) investigated the impacts of postweaning growth rate of replacement beef heifers on reproductive development and productivity as cows. Briefly, they utilized seventy-two Angus × Hereford heifers into one of three treatment groups formulated to yield a postweaning ADG of 0.40, 0.60, and 0.80 kg/d for LGAIN, MGAIN, and HGAIN, respectively. As expected, HGAIN heifers had greater ADG than MGAIN and LGAIN heifers. Additionally, growth rate based on weekly BW values as also greater for HGAIN heifers compared to MGAIN and LGAIN heifers. Heifers assigned to HGAIN and MGAIN were heavier at breeding than LGAIN heifers, which is likely due to the increase in kg/d provided during the study. No treatment differences were noted for heifer BCS at calving or incidence of dystocia. There were also no treatment differences for milk yield and composition.

Reproductive efficiency has been considered on the most important aspects of cow-calf production systems. Adequate reproduction and calf growth are vitally important to profitability of cow-calf producers. The lifetime productivity of a beef female begins at the onset of puberty and ends when a producer determines she is no longer a valuable part of their operation. Depending on the occurrence of specific events, a cow may or may not remain in the herd. These events may include age at first calving, milk production, calving issues, or postpartum intervals and rebreeding (Diskin and Kenny, 2014).

The attainment of specific reproductive targets for beef females helps ensure short calving windows and consistent calving groups. There are significant costs associated with raising replacement heifers. It is vitally important that they become pregnant early in their first breeding season, birth and rear and calf through weaning, become rebred and have another calf within a 365-d calving interval (Diskin and Kenny, 2014). Browning et al. (1994) and Strauch et al. (2001) have shown that primiparous cows have a longer postpartum interval (PPI) and lower pregnancy rates than multiparous individuals. Kress et al. (1990) and van Oijen et al (1993) showed that younger cows had a lower calving rate than cows that were 4-yrs old or greater.

Low levels of nutrition following weaning of replacement heifers delayed puberty (Wiltbank et al., 1966; Clanton and Zimmerman, 1970; Arije and Wiltbank, 1971; Short and Bellows, 1971) and resulted in less than optimum conception rates when heifers were bred as yearlings. On the other hand, heifer fed at high levels of nutrition after weaning have a reduced life span and limited milking ability (Swanson, 1960; Pinney et al., 1972).

Current NRC models (2016) indicate that older animals generally consume more feed per unit of BW than younger animals due to the difference in age relative to mature body composition. Smaller framed cows may be more ideal to beef producers in semi-arid regions of the United States where forage quality and availability is scarce. It is well understood that increase in cow size leads to an increase in overall capacity, maintenance requirements and therefore increased feed inputs. These factors directly impact the number of animals that can be grazed in a specific location (Beck et al., 2016). Beard and colleagues (2019) also reported that calves born to moderately aged or older cows had greater percentage of offspring that reached puberty prior to their first breeding season when compared to heifers born to young cows.

Limitations of Research to Date

As discussed earlier, there are very few studies related to post-weaning voluntary feed intake in heifers offered forage-based diets, specifically the impact of intake as a heifer on lifetime productivity. In addition, research is needed to determine the ideal timepoint, post-weaning, to measure voluntary feed intake in order to fully understand how it relates to lifetime productivity. A considerable amount of individual animal variation exists regarding feed intake (Herd et al., 2003) and maintenance requirements (Johnson et al., 2003). Heifer development programs should consider a synergistic combination of nutrition, genetics and environment in order to allow females to be the most productive over a lifetime. Therefore, it is important to consider many potential metrics in beef heifer selection to improve lifetime productivity.

Conclusion

Due to the cost and technology necessary, there is very little research examining the influence of heifer post-weaning voluntary feed intake classification on production and reproduction measurements, as well as lifetime productivity of replacement beef females. In Chapter 2, we evaluate impact of dam age on the lifetime productivity of replacement beef females. In Chapter 3, we evaluate the influence of heifer post-weaning voluntary feed intake classification on lifetime productivity in Black Angus females. In Chapter 4, we evaluate the impacts of heifer post-weaning intake classification on performance measurements of lactating and non-lactating two-, five- and eight-year-old Angus beef females. In Chapter 5, we discuss overall conclusions from our research and discuss how our results will lead to future studies related to dam age and voluntary feed intake and the potential impacts on lifetime productivity of replacement beef females in commercial beef cattle production.

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CHAPTER TWO

IMPACTS OF DAM AGE ON LIFETIME PRODUCTIVITY OF ANGUS REPLACEMENT BEEF FEMALES

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CHAPTER TWO

IMPACTS OF DAM AGE ON LIFETIME PRODUCTIVITY OF ANGUS REPLACEMENT BEEF FEMALES

Abstract

Comprehensive cow-calf production data was utilized to evaluate the impact of dam age on lifetime productivity of Angus replacement beef females. Cows used in this study were commercial Angus replacement females born between 2006 and 2020, ranging in age from 1 to 14 yr of age (*n* = 3,568). To determine the impact of dam age on lifetime productivity, cows were classified by age groups, specifically 2-, 3-, 4-, 5-, 6/7-, and 8-yrs old and older. The 8-yr and older group consisted of females that were up to 14-yr of age. Cow BW at breeding exhibited a cow age × dam age interaction ($P < 0.01$). Cows at 5-yrs of age from 2-yr old dams weighed less at breeding than cows at 5-yrs of age from 3-, 4-, 5- and 8-years and older dams, with cows at 5-yr of age from 6/7-yr old dams being intermediate. The probability of remaining in the herd at the age of 5 was significant for dam age ($P = 0.05$) averaging 69.41%, with cows from 2-, 5- and 8-yr old and older dams remaining in the herd longer than cows from 3-, 4-, and 6/7-yr old dams. Productivity as a measure of total pounds of calf weaned through 5-yrs displayed a dam age effect ($P = 0.01$) with cows from 8-yrs or older dams weaning more total pounds of calf, than cows from 3-yr-old dams. In summary, the impact of dam age on lifetime productivity indicates that dam age can impact future productivity of their offspring.

Keywords: dam age, lifetime productivity, replacement heifer

Introduction

Lifetime productivity, typically measured as the total weight of calves weaned during a cow's lifetime, is one of the most important components of efficiency in beef cow-calf production because it is a function of survival and reproductive performance of cows and of survival and growth rate of their offspring (Cundiff et al., 1992). Additionally, cows that remain in a herd longer reduce the cost of replacements on a yearly basis. These traits are a function of fertility, maternal ability and survival of the cows, as well as, of prenatal and postnatal survival and preweaning growth of their offspring. Average cow age (generational interval) in the producing cow herd is a function of when a cow is no longer productive due to the loss of calf, poor calf performance, illness, death, infertility, and/or unsoundness.

For a herd to be profitable, cows should remain in the herd long enough to pay for their development and maintenance cost. The number of cows remaining in production past this breakeven age, typically 5-yrs in beef herds, must compensate for those cows that are culled before that age (Snelling et al., 1995). Greater longevity also allows producers to be more selective when choosing replacement females; although, this may increase generation intervals. Longevity traits reflect the performance of a cow over her total herd life and can only be measured after the cow has been culled. An alternative measure of herd life is the use of stayability traits. Stayability, as a measure of herd life, is defined as the probability of surviving to a specific age, given the opportunity to reach that age (Hudson and Van Vleck, 1981).

Selection of replacement heifers plays a key role in productivity of beef cow herds as well. Typically, heifers born earlier in the calving season are more likely to be retained as they have an increased likelihood of being greater in size and capacity then their younger counterparts at selection. In addition, heifers born to cows that have had one or more calves have shown increased pregnancy rates in their second breeding season when compared to first-calf heifers (da Silva et al., 2016). Furthermore, early born calves are also born to dams that were fertile at the beginning of the breeding season (Roberts et al., 2017) and, as a result, likely are more suited to the reproductive environment.

Herd structure, based on individual management decisions related to culling requires considerable discussion. Maintaining cows in a herd for a shorter period of time requires increased replacement heifers, therefore shifting the median age to younger animals. It is well understood that younger/smaller females will require less feed resources than older females, but also potentially sacrifice total calf weaned compared to older more mature females. Therefore, the objectives of this study were to determine the impacts of dam age on lifetime productivity of their female offspring.

Materials and Methods

Experimental procedures utilized in this study were approved by the MSU Agriculture Animal Care and Use Committee of Montana State University (2021-AA09 & 2021-AA10).

Cow-Calf Production Data

Comprehensive cow and calf performance data has been collected at Northern Agri-cultural Research Center, Havre, MT, since 2005. Cows used in this study are commercial Angus females (*n* = 3,568; Supplementary Table 1) born between 2006 and 2020, ranging in age from 1 to 14-yr of age. To determine the impact of dam age on lifetime productivity, progeny and yearling heifer data were used. In addition, bred cows were classified by age group, specifically 2-, 3-, 4-, 5-, 6/7-, and 8-yr old and older to determine the impact of dam age on lifetime productivity. The 8-yr and older group consisted of females 8 and 14-yr of age. The 6 and 7-yr-old cows were combined to ensure group sizes were similar. All animals used in this study were housed at the Northern Agricultural Research Center (NARC), a part of the Montana Agricultural Experiment Stations, (Havre, MT, USA, Montana; 48.5500° N, 109.6841° W). Individual animal data is collected on all NARC females throughout their lifetime. Individual animal data includes calf Julian birth date, calf birth weight, calf weaning weight (WW), calf 205-d weight, calf yearling weight (YW), weaning weight ratio (WWR), cow body weight (BW) at weaning and breeding, and cow body condition scores (BCS). As females are bred, lifetime productivity data is collected each year, specifically reproductive data including pregnancy status, conception percentage and whether or not females were bred via artificial insemination or natural service. This data is collected starting at birth and ends when an animal is culled from the herd. All females that are culled from the herd are recorded for cause of culling which may include pregnancy status (open or out of normal breeding season), disposition concerns, or displayed structural concerns (lameness, teeth, feet/legs, udder). In addition, beginning in 2011, females that did not conceive via artificial insemination did not remain in the herd. For clarification, dam age data should be thought of as the data related to the mother of the calf, while cow age is related to the females as they become productive bred females within the herd.

Statistical Analysis

The data and number of observations in each age category used in this manuscript are available in the Supplementary Lifetime Productivity Table file. Beef cow production and reproduction data parameters include cow yearling weight, cow weight at breeding, cow BCS at calving, cow weight at weaning, cow BCS at calving, cow years in the herd, productivity through

5-yrs, calf BW, calf 205-d weight, calf WW, weaning weight ratio (WWR) and calf Julian birth date. These characteristics were analyzed using ANOVA with a mixed model that included cow age, dam age, and the interaction of cow age and dam age as fixed effects, and individual cow as the random effect (lme4; Bates et al., 2015). Data were plotted and transformed if needed to satisfy assumptions of normality and homogeneity of variance. Individual animal was considered the experimental unit. In addition, pregnancy status and AI conception rate were analyzed using generalized linear models following a binomial distribution in an ANOVA framework (car; glm; Fox and Weisberg, 2011; R Core Team, 2020). An alpha ≤ 0.05 was considered significant. Tendencies were reported when significance was $P \leq 0.10$. The Tukey method was used to separate means when alpha was < 0.05 (emmeans; Lenth, 2019). All statistical analyses were performed in R (R Core Team, 2020).

Results

The effect of dam age on subsequent production measures and cow longevity of Angus beef females is detailed in Table 1 and Table 2. Cow BW at breeding exhibited a cow × dam age interaction ($P < 0.01$). Cows at 5-yrs of age born from 2-yr old dams weighed less at breeding than cows at 5-yrs of age born from 3-, 4-, 5- and 8-years and older dams, with cows at 5-yr of age born from 6/7-yr old dams being intermediate. There were no significant cow age × dam age interactions ($P \geq 0.16$) for lifetime productivity variables. Therefore, only main effects will be presented for all other variables.

Dam Age Effects

Cow BW at weaning displayed significance for dam age (*P* = 0.04) with cows born from 5- and 8-yr old and older dams having greater BW than cows born from 2-yr old dams with 3-, 4-, and 6/7-yr old dams being intermediate. Calculated calf 205-d weights displayed an effect of dam age (*P* = 0.03) with cows born from 2- and 3-yr old dams producing calves with greater 205-d weights than cows born from 6/7- and 8-yr old and older dams, while cows born from 3- and 4-yr old dams were intermediate. Weaning weight ratio (WWR) displayed a tendency for dam age (*P* = 0.10) with cows born from 2- and 3-yr old dams having the greatest WWR. Pregnancy status displayed tendency for dam age (*P* = 0.08) with cows from 8-yr old dams having greater pregnancy rates than all other age classes. There was no effect ($P \geq 0.19$) of dam age on BCS at calving, calf birth weight, calf weaning weight, calf Julian birth date or AI conception.

Cow yearling weight (Table 2) was significant for dam age ($P < 0.01$) with cows from 5-, 6/7-, and 8-years and older dams having greater yearling weights than cows from 2- and 3-yr old dams, with cows from 4-yr old dams being intermediate. The probability of remaining in the herd at 5-yr old varied across dam age groups with cows from 2-yr old and 5-yr old dams having greater probability to remain in the herd than the other age groups. The probability of remaining in the herd until the age of 5 averaged 69.41% across all age groups. Productivity as a measure of total pounds of calf weaned through 5 yrs displayed a dam age effect (*P* = 0.01) with cows from 8-yrs or older dams weaning more total pounds of calf than cows from 3-yr old dams. All other age groups were intermediate.

Cow Age Effects

The influence of cow age on beef cow production and reproductive measurements for Angus beef females is detailed in Table 3. Cow BCS were significant for cow age ($P < 0.01$) with BCS increasing from 2 through 7-yrs of age before decreasing in cows that were 8-yr or older. Cow weight at weaning displayed an effect of cow age ($P < 0.01$) with weights increasing from 2 through 7 yrs of age before declining in cows that were 8-yrs of age or older. As expected, calf birth weights were significant for cow age ($P < 0.01$) with 2- and 3-yr old cows having lighter offspring, while 6–7- and 8-yr old cows had the heaviest calves, while 4- and 5-yr old cows being intermediate. In addition, calf 205-d weights displayed an effect of cow age ($P < 0.01$) with 205-d weights increasing from 2 through 4 years of age, with 6/7-yr old cows having the heaviest weights, while 5- and 8- and older cows were intermediate. Calf weaning weights displayed an effect of age ($P < 0.01$) with increasing weights from 2 through 4 years of age, while 6/7- and 8 and older cows had the heaviest offspring with 5-yr old cows being intermediate.

Discussion

Cow longevity is a major factor to consider in commercial cow-calf production. Increased longevity decreases the need for increased numbers of replacement heifers. Although there is a potential genetic advantage to first-calf heifers, there is also a significant cost associated with raising replacement heifers. The age to which individual cows remain in the herd varies based on individual management decisions and needs of the operation. Multiple studies have determined varying ranges of longevity within beef herds across the United States. Research by Tanida and colleagues (1988) compared two different beef herds (Hereford and

Angus) over 30 yrs and 23 yrs, respectively. It should be noted that the average first calving of the Hereford herd was 3.2-yr of age, while the average age of the Angus females at first calving was 2-yr of age. Furthermore, females from the Hereford herd were typically culled at 10-yr of age, while the Angus herd generally culled based on non-pregnancy, poor production, calving difficulty and poor maternal ability. Results indicated that the average longevity of over time was 4.21 yrs for Hereford and 4.49 yrs for Angus from first calving to removal from the herd and 7.40 and 6.68 yr from birth to removal from the herd, respectively. The lack of differences in production results between the two herds is potentially due to differences in sire, culling criteria, and overall management practices. In relation, Stewart and Martin (1983) analyzed performance data from Angus cows over a 12-yr period and indicated that the average herd life was 7.4 yrs. Our data indicates that longevity within our Angus herd was 7.24.

Although cow longevity and overall herd dynamics is going to vary from herd to herd, one of the major factors influencing this production process is reproductive success of all beef females, first-calf heifers and mature cows. According to National Animal Health Monitoring System (NAHMS) data (2008) one-third of all cows are culled from the herd due to reproductive failure. Data from Boyer and colleagues (2020) indicated that in order for replacement females to cover their developmental costs and maintenance expenses they must have at least six calves. Data from Clark and (2005) reported slightly lower numbers, suggesting 3 to 5 calves in order for a heifer to repay her development costs. Either way it is well understood that reproductively sound females are more likely to remain in the herd longer. Data from Cushman and colleagues (2013) indicated that heifers from the United States Meat Animal Research Center (USMARC) beef herd that calved within the first 21-d of their first calving season had a significantly better chance of remaining in the herd through their fifth calf than females that calved from 23 d to greater than 43 d. This data suggests that females that calve early in the calving season, produce ≥ 5 calves over a six-year period and have the ability to rebreed in a timely manner, have proven reproductive performance. Beef females that have the ability to maintain physical and reproductive soundness in limited nutritional environments while weaning a heavy calf over their productive lifetime provide an economic advantage to beef producers.

A recent study by Beard and colleagues (2019) investigated the impacts of cow age on heifer progeny performance and longevity from 1,059 Husker red cows that ranged from 2 to 11 yrs of age. Data indicated that heifer calves born to younger (2 to 3 yrs old) cows had lighter birth weights and 205-d weights than those born to moderate (4 to 6 yrs old) and old (≥ 7 yrs old) cows, which is similar to the current study. However, in terms of dam age from the current study, cows born to young dams (2- and 3-yrs old) had greater 205-d weights than their older counterparts. Interestingly, Beard and coworkers (2019) did determine that calf crop from progeny within dam age was different among all groups with young dams having more calves than moderate and old cows. However, this in part, may be due to the number of cows in the young category compared with the moderate and old cows, which was not reported.

Additional research out of Nebraska by da Silva and coworkers (2016) evaluated the effects of dam age on female calf productivity through her second breeding season. Their data indicated that as dam age increased, heifer adjusted 205-d BW increased until 7 to 8 yrs of age. In addition, pre-breeding BW were greater in heifer calves born to older dams than younger dams. Data also displayed a tendency for dam age to influence the percentage of heifers that were pre-pubertal prior to breeding season with heifers born to older dams having greater cyclicity rates than heifers born to young dams. In the current study, there only tended to be an increase in pregnancy status in cows from 8-yr and older dams. Pregnancy status or the ability of the females to rebreed in a timely manner is one of the biggest, if not the biggest determinant of a female remaining in the herd. In relation, our data is in agreement with da Silva and coworkers (2016), where calf 205-d weights were greater in calves born to older cows than younger cows which is consistent with our findings. Contradictory to data from da Silva and coworkers, our data displayed an increase in pregnancy status in offspring born to 2-yr old cows compared to other age classes.

In relation to previously mentioned studies, Cundiff and coworkers (1992), determined that WW per cow exposed increased as cow age increased from 2 to 5-yrs of age, peaked from 5 to 9-yrs of age and declined from 9 to 12-yrs of age. This data is in accordance with our data, where WW values increased in offspring through 7-yrs before declining at 8-yrs and older. This suggests that cow age directly impacts calf WW, but the age of the cow's dam has minimal impacts, with only a tendency for younger cows (≤ 4-yrs old) to have greater WWR than older cows (≥ 5-yrs old). Not only are median aged cows weaning heavier calves than younger and more senior cows, their WWR are greater as well.

Although not discussed in this paper, it is also important to consider the differences that may occur in calves due to breed differences. Tanida and colleagues (1988) reported the number of calves weaned in Hereford cows was 3.46 calves and 3.66 for Angus cows over 30 yrs and 23 yrs, respectively. Meanwhile, Stewart and Martin (1983), reported total number of weaned calves to be 6.4 over a 12-yr period. Therefore, the current results are breed specific and this also suggests the differences observed between the current data and previous research.

Stewart and Martin (1983) reported total calf weigh weaned for 113 Angus cows over 12-yr was 1,283 kg respectively. Our research indicates and average of 683.0 kg of total calf weaned for dams from 2 through 8-yr old and older. These differences are likely due to the increase in data available over 12-yrs compared to 5-yrs in our study. In addition, cow size may have been different between studies. Furthermore, there was no effect of cow age or dam age on calf Julian birth date or AI conception percentage. Overall, these previously mentioned studies indicate that older cows may have a positive impact on growth and productivity of female offspring.

Conclusion

Data from our study suggest that dam age impacts the future outcomes of replacement heifers based on productivity and reproductive measures. In general, offspring born to dams that are of moderate age (≥ 5 or older) will have increased productivity compared to those born to younger animals. This data suggests that producers might want to consider the cost-benefit ratio of raising a large number of replacement heifers compared to retaining the older, reproductively sound and proven mature females instead. However, further research is needed to fully understand the impact of dam age on lifetime productivity of female offspring. Specifically, a better understanding of the value of mature, proven females and their success in limited nutrition forage-based beef production systems and the overall economic impact on cow-calf profitability.

Table 1. The effect of dam age on subsequent production measures and cow longevity in Angus beef females.

	Dam Age, Years							*p*-value		
Category	2	3	4	5	6/7	8+	SE[1]	Cow Age	Dam Age	Cow × Dam
Cows, n	733	590	575	427	433	810				
Cow wt. at breeding, kg								< 0.01	0.27	< 0.01
2 yrs.	471.0	486.66	489.90	496.52	497.81	477.34	13.85			
3 yrs.	524.66	520.92	533.82	550.52	522.08	519.96	14.11			
4 yrs.	567.02	586.36	580.25	606.73	581.25	563.72	14.13			
5 yrs.	557.64[a]	609.65[b]	612.53[b]	627.70[b]	584.70[ab]	609.08[b]	15.48			
6/7 yrs.	611.88	621.04	626.35	619.28	643.99	635.20	14.48			
8+ yrs.	627.23	628.54	601.62	600.75	619.70	631.72	15.24			
Cow BCS at calving	5.34	5.32	5.32	5.37	5.33	5.33	0.09	< 0.01	0.34	0.19
Cow wt. at weaning, kg	598.50[a]	617.63[ab]	617.55[ab]	627.94[b]	619.72[ab]	620.39[b]	6.97	< 0.01	0.04	0.16
Calf birth wt., kg	39.55	40.85	40.63	39.39	39.60	39.89	0.63	< 0.01	0.19	0.31
Calf 205 d wt., kg	270.07[a]	271.46[a]	263.32[ab]	265.46[ab]	257.06[b]	261.43[b]	5.39	< 0.01	0.03	0.29
Calf weaning wt[2], kg	254.37	256.30	249.65	252.52	244.04	247.48	5.12	< 0.01	0.24	0.91
Calf Julian birth date	80.97	81.12	80.79	80.07	81.26	81.36	1.74	0.12	0.49	0.81
Weaning weight ratio[3], %	42.49	42.07	40.72	40.32	40.22	40.26	1.02	0.56	0.10	0.63
Pregnancy status, %	88.13	87.16	88.03	88.65	87.95	90.14	1.68	0.44	0.08	0.45
AI conception, %	62.76	59.68	64.42	63.07	64.00	59.67	2.91	0.98	0.85	0.98

[1]Pooled standard error of the means
[2] Calf weaning weight is from the grand dam of the heifer
[3]Actual calf weaning wt./cow wt. at weaning

Table 2. The effect of dam age on production and longevity characteristics in Angus beef females.

	Dam Age, Years							
Category	2	3	4	5	6-7	8+	SE[1]	*p*-value
Cow yearling weight, kg	355.23[a]	371.96[b]	381.51[bc]	386.24[c]	386.58[c]	386.61[c]	6.57	< 0.01
Present at 5 yr, %	76.70	60.47	70.77	77.36	59.01	72.14	5.32	0.05
Productivity thru 5 yr.[2], kg	614.02[ab]	559.79[a]	641.68[ab]	727.87[ab]	757.15[ab]	797.48[b]	60.37	0.01

[1]Pooled standard error of the means
[2]Total pounds of calf weaned through 5 years.

Table 3. The effect of cow age on subsequent production and reproductive characteristics in Angus beef females.

	Cow Age, Years							*p*-value		
Category	2	3	4	5	6-7	8+	SE[1]	Cow Age	Dam Age	Cow × Dam
Cow BCS at calving	4.96[a]	5.17[b]	5.36[c]	5.52[de]	5.60[d]	5.40[ce]	0.09	< 0.01	0.34	0.19
Cow wt. at weaning, kg	526.62[a]	575.95[b]	624.30[c]	650.74[d]	663.51[e]	660.61[de]	5.54	< 0.01	0.04	0.16
Calf birth wt., kg	34.16[a]	39.11[b]	40.29[bc]	41.65[cd]	42.50[d]	42.21[d]	0.59	< 0.01	0.19	0.31
Calf 205 d wt., kg	233.72[a]	257.32[b]	268.92[c]	272.28[cd]	279.65[e]	276.91[de]	5.16	< 0.01	0.03	0.29
Calf weaning wt., kg	223.72[a]	243.51[b]	253.59[c]	259.13[cd]	262.92[d]	261.48[d]	4.89	< 0.01	0.24	0.91
Calf Julian birth date	78.91	81.34	81.31	79.93	82.46	81.65	1.69	0.12	0.49	0.81
WWR[2], %	41.19	41.92	41.45	40.56	40.64	40.32	0.94	0.56	0.10	0.63
Pregnancy status, %	90.42	89.31	89.24	86.40	88.91	85.28	1.70	0.44	0.08	0.45
AI conception, %	60.80	59.98	64.46	61.70	64.79	61.87	2.91	0.98	0.85	0.98

[1]Pooled standard error of the means
[2]WWR = actual calf weaning wt./cow wt. at weaning

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CHAPTER THREE

INFLUENCE OF HEIFER POST-WEANING VOLUNTARY FEED INTAKE CLASSIFICATION ON LIFETIME PRODUCTIVITY IN BLACK ANGUS BEEF FEMALES

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CHAPTER THREE

INFLUENCE OF HEIFER POST-WEANING VOLUNTARY FEED INTAKE CLASSIFICATION ON LIFETIME PRODUCTIVITY IN BLACK ANGUS BEEF FEMALES

Abstract

This study evaluated heifer post-weaning voluntary feed intake (g/kg BW) classification on performance and reproductive measures, as well as impacts on lifetime productivity of 519 commercial Angus beef females. Heifer post-weaning voluntary feed intake (g/kg BW) was calculated over 80 test days following weaning using GrowSafe units. Heifers were categorized based on voluntary feed intake (g/kg BW) as either low (< - 0.50 SD from the mean), average (± 0.50 SD from the mean), or high (> 0.50 SD from the mean) within year. Cow body weight (BW) and body condition score (BCS) at breeding displayed an age effect ($P < 0.001$), with 2- and 3-year old cows having lighter BW and lower BCS than 4-yr-old and older cows. Cow BW at weaning showed significance for age and intake ($P < 0.001$) with younger cows being lighter than older cows, while low intake classified females had greater BW at weaning compared to average and high intake females. Additionally, calf 205-d weights and calf weaning weights ($P < 0.01$) were significant for age with calves born from older cows weighing more than younger cows. Weaning weight ratio displayed a linear increase with increasing intake classification ($P < 0.01$). Heifer yearling BW was significant for intake ($P < 0.01$) with low and average intake heifers classifications having greater heifer yearling BW than cows that had high intake classifications as a heifer. Age and intake classification did not impact ($P \geq 0.22$) pregnancy

status or AI conception. In summary, heifer post-weaning feed intake classification had only minor impacts compared to age effects on lifetime productivity of Angus beef females.

*Keywords***:** beef cattle, efficiency, heifer, intake, productivity

Introduction

The profitability of beef cow-calf production systems is dependent on input and output costs (Arthur and Herd, 2005). Reducing input associated with developing replacement heifers can help reduce cost of production. Development and selection of replacement beef heifers is a key factor to improving overall herd productivity and profitability keeping in mind that feed costs represent about two-thirds of the cost of production for beef cattle producers (Anderson et al., 2005). In addition, the most common period to manipulate heifer growth and development is between weaning and the first breeding season (Funston et al., 2012). Therefore, we need to consider the relationship between heifer development and heritability parameters to improve beef heifer growth and performance in beef cattle production systems.

Moreover, variation in individual animal intake is impacted by stage of production, feeding behavior, environmental challenges, and the specific stage of the animal's development (Arthur and Herd, 2005). Herd and colleagues (2004) identified several physiological processes that impact feed intake across species, specifically digestion of feed, activity level, thermoregulation and metabolism. In order to maximize individual animal growth and overall productivity; we must match animal type to the environment. In low quality forage scenarios, ruminants with greater rumino-reticular capacity are more efficient, (Van Soest, 1996) presumably due to the potential for greater intake and/or retention time. Heifer development programs must consider a synergistic combination of nutrition, genetics and environment in order to allow females to be the most productive over a lifetime. Therefore, it is important to consider potential metrics in beef heifer selection to improve lifetime productivity.

When considering replacement heifers, growth traits (frame size and capacity) are two of the biggest considerations for beef producers as increased size and capacity allow for greater feed intake, as well as the ability to carry a calf. In relation, the expression of feed efficiency traits is dependent on the stage of maturity at which the trait was measured on the animals (Arthur and Herd, 2005). Parsons and coworkers (2021) determined that residual feed intake (RFI) estimates on post-weaning heifers did not significantly predict subsequent lifetime productivity of the cow herd. In addition, Brody (1945) indicated that puberty in heifers leads to changes in the growth curve of developing females which shifts from lean growth towards fat deposition, which could in essence impact intake due to physiological changes. However, having the ability to measure individual intakes on weaned heifers allows us to better understand the relationship between intake, size and potential lifetime productivity. We hypothesized that heifer post-weaning intake classification would not impact lifetime productivity and cow age would have a greater impact on lifetime productivity. Therefore, objectives of this study were to evaluate the relationship between post-weaning heifer intake (g/kg BW) classification on subsequent lifetime productivity of Black Angus beef females.

Materials and Methods

All animals used in this study were housed at the Northern Agricultural Research Center (NARC), a part of the Montana Agricultural Experiment Station, (Havre, MT, USA; 48.5500° N, 109.6841° W). Experimental procedures utilized in this study were approved by the MSU Agriculture Animal Care and Use Committee of Montana State University.

Feeding Trial and Baseline Data

Comprehensive cow and calf performance data has been collected at NARC since 2010. Animals used in this study are commercial Black Angus females born between 2010 and 2019. Data on all females is collected starting at birth and ends when an animal is culled from the herd. To determine the impact of post-weaning voluntary feed intake, all NARC heifer calves are weaned onto pasture from late September to early October as a cohort. Approximately 60 to 85 d post-weaning, heifers were placed in pens equipped with GrowSafe (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada) feed intake units on a feed intake trial where daily individual animal intake was collected. Heifers were provided primarily forage-based diet comprised of corn silage (55-74%) and grass hay (6.5 - 27%) on as fed basis. Individual feedstuff amounts varied from year to year based on availability, but all diets were formulated to meet the maintenance requirements for growing, moderate framed beef heifers (10.5% crude protein and 66% total digestible nutrients; NASEM, 2016). To avoid over-conditioning, diets were calculated for 0.0 ADG when estimating 2% of BW intake; however, with unlimited intake the heifers usually gained 0.68 to .91 kg per day (Parsons, 2021). Heifer BW was collected over two consecutive days at the start and end of the 80-d period, and every 28 d throughout the duration of the trial in order to determine BW change over time. Heifers were categorized based on voluntary feed intake ($g \cdot kg\ BW^{-1}$) as either low (n = 161; < -0.50 SD from the mean), average (n =200; ± 0.50 SD from the mean), or high (n = 158; > 0.50 SD from the mean) within year. Cows were grouped according to their age into five categories, 2-year-olds, 3-year-olds, 4-year-olds, 5- and 6-year-olds and 7 years or older. Five- and six-year-old cows were combined to ensure group sizes were similar.

Heifer Post-Intake Test Management

Following the intake test, diets were reformulated to provide adequate nutrients for heifers to gain 0.68 kg/d and were held in a dry lot until turned out to pasture between April and May each year when range was available. Post-breeding, first-calf heifers and mature females were then wintered together as a cohort at NARC headquarters and grazed summer pastures at the Thackery Ranch (48°21’ N 109°30′ W), which is located south of Havre, MT in the Bear Paw Mountains. All females, first calf heifers and mature cows, were estrous synchronized and artificially inseminated based on timed AI in early June. Natural service bulls were presented to the females for an additional 45 d. Based on these time frames, females were expected to calve from March to April of the following year. At weaning, between mid-September and early October, all females were ultrasounded by a qualified veterinarian to determine pregnancy status. At weaning all calves were returned to the NARC hay grounds for grazing. All pregnant cows remained at the Thackery Ranch through early January and grazed late season dormant forages. All females that were culled from the herd were recorded for cause of culling which included pregnancy status (open or out of normal breeding season), disposition concerns, or displayed structural concerns (lameness, teeth, feet/legs, udder).

Statistical Analysis

Data utilized in this manuscript is located in Supplementary Table 1. Beef female production and reproduction data including cow BW and BCS at breeding, cow BW at weaning, calf birth weight, calf 205-d weight, calf weaning weight, calf weaning weight ratio (WWR), and

Julian birth date were analyzed using ANOVA with a mixed model that included age, intake classification and the interaction of age and intake classification as fixed effects, and individual cow as the random effect (lme4; Bates et al., 2015). Data were plotted and transformed if needed to satisfy assumptions of normality and homogeneity of variance. Preplanned, orthogonal polynomial contrasts were used to determine linear and quadratic effects for intake and age main effects. Individual animal was considered the experimental unit. In addition, pregnancy status and AI conception rate were analyzed using generalized linear models following a binomial distribution in an ANOVA framework (car; Fox and Weiseberg, 2011) (glm; R Core Team 2020). An alpha ≤ 0.05 was considered significant. Tendencies were reported when significance was $P \leq 0.10$. The Tukey method was used to separate means when alpha was < 0.05 (emmeans; Lenth, 2019). All statistical analyses were performed in R (R Core Team 2020).

Results

For clarification, the results presented as cow are the heifer's lifetime data from the initial RFI trial. The calf related data are from the offspring of the heifers in the initial RFI trial. These data were provided in order to determine if intake classification as a heifer impacted their subsequent production as a cow. There were no significant intake × age interactions ($P \geq 0.17$) for lifetime production variables. Therefore, only main effects will be presented.

Intake Classification Effects

Data related to the effect of heifer post-weaning intake classification (g/kg BW) on production and reproductive characteristics can be found in Table 1. Calf birth weight, 205-d weight, calf weaning weight, calf Julian birth date, and pregnancy status were not affected ($P \geq$ 0.15) by intake classification. Cow BW at breeding and weaning and cow BCS at breeding ($P \leq$

0.04) displayed a linear decrease from females classified from low to high intake. Weaning weight ratio displayed a linear increase within increasing intake classification (P < 0.01). AI conception rates showed a tendency (P = 0.08) to increase linearly with increasing intake classification.

Data related to the influence of post-weaning heifer intake classification (g/kg BW) on subsequent beef heifer yearling weight, total pounds of calf weaned and cow longevity spanning 5-breeding seasons and 4 weaned calf crops is in Table 2. Heifer yearling weight displayed a quadratic effect (P = 0.04) with heifers classified as low or average intakes having greater yearling weights than high intake classification females. Total pounds of calf weaned displayed a linear tendency for intake classification (P = 0.07) with low and average intake females weaning more total pounds over their lifetime compared to high intake classified females. Heifer intake classification displayed a linear tendency (P = 0.10) for percent of females remaining in the herd at 5-yrs with high intake classified females remaining in the herd longer than low and average intake classified females.

Cow Age Effects

Data related to the effect of cow age on production characteristics in Angus beef females can be found in Table 3. Cow BW and BCS at breeding (P < 0.001, Table 3) displayed an age effect with cow BW increasing as the females aged. Body condition scores increased linearly from 5.08 in 2-year-old cows to 5.55 in five- and six-year-old cows, before decreasing to 5.33 in cows 7-years-old and greater. In addition, cow BW at weaning also showed significance for age (P < 0.001) and intake (P < 0.001) with younger cows being lighter than older cows, while low and average intake classified females were heavier than high intake classified females.

Additionally, calf 205-d weaning weights ($P < 0.01$) and calf weaning weights ($P < 0.01$) were affected by cow age with calves born from older cows weighing more at 205-d and weaning when compared younger females. Calf Julian birth date, weaning weight ratio, pregnancy status and AI conception were not influenced by cow age ($P \geq 0.15$).

Cow weights at breeding and weaning displayed a quadratic effect ($P < 0.001$) with weights at both timepoints increasing with increasing age. In addition, BCS also displayed a quadratic effect ($P < 0.001$) with increasing body condition as the cows aged. Calf data including calf birth weight, 205-d weights and weaning weights also displayed a quadratic effect ($P < 0.001$). As cows age, the weights of their calves at all three timepoints progressively increased with increasing age. In relationship, weaning weight ratio displayed a quadratic tendency ($P = 0.09$) with younger cows having greater WWR values than older cows through six years of age. There was no linear or quadratic effect of Julian birth date, pregnancy status or AI conception, respectively.

Discussion

Cow Effects

Cow BW and BCS at breeding demonstrated that younger cows are lighter and have reduced BCS compared to mature cows, which was to be expected. Cassady and colleagues (2016), investigated the relationship between heifer feed efficiency measures and intake of high- and low-quality forages and the impact on mature beef cows. Their results indicated that heifers that consumed less feed than the herd average had a 7% reduction in mature cow BW. In addition, cows that ate more feed as heifers, had the greatest DMI as cows, regardless of feed quality classification. Specifically, cows that consumed more feed/forage as heifers consumed greater than 17% more forage compared to cows that were classified as low or moderate intake as heifers.

Consistent with current results, Turner and colleagues (2013) reported that older cows weaned heavier calves compared to younger cows. In addition, calves that were born to older dams had greater calf birth weights, 205-d weights and weaning weights than calves that were born to younger cows. The heavier calves at birth may be due to the allotment of nutrients by the cow during pregnancy, as older cows no longer need to grow, allowing for more nutrients to be partitioned to the fetus.

Data from Ziegler and coworkers (2020) used crossbred mature beef cows, age 5 and over and determined that cow BCS at calving, pre-breeding and weaning was positively correlated with increased cow BW. For every 100-kg increase in cow BW, calf birth weight increased by 2.65 kg and adjusted 205-d weights were increased by 14.54 kg. Moreover, BW of heifer progeny post-weaning increased with every additional 100-kg increase in dam BW. However, in the current study, BCS did increase as BW increased as cows aged, but this increase in BCS plateaued at 5-6 yrs of age. When compared to the current results, a similar increase was observed with cow BW at breeding and weaning between the 2- and 5-yr-old cows being approximately 100-kg difference. In the current study, calf birth weight and 205-d weight increased approximately 16 and 14%, respectively in the heavier 5-yr-old cows compared to the 2-yr-old cows. These weight differences may be related to the utilization of calving ease bulls on 2-yr-olds versus mature cow bulls on the older females.

Cows conceiving to AI did not differ by intake classification with AI conception averaging 62% across all intake classifications. This is likely due to the fact that all females, regardless of age had sufficient body condition in order to successfully conceive. Additionally, there was no difference in pregnancy status based on intake classification. Therefore, heifer intake classification may have minimal impacts on reproductive performance.

Data from Stewart and Martin (1981) reported that smaller framed cows Angus cows remained in the herd longer than larger framed Angus cows, therefore producing more calves over their lifetime. The current study observed that herd longevity tended to increase linearly from low to high intake designation. In general, it is expected that high intake cows will be large framed, which would indicate that the current study suggests herd longevity is opposite of Stewart and Martin (1981). However, as discussed previously, when classifying intake on a per kg BW basis, the classification is greatly influenced by BW and in addition to the lack of influence on calf production, the larger framed/heavier cows may be in the low intake group.

The use of intake (body weight basis) to select heifers has not been readily explored in the literature due to the practical challenges in acquiring individual animal intake estimates. In low-quality, high-fiber forage systems, the ability to select animals with greater ruminal-reticular capacity may yield cattle that are more efficient because of the greater intake potential and the possibility for increased ruminal retention/digestion of low-quality forages (Van Soest, 1996). This does not suggest that the best animals are the biggest with the largest ruminal-reticular volume. Rather, the most efficient animals are those with the greatest portion of their body weight consisting of the ruminal-reticular column and content. In our study, the post-weaning heifer intake classification was influenced by heifer weight. Specifically, the lighter heifers were the individuals more likely to have high intake per unit body weight. This observation is supported by intake models provided by the Beef Cattle NASEM (2016) for growing animals which suggest the intake of weaned animals is greater than yearling intakes when expressed on a body weight basis. As a result, using intake (body weight basis) as a metric for heifer selection may be biased by heifer physiological maturity, and metabolic status.

Calf *Effects*

There were no significant impacts of intake classification on calf data except for WWR. This data indicated that high intake classified cows weaned heavier calves than low and average intake classified cows. This difference may be due to increased rumino-reticular volume, leading to increased intake and therefore potential for increased milk production. As expected, birth weights were lighter for calves born to younger cows than older cows, likely due to the selection of calving ease bulls on younger females. This is consistent with data from Beard and colleagues (2019) who reported that heifer calves that were born to young cows had lighter birth weights than those born to moderate (4 to 6 yr old) and old cows (≥ 7 yr old). Contrary to the current results, Beard and colleagues (2019) reported that calves born to moderate aged or old cows had a greater percentage of offspring that reached puberty prior to their first breeding season when compared to heifers born to young cows.

Conclusion

Classification of heifers based on post-weaning intake classifications had very little effect on subsequent lifetime productivity measures. Slight differences were displayed in heifer BWs with heifers classified as low intake being greater BW than those classified as average or high intake. However, low intake classified females were also culled from the herd sooner than females that were classified as average or high intake. Therefore, this study suggests the selection of replacement heifers based on post-weaning intake classification following weaning may not be the best point in the production cycle as younger/smaller heifers may be at a disadvantage compared to their larger/older counterparts. Therefore, further research is necessary to determine when to collect post-weaning intake information to provide the best indication of subsequent lifetime productivity of replacement females.

Table 1. The influence of heifer post-weaning intake classification expressed as g per kg body weight on subsequent production and reproductive characteristics in Angus beef females.

	Intake Classification[1]				*p*-value			Contrasts	
Category	Low	Average	High	SE[2]	Intake	Age	Intake × Age	Linear	Quadratic
Cow BW at breeding, kg	571.32	565.29	550.13	11.37	0.15	< 0.001	0.92	0.003	0.41
Cow BCS at breeding	5.38	5.33	5.29	0.08	0.58	< 0.001	0.99	0.04	0.96
Cow BW at weaning, kg	611.97^{a}	606.49^{a}	587.87^{b}	6.39	< 0.001	< 0.001	0.67	< 0.001	0.20
Calf birth weight, kg	40.79	39.95	40.42	0.75	0.37	< 0.01	0.32	0.52	0.14
Calf weaning wt., kg	251.94	250.20	252.65	6.85	0.27	< 0.01	0.45	0.79	0.30
205 d wt., kg	270.97	268.72	271.04	6.58	0.63	< 0.01	0.34	0.98	0.27
Calf Julian birth date	83.40	83.20	82.88	1.75	0.49	0.15	0.40	0.68	0.95
Weaning weight ratio[3]	41.37^{a}	41.65^{a}	43.38^{b}	1.24	< 0.01	0.67	0.17	< 0.01	0.15
Pregnancy Status, %	88.26	88.32	86.51	1.51	0.22	0.65	0.38	0.45	0.60
AI Conception, %	57.77	63.46	64.70	2.61	0.38	0.80	0.63	0.08	0.47

[1]Heifers were categorized as either low (> -0.50 SD from the mean; n = 161), or average (± 0.50 SD from mean; n = 200) or high (< + 0.50 SD from the mean; n = 158) intake classes.

[2]Pooled standard error of the mean

[3]WWR = calf 205-d actual weaning wt./cow wt at weaning

[a,b] Means within row and cow age lacking common superscript differ ($p < 0.05$)

Table 2. The influence of heifer post-weaning intake expressed as grams per kg of body weight on subsequent heifer yearling weight, total lbs. of calf weaned and cow longevity spanning 5-breeding seasons and 4 weaned calf crops.

	Intake Classification[1]				*p* - value		
Category	Low	Average	High	SE[2]	Intake	Linear	Quadratic
Heifer yearling BW, kg	380.92[a]	376.05[a]	358.01[b]	7.00	< 0.01	< 0.001	0.04
Total lbs. of calf weaned, kg[3]	484.46	487.25	415.50	27.17	0.09	0.07	0.25
Present at 5 yr, %	63.22	72.12	74.73	4.71	0.22	0.10	0.62

[1]Heifers were categorized as either low (> -0.50 SD from the mean; n = 161), or average (± 0.50 SD from mean; n = 200) or high (< +0.50 SD from the mean; n = 158) intake classes.

[2]Pooled standard error of the means.

[3]Limited to cows that had the opportunity to have at least four calves and were bred for the fifth

[a,b] Means within the row that lack common superscripts differ (p = < 0.05).

Table 3. The influence of cow age on production and longevity characteristics in Angus beef females.

	Cow Age, Years						*p*-value		
Category	2	3	4	5-6	7+	SE[1]	Intake	Age	Intake × Age
Cows, n	441	349	278	356	258				
Cow wt. at breeding, kg	485.08[a]	528.58[b]	579.89[c]	600.83[d]	616.87[d]	11.42	0.15	< 0.001	0.92
Cow BCS at breeding	5.08[a]	5.26[b]	5.44[c]	5.55[d]	5.33[bc]	0.08	0.58	< 0.001	0.99
Cow wt. at weaning, kg	522.90[a]	572.37[b]	620.13[c]	645.18[d]	649.96[d]	6.13	< 0.001	< 0.001	0.67
Calf birth weight, kg	34.19[a]	39.77[b]	41.44[c]	42.78[cd]	43.77[d]	0.77	0.32	0.52	0.14
Calf weaning wt., kg	224.04[a]	244.53[b]	256.10[c]	261.87[c]	271.43[d]	6.86	0.27	< 0.01	0.45
205 d wt., kg	238.27[a]	262.37[b]	275.65[c]	281.81[d]	293.12[e]	6.59	0.63	< 0.01	0.34
Calf Julian birth date	81.53	83.55	83.54	83.31	83.87	1.83	0.49	0.15	0.40
Weaning rate ratio[2]	42.77	42.53	41.84	41.41	42.12	1.23	< 0.01	0.67	0.17
Pregnancy status, %	88.90	87.85	87.96	85.28	88.36	1.93	0.22	0.65	0.38
AI Conception, %	58.49	58.74	65.19	61.19	66.22	3.31	0.38	0.80	0.63

[1]Pooled standard error of the means

[2]WWR = calf 205-d actual weaning wt./cow wt at weaning

*Means within row and cow age lacking common superscript differ ($p < 0.05$)

[a-e] Means within row lacking common superscripts differ ($p < 0.05$).

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CHAPTER FOUR

IMPACTS OF HEIFER POST-WEANING INTAKE CLASSIFICATION ON PERFORMANCE MEASUREMENTS OF LACTATING AND NON-LACTATING TWO-, FIVE-, AND EIGHT-YEAR-OLD ANGUS BEEF FEMALES

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CHAPTER FOUR

IMPACTS OF HEIFER POST-WEANING INTAKE CLASSIFICATION ON PERFORMANCE MEASUREMENTS OF LACTATING AND NON-LACTATING TWO-, FIVE-, AND EIGHT-YEAR-OLD ANGUS BEEF FEMALES

Abstract

Heifer post-weaning intake classification was utilized to evaluate subsequent intake and performance measurements of 2-, 5- and 8-year-old lactating or non-lactating Angus females. For both studies, heifers were categorized based on voluntary feed intake (expressed as g/kg BW) as either low (< -0.50 SD from the mean), average (± 0.50 SD from the mean), or high (> 0.50 SD from the mean) within one year. Intake and production data of pregnant, non-lactating (n = 59; Study 1) and lactating, non-pregnant (n = 54; Study 2) females were evaluated. Heifer post-weaning voluntary feed intake was calculated over 80 test days post-weaning using GrowSafe feed intake units. Cow body weight (BW) for non-lactating cows showed a tendency for age × intake interaction ($P = 0.10$), with older cows weighing more than younger cows. Milk production expressed as kilograms and g/kg BW of the cow had an age × intake ($P < 0.001$) effect. Two-year old cows with low and average intake classifications had greater milk production ($P < 0.001$) and milk produced expressed as g/kg BW ($P < 0.001$) than 2-year-old cows with high intake classifications. Additionally, 5-year-old cows with average and high intake classifications had greater milk production ($P < 0.001$) and g/kg BW ($P < 0.001$) compared to 5-year-old cows classified as low intake. In summary, heifer post-weaning intake classification had minor impacts on performance measurements in three age classes of beef females at two different production levels.

Keywords: beef cattle, efficiency, heifer, intake, lactation

Introduction

Beef heifer development from weaning to breeding is a multifaceted management scheme that takes into account multiple disciplinary subjects including but not limited to physiological age, nutrition, reproduction, genetics, and environment. Development and selection of replacement beef heifers is a key factor to improving overall herd productivity and profitability. The ability to utilize post-weaning feed intake information as a selection tool could improve overall herd productivity (Archer et al., 1997). With modern technology, it is easier to collect accurate individual feed intake patterns over time. However, research related to heifer development and post-weaning intake and management is limited regarding the use of post-weaning intake behavior as a metric to predict lifetime productivity and longevity.

Recommendations for heifer development programs, indicate that heifers should be approximately 60 to 66% of their mature body weight (BW) by breeding (Patterson et al., 1992); while more recent data suggests that 50 to 55% of mature BW is sufficient (Funston et al., 2012; Endecott et al., 2013). In addition, the most common period to manipulate heifer growth and development is between weaning and the first breeding season (Funston et al., 2012). Numerous researchers have determined that feed intake is a heritable trait in beef cattle (Elzo et al., 2009; Fan et al., 1995; Koch et al., 1963; Mao et al., 2013; Nkrumah et al., 2007; Retallick et al., 2017), with heritability values in growing cattle ranging from 0.20 to 0.48, respectively.

Additionally, it is well understood that heifers that conceive early in their first breeding season are more likely to have greater lifetime productivity than those calving later in the season (Lesmeister et al., 1973). Day and Nogueira (2013) also concluded that heifers calving earlier in the breeding season will wean calves with heavier weaning weights. In addition, heifers that calve earlier in the calving season tend to continue to calve earlier in future calving seasons, leading to improved productivity (Short and Bellows, 1971).

In relation to reproduction, nutrition plays a vital role in overall production system efficiency. Research by Wiltbank and coworkers (1969) determined that an increased plane of nutrition following weaning resulted in earlier puberty and increased conception rates (Short and Bellows, 1971) compared to those at a low plane of nutrition. Buskirk et al. (1995) reported that increased post-weaning average daily gain (ADG; 0.6 vs 0.4 kg/d) was beneficial to milk production and overall productivity of traditionally weaned heifers.

Springman and colleagues (2017) conducted a 3-year study utilizing Angus-based heifers where heifers developed in a drylot on a high-energy diet had greater ADG and were heavier prior to breeding and had greater BW and percent of mature BW pre-breeding than range and corn-residue-developed heifers, but no differences were observed from heifers developed in a drylot on a low-energy diet. Interestingly, pregnant heifer initial and final BW, dry-matter intake (DMI), ADG, feed efficiency, and residual feed intake (RFI) were not different between heifer development systems.

Feed efficiency and intake research is not a new idea, but it is becoming more important as feed costs continue to rise and cost of production increases. Selection of replacement beef females that consume less feed per kg of BW may decrease inputs and therefore decrease costs to the producer. However, there is a drastic shift in protein deposition towards fat deposition around the time of puberty (Trenkle and Willham,1977). These changes have the potential to impact how BW changes and intake shift over time, therefore influencing differences between growing and mature animals at different stages of production.

Research evaluating heifer post-weaning intake classification and its impacts on lactating and non-lactating females is limited. Therefore, the objectives of these studies were to evaluate the relationship of heifer post-weaning intake classifications to subsequent performance of lactating and non-lactating cows at three different ages.

Materials and Methods

Data used in these studies were part of a larger project as described by Parsons et al. (2021). Utilization of animals for this study was approved by the Agricultural Animal Care and Use Committee at Montana State University (AACUC #2018-AA12). All studies were carried out at Northern Agricultural Research Center (NARC; Havre, MT, USA; 48.5500° N, 109.6841° W).

Heifer Intake Trials

Since 2010, all newly weaned beef females have been utilized in a heifer RFI trial. Following weaning, all beef females are placed in GrowSafe enabled pens (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada). Each year, calves are weaned from the dam while on pasture between mid-September and early October (150-210 days of age) and the heifer calves remain on pasture for approximately 45 days. Once off pasture, heifers are placed on a forage-based diet for 60 to 85 d in order to determine post-weaning residual feed intake (RFI). All heifers were provided *ad libitum* access to water and forage-based diet composed of primarily corn silage (30.4%), grass hay (41.1%) and alfalfa (28.5%) on a dry matter basis dependent on year and availability of ingredients. All diets are formulated to meet maintenance requirements for growing moderate frame, beef heifers (10.5% crude protein and 66.0% total digestible nutrients; NASEM, 2016). Heifer BW was taken over two consecutive days at the beginning and end of the trial and every 28 d thereafter to record BW gain. Heifers were categorized based on voluntary feed intake (expressed as grams per kg BW) as either low (< -0.50 SD from the mean), average (± 0.50 SD from the mean), or high (> 0.50 SD from the mean) within year for both studies. Individual heifer post-weaning intake information was then utilized to determine potential impacts on productivity of these females during a lactating or non-lactating period.

Lactating and Non-Lactating Intake Trials

Two intake studies were completed in order to evaluate the impact of heifer post-weaning intake at different ages and two stages of beef cattle production. In both studies, individual cow body weights (BW) and body condition scores (BCS) were collected. Following collection of BW and BCS, cattle were placed in Growsafe enable pens for DMI intake analysis. For both studies (lactating vs. non-lactating), treatments were replicated in two pens, each pen containing 16 Growsafe intake feeding units. Prior to the beginning of the study, cows were provided a 7-d acclimation period followed by a 14-d DMI intake recording period. Of those 14-d, seven of the highest accuracy days were used to calculate average DMI per individual animal following the DMI study. During the study, the system was monitored for unaccounted feed balance. When greater than 5% of the feed disappearance was unaccounted for, the GrowSafe system automatically deemed the 24-h period as failed. Therefore, we selected the last 7 days of the 14-d period. In addition, intake behavior variables, including DMI (kg/d and g/kg BW), DMI rate (g/min), time spent at the feeder (min/d) and CV were collected. Variation in dry matter intake (kg/d), measured as the coefficient of variation (% CV) was based on daily intake estimate for individual animals.

Study 1: Pregnant, non-lactating cow

Fifty-nine pregnant, non-lactating black Angus females were used to evaluate the impacts of heifer post-weaning intake and feed efficiency. Cows were provided a commercially available free-choice alfalfa/straw pellet (49.53 % alfalfa hay and 49.52% straw; refer to Appendix B for more detailed diet information) formulated to meet the nutrient requirements for pregnant, non-lactating cows. At the start of the trial, (14-d postweaning), cows were categorized based on intake as heifers as either low (-0.50 SD from the mean), average (± 0.50 SD from the mean), or high (> 0.50 SD from the mean) within year for 2, 5 and 8-yr old cows. At the same time, cows were dry-lotted to obtain consistent shrunk BW values.

Study 2: Non-pregnant, lactating cow

Fifty-four non-pregnant, lactating black Angus females were used to evaluate the impacts of heifer post-weaning intake and feed efficiency. Cows were provided a commercially available free-choice alfalfa/grass pellet (79.05% alfalfa hay and 20.00% corn; refer to Appendix B for more detailed diet information) formulated to meet the nutrient requirements for lactating cows. Similar to study 1 cows were categorized based on intake as heifers as either low (< -0.50 SD from the mean), average (± 0.50 SD from the mean), or high (> 0.50 SD from the mean) within year for 2, 5 and 8-year old cows. However, only cows that calved in the first 42 d of the calving period were used in this study in order to focus the study on calves that were conceived via artificial insemination. On average, the intake study was carried out from day 40 to day 60 postpartum. On average, the intake study was carried out from day 40 to day 60 postpartum.

Following the end of the DMI trial, a weigh-suckle-weigh trial was conducted to evaluate the impacts of heifer post-weaning intake classification and cows age on milk production as described by Williams et al (1979). Calves were weighed before an 8-h separation period and after nursing in order to obtain milk production estimates.

Statistical Analysis

The data used in this manuscript are available in Supplementary Tables S1 and S2. For both studies, the influence of heifer post-weaning intake classification and cow age on initial cow body condition score (BCS) and BW were analyzed using a generalized linear model in an ANOVA framework (car; Fox and Weisberg, 2011) including, intake classification, cow age and the interactions of intake classification and cow age as fixed effects. In addition, the influence of intake classification and cow age on intake and intake behavior variables were analyzed using a generalized linear mixed model (lme4; Bates et al., 2015) in an ANOVA framework (car; Fox and Weisberg, 2011) including intake classification, cow age, and the interactions of intake classification and cow age as fixed effects, with individual cow and pen as random intercepts to account for the autocorrelation of repeated measurements of intake variables. Data were plotted and transformed if needed to satisfy assumptions of normality and homogeneity of variance. An individual animal was considered the experimental unit. An alpha ≤ 0.05 was considered significant. Tendencies were reported when significance was $P \leq 0.10$. The Tukey method was used to separate means when alpha was < 0.05 (emmeans; Lenth, 2019). All statistical analyses were performed in R (R Core Team 2020).

Results

Study 1: Pregnant, non-lactating cow

The effects of heifer post-weaning intake classification on beef cow performance measurements for pregnant, non-lactating females are detailed in Table 1. Cow BW showed significance for age ($P < 0.001$) and intake ($P = 0.03$) with 2-year-old cows being lighter than 5- and 8-year-old cows. Moreover, high intake 2-year-old cows had heavier BW than low intake 2-year-olds, while average intake 2-year-old cows were intermediate. In addition, 5-year-old low intake cows had heavier BW than average intake 5-year-old cows, while high intake 5-year-old cows were intermediate. High intake 8-year-old cows had heavier BW than average intake 8-year-old cows, while low intake 8-year-old cows were intermediate. Cow BCS displayed an age × intake interaction ($P = 0.02$) where average intake 5- and 8-year-old cows tended to have lower BCS than low and high intake cows, with 2-year-old cows having no effect of intake classification on BCS ($P = 0.22$). Cow age had an effect on dry matter intake (kg/d; $P = 0.05$) with all classes of 2-year-old cows consuming less than all classes of 5- and 8-yr old cows. There were no effects of cows age or intake classification observed for DMI (g/kg BW; $P \geq 0.48$). Intake rate (g/min) displayed an age effect ($P < 0.01$) with 5- and 8-year-old cows consuming feed faster than 2-year-old cows. Moreover, intake rate displayed a tendency for the cow age × intake interaction (g/min; $P = 0.08$) with high intake 8-year-old cows consuming feed at a faster rate than low and average 8-year-old cows, while no differences were noted in 2- or 5-year-old cows. Cow CV displayed a tendency for an intake classification effect ($P = 0.07$) with high and average intake 2-year-old cows having greater CV than low intake 2-year-old cows, while low intake 5- and 8-year-old cows had greater CV than average and high intake 5- and 8-year-old cows. Time spent at the feeder displayed an age effect (*P* = 0.03) with 2-year-old cows spending more time at the feeder than 5- and 8-year-old cows. There was no effect of intake classification (*P* ≥ 0.22) for non-lactating females on cow BW, cow BCS, DMI (kg/d and g/kg BW), DMI rate (g/min), time spent at the feeder (min/d) and CV.

Study 2: Non- pregnant, lactating cow

The effects of heifer post-weaning voluntary feed intake (g/kg BW) classification on subsequent beef cow performance, intake, and intake behavior for three age groups of non-pregnant, lactating females are detailed in Table 2. There was no effect of intake classification (*P* ≥ 0.39) for lactating females on DMI (expressed as kg/d or g/kg BW), DMI rate (g/min), coefficient of variation for intake, or time spent at the feeder (min/d). Cow BW displayed a cow age × intake interaction (*P* = 0.002), with low intake 2-year-old cows having lighter BW than high intake 2-year-old cows, while average intake 2-year-old cows were intermediate. Alternatively, 5- and 8-year-old cows classified as low- or high-intake had increased BW when compared to average 5- and 8-year-old cows. Similarly, cow BCS displayed a cow age × intake interaction (*P* = 0.001), with low- and high-intake 5-year-old cows having greater BCS than average-intake 5-year-old cows, while no effect of intake classification were seen in 2- or 8-year-old cows. However, all classes of two-year-old cows displayed a lower BCS than 5- and 8-year-old cows. Calf birth weights displayed an age × intake classification interaction (*P* ≤ 0.001) with offspring from low and average intake 8-year-old cows having heavier birth weights than high-intake 8-year-old cows, while low-intake 5-year-old cows had greater calf BW than average- and high-intake 5-year-old cows. However, calf BW from 2-year-old cows did not differ between intake classification. Calf Julian birth date displayed a cow age × intake interaction (*P* < 0.001) with high-intake 8-year-old cows calving later in the calving season than low- and average-intake 8-year-old cows, while low-intake 5-year-old cows calved earlier compared to average- and high-intake 5-year-old cows. In addition, high-intake 2-year-old cows calved earlier in the calving season compared to average- and low-intake cows. As expected, post-partum interval displayed an age effect ($P < 0.001$) with greater post-partum intervals for 2-year-old cows when compared to 5- and 8-year-old cows. Dry matter intake (kg/d) displayed an age effect ($P = 0.001$) with 2-year-old cows consuming less than 5- and 8-year-old cows. Milk production (kg) displayed an age × intake effect ($P < 0.001$) with low-intake 2-year-old cows having greater daily milk production than average and high-intake 2-year-old cows, while average- and high-intake 5-year-old cows produced more than low-intake 5-year-olds. In addition, milk production did not differ between low-, average- and high intake 8-year-old cows. Similarly, milk production (g/kg BW) displayed an age × intake interaction ($P < 0.001$) with low-intake 2-year-old cows having greater daily milk production on a BW basis than average- and high-intake 2-year-old cows, while average- and high-intake 5-year-olds had greater milk production than low-intake 5-year-old cows. In addition, milk production on a BW basis did not differ between low-, average- and high-intake 8-year-old cows.

Discussion

Development and selection of replacement beef heifers is a key factor to improving overall herd productivity and profitability. The ability to utilize post-weaning feed intake information as a selection tool for replacement heifers could improve overall herd productivity (Elzo et al., 2009). Increased longevity and efficiency in the herd provides economic advantages to the producer, where cows that remain in a herd longer, reduce the cost of replacements on a yearly basis. The benefits from longer herd life come mainly from reduced costs of replacements and from increased income as a result of a higher proportion of cows producing at mature ages (Rendel and Robertson, 1950). In addition, calves born from older cows have shown increased weaning weights and growth rates compared to calves from younger cows (Renquist et al., 2006). This difference is thought to be due to the increase in milk production with increasing age. Lubritz and colleagues (1989) stated that milk production in beef cows plateaus between 6 and 10 years of age. Similar to the current study, 6- and 8-year-old cows had greater milk production compared to 2-year-old cows.

Physiologically, we would also expect heifers that are larger in frame and capacity to have greater reticulo-rumen capacity than smaller framed heifers; greater size leads to greater DMI (NASEM, 2016). Specifically, the capacity of the gut, determines the capacity for digestion in herbivores (Demment and Van Soest, 1985). The increase in reticulo-rumen volume allows for greater retention rates and digestion of forages that are typically high in fiber and low in quality. Ferrell and Jenkins (1985) stated that a cow with genetic potential for high milk production will be more efficient when high-quality forages are available but fail to maintain milk production and body condition when low-quality forages are more prominent within their environment. In turn, the Western US and Northern Great Plains are nutritional environments generally characterized by low-quality high-fiber forages. Presumably, these limited nutrition environments would favor animals with greater reticulo-rumen volume and, as a result, greater forage intake expressed on a per unit of body weight basis. Furthermore, feed intake is going to be influenced by stage of production, environmental factors and the genetic potential for overall size of the reticulo-rumen (Church, 1979). Research by Minson (1990) reported that DMI in lactating cows fed primarily forages increases by 30% during the lactation stage. Parsons and colleagues (2021) reported that cow BW of lactating and non-lactating females were greater in older cows than younger cows, however there were no differences in DMI intake ($g \cdot kg\ BW^{-1}$). This was similar to the current results, where the only DMI difference was observed in 8-year-old cows for DMI rate.

Shike and coworkers (2015) evaluated post-weaning heifer intake, RFI and residual gain (RG) of Angus and Simmental × Angus heifers over a 5-year-period. Similar to the current study, heifers were classified as either low-, medium- or high-intake and evaluated at 2 years of age. Results indicated that a greater percentage of females from the medium- or high-intake groups were retained in the herd compared to the low-intake heifers. This may be because later born, lighter-framed heifers were at a disadvantage due to age and lack of time to grow. In addition, Shike et al. (2015) also determined that cows that were classified as high-intake had calves that were heavier at birth than calves from cows categorized as either medium- or low-intake. Webster (1981) stated that cows that consume more feed as a heifer are more likely to be larger as a mature animal, barring extreme nutritional or environmental stressors. Contrary to the current project, Shike and coworkers (2015) did not observe an impact of heifer intake classification on milk production post-calving, while in the current study there was greater milk production in 2- and 5-year-old cows compared to 8-year-old cows. The data we observed in 2-year-old cows is not surprising as first-calf heifers are using greater amounts of energy than mature cows due to the initiation of lactation, continued skeletal growth and return to a functionally reproductive state for future breeding. While correlations between age of cow and milk production are low (0.32 and 0.22), milk yield has been observed to increase over the first three lactations (Jeffery et al., 1971). In addition, RFI has been reported as moderately heritable at 0.45 (Crowley et al., 2010). Milk production of 5- and 8-year-old cows was greater compared to 2-year-old cows with an average of 3.4 kg, 4.51 kg, and 4.21 kg, respectively. In addition, these same young cows were considerably lighter compared to the 5- and 8-year-old cows. Lubritz and colleagues (1989) reported that milk production in beef cow plateaus between 6 and 10 years of age, which may partly answer the differences we see from other studies. Similarly, Neville (1974) reported that milk production increased linearly until age 6, while Rutledge et al. (1971) reported up to 8 years of age.

In addition, there was no effect of intake classification for lactating females on DMI (kg/d and g/kg BW) DMI rate (g/min), coefficient of variation for intake, or time spent at the feeder (min/d). The current results suggest that heifer DMI classification may not have a long-lasting impact on lifetime productivity. Further research is needed in order to elucidate the differences in intake, BW gain and milk production between two different classes of beef cows classified over multiple age groups.

Conclusion

Results in this study suggest that heifer post-weaning intake classification did not greatly affect mature cow intake when expressed as g · kg BW^{-1} for cows at three different ages and two different production stages - lactating and non-lactating. This information would indicate that utilization of post-weaning heifer intake classifications beginning about 45 d post-weaning may not be a strong metric for measuring the impact of lifetime productivity. This data tend to suggest that cow age has a greater impact on post-weaning intake than intake classification as a heifer. Further research is necessary to determine the ideal time to collect post-weaning intake data in order to accurately determine its overall impact on subsequent productivity in the beef herd.

Table 1. The influence of heifer post-weaning intake expressed as grams per kg of body weight on subsequent beef cow performance of 3 age classes of pregnant, non-lactating beef cows (Study 1).

	Cow age, yrs												
	2			5			8				*p*-value		
Category	Low Intake	Average Intake	High Intake	Low Intake	Average Intake	High Intake	Low Intake	Average Intake	High Intake	SE[1]	Age	Intake	Age × Intake
Cows, n	7	5	8	6	7	7	8	4	7				
Cow BW, kg[2]	431.68[a]	433.63[ab]	540.35[b]	594.96[a]	570.55[b]	587.40[ab]	562.45[ab]	544.31[a]	587.40[b]	5.81	< 0.001	0.03	0.10
Cow BCS[3]	5.50	5.40	5.34	5.71[a]	5.28[b]	5.64[a]	5.41[a]	5.06[b]	5.39[a]	0.07	0.01	0.22	0.02
DMI, kg/d	12.82	12.37	12.84	15.46	16.65	16.13	15.43	17.77	17.19	1.38	0.05	0.91	0.69
DMI, g/kg BW	29.32	28.67	28.69	26.41	29.10	27.28	28.08	32.84	29.86	2.27	0.48	0.95	0.70
DMI, g/min	89.95	90.96	95.50	147.54	146.90	141.91	132.24[ab]	106.99[a]	150.57[b]	12.29	< 0.01	0.87	0.08
CV, %[4]	12.99	20.99	24.57	22.16	20.28	18.04	21.71	18.88	14.92	4.11	0.12	0.07	0.12
Time @ feeder, min/d	149.46	140.97	138.08	108.06	115.49	118.32	127.06[ab]	171.98[a]	114.71[b]	10.51	0.03	0.72	0.06

[1]Pooled standard error of the means

[2]Cow body weight (kg) at initiation of trial

[3]Cow body condition score at initiation of trial

[4]Coefficient of variation for intake expressed as kg/d

[a,b]Means within row and cow age lacking common superscript differ ($p < 0.05$)

[*]Heifers were categorized as either low (> -0.50 SD from the mean), or average (± 0.50 SD from mean) or high (< + 0.50 SD from the mean) intake classes.

Table 2. The influence of heifer post-weaning intake expressed as grams per kg of BW on subsequent beef cow performance of 3 age classes of non-pregnant, lactating beef cows (Study 2).

	Cow age, yrs												
	2			5			8				*p*-value		
Category	Low Intake	Average Intake	High Intake	Low Intake	Average Intake	High Intake	Low Intake	Average Intake	High Intake	SE[1]	Age	Intake	Age × Intake
Cows, n	5	6	7	6	6	6	8	3	7				
Cow BW, kg[2]	386.28[a]	399.46[ab]	417.82[b]	561.32	556.40	565.85	530.42[a]	492.90[b]	533.94[a]	6.25	< 0.001	0.001	0.002
Cow BCS[3]	4.30	4.21	4.14	4.92[a]	4.63[b]	5.04[a]	4.66	4.58	4.57	0.06	< 0.001	0.19	0.001
Calf, n	5	5[x]	7	6	6	6	8	3	7				
Calf BW, kg[4]	93.78	94.26	94.61	102.96[a]	94.72[b]	92.23[b]	109.83[a]	112.19[a]	92.14[b]	1.77	< 0.001	0.95	< 0.001
Calf Julian birth date	69.40	69.83	66.71	68.83[a]	77.67[b]	76.50[b]	70.38[a]	72.33[a]	84.86[b]	1.63	0.75	0.29	< 0.001
Post-partum interval, d	69.60	69.17	72.29	70.17[a]	61.33[b]	62.50[b]	68.63[a]	66.67[a]	54.14[b]	1.63	< 0.001	0.75	0.29
DMI, kg · d^{-1}	17.99	17.41	19.36	23.71	23.33	23.49	22.79	23.78	24.07	1.37	0.001	0.39	0.85
DMI, g/kg BW	45.81	43.58	46.43	43.10	41.97	41.08	44.24	48.79	44.44	2.65	0.73	0.64	0.58
DMI, g/min	127.65	115.52	133.54	165.10	152.54	174.94	152.77[ab]	123.56[a]	198.44[b]	13.87	0.13	0.56	0.21
CV, %[5]	12.85	13.87	12.59	11.51	11.35	8.01	12.97	14.52	10.12	1.85	0.81	0.89	0.79
Time @ feeder, min/d	146.53	155.27	151.50	147.50	158.11	136.17	157.81[ab]	195.09[a]	125.15[b]	14.54	0.73	0.89	0.13
Milk production, kg	4.08[a]	3.54[a]	2.59[b]	3.86[a]	4.84[b]	4.84[b]	4.42	4.08	4.15	0.20	0.07	< 0.001	< 0.001
Milk production, g/kg BW	10.53[a]	8.87[a]	6.18[b]	6.94[a]	8.86[b]	8.63[b]	8.40	8.45	7.93	0.47	< 0.001	< 0.001	< 0.001

[1]Pooled standard error of the means

[2]Cow body weight (kg) at initiation of trial

[3]Cow body condition score at initiation of trial

[4]Calf body weight (kg) at weigh-suckle-weigh

[5]Coefficient of variation for intake expressed as kg/d

[x]One calf died and was removed from the dataset

[a,b]Means within row and cow age lacking common superscript differ ($p < 0.05$)

[*]Heifers were categorized as either low (> -0.50 SD from the mean), or average (± 0.50 SD from mean) or high (< + 0.50 SD from the mean) intake classes.

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CHAPTER FIVE

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Our research provides a comprehensive analysis evaluating the influence of heifer post-weaning voluntary feed intake classification on performance and reproductive measures, overall lifetime productivity, and physiological stages of production. Our objectives were to 1) evaluate the impact of dam age on lifetime productivity of their female offspring, 2) evaluate the relationship of heifer post-weaning heifer intake (g/kg BW) on subsequent lifetime productivity of Black Angus beef females, and 3) evaluate the relationship of heifer post-weaning intake classifications to subsequent intake and performance as lactating and non-lactating cows at three different ages.

Results of our first study suggest that dam age will impact the future outcomes of replacement beef females based on productivity and reproductive measures. Cow BW at breeding exhibited differences with cows at 5 years of age from 2-year-old dams weighing less at breeding than cows at 5 years of age from 3-, 4-, 5- and 8-years and older dams, with cows at 5-years of age from 6/7-year-old dams being intermediate. The probability of remaining in the herd at the age of 5 was significant for dam age averaging 69.41%, with cows from 2-, 5- and 8-year-old and older dams remaining in the herd longer than cows from 3-, 4-, and 6/7-year-old dams. Productivity as a measure of total pounds of calf weaned through 5 years displayed a dam age effect with cows from dams that were 8 years of age or older weaned more total pounds of calf, than cows from 3-year-old dams. Therefore, our study suggests that dam age does have an impact on lifetime productivity of future female offspring. Our study indicates that older dams had a greater ability to produce replacement heifers that have greater lifetime productivity.

Specifically, these mature females seemed to be better able to partition nutrients in order to successfully maintain necessary body condition, milk production and rebreed in a timely fashion compared to the younger 3 and 4-year-old cows that tended to struggle in that area. In addition, this data tends to suggest that the environment was impacting reproductive success of those older females. As it is well understood that it tends to be more difficult to get females bred as three-year-old cows than during any other time point.

However, further research is needed to investigate the relationship of dam age on lifetime productivity, specifically understanding the value of mature, proven females and their success in limited nutrition forage-based beef production systems.

Results of our second study suggest that heifer post-weaning voluntary feed intake classification had minor impacts on subsequent lifetime productivity. Intake classification effects displayed increased weaning weight ratios with increasing intake classification. In addition, there were differences in cow BW and BCS at breeding with younger cows being lighter and having reduced BCS compared to older, mature cows. There were no significant impacts of intake classification on calf data, expect for weaning weight ratio, indicating that high intake classified cows weaned heavier calves than low and average intake classified cows. As expected, birth weights were lighter for calves born to younger cows than older cows. Therefore, our research suggests that heifer post-weaning intake classification collected approximately 45 d post-weaning may not be a good indicator of lifetime productivity due to the changes in rumino-reticular capacity and overall growth.

Results of our third study suggest that heifer post-weaning intake classification did not greatly influence performance measurements, which was consistent for both lactating and non-lactating beef cows. In other words, the intake and intake behaviors of the heifers in the initial intake trial 45 days post-weaning was not repeated as those same females became mature adults. However, cow BW displayed interaction with low intake 2-year-old cows having lighter BW than high intake 2-year-old cows, while average intake 2-year-old cows were intermediate. Alternatively, 5- and 8-year-old cows classified as low or high intake had increased BW when compared to average 5- and 8-year-old cows, respectively. Milk production ($g \cdot kg\ BW^{-1}$) was influenced by heifer post-weaning intake classification with 2-year-old cows having greater daily milk production than average and high intake 2-year-old cow, while average and high intake 5-year-old cows produced more than low intake 5-year-olds. In addition, milk production did not differ between low-, average- and high-intake cows. Therefore, our research suggests that cow age has greater impacts on post-weaning intake than intake classification as a heifer. However, further investigation is necessary in order to determine the ideal time in which to collect post-weaning intake data in order to accurately determine its overall impacts on subsequent productivity of the beef herd.

In conclusion, our studies evaluated the impacts of post-weaning voluntary feed intake classification in heifers, as well as the impacts of intake on lactating and non-lactating beef females at different ages. We also investigated the impact of dam age on lifetime productivity of those female offspring. All studies provided evidence that post-weaning intake classification and dam age may influence lifetime productivity of beef female offspring.

However, future research is necessary to further investigate the impacts of post-weaning voluntary feed intake on subsequent lifetime productivity of female offspring. Specifically, the ideal time to collect post-weaning voluntary feed intake data to ensure we are getting an accurate understanding of how it relates to future lifetime productivity. Perhaps we collect intake data as a yearling to ensure that the rumino-reticular capacity in each individual animal is more developed and therefore allows for a better understanding of individual animal intake and therefore future animal productivity. As far as dam age is considered, I feel it would be beneficial to do an initial intake trial as a yearling and then another intake trial at approximately 5 years of age. The justification for this is that we saw greater productivity and longevity of our females as they reached ≥ 5 years of age. Doing intake trials at both of these timepoints would allow for greater rumino-reticular capacity at the initial intake trial and allow us to have additional information as to why we may have seen increased productivity at ≥5 years of age.

Based on the data that we collected and what we know about beef cattle cow-calf production systems in the Western states there is great need for selection tools for beef cattle in forage-based systems where nutrition may be limited. Specifically, attempting to understand which animals are going to be most efficient during times when forage quality is low and potentially unavailable due to periods of drought or snow events. Understanding how and why specific animals are able to be more productive in these situations can help producers determine which females to retain and which females to cull.

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APPENDICES

APPENDIX A

COW AGE × DAM AGE BREAKDOWN FOR CHAPTER 2

		Dam Age															
Cow Age		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
	1	179	143	128	101	57	40	30	25	22	17	21	16	8	6	4	3
	2	149	121	102	81	48	31	25	20	19	17	20	13	8	5	3	2
	3	113	91	84	64	37	28	16	19	14	12	18	12	7	2	2	2
	4	83	70	76	54	24	22	15	17	12	10	15	10	7	1	2	2
	5	59	55	57	40	22	18	14	16	10	9	14	5	7	1	2	2
	6	43	38	39	26	19	14	11	11	9	8	10	4	5			2
	7	36	25	28	20	9	10	6	7	8	6	8	5	4			2
	8	27	19	23	17	8	7	3	6	8	4	7	4	4			2
	9	21	15	17	7	5	6	3	5	5	3	5	4	1			2
	10	14	7	8	4	3	6	1	3	4	2	3	2	1			2
	11	3	3	3	4	2	3	1	1	3	2	1	1	1			
	12	1	1	3	4	2	3	1	1		1	1		1			
	13	1		1	2	1	3	1			1	1					
	14						2				1	1					

APPENDIX B

INGREDIENTS AND NUTRIENT COMPOSITION (DM BASIS) OF COMMERCIALLY AVAILABLE HAY PELLET PROVIDED AD-LIBITUM TO ANGUS BEEF FEMALES DURING FALL 2019 AND SPRING 2020 21-D DMI TRIALS (PARSONS ET AL., 2021)

APPENDIX B: Ingredients and nutrient composition (DM basis) of commercially available hay pellets provided ad-libitum to Angus beef females during fall 2019 and spring 2020 21-d DMI trials. (Parsons et al., 2021)

Item	Pregnant, non-lactating cow (Study 1)	Non-pregnant, lactating cow (Study 2)
Ingredient, %		
Alfalfa hay	49.53	79.05
Straw	49.52	
Corn, ground		20.0
Ultramin 12-6	0.75	0.75
Trace mineral mix[1]	0.20	0.20
Analyzed nutrient composition, % DM basis		
Dry Matter	93.6	90.4
Crude Protein	10.5	16.8
Total Digestible Nutrients	62.0	65.1
Acid Detergent Fiber	40.4	34.0
Ca	0.96	1.79
P	0.19	0.21
Mg	0.20	0.27
K	2.03	2.03
Na	0.02	0.02
S	0.19	0.21
NEg	0.36	0.40
NEl	0.64	0.67

[1]Trace mineral mix: 285.5 ppm Fe, 71.0 ppm Zn, 59.0 ppm Mn, 25.0 ppm Cu, 1.6 ppm I, 1.45 ppm Mo, 0.4 ppm Se, 1.0 IU/kg vitamin A, 0.1 IU/kg vitamin D, 1.7 IU/kg vitamin E