The Relationship between Carcass Merit and Maternal Traits in Beef Cattle: A Case Study and Literature Review

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Prepared for Certified Angus Beef

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INTRODUCTION

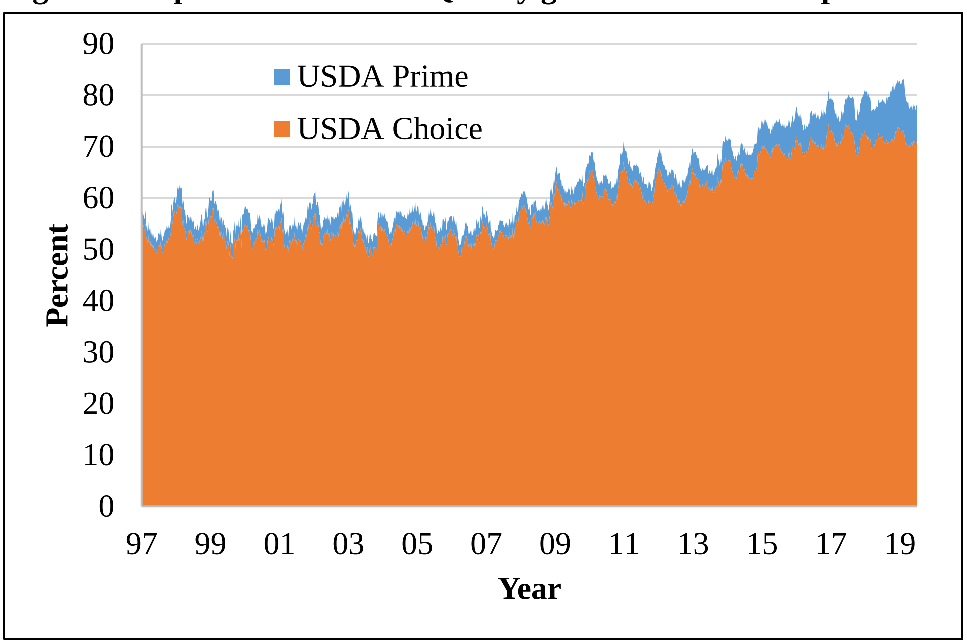
This review evaluates the relationship between carcass merit, specifically marbling, and maternal reproduction in beef cattle. It includes a brief review of current literature and a case study based on an Iowa State University research breeding project where purebred Angus cattle have been selected for marbling or intramuscular fat for over 20 years. While the emphasis of this analysis is on maternal reproductive traits and their relationship to carcass merit, an additional unique dataset allowed us to evaluate direct marbling relationships with semen and scrotal traits in yearling bulls.

LITERATURE REVIEW

Why marbling is important

Marbling is one of the primary determining factors of eating satisfaction of beef. In a recent study by O'Quinn and co-authors (2018), overall liking or acceptability of grain-finished strip loin steaks increased from 75%, 83%, 87% and 91% for USDA Select, low Choice, premium Choice and Prime quality grades, respectively. The beef industry continues to make remarkable progress in improved quality grades in recent years. Figure 1 shows the increase in percent Choice and Prime carcasses from 1997 to present (USDA National Steer and Heifer Estimated Grading Percent Report, various issues). This increase has been driven by beef demand and carcass premiums paid by packers. From January 2018 through August 2019 the average premium above USDA Choice price has been $12.64 per cwt for Prime and $3.84 per cwt for Certified Angus Beef. The average discount for Select carcasses has been $17.15 per cwt over the same time period (USDA National Carcass Premiums and Discounts, various issues).

Figure 1. Improvement in U.S. Quality grades from 1997 to present.



While the percent USDA Prime and Choice in the slaughter mix was relatively flat from 1997 to 2007 with significant increases from 2007 to present (Figure 1), the genetic trend for marbling in the Angus breed has been continually increasing over the past 20 years (Figure 2).

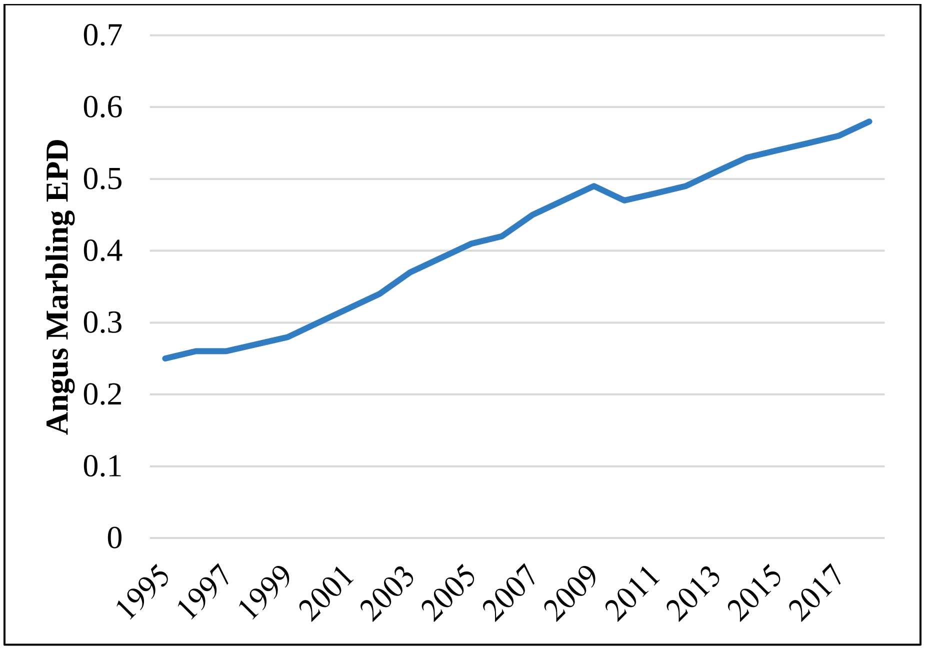


Figure 2. Angus genetic trend for marbling by birth year (as of September 2019)

Relationships between marbling and maternal traits

There is a lingering perception in the industry that selection for marbling may have negative effects on beef cow fertility or maternal traits, including that cows who produce offspring with high marbling phenotypes are less productive from a reproductive standpoint. This perception appears to persist despite thorough literature reviews in the past (Marston et al. 2007; Smith and Greiner, 2013) that found no relationships (positive or negative) between fertility and progeny carcass performance. Marston et al. (2007) mentioned the perceived positive relationship of marbling and milk production as well as a known increase in energy maintenance demands of cows with higher milk production (NASEM, 2106) as questions yet to be answered. Smith and Greiner (2013) found a small positive, but relatively low, association between marbling and milk expected progeny differences (EPD) in the Angus breed. Both reviews encourage the use of multi-trait selection to minimize any potential relationships that may exist.

Part of the breeders' perception of a negative relationship between maternal and terminal selection may stem from popular value indexes that focus on maternal traits such as maternal calf weaned value ($M) vs indexes that focus on terminal traits such as beef value ($B). Breeders may naturally then classify cattle as good "maternal" or "terminal cattle" with the assumption that the traits antagonize each other. Garrick (2018) presented the genetic trends of $B and Cow Energy Value ($EN) in a presentation to the 2018 Beef Improvement Federation Conference (Figure 3). The index $EN uses indicators of cow energy requirements (size and milk production). The index $B uses carcass merit and growth. While one may be labeled a maternal index and the other terminal index, the true antagonism is likely related to selection for growth (and milk production) rather than marbling or beef quality. Garrick concluded by advocating whole-system indexes and placing more emphasis on reproductive efficiency and birth to finish efficiency. There is no evidence that these goals could not be accomplished while improving beef quality or marbling.

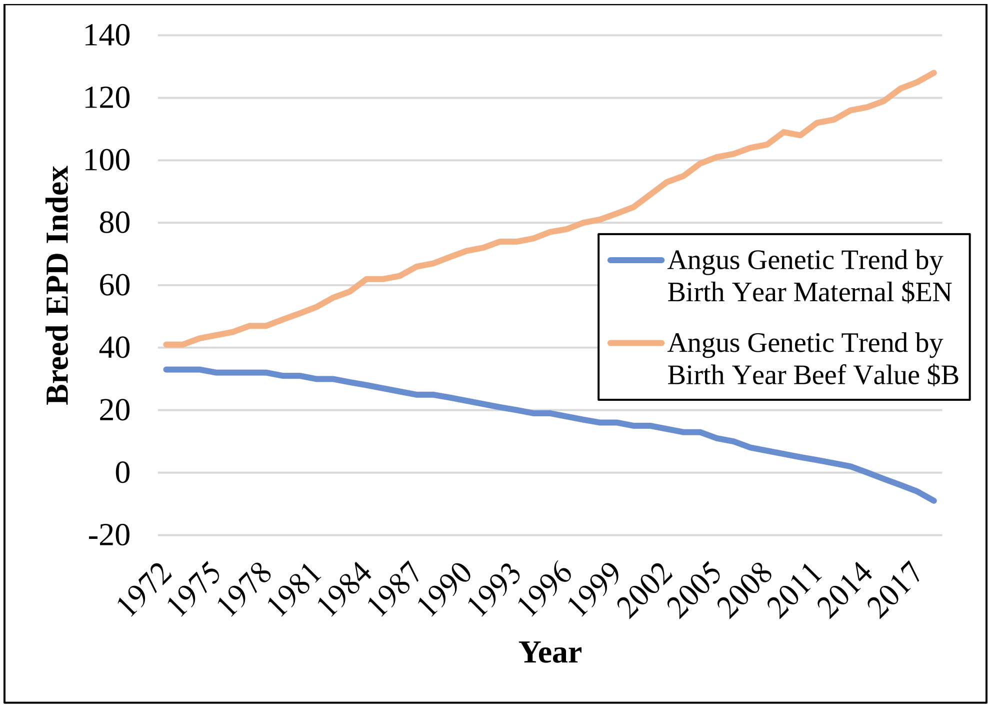


Figure 3. Genetic trends for Maternal Cow Energy Value ($EN) and Beef Value ($B) in the Angus breed (as of September 2019)

Boldt et al. (2018) conducted an extensive evaluation of the Red Angus records evaluating genetic relationships between stayability and heifer pregnancy and production traits including carcass traits. Stayability is defined as the ability of a female to produce five consecutive calves. Heifer pregnancy is defined as the female's ability to become pregnant during the first breeding season. In this study, ultrasound intramuscular fat (UIMF) had little or no genetic relationship to heifer pregnancy (Boldt et al., 2018). In an earlier Red Angus study, McCallister et al. (2011) noted a small (0.13 ± 0.09) positive genetic correlation between heifer pregnancy and intramuscular fat. This relationship was larger than other correlations between heifer pregnancy and traits like scrotal circumference (0.05 ± 0.09; McCallister et al., 2011). While there appears to be little genetic relationship, there still appears to be an influence of intramuscular fat on heifer fertility. In a different study by Evans and coauthors (2004), non-cycling heifers were observed to have lower UIMF (2.93% vs. 3.07%) than cycling heifers at 14 days post-synchronization. Additionally, heifers that failed to conceive after expressing estrus had less backfat than those that successfully conceived (Evans et al., 2004). This is supported by Boldt et al. (2018) who noted a moderate but positive genetic relationship between stayability and UIMF. Further, the trait that showed the best opportunity as a stayability indicator trait was ultrasound backfat (Boldt et al., 2018). These relationships highlight the important role of body composition and energy status on fertility and reproductive function, and should be considered when comparing an animal's genetics for those traits.

Components of maternal productivity

Several factors play a large role in maternal beef cow productivity, including genetics, nutrition, health, environment and feed resources. Female body weight and composition is a critical component in several stages of the reproductive cycle. Adequate feed intake by the cow, in both quantity and quality, affects nutritional balance and body composition - as does demand for milk production. The balance of these are critical to sustained reproductive success in the herd.

Though complex, these factors impact body composition and fat deposition, ultimately influencing reproductive performance in beef cattle. This relationship was demonstrated by Wettemann et al. (2003) who determined body energy reserves at calving, measured in body condition score, to be the most important factor influencing reproduction in cows when compared to nutrient intake and suckling as other factors influencing anestrus (Wettemann et al., 2003). Fatty tissue has long been identified as an indicator of energy reserves by the cow, and does so via a neuroendocrine signaling pathway (Zieba et al., 2005). This pathway involves the release of several hormones including leptin that is produced by adipose tissue. While leptin is a critical biological indicator of energy status in the cow, it also plays a significant role in puberty onset in heifers via chemical changes in the brain that regulate reproductive cyclicity (Cardoso et al., 2018). Therefore, the positive relationships observed in previous work between heifer puberty and measurements of fat deposition are consistent with the known relationship between body composition at certain stages of the reproductive cycle and fertility in beef cows.

In addition to the relationship between heifer pregnancy and stayability with ultrasound backfat observed by Boldt et al. (2018), both were associated with ultrasound ribeye area. The growth characteristics, preweaning gain direct, weaning weight direct and yearling weight were correlated with heifer pregnancy, while the maternal side of those measures, pre-weaning gain maternal, weaning weight maternal and yearling weight maternal were correlated with stayability (Boldt et al., 2018). Collectively, the current literature suggests a positive, although perhaps indirect, relationship between reproductive function, growth, and carcass characteristics and justifies further investigation.

IOWA STATE UNIVERSITY ANGUS BREEDING PROJECT CASE STUDY

Description of the herd and breeding project

The current Iowa State University (ISU) Beef Cattle Breeding Project began with the purchase of virgin heifers from Angus herds from South Dakota and Nebraska in the fall of 1996. Additional heifers were added to the herd as part of an embryo transfer program that occurred in the summer of 1997 (Wilson et al., 2000). During the summer of 1997, the herds from the ISU Rhodes Research and Demonstration Farm and the ISU McNay Memorial Research and Demonstration Farm were combined to establish a single herd to form the base of this project at the McNay Farm near Chariton in Southern Iowa. Today, the herd remains located in Southern Iowa where the pasture base is predominately fescue.

The ISU Breeding Project originally began with three objectives: 1) the development of two divergent genetic lines for high quality beef (Q-Line) and increased retail product (R-Line); 2) to validate the use of ultrasound on live cattle to make genetic progress in carcass traits; and 3) to develop and evaluate new ultrasound methods on live cattle and carcasses (Hassen et al., 2004). The R-Line was discontinued after only 6 years, and the selection is now primarily for intramuscular fat or marbling for all cattle. While other traits such as growth, temperament, calving ease and structural soundness are considered, the primary breeding objective continues to be carcass quality, specifically marbling. The herd consists of over 400 head where approximately 300 cows are maintained in a spring-calving herd. Cows from the Spring herd that fail to breed once are carried over to a fall-calving herd of approximately 100 cows. If a cow fails to breed once in the fall herd, she is culled. The fall-calving herd is terminal. Heifers are selected and retained only from the spring herd. Estrus synchronization and artificial insemination (AI) are used on all cows and heifers in the Spring herd. Clean up bulls are raised within the herd using the selection criteria previously mentioned. Outside AI bulls are used on a limited basis. This, in addition to targeted matings of raised bulls through both AI and cleanup, is employed to maintain an inbreeding coefficient of less than 5%.

A series of figures depicting the genetic progress of the herd in marbling and different reproductive and maternal traits were compiled to demonstrate the genetic makeup of the ISU McNay Breeding Project herd and why it is a unique case study. In each of these figures, a trendline was applied to the genetic trend of the ISU high-quality line to help illustrate the general overall trend in the herd. To illustrate the genetic progress in marbling over time, Figure 4 shows the average expected progeny difference (EPD) for marbling (MARB) in the ISU Breeding Project herd compared to the Angus breed average. The ISU high-quality line has consistently been above the breed average for MARB since the breeding project began. Currently in fall of 2019, the average MARB for the ISU McNay Breeding Project herd is at 1.065, nearly double that for the Angus breed (0.580).

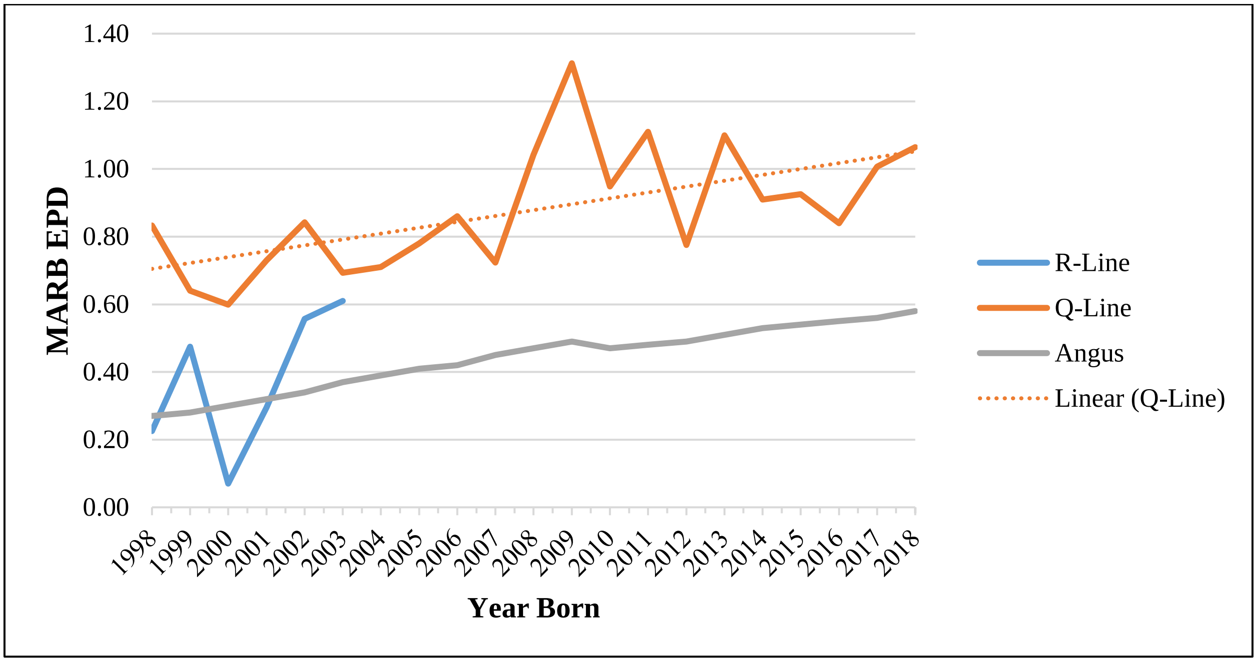


Figure 4. Genetic trends for Marbling (MARB) EPD in the ISU retail product line (R-line), the ISU high-quality line (Q-line), and the Angus breed.

Figure 5 illustrates the genetic progress in heifer pregnancy (HP) EPD over time for the ISU herd as compared to the Angus breed. During the timeframe between 2003 to 2014, there have been years where the ISU herd has fallen below the breed average; however, in more recent years HP EPD in the herd has followed the breed average fairly closely. Currently in fall of 2019, the average HP EPD for the herd is at 11.4 compared to the Angus breed at 11.1. Although HP has not been the primary breeding objective for the ISU herd, it has managed to maintain a level very similar to the overall breed average.

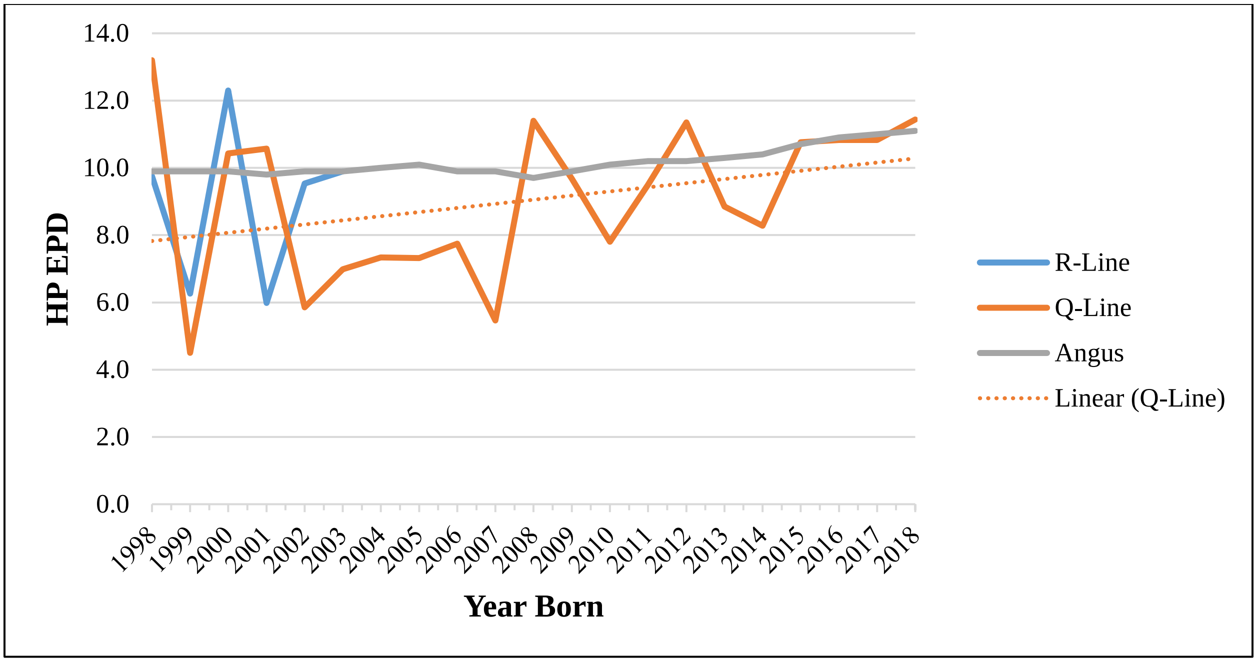


Figure 5. Genetic trends for Heifer Pregnancy (HP) EPD in the ISU retail product line (R-line), the ISU high quality line (Q-line), and the Angus breed.

Genetic progress in maternal milk production (MILK) EPD over time in the ISU herd as compared to the Angus breed is illustrated in Figure 6. The ISU herd has tended to follow the overall trend in the breed average and has even surpassed the breed average at times. Currently the average MILK EPD for the ISU herd and the Angus breed are both at 25.0. Genetic progress in MILK for the ISU herd has tended to remain consistent over time.

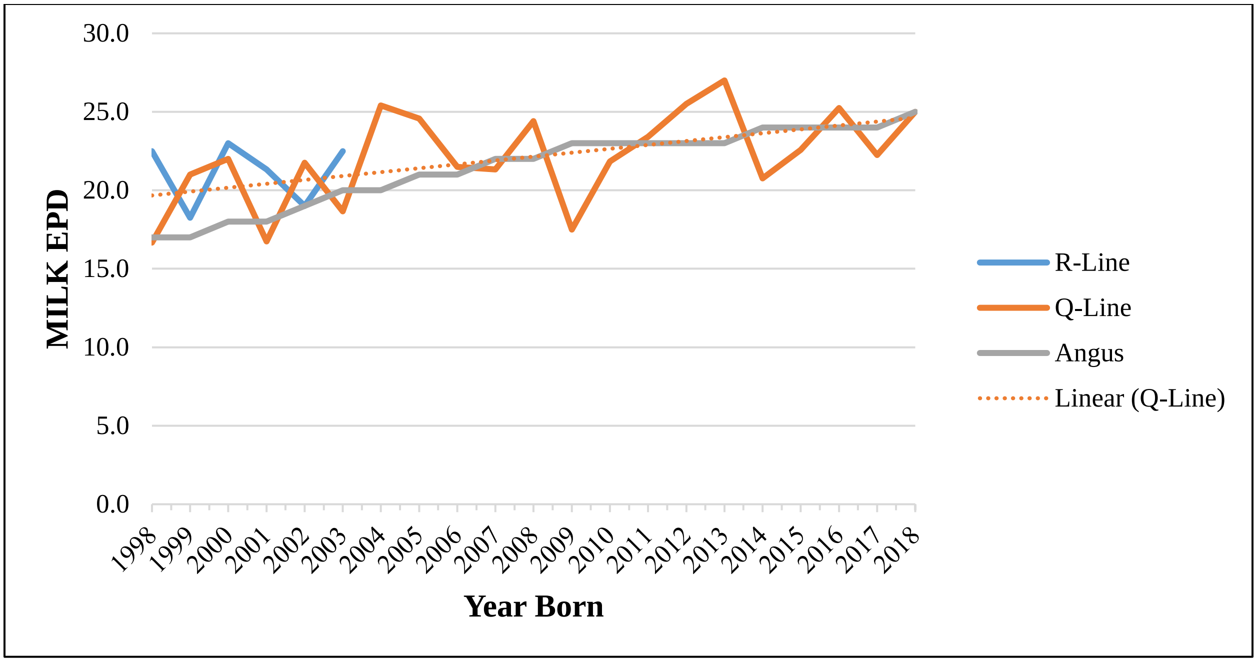


Figure 6. Genetic trends for milk production (MILK) EPD in the ISU retail product line (R-line), the ISU high quality line (Q-line), and the Angus breed.

Reproductive traits from the sire are also important to consider. Figure 7 illustrates the genetic progress in scrotal circumference (SC) EPD over time for the ISU herd as compared to the breed average. Although there have been a few years where the ISU high-quality line has dipped below the breed average, SC EPD in the herd has exceeded the breed average for the most part. Average SC EPD for the ISU McNay herd is currently at 0.98 while that of the Angus breed is at 0.79.

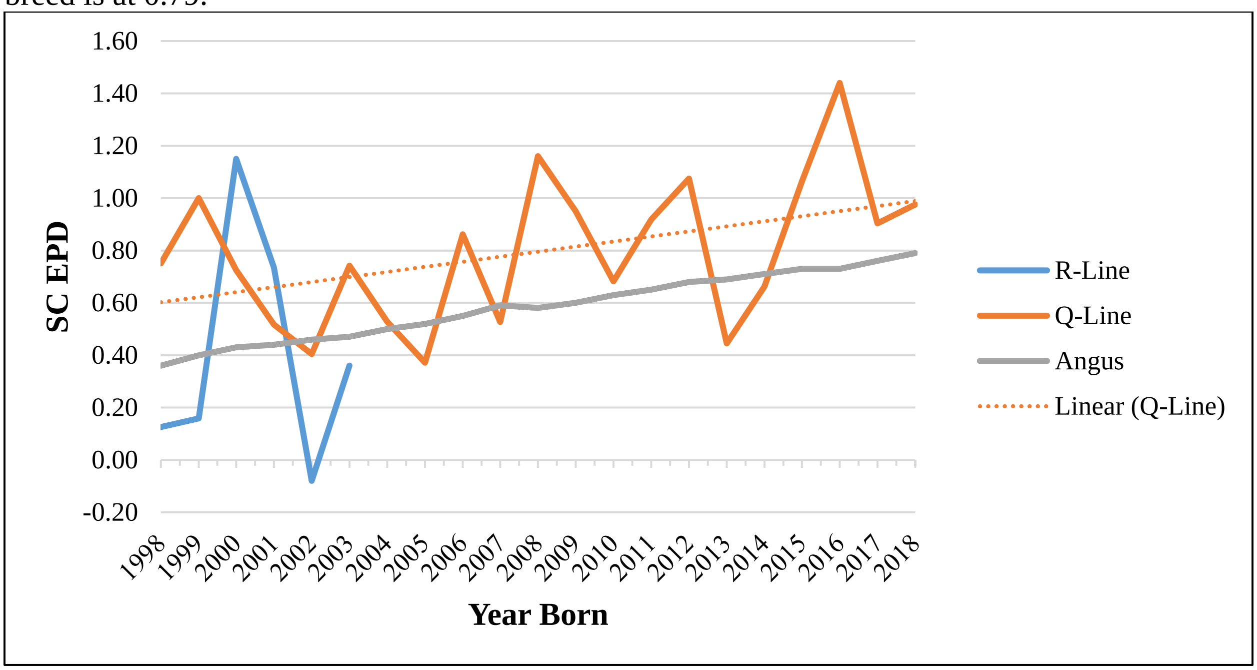


Figure 7. Genetic trends for Scrotal Circumference (SC) EPD in the ISU retail product line (R-line), the ISU high-quality line (Q-line), and the Angus breed.

Genetic progress in weaning weight (WW) EPD over time in the ISU herd as compared to the Angus breed is illustrated in Figure 8. During the timeframe from 2001 to 2014, the ISU high-quality line has closely followed the breed average for WW EPD; however, in more recent years, the herd has fallen below the breed average. Currently, the average WW EPD for the ISU herd is at 47.0 while that for the breed is higher at 56.0.

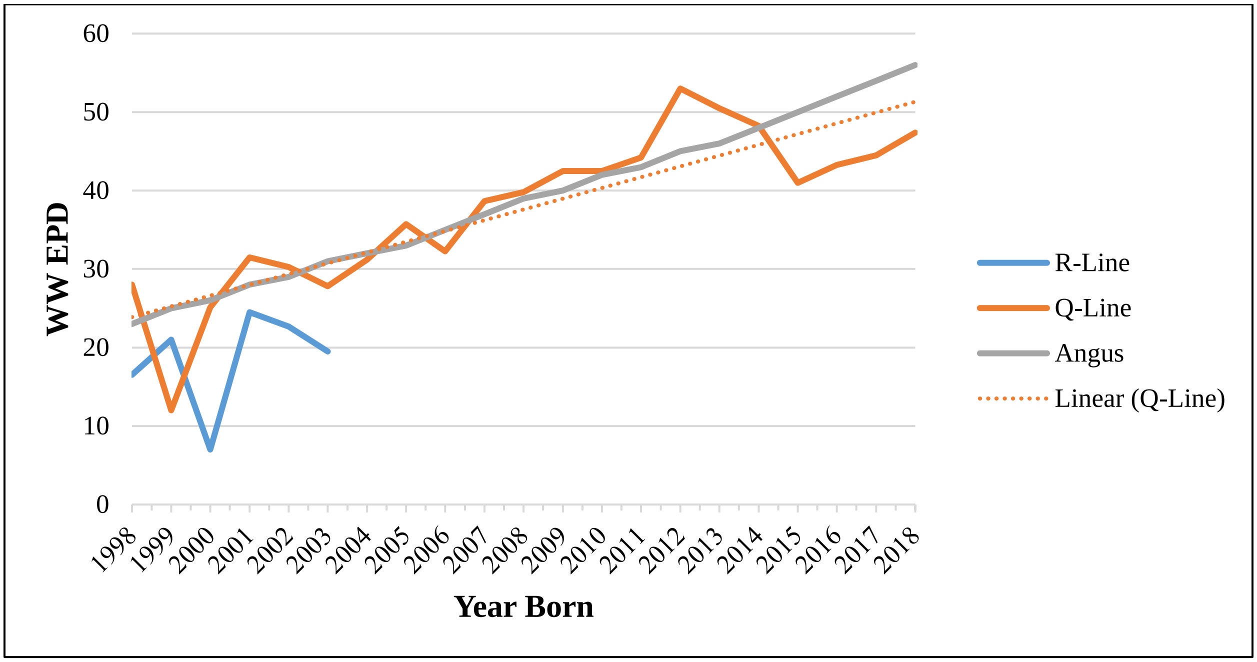


Figure 8. Genetic trends for Weaning Weight (WW) EPD in the ISU retail product line (R-line), the ISU high-quality line (Q-line), and the Angus breed.

The effects of the intense selection for marbling and meat quality in the herd is reflected in Table 1, which presents the percentage of carcasses (steers and heifers) grading USDA Prime, Choice and Premium Choice (average Choice and higher) over the last five years. The percentage grading Prime and Premium Choice has steadily increased from 73.3% in 2014 to 93.0% in 2018. It is also interesting to note the percentage of carcasses grading Prime, specifically, has increased at a higher rate from 26% in 2014 to 57.0% in 2018. Table 2 outlines the average carcass characteristics of animals (steers and heifers) from the ISU McNay Breeding Project herd harvested in the last five years. Over the last five years, average Marbling Score (MS) has improved from average Choice to high Choice, Rib-eye Area (REA) has increased from 12.3 to 12.9 square inches, Back Fat Thickness (FT) has increased from 0.50 to 0.60 inches, Hot Carcass Weight has increased from 700.0 to 792.5 lbs., and Yield Grade (YG) has increased from 2.8 to 3. 3.

Table 1. Percentage of carcasses from the ISU McNay Breeding Project herd grading Prime, Choice and Other[1] by birth year

Year	Total Harvested, *n*	Choice & higher, %	Premium Choice & higher, %	Prime, %	Other, %
2014	146	97.3	73.3	26.0	2.7
2015	169	98.2	87.6	44.4	1.8
2016	204	92.6	84.3	45.1	7.4
2017	238	98.3	91.6	56.3	1.7
2018[2]	100	99.0	93.0	57.0	1.0

[1]Other included Select and Standard
[2]Only includes steers born in the Spring of 2018

Table 2. Average Marbling Score (MS), Ribeye Area (REA), Back Fat Thickness (FT), Hot Carcass Weight (HCW), and Yield Grade (YG) for carcasses harvested from the ISU McNay breeding project herd by birth year

Year	MS[1]	REA, sq. in	FT, in	HCW, lb	YG
2014	1179.6	12.3	0.50	700.0	2.8
2015	1261.6	12.3	0.50	744.0	3.2
2016	1273.5	12.1	0.50	736.5	3.3
2017	1291.9	11.8	0.60	752.1	3.5
2018[2]	1291.7	12.9	0.60	792.5	3.3

[1]900 = Select; 1000 = low Choice; 1100 = average Choice; 1200 = high Choice; 1300 = Prime
[2]Only includes steers born in the Spring of 2018

Data analysis

Four separate datasets were obtained from the ISU Breeding Project for analysis. These included:

1) *ISU Breeding Project EPDs* in which the American Angus Association provided EPDs for all animals born in the herd from 2001 to 2018 on August 8, 2019
2) *Maternal Evaluation* in which lifetime calving interval and reproductive success of cows born in the herd from 2001 to 2016 were evaluated
3) *Ultrasound Data* where ultrasound phenotypes adjusted to yearling age on all cattle born from 2001 to 2011 were analyzed
4) *Yearling Bull Fertility Data* where breeding soundness exams and slaughter data were analyzed from two bull calf crops.

These datasets are described individually in the following sections with details of the analysis conducted.

1. ISU Breeding Project EPDs

Dam and sire EPDs for animals born from 2001-2018 were used to observe any correlations between their EPDs used to measure maternal productive performance and those used to measure their carcass performance. Depending on the trait, this data set included between 1,306 and 1,728 observations. The summary statistics for each EPD are reported in Table 3.

Correlations were estimated between EPD of registered dams and sires from the ISU McNay Breeding Project using the correlation procedure in SAS (SAS Institute, Inc., Cary, NC) and are presented in Table 4. Although small, there was a positive relationship ($P < 0.01$) observed between MARB EPD and MILK EPD, which supports previous findings evaluated in a review by Smith and Greiner (2013). The moderate relationship between MARB and WW EPDs is also not surprising given the positive relationship between MARB and MILK EPDs. Other significant positive correlations ($P < 0.01$) were found between MARB EPD and other maternal and fertility EPDs (CEM, HP and SC). These data do not indicate an antagonistic relationship between increased selection for marbling and heifer pregnancy. In fact, a positive correlation of 0.206 between MARB EPD and HP EPD was observed. This has not been observed in previous literature and is worthy of further investigation.

With the selection pressure on marbling within this herd, genetic indicators of reproduction (SC, HP, CEM and MILK EPDs) were not negatively impacted. In addition to MARB, FAT EPD also had a positive relationship with the fertility and maternal measures (SC, HP, CEM and MILK EPDs), consistent with previous research (Boldt et al., 2018) and our understanding of body composition and reproduction (Wettemann et al., 2003; Cardoso et al., 2018).

Table 3. ISU McNay Breeding Project expected progeny differences (EPD) summary statistics[1]

	n	**Average**	**Std Dev**	**Minimum**	**Maximum**
CED	1,728	4	5.4	-15	18
BW	1,728	1.5	1.90	-4.8	8.8
WW	1,728	33	10.8	-13	66
YW	1,443	58	18.8	-29	122
SC	1,306	0.55	0.47	-0.80	2.82
HP	1,397	9.2	2.84	-0.1	19.3
CEM	1,443	7	4.2	-8	17
MILK	1,443	21	5.2	1	35
CW	1,422	15	14.5	-43	58
MARB	1,422	0.65	0.32	-0.24	1.83
RE	1,422	0.27	0.21	-0.76	0.97
FAT	1,422	0.009	0.023	-0.066	0.084

[1]Abbreviations: CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; YW = yearling weight EPD; SC = scrotal circumference EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; CW = carcass weight EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

Table 4. Correlations of ISU McNay Breeding Project expected progeny differences (EPD)[1]

	BW	WW	YW	SC	HP	CEM	MILK	CW	MARB	RE	FAT
CED	-0.887**	-0.126**	-0.198**	0.036	0.138**	0.768**	0.138**	-0.230**	0.174**	-0.047*	0.129**
BW		0.293**	0.395**	0.073**	-0.094**	-0.611**	-0.037	0.400**	-0.043*	0.143**	-0.087**
WW			0.949**	0.315**	0.104**	-0.150**	0.301**	0.776**	0.373**	0.293**	0.162**
YW				0.260**	0.031	-0.147**	0.267**	0.837**	0.370**	0.356**	0.104**
SC					0.269**	0.015	0.125**	0.180**	0.245**	0.140**	0.185**
HP						0.086**	-0.047*	-0.005	0.206**	0.113**	0.121**
CEM							0.143*	-0.132**	0.101**	-0.037	0.156**
MILK								0.377**	0.088**	0.176**	0.075**
CW									0.229**	0.478**	0.043*
MARB										0.072**	0.417**
RE											-0.374**

[1]Abbreviations: CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; YW = yearling weight EPD; SC = scrotal circumference EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; CW = carcass weight EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

** indicates significant difference ($P \leq 0.05$)

* indicates a tendency for difference ($P = 0.06$ to 0.10)

2. Maternal Evaluation

Cows born in the herd from 2001 to 2016 were evaluated to identify the relationship between dam EPD and her actual reproductive performance. The ISU McNay Breeding Project herd is divided into a spring- and fall-calving herd. As a general rule, open cows in the spring are moved to the fall herd. Once in the fall herd, open cows are culled. Therefore, total calves produced in her lifetime (NCALF) as well as the total number of calves she had in the spring before moving to the fall-calving herd (NSCALF) were analyzed as determinants of reproductive performance. Additionally, her average lifetime calving interval (CI) was calculated based on birth dates of each subsequent calf after her first calf, including those females who moved from the spring to the fall calving herd. Table 5 shows the average reproductive performance of cows in this dataset as well as the average EPDs of those cows. Correlations between dam EPDs and measures of reproductive performance were analyzed using the correlation procedure in SAS (SAS Institute, Inc., Cary, NC) and are presented in Table 6.

In this dataset, cows produced an average of 4.2 calves in her lifetime with 3.0 calves produced in the spring. The range of calves produced was from 1 to 14 calves. The average CI using the criteria in this herd was 392 days. As shown in Table 6, the MARB EPD of the cow does not appear to be related to number of calves or CI. While some of the relationships are statistically significant, MARB EPD explains less than 1% of the variation in number of calves produced or CI. The strongest correlation was a negative relationship between MARB EPD and CI. This is consistent with the literature summarized in the review by Smith and Greiner (2013) as related to calving interval and the more recent Red Angus data evaluated by Boldt et al. (2018) relating to stayability and ultrasound IMF.

Table 5. ISU McNay herd dam expected progeny differences (EPD) and reproductive performance summary statistics used in this analysis[1]

Variable	*n*	Average	Std Dev	Minimum	Maximum
NCALF	1,032	4	3.0	1	14
NSCALF	1,032	3	2.6	0	14
CI	827	392	39.7	305	570
CED	855	4	5.4	-13	18
BW	855	1.5	1.91	-4.8	7.5
WW	855	32	10.3	-13	62
SC	787	0.57	0.48	-0.80	2.11
DOC	830	-7	8.8	-32	22
HP	847	9.6	2.61	2.4	17.4
CEM	855	7	4.3	-8	16
MILK	855	21	5.4	2	35
MARB	850	0.67	0.32	-0.24	1.61
RE	850	0.28	0.21	-0.69	0.88
FAT	850	0.009	0.023	-0.063	0.084

[1]Abbrevations: NCALF = number of calves; NSCALF = number spring-born calves; CI: average calving interval; CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; SC = scrotal circumference EPD; DOC = docility EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

Table 6. Correlation of dam expected progeny differences (EPD) to her reproductive performance as measured by number of calves and average calving interval[1]

	CED	BW	WW	SC	DOC	HP	CEM	MILK	MARB	RE	FAT
NCALF	-0.035	-0.0113	-0.173**	-0.076**	-0.074**	-0.079**	-0.030	-0.014	-0.070**	-0.092**	0.001
NSCALF	0.031	-0.067*	-0.054	0.035	-0.077**	0.028	-0.014	-0.009	0.059*	-0.026	0.044
CI	-0.077**	-0.093**	0.011	-0.073*	0.004	-0.097**	-0.027	-0.024	-0.087**	-0.022	-0.057

[1]Abbrevations: NCALF = number of calves; NSCALF = number spring-born calves; CI = average calving interval; CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; SC = scrotal circumference EPD; DOC = docility EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

** indicates significant difference ($P \leq 0.05$)

* indicate a tendency for difference ($P = 0.06$ to 0.10)

3. Ultrasound Data

This herd has a unique dataset in which calves born between 2001 and 2011 were scanned using real-time ultrasound at a year of age to assess carcass traits in the live animal. For the duration of this dataset, the Classic 200 (Pie Medical) machine was the predominant technology used. Images were interpreted by either the original software developed by ISU's Centralized Ultrasound Processing (CUP) Lab or using software certified by the Ultrasound Guidelines Council. Multiple research projects were nested within this herd, including: intramuscular fat (IMF) model enhancement, the development of rump fat (RUF) data collection to improve retail product, serial scanning studies to gauge growth and development, and bovine genome sequencing. This dataset allowed comparisons to be made between progeny ultrasound traits and dam EPDs with known associations to fertility and reproduction. The summary statistics for animals included in the analysis are reported in Table 7. The EPD correlations were analyzed using the correlation procedure in SAS (SAS Institute, Inc., Cary, NC).

The correlations between progeny ultrasound phenotypes and dam EPDs are reported in Table 8. It is important to note that from 2001 to 2007, the primary criteria for genetic selection was IMF EPD. When the traits were combined in the American Angus Association (AAA) genetic evaluation, the shift focused to MARB EPD. Also unique to this herd, for the bulk of the ISU Breeding Project, all progeny were retained through yearling performance and carcass ultrasound data collection (320-440 days of age). Replacement heifers were selected primarily on marbling genetics, but structural soundness, adequate growth, eyes free of pinkeye, temperament, and even pelvic area were used as additional selection criteria. Bulls were largely retained in the same fashion, but bulls not used in the breeding population remained intact, fed to acceptable market weight, and harvested with full carcass data collected and reported to the AAA.

The simple correlations of the four ultrasound traits {ultrasound adjusted (UA) intramuscular fat (UAIMF), UA ribeye area (UARE), UA rib fat (UARF), and UA rump fat (UARUF)} to dam EPD traits associated with fertility and reproduction, namely CEM, HP, SC and MILK, are all weak ($P \leq 0.13$), even though several traits had significant p-values. This suggests that aggressive selection for either IMF or MARB EPD over a 20-year period has resulted in no negative impact on fertility and reproductive traits as expressed in the EPD profile.

Table 7. ISU McNay Breeding Project progeny ultrasound and dam expected progeny differences (EPD) summary statistics[1]

	n	**Average**	**Std Dev**	**Minimum**	**Maximum**
UAIMF	1,341	4.81	1.21	1.60	10.39
UARE	1,342	10.53	2.28	4.30	16.30
UARF	1,342	0.26	0.11	0.04	0.68
UARUF	1,340	0.27	0.01	0.04	0.65
CED	1,379	3	5.7	-13	18
CEM	1,379	7	5.0	-8	16
HP	1,379	8.68	2.98	0.00	17.40
MILK	1,379	19.64	6.22	0.00	35.00
SC	1,379	0.42	0.47	-0.80	1.93
MARB	1,379	0.54	0.31	-0.24	1.49
RE	1,379	0.23	0.22	-0.76	0.88
FAT	1,379	0.005	0.025	-0.066	0.081

[1]Abbrevations: UAIMF = ultrasound adjusted intramuscular fat; UARE = ultrasound adjusted ribeye area; UARF = ultrasound adjusted rib fat; UARUF = ultrasound adjusted rump fat; CED = calving ease direct EPD; CEM = calving ease maternal EPD; HP = heifer pregnancy EPD; MILK = milk EPD; SC = scrotal circumference EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

Table 8. Correlation of ISU Breeding Project progeny carcass ultrasound data and dam expected progeny differences (EPD)[1]

	UARE	UARF	UARUF	CED	CEM	HP	MILK	SC	MARB	RE	FAT
UAIMF	0.110**	0.376**	0.323**	0.033	-0.001	-0.003	-0.006	0.005	0.340**	-0.005	0.113**
UAREA		0.670**	0.611**	0.026	0.021	-0.085**	0.129**	0.031	0.020	0.222**	-0.055**
UARF			0.810**	0.057**	0.038	-0.054**	0.071**	0.047*	0.066**	0.002	0.170**
UARUF				0.043	0.018	-0.031	0.073**	0.080**	0.058**	0.036	0.158**

[1]Abbrevations: UAIMF = ultrasound adjusted intramuscular fat; UARE = ultrasound adjusted ribeye area; UARF = ultrasound adjusted rib fat; UARUF = ultrasound adjusted rump fat; CED = calving ease direct EPD; CEM = calving ease maternal EPD; HP = heifer pregnancy EPD; MILK = milk EPD; SC = scrotal circumference EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

** indicates significant difference ($P \leq 0.05$)

* indicate a tendency for difference (P = 0.06 to 0.10)

4. Yearling Bull Fertility Data

Two Iowa State University research studies utilizing intact males from the ISU Breeding Project cow herd were conducted focusing on bull development (Dohlman et al., 2016; Lundy et al., unpublished). As part of these studies, breeding soundness exams (BSE) were collected at yearling age (*n* = 120 bulls), and bulls were sent to harvest with full carcass data collected including marbling scores, presenting a unique opportunity to evaluate correlations between yearling bull fertility and subsequent growth and carcass characteristics.

Bull fertility, growth, and carcass performance data were analyzed using PROC Corr procedure of SAS 9.4 (SAS Institute, Inc., Cary, NC). Significance was declared at $P \leq 0.05$ with tendencies declared from $P = 0.06$ to 0.10. Outliers were determined using Cook's D statistics, and if Cook's D values were greater than 0.5, outliers were removed. For average daily gain (ADG), five observations were identified as outliers and removed.

Using 1992 Society of Theriogenology standards (Chenoweth et al., 2010), 46% of the bulls passed their BSE at 372 days of age on average with a 63% pass rate at 410 days of age on average. These rates are deemed adequate when compared to industry BSE rates of 35% and 60%, respectively, of bulls at 12 (365 days) and 14 (426 days) months of age (Perry and Patterson, 2011). Simple summary statistics of the bulls used in this analysis are found in Table 9. Fertility characteristics including raw, unadjusted scrotal circumference (SC), yearling body weight (YBW), and ADG data reported were collected near yearling age. Bulls were harvested at an average of 424 days of age. Bulls had adequate marbling to grade 80% Choice or better, with 31% having the marbling potential to grade premium Choice or higher.

Correlations between BSE-collected fertility data and actual performance data are presented in Table 10. The positive correlations ($P \leq 0.04$) between SC and the growth and carcass parameters of YBW, hot carcass weight (HCW), 12th rib backfat (BF), and ribeye area (REA) is not surprising with the beef industry's emphasis on growth. Further regression analysis (data not presented) shows that HCW, BF, and REA are poor predictors of morphology (MOR) and SC ($r^2 \leq 0.07$ and 0.16, respectively). In this dataset, faster growing bulls were leaner, heavier muscled, and had larger SC, but also had poorer BSE scores (as indicated by MOT and MOR) suggesting that selection for larger SC might not result in better BSE scores and therefore, bull fertility. In a study by Pruitt (1986), bulls that were fed higher energy diets were heavier and had larger SC, but size failed to have an impact on age of puberty. This dataset contradicts what previous research has found indicating that increased scrotal circumference results in improved semen quality and quantity (Knights et al., 1984).

In a study evaluating correlations between SC and marbling scores and intramuscular fat using data provided by the Red Angus Association of America, McAllister and coauthors (2011) determined minimal to no genetic and phenotypic correlations between these traits, concluding that selection for marbling wasn't decreasing fertility related to SC. Furthermore, this current dataset goes on to further show a tendency for a positive correlation ($P = 0.08$) between the two traits, indicating that selection for increased marbling in this herd indirectly impacted SC with marbling having no measurable impact on sperm MOT or MOR. These results indicate that intense selection for marbling in this herd for over 20 years has not resulted in a detrimental effect on bull fertility.

Bull's dam EPD were also used to evaluate the relationship of dam EPD (*n* = 111, as some dams had more than one bull on test in the studies over the two years) to their respective bull progeny's fertility and carcass traits. Additional correlations between bull fertility and dam yearling height, mature height, and docility EPD were estimated, but due to no correlation differences, data are not reported. The summary statistics of the dam EPD are reported in Table 11.

Previous studies have evaluated yearling SC and actual percent heifer pregnancy and determined minimal genetic correlation and low heritability (Evans et al., 1999; McAllister et al., 2011). Lack of differences between SC and heifer pregnancy (HP) EPD in this study support this conclusion (Table 12). However, this may be the first study to look at the correlation of individual male fertility traits (MOT and MOR). When the fertility data were compared to the dam's EPD, a positive correlation (*P* = 0.05) between heifer pregnancy (HP) EPD and sperm MOT was observed, indicating that selecting for heifer fertility, as measured by HP, could enhance bull fertility.

Additionally, a tendency (*P* = 0.08) for a negative correlation between dam calving ease direct (CED) EPD and normal sperm MOR was observed. Coupled with the positive relationship (*P* = 0.05) between CED EPD and sperm head defects at a year of age, these data suggest that intense selection for calving ease may have unintended consequences on bull fertility. While both sperm MOT and MOR go hand-in-hand to determine overall bull fertility, this dataset reiterates the point that single-trait selection for calving ease can have detrimental impacts on other economically relevant traits, especially reproduction.

In this analysis, only dam EPDs were utilized which represents a component of the data that would go into determining progeny EPDs. Additionally, this herd has had limited outside genetics brought in over the past 20 years, and with the increased emphasis on marbling, the herd fell below breed average for several EPDs, particularly growth. The tendencies for dam RE EPD and SC and MOR are likely just noise in the data and represent mating decisions to adjust dam shortfalls based on EPD.

Table 9. ISU Breeding Project yearling bull summary statistics

	n	**Average**	**Std Dev**	**Minimum**	**Maximum**
Scrotal circumference, cm	120	36.4	2.79	31.0	47.0
Motility, %	114	69.2	19.51	10.0	90.0
Normal morphology, %	114	58.0	23.43	8.0	92.0
Head defects, %	114	2.1	1.95	0.0	11.0
Yearling body weight, lb	120	1127	79.8	900	1340
Average daily gain	110	4.38	1.202	1.71	7.20
Hot carcass weight, lb	112	799.2	66.2	627.0	940.0
12th rib back fat thickness, in	112	0.50	0.156	0.20	0.91
Ribeye area, sq. in.	112	13.73	1.392	11.10	18.00
Yield grade	112	2.9	0.57	1.41	4.17
Marbling score[1]	112	1074	99.4	900	1409

[1]900 = Select; 1000 = low Choice; 1100 = average Choice; 1200 = high Choice; 1300 = Prime

Table 10. Correlation of ISU Breeding Project yearling bull fertility and actual growth and carcass traits[1]

	MOT	MOR	HD	YBW	ADG	HCW	BF	REA	YG	MS
SC	-0.161*	-0.175*	-0.223*	0.369**	-0.157*	0.395**	0.188**	0.188**	0.145	0.167*
MOT		0.494**	-0.118	-0.050	0.123	-0.098	-0.183*	-0.039	-0.135	-0.063
MOR			-0.238**	-0.096	0.154	-0.189**	-0.265**	-0.205**	-0.124	-0.035
HD				0.091	-0.053	-0.033	-0.101	-0.024	-0.019	-0.183*
YBW					-0.160*	0.717**	0.165*	0.164*	0.261**	0.095
ADG						-0.014	-0.334**	-0.082	-0.188**	-0.214**
HCW							0.401**	0.551**	0.257**	0.317**
BF								0.170*	0.766**	0.532**
REA									-0.414**	0.152
YG										0.406**

[1]Abbreviations: SC = scrotal circumference; MOT = sperm motility; MOR = sperm normal morphology; HD = sperm head defects; YBW = yearling body weight; HCW = hot carcass weight; BF = 12^{th} rib backfat thickness; REA = ribeye area; YG = yield grade; MS = marbling score.

** indicates significant difference ($P \leq 0.05$)

* indicate a tendency for difference (P = 0.06 to 0.10)

Table 11. ISU Breeding Project dam expected progeny difference (EPD) of yearling bulls used in the analysis[1]

	n	**Average**	**Std Dev**	**Minimum**	**Maximum**
CED	111	4.8	5.09	-9.0	13.0
BW	111	1.32	1.870	-2.00	7.20
WW	111	35.0	8.80	8.0	54.0
YW	111	64.2	15.37	13.0	95.0
SCE	111	0.68	0.492	-0.52	1.89
HP	111	9.89	2.672	3.90	16.10
CEM	111	7.4	3.77	-3.0	16.0
MILK	111	22.4	5.07	12.0	34.0
MW	111	8.8	23.83	-71.0	58.0
CW	111	18.0	13.12	-15.0	49.0
MARB	111	0.77	0.292	0.00	1.56
RE	111	0.29	0.200	-0.36	0.71
FAT	111	0.01	0.020	-0.03	0.08

[1]Abbreviations: CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; YW = yearling weight EPD; SCE = scrotal circumference EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; CW = carcass weight EPD; MARB = marbling EPD; RE = ribeye area EPD; FAT = fat thickness EPD

Table 12. Correlation of ISU Breeding Project dam expected progeny differences (EPD) to yearling bull progeny fertility[1]

	CED	BW	WW	YW	SCE	HP	CEM	MILK	MW	CW	MARB	RE	FAT
SC	-0.036	0.033	-0.078	-0.138	0.136	-0.034	-0.084	-0.087	-0.151**	-0.139	-0.124	-0.160**	-0.088
MOT	-0.062	0.117	0.147	0.129	0.146	0.185*	-0.019	0.064	0.031	0.145	0.155	0.133	0.019
MOR	-0.171**	0.171**	0.033	0.072	0.033	-0.033	-0.026	-0.149	0.073	0.099	-0.096	0.174**	-0.055
HD	0.191*	-0.109	0.131	0.070	0.158**	0.057	0.142	0.013	-0.072	0.065	0.128	0.093	0.054

[1]Abbreviations: SC = scrotal circumference; MOT = sperm motility; MOR = sperm normal morphology; HD = sperm head defects; CED = calving ease direct EPD; BW = birth weight EPD; WW = weaning weight EPD; YW = yearling weight EPD; SCE = scrotal circumference EPD; HP = heifer pregnancy EPD; CEM = calving ease maternal EPD; MILK = milk EPD; CW = carcass weight EPD; MARB = marbling EPD; RE = ribeye area EPD; Fat = fat thickness EPD

** indicates significant difference ($P \leq 0.05$)

* indicates a tendency for difference (P = 0.06 to 0.10)

SUMMARY AND CONCLUSIONS

The results of the analyses conducted on the ISU McNay Breeding Project herd that has been selected for intramuscular fat or marbling are mostly consistent with research reviewed in the literature. These results include:

1) Small, positive relationship between milk and marbling EPDs in the herd
2) A significant positive relationship (r = 0.206) between marbling and heifer pregnancy EPDs in the herd.
3) Positive correlations between marbling EPD and the EPDs for scrotal circumference, heifer pregnancy and maternal calving ease.
4) Marbling EPD of the cows in the herd had a weak negative relationship to total number of calves, a weak positive relationship to number of calves born in the spring herd under the management scheme of the herd, and a weak negative relationship with calving interval.
5) Relationships between ultrasound intramuscular fat phenotypes of the progeny were not significantly related to reproductive EPD (CED, CEM, HP, SC and MILK).
6) A tendency for a positive correlation between yearling bull scrotal circumference and marbling scores indicate that selection for increased marbling in this herd may indirectly impacted SC with marbling having no measurable impact on sperm MOT or MOR.

One interesting and notable result that has not been observed previously is positive relationship between heifer pregnancy and marbling EPDs. This is consistent with the relationship of body composition and heifer growth, as well as the use of intramuscular fat serving as a depot to contribute to the energy demands of pregnancy. Selection for marbling in this herd has also not resulted in a detrimental effect on bull fertility. Overall, we could find minimal data to support the assertion that selection for marbling in Angus cattle would have a negative impact on fertility, reproductive or maternal traits. To the contrary, many of the relationships between carcass quality and cow function, although weak, were positive.

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