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GENETIC SELECTION FOR COW FERTILITY AND LONGEVITY

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Introduction

Genetic selection has driven remarkable change across economically relevant traits in the beef industry. From growth to carcass merit to efficiency, the use of selective matings has helped increase profitability across sectors. Modern breeding programs have placed the majority of their emphasis on increasing productivity traits, particularly those that are important for generating revenue (Rowan et al. 2021; Rowan, Schnabel, and Decker 2024). Other cow-centric traits that increase profitability through reducing maintenance and development costs have traditionally received less emphasis. However, extensive evidence exists that these traits, particularly cow longevity and fertility, play a major role in the profitability of commercial cow-calf herds(Boyer, Griffith, and DeLong 2020; Boyer, Griffith, and Pohler 2020; Griffith, Boyer, and DeLong 2019).

Making bull purchasing or AI sire decisions based on cow longevity and fertility presents multiple challenges. First, unlike performance traits, bulls will never express an equivalent phenotype to the economically relevant one we aim to improve in their daughters. This makes phenotypic selection impossible in bulls and even in females; the lowly heritable nature of these traits makes phenotypic selection difficult(Boldt et al. 2018; Larracharte, Espasandin, and Urioste 2021). To address these challenges, expected progeny differences (EPDs) serve as tools that allow daughter productivity and longevity to enter into bull selection decisions. These tools are reviewed at length by Rowan et al. (2022).

Here, we review genetics best practices and selection tools available to commercial producers aimed at improving longevity and fertility in their cowherds. Additionally, we report results from a large-scale phenotypic and genetic survey of whole herd reporting from the American Simmental Associations.

Fertility and Longevity Traits

The number one reason for the premature culling of cows in commercial beef herds is infertility (USDA-APHIS 2021). Cows that miss breeding are unlikely to ever become profitable, as a year of missed revenue makes offsetting their maintenance and development costs untenable (Boyer, Griffith, and DeLong 2020). Environment and management are the overwhelming drivers of fertility in most beef cattle populations, as early-life events, health, nutrition, environmental stress, and service type (natural vs. AI vs timed AI) all contribute to the success of fertilization and development (Fernandez-Novo et al. 2020; Hess et al. 2005; Diskin and Kenny 2016).

That said, ignoring the modest genetic component predisposition to high or low fertility would be a major mistake. Depending on the population and the trait, the heritabilities of fertility traits can range from ~0.05 to 0.2 (Cammack, Thomas, and Enns 2009). Despite accounting for a modest fraction of the phenotypic variance in fertility, these traits can still be improved through genetic selection. Lowly heritable traits that are expressed only in females make the use of EPDs for selection essential, as bulls never express the economically relevant phenotype that we aim to improve.

Whole Herd Reporting

Fertility traits can be broken into heifer and cow-centric traits, but in general, they lean on many of the same characteristics. In both cases, these traits require unbiased whole herd reporting (WHR) reporting to be effective. Whole herd reporting requires that operations keep an active inventory of cows and report records on every calf born, not just the ones that will go on to be registered (Hough and Ponder 2001). This allows the unbiased collection of reproductive successes and failures based on the existence of a calving record. Few breeds require whole herd reporting, but as selection tools that leverage them become available, seedstock breeders should be aware of the value of engaging with these programs: Providing their customers with better predictions of how a bull's daughters will fare with reproductive success.

Heifer Fertility Traits

Heifer Pregnancy (HP) is the most frequently reported reproductive phenotype across breed associations. It is generally defined as a binary trait that indicates the likelihood that an animal's daughters will conceive during their first breeding season. It tends to be lowly to moderately heritable across breeds, with heritabilities ranging from 0.10 to 0.20 (Boldt et al. 2018; Doyle et al. 2000). Successful breeding as a heifer is likely to have positive effects on an animal's future reproductive success (Wathes et al. 2014), as such it can have a major economic impact beyond its initial incidence. While binary HP is a useful tool, more granular measurements of heifer fertility would also be useful. For example, predicting age at first calving or first-service conception rates may be more informative for continuous phenotypes for understanding heifer fertility. In the work shared in the case study below, we found that heifers that calve early in their initial breeding season (first 30 days) tend to have significantly earlier calving dates throughout their productive lives.

Cow Fertility & Longevity Traits

In addition to predictions of daughters' ability to conceive as heifers, many breeds have phenotypes aimed at predicting fertility in subsequent years. The American Gelbvieh Association reports a 30-

month pregnancy (PG-30) EPD, which predicts the likelihood that a bull's daughters will conceive and calve as three-year-olds, given that they had their first calf. This EPD directly allows for selection on a cow's ability to recuperate from its first anestrus period and begin cycling again (Short et al. 1990).

No other cow fertility traits are directly reported in current genetic evaluations. Rather, whole herd reporting data is used to develop phenotypes for more holistic measures of longevity in cows. Definitions and names may vary across breeds, but generally, this class of traits is referred to as either stayability (STAY), longevity, or sustained fertility. Stayability EPDs are typically defined as the difference in the ability of an animal's retained daughters to remain productive in the herd, calving every year through a particular age. This age is typically six or seven, the point where commercial cows should become profitable after recovering their cumulative development and maintenance costs (Snelling, Golden, and Bourdon 1995; Jamrozik et al. 2013).

A cow's ability to remain in the herd and calve annually is ultimately the economically relevant trait that producers should work towards improving. The economic value of cow longevity is in maximizing a cow's productive and profitable years, as well as decreasing a herd's full heifer development costs. Stayability does encompass traits beyond fertility for which a cow may be culled prematurely. As such, selection on STAY may also improve structural soundness, disposition, udder quality, and productivity, all traits that contribute to a cow's ability to stay in a herd. Multiple breeds report STAY EPDs, and they tend to make up large proportions of maternal and all-purpose selection indexes because of their relatively large economic importance.

Crossbreeding & Heterosis

Despite the generally low heritabilities of fertility and longevity traits, they respond exceptionally well to heterosis in crossbreeding programs (Cundiff, Gregory, and Koch 1974). This is due to a well-known inverse relationship between trait heritabilities and their responses to heterosis. While heterosis (% of crossbred performance above parent expectation) is moderate for growth and performance-related traits, it is substantially higher for lowly heritable traits such as fertility and longevity (**Table 1**). This increased heterosis in maternal traits makes crossbreeding an essential tool for commercial producers that raise or purchase replacement females. While substantial value can be created for producers in added performance (i.e., more weaned calf pounds, higher feedlot performance), the real value of crossbreeding comes in making these longer-lived and more fertile cows. The heterosis response for these maternally-oriented traits is between 4 and 5 times the amount generated across production traits (Gregory, Cundiff, and Koch 1991, 1992).

It is important to note that heterosis is maximized in the first-generation (F1) cross, where the effects of inbreeding are reversed (Chen 2013). Subsequent crosses fail to realize the full amount of heterosis compared with the F1. As such, crossbreeding systems strive to maximize the

Table 1. Observed improvement in crossbred cattle compared to purebreds. The top group are direct estimates of performance differences. The bottom group are female-centric traits. Heterosis for each trait is reported as a percentage improvement over the purebred expectations. Values are all adapted from Gregory et al. 1991 & 1992.

Trait	Observed Improvement	%Heterosis
Calving rate	3.2%	4.4
Survival to weaning	1.4%	1.9
Birth weight	1.7 lbs	2.4
Weaning weight	16.3 lbs	3.9
Average daily gain	0.08 lbs/day	2.6
Yearling weight	29.1 lbs	3.8
Number of calves	0.97 calves	17.0
Longevity	1.36 years	16.2
Cumulative weaning weight	600 lbs	25.3

divergence of crosses made (Gregory and Cundiff 1980). While some heterosis is retained in subsequent generations, it is never as much as that generated in the F1. As such, some commercial producers should consider purchasing replacements rather than raising their own (Willett 1992). While this adds some upfront cost, it may allow producers to continually have F1 females in production and allow them to focus bull purchases on maximizing terminal merit. No one-size-fits-all approach exists for this decision, but it should be a consideration, particularly in small operations where the ability to perform rotational crossbreeding is limited.

A Fertility Case Study from American Simmental's Total Herd Enrollment Dataset

We used the American Simmental Association's Total Herd Enrollment (THE) dataset to calculate and explore five phenotypes associated with heifer pregnancy and sustained cow fertility. This dataset consisted of over 2.5 million records on over 500,000 registered Simmental heifers and cows. We used THE data to calculate phenotypes for various measures of heifer and cow fertility. These were calving date (days from the start of contemporary group's calving season start), discrete calving date (did the animal calve in the first 30 days of the season), calving interval (how many days between calving records), first calving interval (number of days between first and second calves), and heifer pregnancy (did heifer conceive inn first breeding season). **Figure 1** shows visual representations of these phenotypes.

Figure 1. Definitions of phenotypes calculated from the American Simmental Association's Total Herd Reporting dataset that were used to evaluate lifetime measures of fertility across animals.

The mean calving interval for the dataset was 386 days, with a maximum of 3,654 days. Ninety-two percent of females maintained a calving interval of less than 400 days. Although, we do see a small increase in calving interval observations near the 2-year mark. This suggests that many females are retained in herds following a missed breeding. For both heifers and cows, the majority of females calved in the first 30 days of the contemporary group's calving season. The mean calving date for heifers was day 19, while the mean for cows was day 32. For heifers, 78.5% were classified as early calvers compared to only 57.7% of mature cows. This is likely driven by higher levels of estrus synchronization and artificial insemination in the heifer's reproductive management compared with cows. In heifers, 16.4% and 3.8% of animals were considered middle and late calvers, respectively. This proportion of middle and late calvers was much higher in cows: 30% and 9.1%, respectively. A heifer's first breeding season was important for success in subsequent years. We found that heifers that calved in the first 30 days of their contemporary group's calving season went on to calve ten days earlier, on average, as mature cows (CD = 29.9 days vs. 40.2 days).

The THE data allowed us to better understand how attrition occurs in this population. As expected, we observed a steady decline in the number of animals over the course of their lifetimes. Most records in the dataset (88.9%) were from females less than seven years old. Of the 75,114 enrolled animals born prior to 2015 that could have potentially reached seven years of age without missing a calf, only 22.4% reached their theoretical payback point. A small number of females enrolled in THE data even remained productive through age 12 (n = 3,806). With disposal codes being reported in THE, we found that most females are removed from the herd at two years old due to either being sold for breeding purposes to other producers or because they are open. Based on disposal codes, failure to rebreed was the most common reason for removal from the herd, aside from transfers of an animal due to sale.

We also observed changes in females' average calving intervals over their productive lives. Calving intervals between ages 3 to 4 showed the largest changes in the duration of the calving interval, from 380 days to 368 days, respectively. This decrease is likely indicative of a common practice where calving intervals are indirectly elongated due to the management of heifers to calve earlier as they enter production, allowing for a longer period to recover post-partum. The next major change occurred between 11 and 12 years of age, where calving intervals changed from being centered at the 365-day mark to increasing up to 376 days.

We estimated low-to-moderate heritabilities for each of the phenotypes of interest. **Table 2** reports the full set of estimated variance components and their associated standard errors from pedigree and single-step analyses. For cows-centric phenotypes, the permanent environment effect accounted for the greatest proportion of phenotypic variance. Heifer pregnancy was the most highly heritable reproductive phenotype, with h^2 values of 0.23 and 0.24 for pedigree and genomic estimates, respectively. Due to the large size of the dataset, standard errors were quite low (0.000003-0.000099) for all heritability estimates. For cow-focused phenotypes, discrete early calving ($h^2_{pedigree}$ = 0.07 and $h^2_{genomic}$ = 0.07) was the most heritable trait, followed by calving date ($h^2_{pedigree}$ = 0.06 and $h^2_{genomic}$ = 0.06) and CI ($h^2_{pedigree}$ = 0.04 and $h^2_{genomic}$ = 0.04). The first calving interval had the same genomic h^2 estimate as CI with a value of 0.04 but had a slightly higher pedigree h^2 estimate of 0.05.

We observed both positive and negative genetic correlations between the phenotypes in bivariate analyses (**Table 2**). Binary heifer pregnancy phenotypes were minimally phenotypically correlated with all other cow-focused phenotypes (r_P = 0.004-0.03). A moderate genetic correlation (r_G = 0.19) existed between heifer pregnancy and calving date, indicating that shared genetics impact successful breeding as a heifer and lifelong early calving. Calving interval and heifer pregnancy were negatively genetically correlated (r_G = -0.07) but showed minimal phenotypic correlation (r_P = 0.004). In all other cases, the directionality of phenotypic correlations matched those of the genetic correlations, varying in magnitudes. As expected, the strongest genetic correlation existed between calving date and discrete early calving (r_G = 0.96) due to the direct derivative relationship between the two phenotypes. Calving interval and FCI showed low phenotypic correlations (r_P = 0.13) but moderately high genetic correlations (r_G = 0.47). The next highest genetic correlation existed between first calving interval and calving date (r_G = 0.34), suggesting that a genetic predisposition for rebreeding after a cow’s first calf is shared with early calving throughout its productive lifetime. Estimates of genetic correlations all had very small associated standard errors (0.000011 to 0.000273). A cow’s first calving interval showed weak phenotypic correlations with both calving date and calving interval (0.07 and 0.13, respectively).

Table 2. Heritabilities, genetic & phenotypic correlations. Heritabilities and their associated standard errors are reported on the diagonal and are bolded. Upper off-diagonal are genetic correlations and associated standard errors. Lower off-diagonal are phenotypic correlations.

Phenotype	Heifer Pregnancy	Calving Date	Discrete Early Calving	First Calving Interval	Calving Interval
Heifer Pregnancy	**0.24** ±0.000094	0.19 ±0.000200	0.07 ±0.000124	0.01 ±0.000011	-0.07 ±0.000273
Calving Date	0.03	**0.06** ±0.000003	0.96 ±0.000090	0.34 ±0.000075	0.05 ±0.000151
Discrete Early Calving	0.03	0.93	**0.07** ±0.000017	0.17 ±0.000029	0.10 ±0.000149
First Calving Interval	0.02	0.07	0.07	**0.04** ±0.000029	0.47 ±0.000231
Calving Interval	0.004	0.15	0.15	0.13	**0.04** ±0.000005

The unbiased reporting required in THE allowed us to understand culling decisions and cow attrition at the population level. Most seedstock Simmental producers maintain close to a 365-day calving interval on average, but it'll take work to maintain that. Calving date for heifers was predictive of future reproductive performance. Each of these phenotypes was lowly to moderately heritable. All phenotypes showed low-to-moderate phenotypic and genetic correlations with one another. This suggests that genetic improvement is possible for these traits if breed associations develop genetic evaluations and genetic selection tools for them.

Conclusions

Fertility and longevity are two of the most economically important traits to commercial beef operations. Despite their low heritabilities, genetic selection for these phenotypes can drive substantial change in populations. Due to their expression only in females and often not until later in an animal's lifetime, EPDs are essential to helping accelerate genetic gain via bull selection. The most straightforward way to improve fertility and longevity from a breeding standpoint is to utilize structured crossbreeding, as these traits demonstrate large amounts of hybrid vigor. Numerous selection tools exist for producers to make breeding decisions focused on improving fertility and longevity.

Literature Cited

Boldt, Ryan J., Scott E. Speidel, Milton G. Thomas, and R. Mark Enns. 2018. “Genetic Parameters for Fertility and Production Traits in Red Angus Cattle.” *Journal of Animal Science* 96 (10): 4100–4111.

Boyer, Christopher N., Andrew P. Griffith, and Karen L. DeLong. 2020. “Reproductive Failure and Long-Term Profitability of Spring-and Fall-Calving Beef Cows.” *Journal of Agricultural and Resource Economics* 45 (1): 78–91.

Boyer, Christopher N., Andrew P. Griffith, and Ky G. Pohler. 2020. “Improving Beef Cattle Profitability by Changing Calving Season Length.” *Journal of Applied Farm Economics* 3 (1): 2.

Cammack, K. M., M. G. Thomas, and R. M. Enns. 2009. “Reproductive Traits and Their Heritabilities in Beef Cattle.” *The Professional Animal Scientist* 25 (5): 517–28.

Chen, Z. Jeffrey. 2013. “Genomic and Epigenetic Insights into the Molecular Bases of Heterosis.” *Nature Reviews. Genetics* 14 (7): 471–82.

Cundiff, L. V., K. E. Gregory, and R. M. Koch. 1974. “Effects of Heterosis on Reproduction in Herford, Angus and Shorthorn Cattle.” *Journal of Animal Science* 38 (4): 711–27.

Diskin, M. G., and D. A. Kenny. 2016. “Managing the Reproductive Performance of Beef Cows.” *Theriogenology* 86 (1): 379–87.

Doyle, S. P., B. L. Golden, R. D. Green, and J. S. Brinks. 2000. “Additive Genetic Parameter Estimates for Heifer Pregnancy and Subsequent Reproduction in Angus Females.” *Journal of Animal Science* 78 (8): 2091–98.

Fernandez-Novo, Aitor, Sonia S. Pérez-Garnelo, Arantxa Villagrá, Natividad Pérez-Villalobos, and Susana Astiz. 2020. “The Effect of Stress on Reproduction and Reproductive Technologies in Beef Cattle-A Review.” *Animals : An Open Access Journal from MDPI* 10 (11). https://doi.org/10.3390/ani10112096.

Gregory, K. E., and L. V. Cundiff. 1980. “Crossbreeding in Beef Cattle: Evaluation of Systems1.” *Journal of Animal Science* 51 (5): 1224–42.

Gregory, K. E., L. V. Cundiff, and R. M. Koch. 1991. “Breed Effects and Heterosis in Advanced Generations of Composite Populations for Preweaning Traits of Beef Cattle.” *Journal of Animal Science* 69 (3): 947–60.

———. 1992. “Breed Effects and Heterosis in Advanced Generations of Composite Populations for Reproduction and Maternal Traits of Beef Cattle.” *Journal of Animal Science* 70 (3): 656–72.

Griffith, Andrew P., Christopher N. Boyer, and Karen L. DeLong. 2019. “Reproductive Failure Impacts on Retained Beef Heifer Profitability.” https://doi.org/10.22004/ag.econ.302739.

Hess, B. W., S. L. Lake, E. J. Scholljegerdes, T. R. Weston, V. Nayigihugu, J. D. C. Molle, and G. E. Moss. 2005. “Nutritional Controls of Beef Cow reproduction1.” *Journal of Animal Science* 83 (suppl_13): E90–106.

Hough, R. L., and Kenda Ponder. 2001. “Proposed Whole Herd Reporting Guidelines.” In *Proc. 33rd Beef Improv. Fed. Meet., San Antonio, TX*, 120. Beef Improv. Fed., Manhattan, KS.

Jamrozik, J., S. McGrath, R. A. Kemp, and S. P. Miller. 2013. “Estimates of Genetic Parameters for Stayability to Consecutive Calvings of Canadian Simmentals by Random Regression Models.” *Journal of Animal Science* 91 (8): 3634–43.

Larracharte, Andrea, Ana C. Espasandin, and Jorge I. Urioste. 2021. “Longevity and Reproductive Traits in Angus Cattle: Genetic Parameters, Predicted and Realized Genetic

Change.” *Livestock Science* 250 (August):104604.

Rowan, Troy N. 2022. “Invited Review: Genetic Decision Tools for Increasing Cow Efficiency and Sustainability in Forage-Based Beef Systems⁎.” *Applied Animal Science* 38 (6): 660–70.

Rowan, Troy N., Harly J. Durbin, Christopher M. Seabury, Robert D. Schnabel, and Jared E. Decker. 2021. “Powerful Detection of Polygenic Selection and Evidence of Environmental Adaptation in US Beef Cattle.” *PLoS Genetics* 17 (7): e1009652.

Rowan, Troy N., Robert D. Schnabel, and Jared E. Decker. 2024. “Uncovering the Architecture of Selection in Two *Bos Taurus* Cattle Breeds.” *Evolutionary Applications* 17 (2). https://doi.org/10.1111/eva.13666.

Short, R. E., R. A. Bellows, R. B. Staigmiller, J. G. Berardinelli, and E. E. Custer. 1990. “Physiological Mechanisms Controlling Anestrus and Infertility in Postpartum Beef Cattle.” *Journal of Animal Science* 68 (3): 799–816.

Snelling, W. M., B. L. Golden, and R. M. Bourdon. 1995. “Within-Herd Genetic Analyses of Stayability of Beef Females.” *Journal of Animal Science* 73 (4): 993–1001.

Wathes, D. C., G. E. Pollott, K. F. Johnson, H. Richardson, and J. S. Cooke. 2014. “Heifer Fertility and Carry over Consequences for Life Time Production in Dairy and Beef Cattle.” *Animal: An International Journal of Animal Bioscience* 8 Suppl 1 (May):91–104.

Willett, Gayle Steven. 1992. *Analyzing the Economics of Raising Versus Buying Beef Replacement Heifers*. Cooperative Extension, Washington State University.