SDSU Extension

BEEF

Chapter 41

DNA Testing in Beef Production

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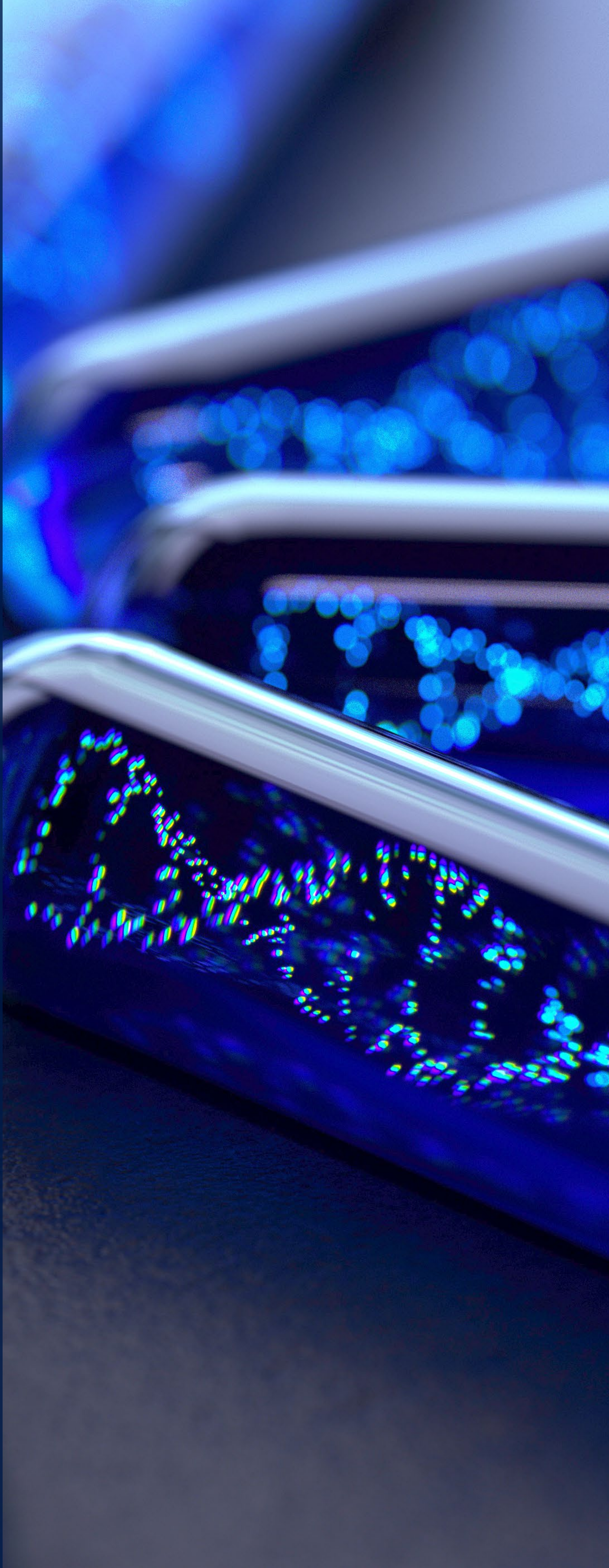

Chapter 41:
DNA Testing in Beef Production

Introduction
How can DNA testing increase profitability?

Genetic selection has clearly resulted in change in economically relevant beef production traits. As one example of many, the average expected progeny difference (EPD) for weaning weight in registered Angus cattle has increased 55 lbs from 1972 to 2012 through genetic selection for heavier weight (Figure 1). Genetic selection works by changing deoxyribonucleic acid (DNA) in a herd. This DNA is present in most cells in all animals and is the biochemical "blueprint" encoding the structure and function of all of the different parts of an animal. The structure and function of the heart, mammary gland, and all other organs is encoded within each animal's DNA. Without DNA, none of the cells, tissues, and organs required by an animal could be created.

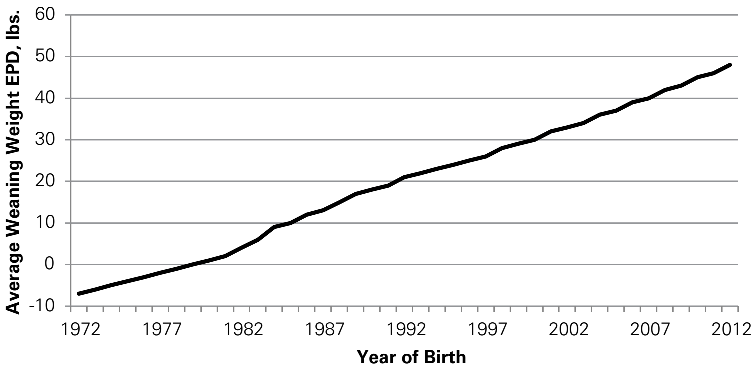

Figure 1: Genetic trend for weaning weight in registered Angus cattle, 1972 to 2012. *Data collected from the American Angus Association website, (http://www.angus.org/Nce/GeneticTrends.aspx), July 23rd 2013.*

Changes to the DNA can affect the structure and function of organ systems. For example, changing DNA that encodes for the structure or function of the mammary gland may affect how much milk the mammary gland can produce or milk quality. In a herd or breed, some animals may carry DNA that is favorable or unfavorable for economically relevant traits. Genetic selection attempts to identify animals with favorable DNA for economically relevant traits and to use these animals as parents. By this process, ideally only animals with high genetic merit will transmit their DNA to the next generation. The DNA encoding economically relevant traits can thus be changed in a population to increase profitability.

Beef cattle producers have historically relied on visual appearance, own performance data, and performance data on relatives and progeny to practice genetic selection. This information has been utilized to estimate EPDs for economically relevant traits. These EPDs have successfully been used to change breed characteristics and allele frequencies over time (Huang et al., 2012); the genetic change in weaning weight in Angus cattle was largely accomplished through the use of weaning weight EPDs (Figure 1). The EPDs will continue to play a large role in genetic selection. However, could we further increase profitability by testing DNA directly?

This chapter will discuss the applications, benefits, and limitations of DNA testing in the beef cattle industry. The economics of DNA testing will also be discussed. Any service that assists with selecting or managing animals by examining an animal's DNA directly is defined as DNA testing. This definition includes testing for genetic abnormalities and other simply-inherited traits (e.g., red/black coat color in Angus cattle), parentage testing, and marker-assisted selection.

DNA testing for genetic abnormalities and other simply-inherited traits

Genetic abnormalities can result in a calf that is not viable or thrifty. Many genetic abnormalities result in conception failure, abortion (VanRaden et al., 2011) or a dead calf before or shortly after birth. Further, calves with some genetic abnormalities can increase the risk of dystocia during parturition (e.g., Neuropathic Hydrocephalus). Genetic abnormalities are usually caused by mutations in a single gene in DNA. A gene is part of the DNA that encodes for a specific biological molecule important for the function of an animal's cells, tissues, and organ systems. Each animal has two copies of a gene in its DNA and each copy is called an allele. If both alleles of the gene harbor the mutation that causes the abnormality, then the animal will have the genetic abnormality (Figure 2). If only one allele harbors the mutation, then the animal will be a carrier of the genetic abnormality. Carriers can transmit the mutation to their offspring but do not have the genetic abnormality themselves. If neither allele harbors the mutation, then the animal is a non-carrier and cannot transmit the mutation to offspring.

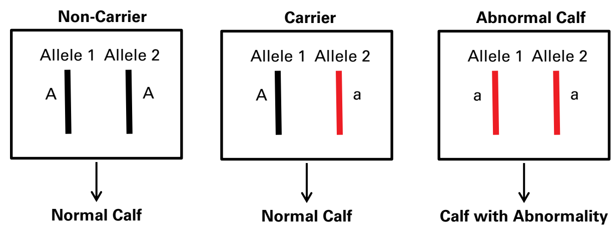

Figure 2: Cause of recessive genetic abnormalities in livestock.

For recessive genetic abnormalities, we cannot distinguish between carriers and non-carriers by visual appearance alone.

Producers can predict whether an animal is a carrier of a genetic abnormality quickly and accurately with DNA testing. With DNA testing, carrier status can be determined well before the animal reaches reproductive maturity. Assuming the laboratory carrying out the DNA test follows proper procedures, DNA testing can determine carrier status with 100% accuracy. A DNA test has been developed for most of the more prevalent genetic abnormalities in the beef industry (Table 1). As of July 2013, most of these DNA tests cost approximately $20 to $25 and discounts are usually offered when testing for more than one abnormality. Although several companies often offer DNA testing services for the same genetic abnormality, breed associations may accept DNA test results from only specific companies.

Once discovered in a herd, beef producers have two options for eliminating the appearance of these genetic abnormalities.

1. **Sell to slaughter carriers of the genetic abnormality or do not use as breeding stock.** Culling carriers is the easiest option. If the animal cannot contribute DNA to progeny, then

Table 1: Available DNA tests for genetic abnormalities. "Breed" refers to the breed(s) of cattle where the genetic abnormality predominantly has been observed.

Genetic Abnormality	Breed[1]	Description
Alpha-Mannosidosis	Red Angus	Lethal; calves often die before reaching sexual maturity. Failure to thrive, progressive incoordination, and aggressive disposition when disturbed.
Arthrogryposis Multiplex	Angus and Angus-Influenced	Lethal at or shortly after birth. Twisted spine and legs. Leg joints are fixed. Front legs contracted and rear legs either contracted or extended. Calf is small and thin. Cleft palate may be present.
Chondrodysplasia	Angus and Dexter[2]	Variable expression, but if the calf is not aborted will result in short stature ("dwarfism"). Various deformities of the head, limbs, and spine can also occur.
Contractural Arachnodactyly	Angus and Angus-Influenced	Abnormal crouched posture at birth, with reduced range of angular movement in upper limb joints but increased extensibility of lower limb joints. Most signs of the abnormality disappear at 4-6 months of age, but calves will be tall, slender, lack muscle mass, and often have poor foot conformation.
Hypotrichosis	Hereford	Partial to almost complete lack of hair at birth. Hair present is short and kinky and can be lost, leading to bald spots. Abnormality is less noticeable with advancing age.
Idiopathic Epilepsy	Hereford	Causes seizures, which may last several minutes to an hour.
Neuropathic Hydrocephalus	Angus and Angus-Influenced	Lethal. Calf will be born deceased with a light birth weight. Enlarged head caused by excess water present in cranium.
Osteopetrosis	Red Angus	Lethal; calf born dead or dies shortly after birth. Calf is usually born prematurely with short lower jaw, impacted molars, and fragile long bones.
Pulmonary Hypoplasia with Anasarca	Chianina, Dexter, Maine-Anjou, and Shorthorn	Lethal; calf is born dead with underdeveloped lungs and swelling caused by excessive fluid accumulation.
Tibial Hemimelia	Chianina, Maine-Anjou, and Shorthorn	Lethal; calves are born dead, die shortly after birth, or need to be euthanized because they cannot stand to nurse. Abnormality can result in twisted rear legs, fused joints, abdominal hernias, and skull deformities.

[1] In addition to the breed(s) listed, these genetic abnormalities may appear in all breeds with an open herdbook (e.g., Simmental). These abnormalities may also be found in crossbred herds which raise their own replacement females.
[2] The DNA tests for chondrodysplasia are different for Angus and Dexter breeds.

the mutation will not be passed on to future calves. Carriers can still be fattened and sold for slaughter because carriers do not express the genetic abnormality.

2. **Mate carriers only to known non-carriers.** If the carrier is mated only to known non-carriers, then his or her offspring can never express the genetic abnormality. However, the progeny of these matings may still be carriers for the genetic abnormality (Figure 3). All of the progeny that might be retained as replacements should be tested for the presence of the mutation. Alternatively, carriers can be crossed with a breed known not to segregate the genetic abnormality as long as the producer is certain that the breed used is 100% purebred.

a) Carrier **(Dd)** mated to non-carrier **(DD)**

	D	D
D	DD	DD
d	Dd	Dd

50% probability offspring will be non-carriers
50% probability offspring will be carriers
0% probability offspring will have abnormality

b) Carrier **(Dd)** mated to carrier **(Dd)**

	D	d
D	DD	Dd
d	Dd	**dd**

25% probability offspring will be non-carriers
50% probability offspring will be carriers
25% probability offspring will have abnormality

Figure 3: Probability that a carrier transmits the recessive mutation allele to his or her offspring when mated to a) non-carriers and b) other carriers. The normal allele is indicated with the letter D and the recessive mutation allele is indicated with the letter d. Each parent transmits only one allele to his or her offspring. An individual can only be born with the genetic abnormality when two carriers are mated together.

Many genetic abnormalities are simply-inherited because expression of the genetic abnormality depends only on the alleles present at one gene. Other types of simply-inherited traits with available DNA tests include black/red coat color, double muscling, and horns/polled. The vast majority of economically relevant traits to the beef industry are polygenic. Polygenic traits are affected by hundreds of genes and the environment. An example of a polygenic trait is weaning weight, which is not only affected by many genes but also many environmental factors including mothering ability and milk production of the calf's dam, pre-weaning nutrition, stress, and disease challenge. Marker-assisted selection (MAS) is genetic selection based at least in part on DNA test results. Marker-assisted selection can be applied to both simply-inherited and polygenic traits. However, MAS for polygenic traits is more complicated because of the many genes and environmental factors that are involved in expression of these traits. The next section of this chapter discusses MAS for polygenic traits.

Marker-Assisted Selection for polygenic traits

Benefits of marker-assisted selection

The goal of selection is to change the genetics of a population in a manner that improves profitability. The rate of genetic improvement over time (ΔEPD/t), as shown in the equation below, is affected by four factors: 1) accuracy of selection (r), 2) intensity of selection (i), 3) genetic variation (σ), and 4) generation interval (L).

Marker-assisted selection can increase selection accuracy and decrease generation interval, leading to faster genetic improvement. As an example, two full-sib bull calves at birth will have the same EPDs for most traits because most of their EPDs are estimated only from pedigree data. Accuracy of these EPDs will be low because we don't know if each bull calf received favorable or unfavorable DNA from his parents. Testing each calf's DNA will help determine if favorable or unfavorable DNA for economically relevant traits was transmitted from the parents. This information will improve the accuracy of the EPD, thus allowing more accurate selection decisions and faster genetic improvement.

Improvement in selection accuracy depends on how much of the genetic variation is explained by the DNA test (see "limitations of DNA testing"). For example, a DNA test that explains only 9% of genetic variation will result in selection accuracy of 0.05, while a DNA test that explains 49% of genetic variation will result in selection accuracy of 0.29. Rephrased in terms of progeny equivalents, a DNA test explaining 9% of genetic variation for a moderately heritable trait (h2 = 0.30) is equivalent to testing performance of five progeny of each bull. In comparison, a DNA test explaining 49% of genetic variation for this same trait is equivalent to testing performance of 12 progeny of each bull. The DNA test explaining 49% of genetic variation therefore provides more information about genetic merit for each bull than the DNA test explaining only 9% of genetic variation.

Further, producers may decide that a yearling bull is genetically superior based in part on his DNA test and begin using the bull to produce more progeny at an earlier age. Using a bull to produce more progeny at a younger age will decrease the generation interval and increase the rate of genetic improvement. The reason why shorter generation intervals increases the rate of genetic gain can be demonstrated by comparing cattle production to production of chickens or turkeys. Poultry reach sexual maturity at an earlier age than cattle. As a result, poultry breeders can turn over their flocks much faster than cattle breeders and are able to achieve faster genetic progress. On a smaller scale, producers will make faster genetic improvement if they can more confidently use bulls to produce progeny at an earlier age. In fact, many AI studs in the dairy industry begin marketing DNA tested semen from young bulls that have not been progeny tested. In the beef industry, impact of DNA testing on generation interval will be less because progeny testing is not used as frequently (e.g., herd bull selection).

When marker-assisted selection will be most effective

Producers will gain more value from DNA testing young bulls instead of heifers or cows. From a selection standpoint, the value of an animal is not in the performance of the animal itself but in the performance of the animal's progeny. Bulls can produce many more progeny than heifers over their lifetimes. Opportunities for MAS in heifers should not be ignored, but producers will receive more value from MAS on bulls, all else being equal.

Although DNA testing can increase the accuracy of selection for all traits, testing will be most beneficial for the following traits:

1. Traits without routinely recorded performance data (e.g., fertility, disease susceptibility, feed efficiency)
2. Performance traits that are recorded late in an animal's life (e.g., stayability)

Not coincidentally, EPDs for these traits are either not available or are less accurate than EPDs for other traits. Unfortunately, accurate DNA tests are also not easily developed for these traits because this data is not routinely recorded by many breed associations. Because of the impact DNA testing could have on genetic improvement for these traits, a significant amount of research is being devoted to developing these DNA tests.

Finally, almost no value is obtained from using a DNA test on a proven bull. Proven bulls already have accurate EPDs. The addition of DNA test information will result in essentially no improvement in the accuracy of their EPDs. The only reason why DNA testing may be beneficial for a proven bull is if the DNA test estimates genetic merit for a trait that is not routinely recorded by the bull's breed association.

Limitations of DNA testing

The first major limitation is that available DNA tests are not able to account for all of the available genetic variation affecting traits. A DNA test should be treated as another piece of information that can be used to estimate EPDs, similar to progeny, own performance, and pedigree records. Many available DNA tests will increase accuracy of selection, but none can increase accuracy of selection to 1.0. An accuracy of 1.0 would mean that the DNA test perfectly predicts the true genetic merit of the animal. Unfortunately, DNA tests cannot achieve this level of accuracy; most available DNA tests alone (without inclusion of pedigree, own performance, or progeny information) will result in EPD accuracies of ≤ 0.25, depending on the percent genetic variation explained by the test. When DNA test results are added to existing information on an animal (such as own performance or progeny records), improvements in EPD accuracies will be lower.

All DNA tests on the market also do not explain the same amount of genetic variation; in other words, some DNA tests are better than others. Beef cattle DNA tests can be categorized into either "breed-specific" or "non-breed specific" DNA tests. Generally, the breed-specific DNA tests explain a larger fraction of the genetic variation. The "breed-specific" DNA tests explain about 10-50% of genetic variation, depending on the trait evaluated and the breed. Obviously, "breed-specific" tests are only valid for a single breed. The "non-breed specific" DNA tests can be utilized for most breeds and crossbred animals, but explain a smaller fraction of the genetic variation.

The second major limitation is with the inconsistency in how DNA test results are reported. Presently, DNA test results can be reported as genomic-enhanced EPDs, molecular breeding values (or "MVPs"), 1-5 or 1-10 numerical scores, and percentile rankings. Interpreting these results and then using them appropriately can be a major challenge for producers. Fortunately, breed associations with breed-specific DNA tests have opted to use genomically-enhanced EPDs. Genomically-enhanced EPDs incorporate the DNA test results into the association's EPD calculation, weighting the DNA test results according to the percent genetic variation explained by the test and available performance records on the animal and its relatives. Therefore, if the DNA test explains a small fraction of the genetic variation for a trait or much information on the trait is already available through performance testing, then the DNA test will not contribute significantly to the EPD calculation. Thus, genomically-enhanced EPDs account for the accuracy of the DNA test and information already available for calculating the EPD. Genomically-enhanced EPDs are interpreted the same as other EPDs. Because DNA test results are incorporated into genomically-enhanced EPDs, producers don't need to decide whether to trust DNA test results or EPDs when selecting animals.

Molecular breeding values look like EPDs, but in reality these numbers are estimated breeding values (EBVs) based on DNA test results alone. An EBV is an estimate of the genetic value of the individual as a parent. In contrast, an expected progeny difference (EPD) is the expected performance of the individual's progeny. The definitions are similar, except that the EBV refers to the value of the individual while the EPD refers to the value of the individual's progeny. The relationship between an EBV and an EPD is exactly as shown below.

To convert EBVs to EPDs, multiply the EBV by one-half. After converting an EBV to an EPD, these EPDs can be interpreted the same as all other EPDs. One caveat is that the accuracy of molecular EBVs is often low.

Some DNA test results are reported as 1-5 or 1-10 numerical scores. In this scenario, an animal is assigned a specific number for a trait based on the animal's DNA test results. Larger numbers are usually (but not always) indicative of superior performance for a trait. For example, a score of "10" is more desirable for stayability than a score of "1". An extra step needs to be taken to interpret these numerical scores quantitatively. Companies that provide numerical scores to producers usually provide a "results key". The results key can be used to provide a quantitative meaning to these numerical scores.

For example, suppose that you want to compare two bull calves using DNA test results from Igenity's PROFILETM. Bull calf "George" received a score of "7" for average daily gain (ADG) while bull calf "John" received a score of "5". According to the Igenity results key, a score of 7 equals 0.54 lbs gain per day while a score of 5 equals 0.34 lbs gain per day. Therefore, George's estimated breeding value is 0.54 lbs and John's estimated breeding value is 0.34 lbs. As shown previously, we convert these EBVs to EPDs by multiplying the EBV by one-half. George's EPD for ADG is 0.27 lbs and John's EPD is 0.17 lbs. George's progeny would be expected to gain 0.10 lbs more per day than John's progeny based only on the results of this DNA test.

The third major limitation is the difficulty in interpreting some DNA tests. Genomically enhanced EPDs weight DNA test results relative to other information about genetic merit appropriately. When using genomically enhanced EPDs, producers do not need to interpret DNA test results directly. However, as described above, other methods for reporting DNA test results exist. How should a producer interpret the genetic value of an animal when DNA test results and EPDs conflict with each other? As an example, a recent Gelbvieh sale advertised a bull with a +0.02 marbling EPD and a -0.29 GeneSTARTM marbling MVP (or molecular breeding value). This bull's marbling EPD placed him in the top 15% of non-parent Gelbvieh animals, but his molecular breeding value placed him in the bottom 5% of all animals tested for marbling GeneSTARTM markers. When the DNA test results and EPD are in disagreement, producers should trust the most reliable (or accurate) data. In this example, both the EPD and GeneSTARTM test had low accuracies. The GeneSTARTM marbling test explains only about 9.2% of the genetic variation for marbling and the EPD was estimated on a yearling bull with no ultrasound data. Unfortunately, the EPD and GeneSTARTM DNA test tell us very little about the genetic merit of this bull for marbling.

Availability of DNA testing

Three standalone DNA tests are available as of September 2013 (Table 2), which cannot be incorporated into genomically-enhanced EPDs. Two of these DNA tests are marketed for cattle of all breeds (including crossbred cattle), and one DNA test is marketed for cattle that are ≥ 75% American Angus. As discussed above, all three DNA tests report results differently, making them more difficult for producers to interpret. As of the summer of 2013, these tests cost approximately $20-$40 per animal.

Table 2: Available standalone DNA tests (current as of 8/2/2013) by breed of beef cattle in the USA. This list does not include DNA tests incorporated into genomic-enhanced EPDs.

DNA Test	Breed	Traits	Reporting Method
GeneSTAR MVP (Zoetis)	All breeds and crossbreds	Feed efficiency Marbling Tenderness	Molecular EBV
Igenity PROFILE (Neogen)	All breeds and crossbreds	Residual feed intake Average daily gain Tenderness Marbling Yield grade Backfat Ribeye area Heifer pregnancy rate Stayability Maternal calving ease Docility	1-10 scores
Genemax	≥ 75% Angus	Average daily gain Marbling	Percentile rankings

Many beef cattle breed associations have begun to use genomically-enhanced EPDs, including American Angus, Red Angus, Hereford, Limousin, and Simmental breeds. The Gelbvieh and Maine Anjou breed associations will soon be publishing genomically-enhanced EPDs while Charolais and Brangus associations are beginning the process needed to incorporate DNA testing into their genetic evaluations.

Genomically-enhanced EPDs will be calculated for most of the traits evaluated by each of these breed associations. The cost of utilizing genomically-enhanced EPDs ranges from approximately $65 to $85 per animal.

Parentage Testing

Parentage testing can be useful with multi-sire breeding pastures. Parentage testing can increase profitability for producers in three ways:

1. Producers can identify how many calves were sired by each bull. In this way, producers may be able to identify bulls that are not producing calves because of fertility problems or other reasons. Bulls do not sire an equal number of calves in multi-sire breeding pasture, even after accounting for the fact that older bulls will be expected to sire more calves than younger bulls on average.

2. Producers can identify bulls that are carriers of genetic abnormalities. If a suspected genetic abnormality is segregating in a herd and a DNA test for the abnormality does not yet exist, parentage testing can be used to identify the bull(s) that may carry the abnormality.

3. Producers can progeny test their herd bulls. Performance traits for calves sired by each bull can be averaged to determine which bulls are producing the best calves. This information can be used to calculate within-herd EPDs for performance traits and cull bulls that tend to produce less desirable calves.

As of August 2013, parentage testing costs approximately $15 to $25 per animal. Producers need to submit both DNA samples from all bulls and calves. One limitation of parentage testing is that the parent cannot always be narrowed down to a single sire. The accuracy of parentage identification depends on the number of possible sires and relationships among sires.

Economics of DNA Testing in Beef Production

The economic benefit of DNA testing will vary among producers, depending on the genetics of animals in the herd, management practices, and the market where animals are sold. The economic value of DNA testing in beef production is largely affected by six factors: 1) economic relevance of traits with available DNA tests, 2) available information in addition to the DNA test, 3) percent genetic variation explained by the DNA test, 4) selection intensity, 5) degree to which germplasm can be multiplied (e.g., bulls can produce more calves than cows), and 6) cost of DNA testing. All six factors need to be considered before concluding whether DNA testing will be beneficial for your operation.

Economic relevance of trait – This factor may be the single most important variable affecting profitability of a DNA test and is also highly relevant for all selection tools, including EPDs. If a DNA test is used for a trait that is not economically relevant for your operation, then DNA testing for this trait will not be profitable. Selection goals should align with traits that affect profitability. These traits will depend on the characteristics of the herd and herd management practices, segment of the beef industry (e.g., seedstock, cow-calf), and how animals are marketed (e.g., sold at weaning, retained ownership).

Available information – A DNA test is most beneficial for performance traits that are not routinely recorded (e.g., disease susceptibility) or traits recorded late in life (e.g., stayability) and have high economic value. Unfortunately, DNA tests for these types of traits are less commonly available. For example, reproductive performance is perhaps the most economically relevant trait to cow-calf producers, but a DNA test for reproductive performance is not currently available. As the number of performance records for a trait increases, the value of DNA testing decreases. Thus, DNA testing is not valuable for a proven bull with 30-50 progeny records.

Percent genetic variation explained – A DNA test that explains a greater percentage of genetic variation in a trait will be more accurate and thus be a better predictor of genetic merit. Even when a trait is highly relevant to your operation, a DNA test will not be beneficial if the test explains only a small percentage of the genetic variation. Not all DNA tests are equal and producers should be provided with an estimate of the percent genetic variation explained by any DNA testing service.

Selection intensity – It is easier to select more intensely on bulls than on heifers because fewer bulls are needed to produce calves than heifers. As a consequence, bulls can produce many more offspring over the course of their lifetimes than cows. Thus, using a DNA test for bull selection will be more economically beneficial than for replacement female selection. Although DNA testing is most valuable for bulls, females may also benefit from DNA testing when the cost of the test is not prohibitive.

Cost of DNA testing – Obviously cost of the DNA test plays a role. As of September 2013, most DNA tests cost about $18 to $85 per animal, depending on number of traits tested and accuracy of the tests. Further, cost of DNA testing is expected to decrease with time.

Summary

Even if you do not use DNA testing, you should understand how to interpret a DNA test, their uses in the beef industry, and their limitations. A DNA test can be useful for identifying carriers of genetic abnormalities, parentage testing, and increasing the accuracy of selection decisions. However, DNA testing will only supplement and not replace EPDs. Producers still need to understand which traits (and their corresponding DNA tests) to focus on when implementing a selection program. Additionally, producers need to continue collecting accurate performance records because these performance records are used to update DNA tests. Over time, the accuracy of DNA tests decrease unless DNA tests are continually updated (or “re-trained”) with recent performance records. Therefore, DNA testing vitally depends on the database of performance records collected by beef producers.

When possible, producers should rely on their breed associations to incorporate DNA test results into EPD calculations (“genomically-enhanced EPDs”) and use these genomic-enhanced EPDs for selecting animals. Genomically-enhanced EPDs simplify selection decisions for producers by integrating DNA test results with performance records. Thus, a single number can be used to evaluate genetic merit for a trait.

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