THESIS

CAN DNA MARKER TECHNOLOGY IMPROVE FEEDLOT GROWTH PROMOTION MANAGEMENT DECISIONS TO ULTIMATELY IMPROVE THE CONSUMER'S BEEF EATING EXPERIENCE?

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ABSTRACT

CAN DNA MARKER TECHNOLOGY IMPROVE FEEDLOT GROWTH PROMOTION MANAGEMENT DECISIONS TO ULTIMATELY IMPROVE THE CONSUMER'S BEEF EATING EXPERIENCE?

Three hundred and sixty crossbred yearling steers that were sorted from an initial group of 1,100 steers were used to evaluate the effectiveness of sorting feedlot cattle into tenderness and marbling outcome groups based on DNA marker technology and to determine if interactions related to end-product quality and palatability existed between predicted outcome group and growth promotion management strategy. Treatment factors included in the study were tenderness genotype (low versus high), marbling genotype (low versus high), and growth promotion strategy {moderate (Revalor-IS d 1 and d 70) versus aggressive (Revalor-XS d 1 and Zilpaterol supplementation)}. Interactions between tenderness and marbling genotypes and between tenderness genotype and growth promotion treatment were not significant ($P > 0.10$) for all feedlot performance variables. Steers sorted into the high tenderness (**HT**) genotype were 5.9 kg heavier at the start of the study ($P < 0.05$), 11.8 kg heavier at harvest ($P < 0.01$), and achieved greater DMI ($P < 0.05$) from d 1 – harvest (9.80 versus 9.38 $kg \bullet hd^{-1} \bullet d^{-1}$) as compared with the low tenderness (**LT**) steers. Warner-

Bratzler shear force (**WBSF**) was 0.33 kg lower (more tender) for the HT longissimus steaks as compared with the LT steaks. Steers sorted into the high marbling (**HM**) genotype were 9.1 kg heavier at the start of the study ($P < 0.001$), 20.9 kg heavier at harvest ($P < 0.0001$), and ADG ($P < 0.01$, 1.56 versus 1.47 $kg•hd^{-1}•d^{-1}$) and DMI were greater ($P < 0.05$, 9.80 versus 9.39 $kg•hd^{-1}•d^{-1}$) as compared with the low marbling (**LM**) genotype from d 1 – harvest. High marbling genotype carcasses were 12.7 lb heavier ($P < 0.05$); had greater fat depth ($P < 0.06$); adjusted fat depth ($P < 0.08$); higher measured ($P < 0.06$), adjusted ($P < 0.08$), and camera adjusted ($P < 0.10$) PYG; and greater average yield grade ($P < 0.09$), marbling score ($P < 0.05$), and camera marbling score ($P < 0.05$) as compared with the LM genotype. There were no differences ($P > 0.60$) in WBSF associated with predicted marbling genotype. From d 107 – harvest, steers subjected to the aggressive growth promotion program (**AGP**) had greater ADG ($P < 0.01$) and superior ($P < 0.001$) FG, GF, and NE recovery as compared with steers subjected to the moderate program (**MGP**). Steers subjected to AGP were 8.2 kg heavier ($P < 0.06$) at harvest and had 12.2 kg heavier ($P < 0.05$) HCW and greater ($P < 0.01$) dressing percentages than steers subjected to MGP. From d 1 – harvest, ADG ($P < 0.05$), FG ($P < 0.01$), GF ($P < 0.01$, and recovered NEm and NEg ($P < 0.05$) were improved for AGP as compared with MGP steers. Camera adjusted PYG ($P < 0.07$), calculated yield grade ($P < 0.05$), and camera yield grade ($P < 0.05$) were lower and grader LM area ($P < 0.01$) and camera LM area ($P < 01$) were greater for AGP as compared with MGP carcasses. Marbling score and the distribution of USDA quality grades

were not affected by growth promotion strategy. Aggressive strategy steaks had increased ($P < 0.01$) WBSF as compared with MGP steaks. Interactions between marbling genotype and growth promotion strategy suggest that steers categorized as HM genotypes did not respond to Zilpaterol to the same degree as LM genotypes. Three-way interactions for USDA yield grade distribution indicated that for HT – LM and the LT – HM steers, AGP had limited impact on the percentage USDA yield grade 3 carcasses but reduced the percentage USDA yield grade 4 carcasses as compared with MGP. Yearling steers can successfully be sorted into marbling or tenderness outcome groups based on DNA marker technology. Tenderness can be improved by using MGP as compared with AGP; however, growth promotion strategy did not impact marbling or USDA quality grade distribution and few interactions related to end-product quality and no interactions for WBSF existed between predicted outcome group and growth promotion management strategy indicating that the degree that end product quality is impacted by growth promotion strategy is largely independent of marbling and tenderness genotype.

Key words: genotype, marbling, tenderness, implants, beta-agonists.

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INTRODUCTION

Beef Industry Advancements

The beef cattle industry in the United States has observed many advances since the middle of the 20th century. Improvements have been witnessed in multiple areas of beef production including but not limited to: nutrition, management, technology, and genetics. Feedlots became predominate way to finish out cattle and 95% of feedlots are implementing technologies that achieve better gains and improve efficiency (Lawrence and Ibarburu, 2007). Producers are capable of producing greater pounds of beef with fewer animals and strides are being made to make each animal even more productive. Efficiencies of gains and accessibility to feedstuffs drove the move to feeding cattle in feedlots and with that move producers have kept improving efficiencies by adapting to new technologies and management practices. "Consumer demand for lean yet tender, tasty beef was a force for change" (Koch and Algeo, 1983) and this consumer driven force has changed the way animals are bred and raised. Even though this statement was made nearly three decades ago it still applies to today's consumer demands. Further change is inevitable in an industry where

efficiency and consumers preferences are driving forces. These changing forces lead to the need for further research with emerging technologies and new frontiers to be conquered. With the emergence of DNA marker technology and the growing use of growth promotion technologies it is imperative that an understanding of these technologies and advancements gains a scientific understanding.

Since the 1980's many strides have been made in achieving a more consumer enjoyable and desirable product. Furthermore, producers are intent on making forward strides to become more efficient at raising beef. The industry has seen the growth of Expected Progeny Differences (EPD) to DNA marker assisted technology, the growth and refinement of growth promotion implants and the use of beta agonists to create an even more efficient grain fed beef. Cattle have become more efficient in terms of cattle gaining more pounds of body weight per day, converting feed to body weight gain more effectively, making growth management decisions that get cattle from start to slaughter sooner and making genetic decisions at the cow/calf level to have more productive beef animals at the feedlot level among other efficiencies.

National Cattlemen's Beef Association and Beef Checkoff Program

The establishment of National Cattleman's Beef Association (NCBA) gave the nation's cattle producers a voice in government and the ability to share the knowledge of new technologies, revolutionary management practices, evolving genetic facts and tools and improvements in nutrition. National Cattlemen's Beef

Association has its beginnings in the late 19th century (National Cattlemen's Beef Association, 2011). The association has seen many mergers and changes over the decades but, throughout all of the changes the voice for the American beef industry has been maintained (National Cattlemen's Beef Association, 2011). With the assistance of the Beef Checkoff Program many programs are implemented to promote beef, educate consumers and producers and fund research committed to bettering the beef industry. Through the implementation of the Beef Checkoff Program in the 1985 Farm Bill $1 per head every time a beef animal is sold or imported $0.50 goes to state beef councils and $0.50 to the National Cattlemen's Beef Board (Beef Checkoff Program). The infusion of this funding in the beef industry is aimed at motivating consumers to purchase more beef and making the market a stronger one for producers (Beef Checkoff Program).

Consumer Demand and Demands

The demands of the consumer are a very integral part of the beef industry. It is a driver for change and one of the things that drives new research and production adaptions in the industry. This topic will be discussed further to better understand how the consumer can influence changes in the beef industry and management practices that produces implement in their operations to better meet demands. Consumer demand is the amount of beef that is consumed and

the price at which it was purchased. Consumer demand is not the same as per capita consumption, beef's relative share in the meat marketplace, or the portion of income that the consumer spends on beef (Schroeder and Mark, 2000). Schroeder and Mark (2000) also state that the amount produced is the amount of beef that is consumed and that the fluctuation to a lower price is a surplus of beef and a raise in price is due to decline in beef available. Some may scoff at the idea of catering to the consumer but, without the consumer the producer has no market for their product. Likewise for the consumer, without the producer, the consumer has no product such as beef to enjoy. This being the case, there has to be a balance between what is marketed and what is in demand.

Beef industry producers have to consider several components that influence consumers purchasing decision. These components include: relative prices for competing meats, consumer income, health and nutrition concerns, food safety, and product attributes relative to changing consumer preferences (Schroeder and Mark, 2000). This is why a progressive attitude that looks for new ways to hold consumers attention at the grocery store is important for the beef industry to attain. Between the years of 1996 and 2008 there were 2,500 new beef products that entered the market aiming to satisfy the wants of the consumer (Beef Checkoff Program). When producers are making management decisions for their operation they have to consider how meat quality will be impacted and how the consumer might respond. The industry as a whole has made strides to make beef more appealing to consumers and a producer does not want to make decisions that will negatively impact those strides made

forward. This means that research that can be conducted to make better decisions on how to positively impact meat quality using new technologies is a must for the beef industry.

GENETIC ANALYSIS ROLE IN THE CATTLE FEEDING INDUSTRY

The mapping of the bovine genome in 2009 opened doors in making DNA marker assisted technology more efficient and beneficial to beef producers. The ability of the cattle industry to utilize DNA analysis has created many opportunities for genetic improvement at the cow/calf level of production. Even with the great strides that have been made with DNA marker technology, some enhancements are needed for it to be a convenient and efficient tool to be used in feedlots for sorting cattle into outcome groups. Currently turnaround of commercial samples is only a matter of 1 to 2 weeks, in an industry where it is essential to get cattle placed and on feed, a matter of weeks does not fit into the system. With the possibility of a chute side analysis in the future DNA analysis would then be very efficient for the feedlot industry to sort cattle and more appropriate management decisions.

Analysis of DNA is available for a multitude of traits from which producers are able to select individually. Many times producers are simply interested in a paternity test but, they can also take advantage of analysis for genetic disorders and the propensity for certain carcass traits. While paternity and genetic disorders are of great importance to the cow/calf industry both the cow/calf and feedlot segments are interested in carcass traits that can be analyzed, more specifically marbling and tenderness markers. These economically important

traits are not as simple to measure and analyze but, with markers identified it is possible for DNA tests to determine molecular breeding values (Duff, 2009). Molecular breeding values are an individual animal's genetic potential for a specific trait being analyzed and are reported in units of the specific trait (Spangler, 2099). The higher a molecular breeding value is the more potential an animal has for that trait. Molecular breeding values than can be translated to fit a specific scale such as the 1-10 scale that Igenity uses. As an example using the Igenity scale an animal that scores a 2 for marbling is likely to have less marbling than an animal that scores an 8. A main advantage in using DNA marker technology is it allows for early prediction of the potential of an animal and therefore shorten the generation interval and make genetic improvement more rapid (Spangler, 2009).

Functional Genomics

Igenity, a commercial genomics firm owned by Merial, defines functional genomics on their web-site (Merial, 2009). Briefly: when concerned with DNA analysis one is dealing with functional genomics and the genotype of the animal. Genetic variation from animal to animal creates changes in the structure or function of the proteins produced by the gene. Analyzing the genes from animals can identify the variations in the genes and therefore the correlating performance variations. Functional genomics takes the information from DNA analysis and utilizes the compiled genome maps to determine the functions and interactions of

the genes. The performance of genes depends on the 30 pairs of chromosomes found in every cell in cattle. Each of the 30 pairs gains one chromosome from the sire and one chromosome from the dam. These chromosomes each contain several thousand genes. The type of genes contained is dependent on the type of cell. How the genes are structured derives how they will perform in the animal. Genes have the ability to impact how and animal will perform in the feedlot. Understanding the connection between genes and production methods is vital to furthering improvements in production and efficiency for the beef cattle industry.

Sampling for DNA Analysis

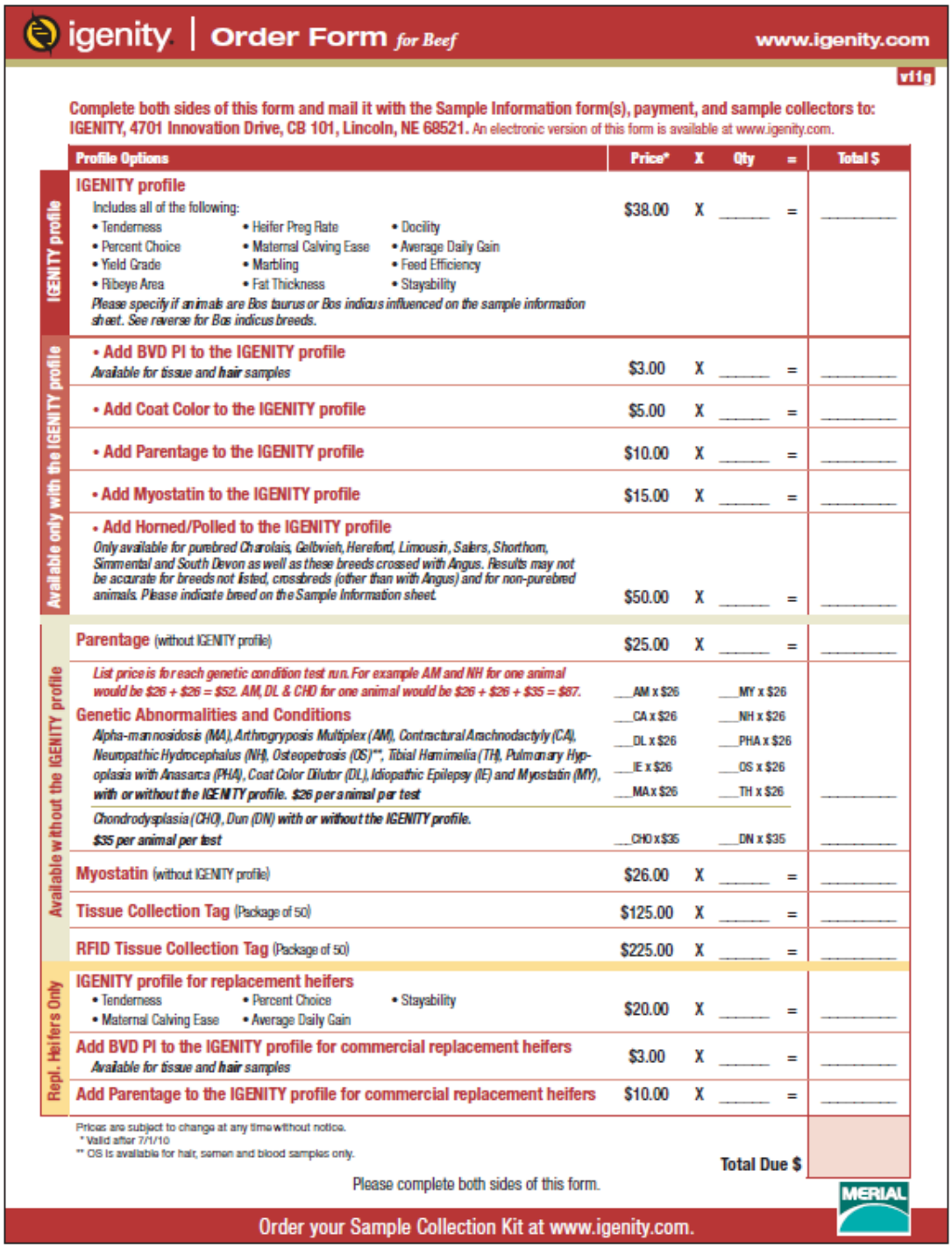
Samples for DNA analysis can be derived in several different ways. Depending on resources available and the setup of the sampling location the best method can be chosen. Ways to sample for DNA include but, are not limited to blood and hair samples. In any sampling method used it is most important to keep samples separate and individually labeled. The last thing a producer wants to encounter is mislabeled samples which could lead to management decisions on the wrong animal. Cross contamination can cause the loss of the integrity of a sample and therefore leave the producer without proper results for an individual in the herd. Blood samples can be obtained via the jugular vein or under the tail in the coccygeal vein (Sears et al., 1978). The blood sample is collected in a vial containing EDTA (ethylenediaminetetraacetic acid). EDTA serves as an anticoagulant (Lam et al., 2004). EDTA is the choice

anticoagulant for delayed DNA processing however; heparin or citrate can be used (Lam et al., 2004). It is important to make sure the sampling area is clean to prevent any contamination. Hair samples can be obtained from the switch of the tail and must be pulled out and not cut because the hair root is what is needed for the DNA analysis process. The sample is then attached securely to a hair card and labeled with the individual's identification. Both methods are feasible collection methods for DNA samples. Proper and successful sampling is an essential component to accurate and reliable results that can then be implemented in a beef producers operation.

Cost Analysis of DNA marker technology

The cost of DNA marker technology is really a multi-level situation. This is so because it is the end product quality that is the most important issue and the factors that determine quality also determine how genes will act in different environments. For both marbling and tenderness traits the beef industry is taking strides to accomplish a better product. Management and nutrition decisions on the live side help to produce a higher marbling beef animal and techniques on the postmortem side work to make steaks as tender as possible (Akhimienmhonan and Vercammen, 2007). Figure 1 is a sample of a DNA analysis order form for beef cattle from Igenity. As can be seen the cost of the analysis can be expensive and depending on the herd size and the number of traits that a producer desires to have evaluated may not be a feasible option.

The goal for producers using DNA marker technology will be to fit it economically in to their management plan while making prudent decisions of traits to test. The costs on the order form include those for the lab processing and analysis of the DNA samples and the sample collection vessels but, it does not include the cost for time and labor used at the collection site for collection or shipping costs. Shipping and labor costs can vary greatly depending on number of animals being sampled and desired shipping length.



igenity | Order Form *for Beef* www.igenity.com

v11g

Complete both sides of this form and mail it with the Sample Information form(s), payment, and sample collectors to: IGENITY, 4701 Innovation Drive, CB 101, Lincoln, NE 68521. An electronic version of this form is available at www.igenity.com.

	Profile Options	Price*	X	Qty	=	Total $
IGENITY profile	**IGENITY profile** Includes all of the following: • Tenderness • Heifer Preg Rate • Docility • Percent Choice • Maternal Calving Ease • Average Daily Gain • Yield Grade • Marbling • Feed Efficiency • Ribeye Area • Fat Thickness • Stayability *Please specify if animals are Bos taurus or Bos indicus influenced on the sample information sheet. See reverse for Bos indicus breeds.*	$38.00	X	_____	=	_____
Available only with the IGENITY profile	• Add BVD PI to the IGENITY profile *Available for tissue and hair samples*	$3.00	X	_____	=	_____
	• Add Coat Color to the IGENITY profile	$5.00	X	_____	=	_____
	• Add Parentage to the IGENITY profile	$10.00	X	_____	=	_____
	• Add Myostatin to the IGENITY profile	$15.00	X	_____	=	_____
	• Add Horned/Polled to the IGENITY profile *Only available for purebred Charolais, Gelbvieh, Hereford, Limousin, Salers, Shorthorn, Simmental and South Devon as well as these breeds crossed with Angus. Results may not be accurate for breeds not listed, crossbreds (other than with Angus) and for non-purebred animals. Please indicate breed on the Sample Information sheet.*	$50.00	X	_____	=	_____
Available without the IGENITY profile	**Parentage** (without IGENITY profile)	$25.00	X	_____	=	_____
	List price is for each genetic condition test run. For example AM and NH for one animal would be $26 + $26 = $52. AM, DL & CHD for one animal would be $26 + $26 + $35 = $87. **Genetic Abnormalities and Conditions** *Alpha-mannosidosis (MA), Arthrogryposis Multiplex (AM), Contractural Arachnodactyly (CA), Neuropathic Hydrocephalus (NH), Osteopetrosis (OS)**, Tibial Hemimelia (TH), Pulmonary Hypoplasia with Anasarca (PHA), Coat Color Dilutor (DL), Idiopathic Epilepsy (IE) and Myostatin (MY), with or without the IGENITY profile. $26 per animal per test* *Chondrodysplasia (CHD), Dun (DN) with or without the IGENITY profile. $35 per animal per test*	___AM x $26 ___CA x $26 ___DL x $26 ___IE x $26 ___MA x $26 ___CHD x $35		___MY x $26 ___NH x $26 ___PHA x $26 ___OS x $26 ___TH x $26 ___DN x $35		_____
	Myostatin (without IGENITY profile)	$26.00	X	_____	=	_____
	Tissue Collection Tag (Package of 50)	$125.00	X	_____	=	_____
	RFID Tissue Collection Tag (Package of 50)	$225.00	X	_____	=	_____
Repl. Heifers Only	**IGENITY profile for replacement heifers** • Tenderness • Percent Choice • Stayability • Maternal Calving Ease • Average Daily Gain	$20.00	X	_____	=	_____
	Add BVD PI to the IGENITY profile for commercial replacement heifers *Available for tissue and hair samples*	$3.00	X	_____	=	_____
	Add Parentage to the IGENITY profile for commercial replacement heifers	$10.00	X	_____	=	_____

Prices are subject to change at any time without notice.
* Valid after 7/1/10
** OS is available for hair, semen and blood samples only.

Total Due $

Please complete both sides of this form.

MERIAL

Order your Sample Collection Kit at www.igenity.com.

Figure 2. IGENITY DNA analysis order form. (Merial , 2009)

To put the cost in to perspective the following example will demonstrate the cost of DNA analysis for a cow/calf producer wanting to have DNA analyzed for both tenderness and marbling for 50 calves using the Igenity profile option with a radio frequency identification (RFID) tissue collector. Figure 2 is a depiction of the RFID tissue sample collectors (Merial, 2009).

Figure 2. IGENITY RFID tissue collectors.

(Merial, 2009)

The Igenity profile option includes analysis for: tenderness, marbling, percent choice, yield grade, ribeye area, fat thickness, feed efficiency, average daily gain, heifer pregnancy rate, maternal calving ease, docility, and stayability. The cost will also include that of the RFID applicator, chute fee and shipping of samples.

Igenity profile analysis= $38/head x 50 head= $1,900

RFID tissue collectors= $4.50/head x 50 head= $225

RFID applicator= $30

Chute fee= $2/head x 50 head= $100

Shipping= $17

Total DNA analysis cost= $2,272/50

DNA analysis cost per head= $44

This cost is not something that a producer can take lightly. In order to justify the cost of using this technology a producer needs to have specific management and/or production goals in mind and be able to implement those goals when results are received. A cow/calf producer can more readily utilize DNA marker technology than a feedlot producer is able to. Cow/calf producers can make breeding decisions based on the knowledge gained from DNA analysis results to improve their herd's genetic potential and therefore how future offspring will perform. This will hopefully bring the producer added benefits in productivity of animals. A feedlot producer is not able to improve their base herd genetics with DNA marker technology however; they are able to sort cattle into perspective groups such as ranked marbling and tenderness groups to predict for potential carcass outcomes. The DNA marker technology can help producers make genetic selections that will lead toward more efficient and desirable animals but, it has to be properly worked into the unique management and economical situations.

Expected Progeny Differences

Expected Progeny Differences (EPD) are a genetic based tool that producers can use to make selection choices (Rumph, 2009). The determination of EPD does not use DNA analysis. Data collected from offspring are compiled to create an EPD. As more data are collected from more offspring the more accurate EPD's becomes. This being said, a sire with data collected from only 5 offspring will not have as a reliable set of EPD's as a sire with data collected from 100 offspring. Expected progeny differences have been in the industry for a number of years and many herds and sires have solid information and numbers accumulated to support sound genetic selection for improvement in a multitude of traits. Breed associations develop and manage EPD information and breed EPD's are not interchangeable (Rumph, 2009). This means that Angus EPD's cannot be applied to Hereford because the numbers will not mean the same thing. Considering that most sires are more prolific than the typical dam more data are collected and assembled for sires from their progeny and maintained in a database to determine each sires potential. Furthermore, EPD's cannot be used with just one single animal because EPD's use a base determined in each breed and compare animals to the base and each other to determine which animal has greater genetic potential for a specific operation (Rumph, 2009). Combining EPD's with DNA marker assisted technology may provide more accurate genetic selection options for cattle producers (Rincker et al., 2006). The greater opportunities that beef producers have available to them the more educated and efficient decisions they can make to improve their product.

Utilizing both of the EPD's and DNA analysis should allow for the most accurate choices possible and make the beef industry more efficient at raising an efficient and profitable animal. However, the pitfall that producers must take note of is to not single trait select. It may seem so simple to choose one trait and focus on that but, doing that neglects all the other traits that are just as essential to a thriving and productive beef industry.

GROWTH PROMOTION TECHNOLOGIES ROLE IN THE CATTLE FEEDING INDUSTRY

The use of technologies in the cattle industry is essential for maintaining a competitive market (Elam and Preston, 2004). Cattle producers must be efficient in all aspects of production. Overall demand for beef has risen due to the increasing population however; on an individual basis demand has not demonstrated much of an incline considering that the amount of beef that each consumer consumes has not risen (Elam and Preston, 2004). Growth promotion technologies in the form of metabolic modifiers assist in procuring the beef demanded by the increasing population. The metabolic modifiers contemplated below are anabolic steroids and beta-agonists. The anabolic steroids and beta-agonists compounds are implanted and fed, respectively (Dikeman, 2007). The use of both implants and beta-agonists are meant to improve feed efficiency, improve rate of gain, increase dressing percent and improve carcass meat yield percent (Dikeman, 2007). In today's economic climate maintaining these points are of the upmost importance to economic success.

Growth Promotion Implants Role in the Cattle Feeding Industry

The utilization of growth promoting implants in the feedlot industry has had an instrumental role in increasing profit margins. According to Fort Dodge Animal Health implants improves average daily gain (ADG), feed efficiency, and feed intake by 12-21%, 6-12% and 4-6%, respectively (Prouty, 2002). This

converted to a dollars and cents number means that producers can expect to increase profits by $30 to $60.00 per head (Prouty, 2002). This is a significant number when every penny counts in the cattle feeding business. The use of growth promotion products began in the mid-1950's using diethylstilbestrol as a feed additive (Gould, 2000). When growth promotants were first used they were added to the feed that the steers and heifers would consume. Later on the growth promotion implants were found to be more affective if they were placed just under the skin. Many things have changed since then including how growth promotants are administered to have the least potential impact on food safety. Since the 1950's implants have made many changes and strides toward products that have no withdrawal period and have no residual effect on those who consume the meat products from implanted cattle (ZoBell et al., 2000). Figure 3 demonstrates the proper placement of any type of implant on the market for either steers or heifers (www.mtbqa.org, November 24, 2010). The use of implants is regulated by the United States Food and Drug Administration (FDA). Today there is one approved location and the implant dosage must be in the middle third on the back side of the ear of the animal (Gould, 2000). The reason for this placement is because when the cattle are harvested the ear is removed from the carcass and does not go into the food supply chain (ZoBell et al., 2000). This reduces the risk of any of the hormones in the implant contaminating the food supply chain (ZoBell et al., 2000).

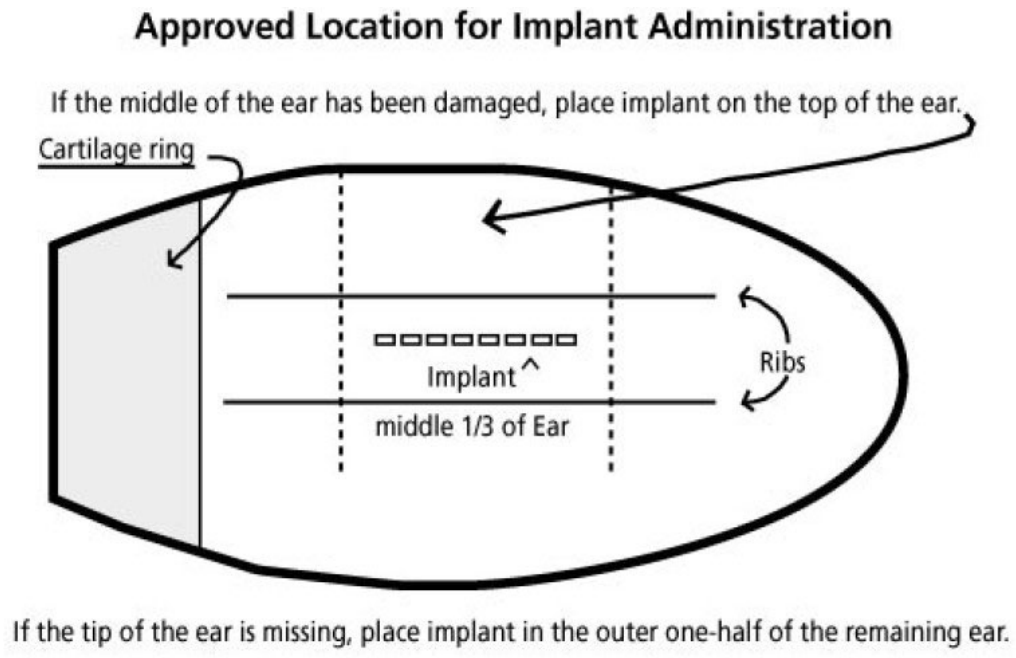


Figure 3. Approved Location for Implant Administration

*Figure provided by: Montana Beef Quality Assurance

The implants of today include several different hormones that are either combined or used individually (Preston, 1999). The estrogen hormones include estradiol, estradiol benzoate and zeranol. Implants can also include the androgen trenbolone acetate (TBA). Some implants also include progesterone and testosterone. The design of these growth promotants are dependent on whether the implant will be used in a steer or a heifer. Due to the different levels of hormones between the two sexes it is imperative to design implants that will incorporate compounds that compliment endogenous hormones to enhance growth for increased profitability. Implants are accessible for all cattle except in

breeding stock and those less than 45 days of age (ZoBell et al., 2000). Implants are not available for calves less than 45 days of age because they are not yet producing hormones at normal levels (ZoBell et al., 2000). The last 50 years of growth promoting implant research has been very active and many changes have come about to lead to safer products. Products have been created that allow producers to choose a management strategy that fits their operation.

Determining which implant to administer to a group of cattle typically depends on three factors. The list includes sex, age and length of time the animals will be on feed. In certain cases all three of these factors need to be taken into consideration and sometimes it is just a matter of one or two factors. These factors have to be taken into consideration because all implants have a length of time that they are effective for to gain the most economic advantage. It is important to know whether the cattle will need to be re-implanted or whether a long term implant like Revalor XS (Intervet/Schering-Plough Animal Health), a high potency implant, would be more beneficial to a specific operation (Vigortone, 2000). The understanding of whether or not a producer should use a timed release implant like Revalor XS or not depends on the specific management situation and the producer's production goals. Revalor XS has the distinct advantage of only needing one implant per animal for the feeding period due to an initial hormone release and then a secondary release 70 to 80 days later.

Choosing the correct implant for an operation depends on the management strategies used by the feedlot. When choosing a management strategy for the use of implants there are several choices: low, moderate,

intermediate, high and highest potency implants (Vigortone, 2000). These implants vary in the type of hormone used and the levels of concentration that the implants have of the hormone. “Low potency implants contain only estrogen”, “moderate implants contain estrogen and testosterone or estrogen and progesterone in varying amounts”, “intermediate and high potency implants contain trenbolone acetate (TBA) with or without estrogen” (Vigortone, 2000). Nutrition must also be taken in to consideration when evaluating the effectiveness of implanting cattle. If cattle are not supplied with appropriate nutrition response to the implants will not be seen in terms of better feed efficiency and higher gains (ZoBell et al., 2000). The greatest response seen with the use of implants is in yearling cattle that are at the peak of lying down lean tissue (ZoBell et al., 2000). When cattle are given a ration that is adequate in high energy feed stuff that is when the producer should see the most return on the capital invested (ZoBell et al., 2000). However, implants can be implemented in stocker and back grounding enterprises as well and gains will be observed. The gains will not be as impressive as those for cattle in a feedlot on a finisher ration (Gould, 2000). Managing implants in steers is different as compared to heifers. This is due to the fact that steers and heifers produce different levels of hormones and are able to utilize different levels of hormones in implants. Different levels of hormones in the implants stimulate the production of subsequent hormones in the animal’s body when the implants are administered (Gould, 2000).

When an implant is placed in the ear of a steer or heifer the hormones are slowly released into the blood stream (Gould, 2000). The type of implant used determines of how long and fast hormones will actually be available for release from a single implant (ZoBell et al., 2000). When the hormone is released into the blood stream it increases the level of hormone in the blood. With the slightly increased blood hormone levels it is enough to stimulate added growth. The increased level of hormone "directs more of the feed energy consumed toward the production of lean muscle and away from additional fat production" (Gould, 2000). With the animal laying down more lean tissue instead of fat this allows for faster gains (Gould, 2000). The animal would be taking in the feed stuff and instead of meeting its nutritional requirements and then converting the excessive nutrients to adipose tissue more would be metabolized into protein synthesis. Implants now contain a combination of androgenic and estrogenic hormones. The androgenic hormones are those that are the tissue building hormones and they therefore can increase the amount of muscle tissue that the animal puts down (ZoBell et al., 2000). The androgenic hormone implants are usually more productive in heifers (Dikeman, 2007). The estrogenic hormones are capable of taking the available nutrients and more readily converting them to improve growth (ZoBell et al., 2000). The estrogenic implants generally are more productive in steers (Dikeman, 2007). The combination of androgenic and estrogenic hormones into one implant has shown added benefits for both steers and heifers (Dikeman, 2007).

Implants are a practical and functional tool in today's beef production industry. From an economic aspect producers need to be able to get the most for what they invest. It is like in any business if there is no money being made then the business will only survive for so long and then financial burdens become too much. When a producer can implement technology that is cost effective and generates returns they are likely to take advantage of that technology. Cattle production is largest segment of agriculture in the United States generating the greatest amount of money (Lawerance and Ibarburu, 2007). Beef cattle producers in the United States use technologies like growth promotants and insecticides to promote animal well-being and performance on a regular basis (Lawerance and Ibarburu, 2007). Implants are used in 96.1% of all feedlot operations upon processing newly arrived cattle into a feedlot (USDA, 1999). Using the implants permits the cattle feeder to make a marginal amount more after all costs are deducted. The amount of profit actually returned compared to the amount spent depends and many of the same factors that are considered when choosing the correct implant to use. According to some feed efficiency can improve by 8 to 12% and growth rate can improve by 15 to 20% (Elam and Preston, 2004). These improvements are exceedingly growing in importance as markets increase in volatility and producers are looking for more progressive ways to increase profit margins.

From the start of using growth promotants in cattle feeding to the new technologies of today there have been many obstacles and challenges to overcome but, today producers are offered a multitude of safe and efficient

variety of technologies. Technologies are on the market that can help the producer to create a better business and insure a greater supply for the demand. In conclusion about the implementation of implants in any cattle feeding operation there are choices to be made. Producers need to be aware of how long cattle need to be on feed, implants that are for steers versus heifers, economic importance, nutrition being offered and a multitude of other reasons when making management decisions. Implants are very useful tools that over time have become more like "designer products" dependent on what the specific situation calls for (ZoBell et al., 2000). With the demand of beef being influenced by an increasing population it is important to be able to utilize technologies that make it possible to produce more product using less resources and taking up less space (Elam and Preston, 2004). Producers need to be able to utilize the most advance technology that will allow them to be economically efficient will still providing a wholesome and nutrition to meet the consumer's demands.

Beta-Agonists Role in the Cattle Feeding Industry

Beta adrenergic agonist's are a relatively recent addition to the cattle feeding industry. Much research has been conducted to ascertain the capabilities of these compounds and whether the resulting meat product is safe for human consumption. The product Zilmax, marketed by Intervet/Schering Plough has only been available for the United States cattle feeding industry since 2006. This product is also legal for use in Mexico and South Africa however; it is banned in the European Union (Avendano-Reyes et al., 2006). Zilmax's major

competitor Optaflexx (marketed by Elanco Animal Health) has been in use since 2004. Montgomery et al. (2009) stated that Zilmax has a performance advantage over Optaflexx in the gain to feed ratio. Both of these beta adrenergic agonist's are extremely useful in the cattle feeding business providing economic benefits to the producers without sacrificing meat quality. Some major differences and similarities are summed up below in Table 4.

Differences in Beta Agonists

Item	Optaflexx™	Zilmax™
Active ingredient	ractopamine hyperchloride	zilpaterol hydrochloride
Approved Label Guidelines		
Duration of feeding	28-42 days	20-40 days
Optimal feeding duration	28-35 days	20 days
Withdrawal time	None	3 days
Weight gain	Increased by 10-21 lbs	Increased up to 21 lbs
Feed efficiency	Improved 14-21%	Improved 14-21%
Ribeye area	Up to 0.5 sq. in.	Up to 0.5 sq.in.
Quality grade	Minimal impact	None to slight reduction
Tenderness	Minimal impact	None to slight reduction

Table 4. Differences between the beta agonists Optaflexx and Zilmax.

(Radunz, 2010)

As can be seen in Table 4, Zilmax is typically the stronger beta agonist over Optaflexx.

The purpose of beta adrenergic agonists in cattle is to divert the nutrient utilization in the body from fat deposition to lean tissue deposition (Cleere, 2010). Beta adrenergic agonist (beta agonist) mechanism of action focuses on increasing skeletal muscle (Yang and McElligott, 1989). Beta agonists have a great effect on the metabolism of lipids, proteins and carbohydrates and they are the most potent agents that can promote normal skeletal muscle growth (Yang

and McElligott, 1989). The muscle growth experienced with the use of a beta agonist is muscle hypertrophy (Yang and McElligott, 1989). Muscle hypertrophy is growth of the muscle by the increase in the size of the muscle cells (Glass, 2005). The organic beta adrenergic agonists enable muscle hypertrophy by binding to beta adrenergic agonists receptors (Mersmann, 1998). These receptors can be found throughout most every type of mammalian cell on the cell surface (Mersmann, 1998). The depiction below in Figure 5 is the projected structure of a beta adrenergic receptor (Mersmann, 1998).

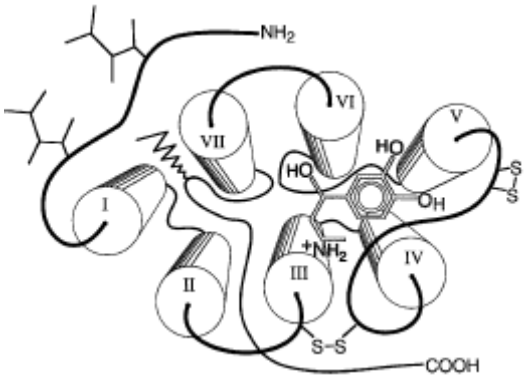


Figure 5. Projected structure of a beta adrenergic receptor.

(Mersmann, 1998)

The beta adrenergic agonist receptors are triggered by norepinephrine and epinephrine but, modifications do occur due to specie differences and other factors (Mersmann, 1998). There is a great complexity in the mechanisms of the way beta adrenergic agonists work to achieve a greater percent lean carcass and it is not fully understood how the job is done (Avendano-Reyes et al., 2006).

There are many factors that must be taken into consideration when considering the methods of the functionality of beta adrenergic agonists such as the ration fed, age of the animal, release of hormones and blood flow rate (Mersmann, 1998). In ruminants beta adrenergic agonist have the additional effect of decreasing fat accretion (lipogenesis) and increasing fat mobilization and hydrolysis (lipolysis; Dunshea et al., 2005). However, this effect is not directly conducted it is indirectly accomplished by a signaling cascade influencing cellular metabolism (Dunshea et al., 2005). The overall effect of the beta adrenergic agonist is to create more muscle accretion and stimulate more lipolysis by manipulating the animal into muscle hypertrophy during the end of the finishing phase when the body is content to just increase lipogenesis; thus manipulating the growth curve.

When utilizing a beta adrenergic agonist cattle feeders can expect to see increases in feedlot performance across several important feedlot performance indicators. Producers can expect to see improvements in average daily gains, gain to feed ratios, and final body weight (Montgomery et al., 2009). These improvements can be seen in both steers and heifers. In most cases heifers improvements are on a smaller scale however; using a beta adrenergic has a distinct advantage in performance versus not utilizing one (Montgomery et al., 2009). Steers can be expected to experience improvements in average daily gains from 17 – 36% (Montgomery et al., 2009). Heifers can be expected to experience improvements in average daily gains from 18 – 20% (Montgomery et al., 2009). Additionally, both sexes will exhibit higher final body weights and

while on the beta agonist will convert feed to gain more efficiently (Montgomery et al., 2009). Overall on the feedlot side of feeding a beta agonist producers can expect both steers and heifers to outperform their counterparts that are not exposed to a beta agonist.

The impact that beta adrenergic agonists pose to meat quality is of great importance. If a product is going to severely decrease the consumer's beef eating experience and therefore push the consumer to another protein source the costs' and benefits most be analyzed. Considering the mechanics behind beta adrenergic agonists divert nutrients from fat deposition to muscle accretion it makes sense that when cattle are harvested their carcasses are leaner and exhibit a greater amount of saleable product. Beta agonists have been shown to affect hot carcass weight, yield grade, marbling, and tenderness (Baxa et al., 2010; Montgomery et al., 2009). Beta agonist's propensity for increasing final body weight transfers over to increased hot carcass weight very effectively. The inclination for the animal's increased muscle increases the dressing percent. Carcasses that were fed the beta agonist Zilpaterol hydrochloride for either 20 or 40 days did indeed have a greater amount of saleable weight and have more closely trimmed sub-primal cuts making the fabricated carcass more valuable (Hilton et al., 2010; Plascencia et al., 2008). The value is due to the increased number of salable retail cuts that can be merchandised; thereby increasing the value of a single carcass administered a beta agonist and thus generating more revenue for the beef industry. However, overall beta agonists did increase the amount of saleable retail product some cuts did decrease in the total percentage

of the carcass that they constituted (Hilton et al., 2010; Plascencia et al., 2008). Plascencia et al. (2008) noted that the decline in percentage total could be attributed to the quantity and specificity of beta receptors found on particular muscles therefor, a particular muscle may not experience such extensive muscle hypertrophy and gain from the advantages of a beta agonist. The potential pitfall for the beta agonist can be found in the decrease in marbling and down grade in USDA quality grade. When feeding a beta agonist carcasses can be expected to decrease in the amount of marbling accumulated (Baxa et al., 2010; Montgomery et al., 2009; Beckett et al., 2009). The lesser amount of marbling leads to a shift in quality grades, most notably from USDA Choice to USDA Select. When feeding a beta agonist to a group of cattle the predisposition for a slide from USDA quality grade choice to select is very possible (Elam et al., 2009). This shift is not as significant in heifers as it is in steers (Montgomery et al., 2009) and is of minimal importance when the choice select spread is small. The effect on marbling can also be affected by the duration the cattle are fed a beta agonists. Montgomery et al. (2009) also showed that the longer, 40 versus 20 days, that cattle were fed the beta agonist Zilpaterol hydrochloride a greater decrease in marbling can be found. It is suggested that feeding Zilpaterol hydrochloride for the minimal approved feeding period allows for the advantages of increased gains while serving the least impact on carcass quality (Elam et al., 2009). When considering the effect to tenderness a review of metabolic modifiers found that the conservative use of metabolic modifier technologies increased shear force tenderness by 5-10% and similar results in perception of tenderness (Dunshea et

al., 2005). It is also suggested that reduction in tenderness can be derived from the increase in leanness attributed to change in nutrition and genetic selection (Dunshea et al., 2005). Avendano-Reyes et al. (2006) reported that the beta agonists Zilpaterol hychloride and ractopamine hydrochloride both resulted in tougher meat with higher Waren-Bratzler Shear Force measurments yet, the steers still ranked as being intermediately tough. This concludes that tenderness is effected by the use of beta agonists, but not to the point of sacrificing meat quality and consumer acceptance.

Zilpaterol hydrochloride is a beta adrenergic agonist that has the purpose to increase lean gain and feed conversion (Avendano-Reyeset et al., 2006). Zilpaterol hydrochloride is a product produced and distributed by Intervet Schering/Plough Animal Health and can also be known by the trade name Zilmax (Zilmax, 2011). Zilpaterol hydrochloride was approved for feeding in the United States in 2006 and is also approved for use in Mexico and South Africa for cattle not intended for breeding purposes (Avendano-Reyes et al., 2006; Zilmax, 2011). Application of Zilpaterol hydrochloride is as an oral component of the ration (Zilmax, 2011). It is added to the feed during the final 20 to 40 days that the cattle are on feed (Zilmax, 2011). There is a mandatory three day withdrawal period before cattle can be harvested allowing enough time clear for Zilmax to clear the system and not leave any residue behind ensuring food safety (Zilmax, 2011). Any off label use of Zilmax is considered illegal and should not be done (Zilmax, 2011).

The cost of using the beta adrenergic agonist, Zilmax, is based on current market cattle prices and therefore can fluctuate as the market does. Zilmax pricing equation is based on the value of a 600-900 pound carcass grading USDA Select and is multiplied by a constant factor of 50. The price is calculated monthly (Zilmax, 2011). The economic gains that are witnessed from the implementation of Zilmax can be shared with both the feeder and the packer. The feeder can estimate that 55% of the benefits from Zilpaterol hydrochloride will be achieved at the feed yard (Plascencia et al., 2008). The packer can expect to be privy to the remaining 45% of net benefits experienced from using Zilpaterol hydrochloride (Plascencia et al., 2008).

MEAT QUALITY

Marbling

Marbling or intramuscular fat is an important aspect in the United States beef market in determining the USDA quality grade and therefore the pricing of beef cuts. Marbling also plays a role in the taste of beef and is highly correlated with palatability of beef (Vieselmeyer et al., 1996) Intramuscular fat is stored between muscle fiber bundles (Albrecht et al., 2006) and is the last adipose tissue to be deposited (Sainz and Hasting, 2000). The accretion of intramuscular fat can be attributed to the development of new adipocytes and the hypertrophy of existing adipose cells (Sainz and Hasting, 2000). The cellular composition of marbling is adipocytes rooted in a connective tissue matrix close to a blood capillary system (Albrecht et al., 2006). The amount of marbling that can be found in beef varies across breeds with Wagyu and dairy breeds notably having more marbling (Kauffman et al., 1968). In cattle marbling is a genetic based difference that stretches across breeds (Numberg et al., 1998). Intramuscular fat is highly heritable and therefore has been the focus of many genetic studies and of EPD's (expected progeny differences). Prior to the ability of testing individual animals DNA for likelihood of marbling well producers were able to use EPD's and make genetic decisions. Using marbling EPDs allowed for the selection of cattle with higher marbling without increasing subcutaneous fat which can decrease the value of a beef carcass (Gwartney et al., 1996; Vieselmeyer et al.,

1996). Marbling is a driving force in the cattle industry in the United States and it is important to find ways to maximize marbling without decreasing the value of the carcass in other ways.

Tenderness

Tenderness is one of the most important factors involved in meeting the consumer's expectations during the eating experience. The industry faces a number of challenges when dealing with tenderness such as differences between sub species and the implementation of feed technologies and post-harvest processes. Tenderness is measured by Warner-Bratzler shear force (WBSF) value. K. F. Warner invented the device and since then adjustment and refinements have been made notably by Bratzler (Wheeler et al., 1996). Measuring tenderness has proven tricky. It has been shown that to reduce the variable of the tenderness results it is imperative to maintain and strictly follow a protocol so that repeatable measures can be obtained (Wheeler et al., 1997). It is important to remember that the relationship between WBSF and the consumers eating experience is not perfect.

Pre-mortem tenderness can be attributed to sub spices, breed and age of the animal. Tenderness varies greatly between *Bos taurus* and *Bos indicus* cattle. The differences in tenderness that can be attributed differences in breeds are related to the calpastatin levels. Higher the levels of calpastatin the tougher the cuts of meat will be (Geesink and Koohmaraie, 1999). Age is also a factor in

tenderness. As a beef animal ages the muscle changes and the connective tissue, collagen, becomes stronger and more multifarious (Epley, 1992). This change leads to tougher meat that needs further tenderization postmortem.

Postmortem tenderness can be influenced by processing and amount of time the carcass is allowed to age. Utilizing an appropriately timed aging program and high frequency electrical stimulation are both methods to provide tenderer and consistently tenderer cuts of beef for consumers (Eilers et al., 1996). Amount of time required for aging depends on the cut of meat. For example the top sirloin need 24 days while the top round steaks take half the time at 12 days of aging (Eilers et al., 1996). The difference in tenderness between cuts of meat can be attributed to the amount of connective found in the various muscles (Epley, 1992). Both sensory panels and Warner Bratzler shear force values indicate that tenderness increases with the increase in amount of time a cut is aged (Morgan et al., 1993). Using high frequency electrical stimulation is a method used to accelerate the decline in pH and in turn improves the tenderness of steaks (Eilers et al., 1996). Eilers et al. (1996) stated that reducing the pH to approximately 5.5 to 6.0 during early postmortem period improves tenderness.

An additional factor effecting postmortem tenderness is the activity of calpain and the inhibitor calpastatin (Morgan et al., 1993; Geesink and Koohmaraie, 1999). Calpain has been indicated as a key factor in the tenderization of a carcass postmortem (Geesink and Koohmaraie, 1999). When calpastatin activity is not inhibited toughening occurs and tenderness is not

regained until aging proceeds and calpastatin breaks down. Calpastatin activity is influenced by breed and sex of the animal, with bulls and *Bos indicus* cattle having higher activity levels (Morgan et al., 1993). Preventing postmortem rigor can inhibit the toughening of carcasses (Koohmaraie et al., 1996). By preventing postmortem rigor sarcomeres are not allowed to shorten which cause the toughness in meat (Koohmaraie et al., 1996). However, if rigor is not prevented and the sarcomeres shorten aging will allow the proteins to breakdown and extension to occur once again making the meat tenderer. Tenderness DNA analysis is based on calpastatin markers discovered by The University of Guelph. This marker known as UoGCAST1 is licensed to Igenity to constitute part of the panel for tenderness analysis (Miller, 2010).

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CHAPTER 2

INTRODUCTION

Millions of dollars have been invested in studying and mapping the bovine genome (Snelling et al., 2007; Zimin et al., 2009). These investments have resulted in considerable insight into where basic genetic controls of key traits of economic importance occur. Building on the bovine genome and the identification of single nucleotide polymorphisms that are associated with differences in animal performance, diagnostic tools have been developed to predict genetic potential for numerous traits. Research has shown that it is possible to use these tools to assist in selecting breeding stock with superior genetics for marbling and tenderness, as well as other traits. These genetic tools may also be used to sort feedlot cattle upon arrival into predicted outcome groups with carcasses of similar predicted marbling or tenderness. Sorting cattle into outcome groups may optimize the use of targeted growth promotion management programs, resulting in economic benefit to the feeder and a predictable higher quality end-product for resale. Aggressive growth promotion strategies involving the highest doses of trenbolone acetate implants and beta-agonist administration may be better suited to certain groups of cattle, while more moderate growth promotion strategies may be best suited for cattle from other

outcome groups. Utilizing DNA marker assisted technology and different growth promotion management strategies have the potential to create a positive impact on the economic and production aspects of a beef producers operation.

End-product quality may be improved if DNA marker assisted technology can allow feedlot operators to make more appropriate growth promotion technology decisions. The use of growth promotion technology has significantly reduced beef production costs (Lawrence and Ibarburu, 2007). However, maintaining end-product quality is important as well. The ultimate goal is to produce beef that provides a consistently superior eating experience for consumers at an affordable price. With the combination of both these technologies producers would potentially be able to improve efficiencies however; producers need to be aware of the costs that are incurred with the use of technologies and determine if the gains received outweigh the costs.

The objectives of this study were to: 1) evaluate the effectiveness of sorting feedlot cattle into marbling or tenderness outcome groups based on DNA marker technology and 2) determine if interactions related to end-product quality and palatability exist between predicted outcome group and growth promotion management strategy.

MATERIALS AND METHODS

One thousand, one hundred crossbred yearling steers (pay-weight 360 kg) arrived at a commercial feedlot (Colorado Beef; JBS Five Rivers Cattle Feeding) on August 19, 2010. Upon arrival, steers had overnight access to long-stemmed grass hay and water. Steers were processed at the commercial feedlot on the morning after arrival and were housed there until the completion of DNA marbling and tenderness marker analysis. Processing procedures included the application of a lot tag, an electronic identification tag with a corresponding visual tag, collection of whole blood samples for DNA analysis (IGENITY R and D, Merial Limited, Duluth, GA), vaccination for control of respiratory disease (Express® 3, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), and treating for internal and external parasites with ivermectin injection (Noromectin, Norbrook Inc., Lenexa, KS) and fendbendazole drench (Panacur, Intervet/Schering-Plough Animal Health). Steers were also weighed individually and breed type was assessed by subjective visual appraisal.

Thirty-four days post-processing, DNA profile data were received from the DNA analysis service provider and steers were moved to the Southeast Colorado Research Center (**SECRC**). DNA profile data were used to identify individuals with: 1) low tenderness and low marbling (**LL**), 2) low tenderness and high marbling (**LH**), 3) high tenderness and low marbling (**HL**), and 4) high tenderness and high marbling (**HH**). Within each of these 4 tenderness x marbling outcome

groups, 90 steers that were the furthest from the mean for predicted marbling and tenderness were selected for the study, stratified by weight into 5 weight strata, and randomly assigned within weight stratum to 2 pens of 9 steers. The cattle were selected the furthest from the mean to ensure that there was a distinct separation between the high and low predicted outcome groups. The 2 pens within each weight stratum were randomly assigned to a growth promotion strategy treatment (moderate versus aggressive). The moderate growth promotion strategy (**MGP**) included an initial (d 0) and re-implant (d 70) with 16 mg estradiol and 80 mg trenbolone acetate (Revalor-IS, Intervet/Schering-Plough Animal Health, Millsboro, DE) and no ß – agonist. The aggressive growth promotion strategy (**AGP**) included a 40 mg estradiol and 200 mg trenbolone acetate controlled release implant (Revalor-XS, Intervet/Schering-Plough Animal Health) on d 0 and Zilpaterol HCl (Zilmax, Intervet/Schering-Plough Animal Health) at 7.5 mg•kg^{-1} of DM for 20 of the final 23 days on feed.

Due to unforeseen complications, modifications of the project from the original proposal were required. The original proposal called for selecting the 360 steers needed for the study from 1,100 steers with genotype results. Laboratory analysis issues delayed the genotype results for 255 steers. Pen space issues at the commercial feedlot required the movement of the 360 steers to SECRC by September 18; therefore, the study steers were selected from an initial group of 845 steers with genotype data. This change in methodology likely had minimal impact on study results.

A starting and 2 step-up diets were used to acclimatize the steers to grain and the appropriate roughage sources before the study began while the cattle were housed at the commercial feedlot. Finishing diets used for the study once the steers were at SECRC are displayed in Table 8. All diets were formulated to contain similar amounts of ether extract, crude protein, NPN, vitamins, and minerals across treatments. Monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and tylosin (Tylan, Elanco Animal Health) were included in the SECRC diets at 33 and 11 mg•kg^{-1} of DM, respectively. Granular supplements (Table 9) containing minerals, urea, vitamin A and E, monensin, and tylosin were manufactured at the start and throughout the duration of the study as needed at SECRC.

Diets were fed 2 times daily and were manufactured immediately before feeding utilizing a 4 auger stationary mixer (Harsh Manufacturing, Dodge City, KS). Feed bunks were evaluated each morning and the target was to have a few crumbles of feed remaining in the bunk at this time. If the bunks were empty for 2 consecutive mornings, the daily feed amount was increased by 0.2 kg DM per steer. Diets and feed ingredients were sampled every week during the study. A sub-sample of each feed commodity and diet sample (≈ 100 g) was analyzed for dry matter at SECRC using a forced-air oven set at 60ºC for 48 h. The remaining portion of each feed ingredient and diet sample was composited by diet or feed ingredient per month and shipped to a commercial laboratory (SDK Laboratories, Hutchinson, KS) for routine DM, NDF, and nutrient analyses.

Feed refusals were weighed and sampled for dry matter determination when feed became spoiled due to adverse weather conditions, on weigh days, and at the conclusion of the study. Feed refusal samples were evaluated for dry matter content at SECRC by drying the samples for 48 h in a forced-air oven set at 60ºC. Dry matter consumption for each pen was calculated by subtracting the amount of DM weighed back from the amount of DM delivered and dividing the result by head days for the pen.

The initial weight utilized for the study was the individual weight obtained on September 17, 2010 when steers were sorted into predicted outcome groups. An interim pen weight was obtained on d 35 (October 28, 2010). Interim individual weights were obtained on d 70 (December 2, 2010) and d 106 (January 6, 2010). The final weight was determined by computing the average of 2 full weights obtained on 2 consecutive days immediately prior to slaughter (d 138 and 139 for weight block 3, 4, and 5, d 152 and 153 for weight block replicates 1 and 2). A 4% pencil shrink was applied to all weights prior to data analysis.

Two preselected groups of steers, determined by weight, were harvested at a commercial beef processing facility in northern Colorado on February 11 (replicates 3, 4, and 5) and February 22, 2011 (replicates 1 and 2) using conventional, humane procedures. Steers had access to feed in the morning of slaughter and were loaded on to trucks for a late afternoon or evening same day harvest. Steers were harvested in a random order and steer identification was maintained throughout the slaughter process. Upon completion of the slaughter

process, hot carcass weight (HCW) was recorded for each animal and carcass sides traveled through 4 zones of electrical stimulation: 1) 16 V, 60 Hz, 15 s (1 s on, 1 s off); 2) 20 V, 60 Hz, 15 s (1 s on, 1 s off); 3) 24 V, 60 Hz, 20 s (1 s on, 1 s off); 4) 28 V, 60 Hz, 15 s (1 s on, 1 s off). Carcasses then were chilled (air temperature 2℃) for 36 h. During the first 8 h of the chilling period, carcasses were intermittently sprayed (2 min on, 8 min off) with chilled (2℃) water.

Upon ribbing, 2 experienced carcass evaluators from Colorado State University independently assessed 12th rib fat thickness, adjusted preliminary yield grade (**APYG**), *Longissimus* muscle area (**LMA**), percentage of kidney, pelvic, and heart fat (**KPH**), USDA marbling score, skeletal and lean maturity for each carcass. Measurements from both evaluators were averaged for a single value for each factor and a final USDA yield grade (**YG**) and USDA quality grade were determined. Additionally, adjusted fat thickness, LMA, YG, and USDA marbling score were obtained from the in-plant camera cold carcass grading device (VBG2000, E+V Technology, Oranienburg, Germany). Objective lean color measurements were obtained for each carcass at the 12th-13th rib interface using a hand-held spectrophotometer (model 45/O-S, Hunter Associates Laboratory, Reston, VA), which measured an area 6 mm in diameter. Three color measurements from each carcass were averaged for a single L*, a*, b* for each carcass.

A 5 cm portion from the 13th rib portion of the *longissimus* muscle (LM) was removed from the right side of 3 carcasses from each pen. All LM portions were vacuum-packaged and stored in the absence of light at 2℃ for 14 days.

Longissimus muscle portions were frozen at the end of the aging period and stored at -20℃ prior to steak fabrication. One 2.54 cm thick steak was fabricated from each LM portion. Steaks were stored at -20℃ prior to shear force testing. Steaks were thawed at 2℃ for approximately 36 h to an internal temperature of between 1 and 5℃ prior to Warner-Bratzler shear force (**WBSF**) measurements. Steaks were cooked on an impingement conveyor oven (XLT Oven model 1832-EL, BOFI Inc., Wichita, KS) at 204℃ to a target internal temperature of 71℃. Peak internal temperature of steaks was measured at the geometric center of each steak using a Type K thermocouple (model 34040, Cooper-Atkins Corporation, Middlefield, CT) and recorded. After cooking, steaks were allowed to equilibrate to room temperature (22℃). Six cores (1.3 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, using a universal testing machine (model 4443, Instron Corp., Canton, MA) equipped with a Warner-Bratzler shear attachment with a crosshead speed of 200 $mm \cdot min^{-1}$. Peak shear force (kg) was recorded for each core and a single average WBSF value was calculated for each steak.

Net energy requirements for maintenance (**NEm**) and gain (**NEg**) for each pen of steers from d 0 – 35, d 36 – 70, d 71 – 106, d 107 through slaughter, and d 0 through slaughter were calculated using equations published by NRC (2000). Net energy for maintenance and NEg derived from the diet for each pen were calculated from pen performance and pen requirements for NEm and NEg using

the quadratic equation derivation of the energy equations (Appendix A; further described by Zinn, 1992).

Pens were checked daily to monitor cattle for health problems. Steers showing significant signs of disease were removed from the pens and assigned scores of 0 or 1 for each of the following respiratory symptoms: eye discharge, nasal discharge, coughing, rapid breathing, and depressed appearance. Rectal body temperatures were also recorded for suspect steers that were removed from the pen. Two additional points were assigned to steers exhibiting body temperatures greater than 39.7ºC. Steers with a total of 4 or more points were considered morbid and treated according to the appropriate treatment schedule and immediately returned to the pen. If problems persisted concerning the health status of specific steers, they were removed from the trial. Steers that died during the course of the trial were necropsied to determine the cause of death.

Data Analysis.

Data were analyzed as a randomized complete block experiment with a 2 x 2 x 2 factorial treatment arrangement using mixed model procedures of SAS (Release 9.2, SAS Institute, Inc., Cary, NC). Predicted tenderness group (low versus high), predicted marbling group (low versus high), and growth promotion strategy (moderate versus aggressive) were included in the model as fixed classification effects. Two-way interactions of predicted marbling x predicted tenderness, predicted marbling x growth promotion strategy, and predicted tenderness x growth promotion strategy; and the three-way interaction of

marbling x tenderness x growth promotion were also included in the model if significant ($P < 0.10$). Pen replicate was included in the model as a random classification effect. For WBSF values, steak peak internal temperature was used as a covariate. Significant differences were separated using the PDIFF option of the LSMEANS statement at $P < 0.05$. Quality grade and yield grade distribution and liver abscess prevalence data were evaluated as categorical data using PROC GLIMMIX of SAS assuming a binomial distribution and using similar models as described above. The Link = Logit option of the model statement and the ILINK option of the LSMEANS statement were used to calculate the likelihood ± SEM that an individual within each pen qualified for a specific category. Pen was considered the experimental unit for all data analyzed. Correlations between marbling molecular breeding value (**MBV**) and marbling score and between tenderness MBV and WBSF for individual steers were examined using PROC CORR of SAS.

RESULTS AND DISCUSSION

Figure 6 displays the distribution of marbling score MBV plotted for each IGENITY® Tenderness Profile Score (**TPS**). No steers were found to qualify as TPS 2. The mean marbling score MBV was similar for each TPS ranging from 89.4 for TPS 5 to 103.7 for TPS 8. For the purpose of assigning steers to genotype group for the study, steers from TPS 1, 3, and 4 were pooled to represent steers with reduced genetic potential for tender beef. Steers from TPS 7, 8, 9, and 10 were pooled to represent steers with greater genetic potential for tender beef. Steers with TPS 5 and 6 were not used in the present study. Within the low and high tenderness groups, steers were ranked by marbling score MBV. The 90 steers in the low tenderness group with the lowest marbling score MBV were classified as LL steers and the 90 steers within the low tenderness group with the highest marbling score MBV were classified as LH steers. The 90 steers in the high tenderness group with the highest marbling score MBV were classified as HH steers and the 90 steers within the high tenderness group with the lowest marbling score MBV were classified as HL steers.

Figure 7 illustrates the data distribution for the genotypes selected for the study. The TPS 3 and the TPS 4 steers with a marbling MBV of approximately 90 were inadvertently included in the study cattle. The genotype that they seemed to fit the best and maintain ≤ 9 steers in a pen was the LH genotype. Table 3 displays the results for the TPS, tenderness MBV, IGENITY® Marbling

Score Profile, marbling MBV, feedlot arrival weight, and study start weight for each of the 4 genotype groups set up for the study.

Steer Health

The health summary for the steers utilized for the marbling and tenderness study is shown in Table 11. There were not enough health issues observed to effectively subject the data to statistical evaluation. One steer (24066) was pulled for respiratory disease. This case was treated with tulathromycin (Draxxin, Pfizer Animal Health, Kalamazoo, MI) and flunixin meglumine (Flunixin, Phoenix Scientific, Inc., St. Joseph, MO) and returned to the home pen. This steer did not recover and was later removed from the study. One steer (22016) was found dead in its pen due to bloat. One steer (22021) was found dead in the pen due to pen injury. Two steers (21039 and 22058) were removed from the study due to chronic lameness.

Nutrient Composition of Feed Ingredients

Table 12 shows the nutrient composition of the feed ingredients used in the diets. Composition of steam-flaked corn and corn steep liquor were reasonably close to assumed values used for diet formulation purposes. The corn silage NDF, phosphorus, and potassium concentrations (41.50%. 0.13%, and 0.67% respectively) were lower than the assumed values (46.0%, 0.22%, and 1.14% respectively) and calcium concentration (0.41%) was higher than the assumed concentration (0.25%) for corn silage.

Nutrient Composition of Finishing Diets

The nutrient analyses for the finishing diets used for the study are displayed in Table 13. Dry matter concentration was similar among all diets and was slightly higher than the formulated concentration of approximately 68%. All treatments received the same diet (Ration 316) through most of the study. From 23 days prior to harvest through 3 days prior to harvest the moderate growth promotion strategy steers were fed Ration 214 while the aggressive growth promotion strategy steers were fed Ration 224 containing Zilpaterol. For the final 3 days of the study all treatments were fed Ration 214 to accommodate the 3 day withdrawal period required for Zilpaterol. The analyzed crude protein (12.57 versus 13.81), NPN (2.68 versus 3.18), NDF (12.62 versus 13.08), ether extract (6.08 versus 7.00), and calcium (0.56 versus 0.70) were slightly lower for ration 214 as compared with ration 224. The differences may partially reflect the nutrient concentration in the carrier used for the Zilmax that was included in diet 224 but, not in diet 214. Remaining nutrients were similar for rations 214 and 224. The finishing supplement DM and nutrient concentration were similar across diets 214 and 224. The analyzed nutrient concentration of both rations exceeded dietary recommendations listed by NRC (2000) and it is therefore unlikely that observed performance differences between the moderate versus aggressive technology groups were affected by slight differences in analyzed nutrient concentration.

Feedlot Performance.

Raw means ± SEM showing the effects of growth promotion strategy for each tenderness x marbling genotype are shown in Appendix B. Least squares means illustrating the effect of tenderness genotype, marbling genotype, and technology treatment are shown in Tables 14, 15, and 16, respectively. Interactions between tenderness and marbling genotypes and between tenderness genotype and growth promotion treatment were not significant ($P > 0.10$) for all feedlot performance variables. The marbling genotype by growth promotion treatment interaction was important for d 70 BW ($P < 0.07$); ADG, FG, and GF d 107 – harvest ($P < 0.01$); and calculated NEm and NEg d 107 – harvest ($P < 0.05$). The tenderness by marbling by growth promotion interaction was important from d 107 – harvest for FG ($P < 0.05$), GF ($P < 0.05$), and calculated NEm and NEg ($P < 0.06$). Significant interactions are illustrated in Tables 17 and 18.

Predicted Tenderness

Table 14 shows the effect of predicted tenderness on BW and feedlot performance. Steers sorted into the high tenderness (**HT**) genotype (lower WB shear force) were 5.9 kg heavier at the start of the study ($P < 0.05$), 5.0 kg heavier on d 35 ($P < 0.06$), 10.4 kg heavier on d 106 ($P < 0.001$), and 11.8 kg heavier at harvest ($P < 0.01$) than steers sorted into the low tenderness (**LT**) genotypes. Average daily gain through most of the study was not affected ($P > 0.10$) by tenderness genotype. This is in agreement with Purchas et al. (2002) in

that tenderness is more reliant on age of beef at slaughter and less reliant on the rate of gain in reaching slaughter stage. However, from d 71 – 106, ADG was greater ($P < 0.01$) for the HT steers as compared with the LT steers (1.96 versus 1.70 kg•hd^{-1}•d^{-1}). Dry matter intake was greater for the HT genotype steers as compared with the LT genotype from d 1 – 35 ($P < 0.09$), d 71 – 106 ($P < 0.02$), and d 107 – harvest ($P < 0.02$). Dry matter intake d 1 – harvest was greater for the HT steers as compared with the LT steers (9.80 versus 9.38 kg•hd^{-1}•d^{-1}). The observed increase in DMI was only partially a function of larger BW for the HT steers as DMI averaged 1.97 and 1.92% of average BW for the HT and LT, respectively. Although early in the feeding period there was some evidence suggesting that feed and gain efficiency as well as net energy recovery from the diet was slightly better for the LT steers as compared with the HT steers, there were no efficiency or energy recovery differences from d 107 – harvest or from d 1 – harvest associated with tenderness genotype.

Predicted Marbling

Table 15 shows the effect of predicted marbling on BW and feedlot performance. Steers sorted into the high marbling (**HM**) genotype were 9.1 kg heavier at the start of the study ($P < 0.001$), 6.4 kg heavier on d 35 ($P < 0.05$), 15.4 kg heavier on d 106 ($P < 0.0001$), and 20.9 kg heavier at harvest ($P < 0.0001$) than steers sorted into the low marbling (**LM**) genotype. Average daily gain through d 70 of the study was not affected ($P > 0.10$) by marbling genotype; however, from d 71 – 106 ($P < 0.01$) and from d 107 – harvest ($P < 0.05$), ADG

was greater for the HM steers as compared with the LM steers. From d 1 – harvest, ADG was higher ($P < 0.01$) for the HM steers as compared with the LM steers (1.56 versus 1.47 kg•hd^{-1}•d^{-1}). This coincides with Arnold et al. (1991) stating that there is a high correlation between ADG and MARB. Additionally, it was stated that the correlation could be related to higher marbling cattle reaching maturity at an earlier age than lower marbling cattle therefore depositing more marbling earlier. Dry matter intake was not affected ($P > 0.10$) by predicted marbling from d 1 – 70 but was increased ($P < 0.05$) for the HM steers from d 71 – harvest as compared with the LM steers. Daily DMI was 10.36 and 9.69 versus 9.76 and 8.69 kg•hd^{-1}•d^{-1} from d 71 – 106 and from d 107 – harvest for the HM group as compared with the LM steers, respectively. Average DMI was greater ($P < 0.05$) for the HM genotype steers as compared with the LM genotype from d 1 – harvest (9.80 versus 9.39 kg•hd^{-1}•d^{-1}) and was likely a function of increased BW for the HM steers as compared with the LM steers (1.96 versus 1.93% of BW). Feed and gain efficiency tended to be improved ($P < 0.07$) for the HM genotype steers as compared with the LM genotype steers from d 71 – 106; however, FG, GF, and net energy recovery for other time periods and from d 1 – harvest were not affected ($P > 0.10$) by marbling genotype.

Growth Promotion Strategy

The effect of growth promotion strategy is displayed in Table 16. Growth promotion strategy had no impact of BW, ADG, and DMI through study d 106. These data are in accordance with Nichols et al. (2010) where performance of

Revalor XS was compared to Revalor IS/Revalor S found that cattle will perform similarly with either treatment. There was a tendency for improved FG ($P < 0.06$), GF ($P < 0.06$), and NE recovery ($P < 0.08$) from the diet from d 1 – 35 for the AGP (Revalor XS at d 1) versus the MGP (Revalor IS initial implant at d 1). From d 107 – harvest, steers subjected to the AGP strategy (which included Zilmax supplementation for 20 of the final 23 days on feed) had greater ADG ($P < 0.01$) and superior ($P < 0.001$) FG, GF, and NE recovery as compared with steers subjected to the MGP. Steers subjected to the AGP were 8.2 kg heavier ($P < 0.06$) at harvest than steers subjected to the MGP. The heavier weights and superior ADG is consistent with previous studies (Avendano-Reyes et al., 2006; Plascencia et al. 2008). From d 1 – harvest, DMI was not affected by growth promotion strategy; however, ADG ($P < 0.05$), FG ($P < 0.01$), GF ($P < 0.01$, recovered NEm ($P < 0.05$), and recovered NEg ($P < 0.05$) were improved for AGP steers as compared with MGP steers. The increase in feedlot performance associated with Zilpaterol feeding is in accordance with Elam et al. (2009).

The significant 2- and 3-way interactions are shown in Tables 17 and 18, respectively. These interactions suggest that steers categorized as HM genotypes did not respond to Zilpaterol to the same degree as LM genotypes. This was especially true if the HM steers were also LT genotypes. No other performance interactions were found.

Carcass Merit

Raw means ± SEM showing the effects of growth promotion strategy for each tenderness x marbling genotype are shown in Appendix C. Least squares means illustrating the effect of tenderness genotype, marbling genotype, and technology treatment on carcass merit are shown in Tables 19, 20, and 21, respectively. Interactions between tenderness and marbling genotypes and between tenderness genotype and growth promotion treatment were not significant ($P > 0.05$) for most carcass measurements. Although all study diets contained Tylan, the liver abscess prevalence rate averaged over 38% of all carcasses and was not affected by tenderness and marbling genotype or growth promotion strategy.

Predicted Tenderness

Most carcass variables were not affected ($P > 0.10$) by tenderness genotype (Table 19). There was a tendency for steers from the HT group to have slightly lower lean maturity scores than the LT group. Meyer et al. (2005) concur that younger animals will produce more tender steaks. Lean color factor L was greater ($P < 0.05$) for the HT genotype as compared with the LT steers. Hot carcass weight was numerically, but not statistically, higher for the HT steers as compared with LT steers. The likelihood that an individual carcass within each pen qualified as USDA yield grade 1 was greater ($P < 0.05$) for the LT genotype as compared with the HT genotype (Table 24). Shear force was 0.33

kg lower (more tender, $P < 0.05$) for the HT steaks as compared with the LT steaks (Table 19).

Predicted Marbling

Hot carcass weight was 12.7 kg heavier ($P < 0.05$) for HM steers as compared with LM steers (Table 21). Increased HCW for HM steers was likely driven by greater initial weights and ADG for study steers classified as HM as compared with LM. High marbling carcasses were also fatter than LM carcasses as indicated by greater fat depth ($P < 0.06$) and adjusted fat depth ($P < 0.08$); higher measured ($P < 0.06$), adjusted ($P < 0.08$), and camera adjusted ($P < 0.10$) PYG; and greater average yield grade calculated from carcass measurements ($P < 0.09$). Bruns et al. (2004) stated that marbling score increased linearly with HCW. However, Vieselmeyer et al. (1996) stated that marbling scores can be increased without increasing back fat at the 12th rib. Marbling score ($P < 0.05$) and camera marbling score ($P < 0.05$) were greater for HM steers as compared with LM steers. Color profile b* was greater ($P < 0.05$) for HM steers as compared with LM steers. Carcasses of steers from the LM genotype were more likely to grade USDA Select ($P < 0.01$) and to qualify for USDA yield grade 2 ($P < 0.05$) as compared with carcasses of steers from the HM group. Vieselmeyer et al. (1996) found that cattle with greater marbling EPD were more likely to grade USDA Choice than cattle with lower marbling EPD. No additional carcass traits were impacted by predicted marbling genotype. There were no differences ($P > 0.60$) in WBSF associated with predicted marbling genotype.

Growth Promotion Strategy

The effect of growth promotion strategy on carcass merit is displayed in Table 22. Hot carcass weight was increased ($P < 0.05$) 12.2 kg for steers assigned to the AGP as compared with MGP. Increased HCW was a function of an increase ($P < 0.01$) in dressing percentage for the AGP compared with MGP steers. The increase in dressing percent and therefore HCW is consistent with data reported by both Avendano-Reyes et al. (2006) and Plascencia et al. (2008). Fat depth, adjusted fat depth, measured PYG, and adjusted PYG were numerically lower ($P < 0.17$) for AGP as compared to MGP carcasses. Adjusted camera PYG ($P < 0.07$), calculated yield grade ($P < 0.05$), and camera yield grade ($P < 0.05$) were lower and grader LM area and camera LM area were greater ($P < 01$) for the AGP as compared with the MGP. Lower yield grade were also noted in previous studies (Avendano-Reyes et al., 2006; Plascencia et al., 2008; Montgomery et al., 2009) that analyzed the use of Zilpaterol hydrochloride versus no Zilpaterol hydrochloride. There was a trend ($P < 0.12$) for increased lean maturity and color profiles L^* ($P < 0.07$) and b^* ($P < 0.01$) were reduced for the AGP as compared with the MGP. Marbling score and the distribution of USDA quality grades were not affected by growth promotion strategy. Elam et al. (2007) reported a linear decrease in marbling score as the length of feeding Zilpaterol hydrochloride increased. The percentage USDA yield grade 2 carcasses were greater ($P < 0.01$) for AGP as compared with MGP carcasses. Steaks from the AGP carcasses had increased ($P < 0.01$) WBSF as

compared with MGP steaks. This result is consistent with data reported by Garmyn et al. (2010) that the use of Zilpaterol hydrochloride decreases tenderness.

Significant 2- and 3-way interactions for carcass merit are shown in Tables 26 and 27, respectively. The interaction between tenderness group and marbling genotype was significant ($P < 0.05$) for USDA average and high Choice. Marbling score genotype had no impact ($P > 0.52$) on percentage USDA average and high low Choice if steers were also classified as HT. Alternatively, more ($P < 0.01$) carcasses qualified as USDA average and high Choice for the LT – HM genotype as compared with the LT – LM genotype. Three-way interactions for USDA yield grade 3 and USDA yield grade 4 carcasses indicate that for HT – LM and the LT – HM steers, the AGP strategy had limited impact on the percentage USDA yield grade 3 carcasses but reduced the percentage USDA yield grade 4 carcasses as compared with the MGP strategy. There was a tendency for a lower percentage USDA yield grade 3 carcasses for the AGP as compared to the MGP for steers classified as HT – HM or LT – LM; however, the percentage USDA yield grade 4 carcasses was not impacted by growth promotion strategy for the HT – HM or LT – LM genotypes.

Conclusions

Yearling steers can successfully be sorted into marbling or tenderness outcome groups using DNA marker technology. Correlations between tenderness MBV and WBSF were 0.20 ($P < 0.03$) and between marbling MBV

and camera marbling ($P < 0.0001$) and called marbling score ($P < 0.0001$) were 0.29 and 0.23, respectively. Steers sorted into the HT genotypes had reduced WBSF values as compared with steers sorted into LT genotypes. Steers sorted into HM groups demonstrated greater marbling scores upon harvest than steers sorted into LM groups. Tenderness can be improved by using MGP as compared with AGP; however, growth promotion strategy did not impact marbling or USDA quality grade distribution and few interactions related to end-product quality and no interactions for WBSF existed between predicted outcome group and growth promotion management strategy indicating that the degree that end product quality is impacted by growth promotion strategy is largely independent of marbling and tenderness genotype.

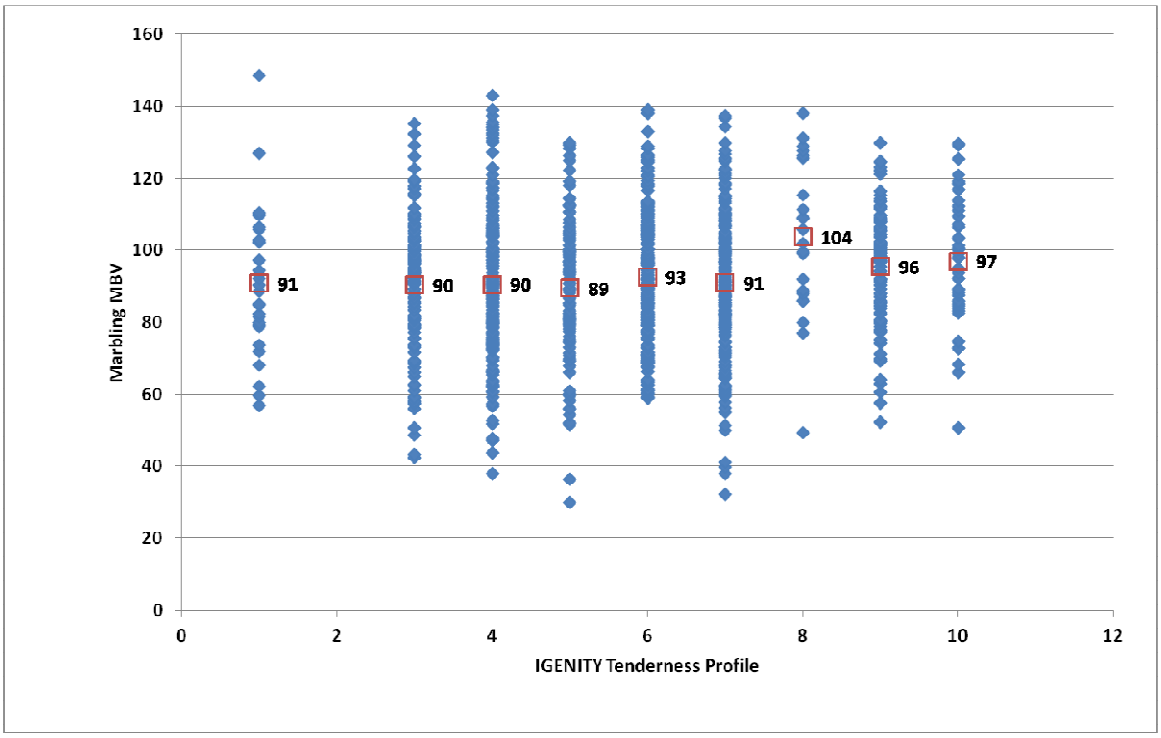

Figure 6. Marbling score molecular breeding value versus IGENITY® Tenderness Profile for all steers.

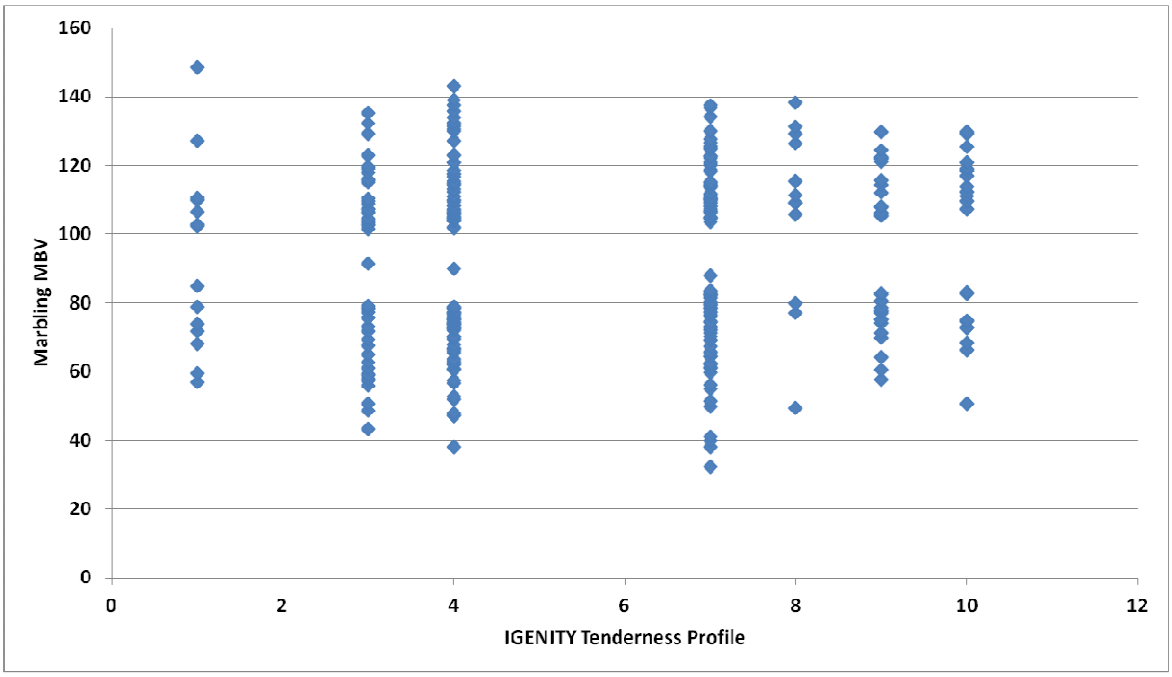

Figure 7. Data distribution for each of the 4 genotype groups selected for the study.

Table 8. Dry matter composition of the finishing rations for NCBA marbling and tenderness study.

Item[1]	Ration 316	Ration 214	Ration 224
Ingredients			
Corn silage	9.87	9.78	9.78
Steam flaked corn	76.13	75.51	68.89
Corn steep liquor	3.00	3.00	3.00
Tallow	2.93	3.80	3.80
DDG[2]	4.47	4.57	6.63
Zilmax 150[3]			4.53
Supplement[4]	3.54	3.34	3.37
Theoretical Nutrients			
Dry matter, % as-fed[5]	67.74	67.75	68.53
Crude protein	13.50	13.50	13.50
Non-protein nitrogen[6]	3.50	3.50	3.50
Acid detergent fiber	5.27	5.29	5.49
Neutral detergent fiber	13.40	13.30	13.20
eNDF[7]	4.50	8.02	7.60
fNDF[8]	4.00	4.00	4.00
NEm, Mcal/kg[9]	2.17	2.19	2.07
NEg, Mcal/kg[10]	1.48	1.49	1.42
Ether extract	8.00	7.50	7.50
Calcium	0.70	0.70	0.70
Phosphorus	0.36	0.36	0.36
Potassium	0.70	0.70	0.70
Magnesium	0.25	0.19	0.19

[1] Percentage of dry matter unless stated otherwise.
[2] Dry distiller grain plus solubles.
[3] 150 g/ton Zilpaterol HCl.
[4] See table 2 for supplement composition.
[5] Dry matter content of initial formulation, percentage of as-fed.
[6] Crude protein equivalent.
[7] Effective neutral detergent fiber. Calculated from NRC (2000).
[8] Forage neutral detergent fiber.
[9] Net energy for maintenance.
[10] Net energy for gain.

Table 9. As-fed composition of the finishing supplements for the NCBA marbling and tenderness study.

Ingredients[1]	Ration 316	Ration 214	Ration 224
Calcium Carbonate	49.80	44.74	45.01
Urea	32.93	36.60	36.27
Salt	6.91	7.44	7.39
Potassium Chloride	5.03	5.52	5.70
TM premix[2]	2.21	2.36	2.34
Mineral oil	2.00	2.14	2.10
Vitamin E premix[3]	0.46	0.50	0.49
Rumensin 90[4]	0.46	0.50	0.49
Vitamin A premix[5]	0.06	0.06	0.06
Tylan 100[6]	0.14	0.15	0.15

[1] Percentage of as-fed.
[2] Trace mineral premix: Cobalt, 500 mg•kg^{-1}; Copper, 2.5%; Maganese, 6.25%; Zinc, 18.75%; Iodine, 630 mg•kg^{-1}; and Selenium, 380 mg•kg^{-1}.
[3] 198,360 IU•kg^{-1} vitamin E.
[4] Monensin, 198 g•kg^{-1}.
[5] 110,200,000 IU•kg^{-1} vitamin A.
[6] Tylosin, 220 g•kg^{-1}.

Table 10. IGENITY® Tenderness and Marbling Score Profiles and Molecular Breeding Values and initial weight for steers selected for the study.

	Genotype Group[1]			
Item	LT – LM	LT – HM	HT – LM	HT – HM
N	90	89	89	90
IGENITY Tenderness Profile[2]				
1	6	10		
2				
3	21	24		
4	63	55		
5				
6				
7			61	54
8			3	9
9			16	15
10			9	12
Tenderness MBV[3]	- 0.66 ± 0.03	- 0.61 ± 0.03	- 1.72 ± 0.03	- 1.75 ± 0.03
IGENITY Marbling Profile[2]				
1				
2				
3	3		4	
4	29		21	
5	59		60	
6		5	4	
7		63		60
8		18		30
9		3		
10				
Marbling MBV	67.66 ± 1.00	113.42 ± 1.27	70.77 ± 1.22	115.99 ± 0.93
Arrival weight (kg)	347.04 ± 3.81	353.67 ± 4.31	348.95 ± 4.04	354.07 ± 4.90
Study start weight (kg)	390.1 ± 4.40	400.5 ± 5.03	394.9 ± 4.13	404.6 ± 5.53

[1] LT = Low tenderness, LM = Low marbling, HT = High tenderness, HT = High tenderness.
[2] Number of steers qualifying for each IGENITY Profile.
[3] Molecular breeding value.

Table 11. Cattle health summary for NCBA marbling and tenderness study.

Date	Steer	Pen	Treatment[1]	ºC	SC[2]	Diagnosis	Outcome
10/04/10	21039	113	LT/LM/M	39.7		Lame	Railed
10/04/10	22016	201	LT/HM/M			Enterotoxemia	Found dead in pen
10/22/10	24066	208	HT/HM/A	39.7	5	Respiratory	Railed
10/22/10	22058	512	LT/HM/M	38.9		Lame	Railed
02/16/11	22021	210	LT/HM/M			Pen injury	Found dead in pen

[1] LT = Low tenderness, HT = High tenderness, LM = Low marbling, HM = High marbling, M = Moderate growth promotion strategy, A = Aggressive growth promotion strategy.
[2] Respiratory score – 1 point for each of the following symptoms: eye discharge, nasal discharge, depression, cough, and rapid breathing.

Table 12. Dry matter nutrient composition of feed ingredients for the NCBA marbling and tenderness study.

Item[1]	Corn steep liquor	Corn silage	Steam-flaked corn	DDG[2]
Dry Matter	45.09 ± 1.22	36.40 ±1.38	75.31 ± 0.37	90.77 ± 0.59
Crude Protein	36.78 ± 1.17	9.12 ± 0.18	9.07 ± 0.13	29.81 ± 0.46
ADF[3]	2.53 ± 0.15	25.37 ± 0.86	2.72 ± 0.09	0.38 ± 0.13
NDF[4]	3.24 ± 0.18	41.33 ± 1.31	9.67 ± 0.20	27.35 ± 0.94
Calcium	0.08 ± 1.12	0.37 ± 0.02	0.15 ± 0.00	0.08 ± 0.02
Phosphorus	2.97 ± 0.14	0.15 ± 0.01	0.28 ± 0.01	0.86 ± 0.01
Potassium	4.24 ± 0.22	1.36 ± 0.06	0.39 ± 0.00	1.09 ± 0.03
Magnesium	1.01 ± 0.03	0.18 ± 0.00	0.12 ± 0.00	0.32 ± 0.02

[1] Means ± standard error of the mean.
[2] Dried distillers grains plus solubles.
[3] Acid detergent fiber.
[4] Neutral detergent fiber.

Table 13. Nutrient composition of finishing rations for the NCBA marbling and tenderness study.

Item[1]	Ration 316	Ration 214	Ration 224	Supplement 316	Supplement 214	Supplement 224
Dry Matter	70.71 ± 0.27	70.96 ± 0.29	72.04 ± 0.08	97.17 ± 0.33	97.55 ± 0.75	97.58 ± 0.68
Crude Protein	13.49 ± 0.49	12.57 ± 0.54	13.81 ± 0.68	96.09 ± 1.72	106.69 ± 5.29	113.87 ± 0.36
NPN[2]	3.31 ± 0.0.06	2.68 ± 0.23	3.18 ± 0.09	91.26 ± 1.13	103.83 ± 3.98	110.5 ± 2.1
NDF[3]	11.93 ± 0.28	12.62 ± 0.17	13.08 ± 0.21			
Ether Extract	5.90 ± 0.44	6.08 ± 1.86	7.00 ± 2.10			
Calcium	0.77 ± 0.03	0.56 ± 0.03	0.70 ± 0.05	18.90 ± 0.50	16.97 ± 0.60	16.84 ± 0.09
Phosphorus	0.37 ± 0.02	0.34 ± 0.04	0.39 ± 0.03	0.00 ± 0.0	0.01 ± 0.01	0.00 ± 0.00
Potassium	0.70 ± 0.03	0.70 ± 0.07	0.68 ± 0.05	2.57 ± 0.07	2.85 ± 0.19	2.06 ± 0.38
Magnesium	0.19 ± 0.02	0.15 ± 0.03	0.17 ± 0.02	1.03 ± 0.44	0.20 ± 0.00	0.60 ± 0.40
Sulfur	0.22 ± 0.01	0.19 ± 0.01	0.21 ± 0.02			

[1] Means ± standard error of the mean.
[2] Non-protein nitrogen.
[3] Neutral detergent fiber.

Table 14. Least square means showing the effects of predicted tenderness on feedlot performance.

Item[1]	Predicted Tenderness		SEM	Prob. > F
	Low	High		
Initial weight, kg	379.7	385.6	19.23	0.0154
Day 35, kg	459.9	464.9	18.96	0.0544
Day 70, kg	495.3	496.2	17.06	0.7725
Day 106, kg	556.6	567.0	19.69	0.0028
Final weight, kg	596.9	608.7	19.01	0.0047
ADG (d 1 - 35)	2.30	2.27	0.059	0.7007
ADG (d 36 - 70)	1.02	0.90	0.068	0.1702
ADG (d 71 - 106)	1.70	1.96	0.091	0.0052
ADG (d 107 - finish)	1.04	1.08	0.082	0.5129
ADG (d 1 - finish)	1.50	1.54	0.032	0.1021
DMI (d 1 - 35)	8.70	8.99	0.200	0.0894
DMI (d 36 - 70)	10.21	10.33	0.290	0.5976
DMI (d 71 - 106)	9.75	10.37	0.308	0.0132
DMI (d 107 - finish)	8.88	9.50	0.308	0.0146
DMI (d 1 - finish)	9.38	9.80	0.259	0.0140
GF (d 1 - 35)	0.2643	0.2523	0.0078	0.0595
GF (d 36 - 70)	0.1000	0.0875	0.0084	0.1088
GF (d 71 - 106)	0.1730	0.1898	0.0068	0.0880
GF (d 107 - finish)	0.1166	0.1143	0.0072	0.7126
GF (d 1 - finish)	0.1595	0.1573	0.0023	0.4385
NEm (d 1 - 35)	2.56	2.46	0.033	0.0310
NEm (d 36 - 70)	1.55	1.46	0.055	0.0821
NEm (d 71 - 106)	2.22	2.31	0.056	0.2466
NEm (d 107 - finish)	1.99	1.93	0.054	0.2966
NEm (d 1 - finish)	2.05	2.01	0.018	0.1932
NEg (d 1 - 35)	1.86	1.75	0.029	0.0310
NEg (d 36 - 70)	0.95	0.87	0.048	0.0821
NEg (d 71 - 106)	1.54	1.61	0.049	0.2466
NEg (d 107 - finish)	1.33	1.28	0.048	0.2966
NEg (d 1 - finish)	1.38	1.36	0.015	0.1932

[1] ADG = Average daily gain, kg•head^{-1}•d^{-1}; DMI = Dry matter intake, kg•head^{-1}•d^{-1}; GF = Gain/feed DM, NEm = Net energy for maintenance, Mcal/kg DM; NEg = Net energy for gain, Mcal/kg DM.

Table 15. Least square means showing the effects of predicted marbling on feedlot performance.

	Predicted Marbling			
Item[1]	Low	High	SEM	Prob. > F
Initial weight, kg	377.8	386.9	19.23	0.0004
Day 35, kg	459.0	465.4	18.96	0.0214
Day 70, kg	494.0	498.0	17.06	0.2661
Day 106, kg	553.8	569.3	19.69	< 0.0001
Final weight, kg	592.8	613.7	19.01	< 0.0001
ADG (d 1 - 35)	2.33	2.24	0.059	0.1990
ADG (d 36 - 70)	0.99	0.93	0.068	0.4796
ADG (d 71 - 106)	1.67	1.98	0.091	0.0013
ADG (d 107 - finish)	0.98	1.14	0.082	0.0246
ADG (d 1 - finish)	1.47	1.56	0.032	0.0031
DMI (d 1 - 35)	8.89	8.01	0.200	0.6455
DMI (d 36 - 70)	10.22	10.32	0.290	0.6650
DMI (d 71 - 106)	9.76	10.36	0.308	0.0168
DMI (d 107 - finish)	8.69	9.69	0.308	0.0003
DMI (d 1 - finish)	9.39	9.80	0.259	0.0158
GF (d 1 - 35)	0.2622	0.2543	0.0078	0.2076
GF (d 36 - 70)	0.0972	0.0904	0.0084	0.3757
GF (d 71 - 106)	0.1706	0.1922	0.0068	0.0311
GF (d 107 - finish)	0.1135	0.1174	0.0072	0.5364
GF (d 1 - finish)	0.1574	0.1594	0.0023	0.4904
NEm (d 1 - 35)	2.54	2.48	0.033	0.1854
NEm (d 36 - 70)	1.53	1.47	0.055	0.2927
NEm (d 71 - 106)	2.21	2.33	0.056	0.1147
NEm (d 107 - finish)	1.98	1.94	0.054	0.5639
NEm (d 1 - finish)	1.83	2.10	0.018	0.9778
NEg (d 1 - 35)	1.82	1.77	0.029	0.1854
NEg (d 36 - 70)	0.93	0.88	0.048	0.2927
NEg (d 71 - 106)	1.52	1.63	0.049	0.1147
NEg (d 107 - finish)	1.32	1.30	0.048	0.5639
NEg (d 1 - finish)	1.37	1.37	0.015	0.9778

[1] ADG = Average daily gain, kg•head^{-1}•d^{-1}; DMI = Dry matter intake, kg•head^{-1}•d^{-1}; GF = Gain/feed DM, NEm = Net energy for maintenance, Mcal/kg DM; NEg = Net energy for gain, Mcal/kg DM.

Table 16. Least square means showing the effects of growth promotion strategy on feedlot performance.

Item[1]	Growth promotion strategy		SEM	Prob. > F
	Moderate	Aggressive		
Initial weight, kg	382.4	382.4	19.41	0.9622
Day 35, kg	461.8	463.1	18.96	0.5812
Day 70, kg	496.2	495.3	17.06	0.8303
Day 106, kg	561.5	562.0	19.69	0.9081
Final weight, kg	599.2	607.4	19.01	0.0536
ADG (d 1 - 35)	2.22	2.30	0.059	0.5291
ADG (d 36 - 70)	0.99	0.93	0.068	0.4486
ADG (d 71 - 106)	1.81	1.85	0.091	0.7126
ADG (d 107 - finish)	0.96	1.17	0.082	0.0039
ADG (d 1 - finish)	1.49	1.54	0.032	0.0347
DMI (d 1 - 35)	8.96	8.73	0.200	0.1649
DMI (d 36 - 70)	10.26	10.28	0.290	0.9588
DMI (d 71 - 106)	10.03	10.09	0.308	0.8218
DMI (d 107 - finish)	9.34	9.04	0.308	0.2162
DMI (d 1 - finish)	9.65	9.53	0.259	0.4626
GF (d 1 - 35)	0.2522	0.2643	0.0078	0.0586
GF (d 36 - 70)	0.0967	0.0908	0.0084	0.4364
GF (d 71 - 106)	0.1796	0.1832	0.0068	0.7114
GF (d 107 - finish)	0.1022	0.1287	0.0072	0.0002
GF (d 1 - finish)	0.1545	0.1624	0.0023	0.0081
NEm (d 1 - 35)	2.47	2.55	0.033	0.0735
NEm (d 36 - 70)	1.53	1.48	0.055	0.3501
NEm (d 71 - 106)	2.26	2.27	0.056	0.8515
NEm (d 107 - finish)	1.84	2.08	0.054	0.0002
NEm (d 1 - finish)	2.00	2.06	0.018	0.0154
NEg (d 1 - 35)	1.76	1.82	0.029	0.0735
NEg (d 36 - 70)	0.931	0.887	0.048	0.3501
NEg (d 71 - 106)	1.57	1.58	0.049	0.8515
NEg (d 107 - finish)	1.21	1.41	0.048	0.0002
NEg (d 1 - finish)	1.34	1.40	0.015	0.0154

[1] ADG = Average daily gain, kg•head^{-1}•d^{-1}; DMI = Dry matter intake, kg•head^{-1}•d^{-1}; GF = Gain/feed DM, NEm = Net energy for maintenance, Mcal/kg DM; NEg = Net energy for gain, Mcal/kg DM.

[1] Marbling genotype by growth promotion strategy interaction.

Table 17. The effect of marbling genotype and growth promotion strategy on select feedlot performance measurements.

	Low Marbling		High Marbling			Inter.[1]
Item[2]	Mod.[3]	Aggr.[4]	Mod.	Aggr.	SEM	Prob > F
d 70 weight, kg	497.6	489.9	494.8	500.8	17.28	0.0673
ADG (d 107 – finish)	0.78	1.19	1.14	1.14	0.095	0.0037
DMI (d 107 – finish)	8.64	8.73	10.04	9.34	0.354	0.1137
GF (d 107 – finish)	0.0904	0.1366	0.1140	0.1208	0.0085	0.0037
NEm (d 107 – finish)	1.80	2.15	1.89	2.00	0.067	0.0383
NEg (d 107 – finish)	1.17	1.48	1.24	1.35	0.059	0.0383

[2] ADG = Average daily gain, kg•head^{-1}•d^{-1}; DMI = Dry matter intake, lb•head^{-1}•d^{-1}; FG = Feed DM/gain; GF = Gain/feed DM; NEm = Net energy for maintenance, Mcal/cwt DM; NEg = Net energy for gain, Mcal/cwt DM.

[3] Moderate growth promotion strategy. Revalor-IS and no beta agonist.

[4] Aggressive growth promotion strategy. Revalor-XS and Zilmax at 6.8 g/ton diet DM for 20 of the final 23 days on feed.

Table 18. Effect of tenderness and marbling genotype and growth promotion strategy on select feedlot performance measurements.

	Low Tenderness				High Tenderness					3 – way
	Low Marbling		High Marbling		Low Marbling		High Marbling			Inter.
Item[1]	M[2]	A[3]	M	A	M	A	M	A	SEM	P > F
GF4	0.0813	0.1413	0.1245	0.1195	0.0995	0.1320	0.1035	0.1222	0.0105	0.0492
NEm4	1.76	2.20	2.01	1.99	1.85	2.10	1.76	2.01	0.864	0.0520
NEg4	1.14	1.30	1.35	1.34	1.20	1.44	1.14	1.36	0.758	0.0520

[1] FG4 = Feed DM/gain, d 107 – harvest; GF4 = Gain/feed DM, d 107 – harvest; NEm4 = Net energy for maintenance recovered from diet DM, d 107 - harvest, Mcal/cwt DM; NEg4 = Net energy for gain recovered from diet DM, d 107 - harvest, Mcal/cwt DM.
[2] Moderate growth promotion strategy. Revalor-IS and no beta agonist.
[3] Aggressive growth promotion strategy. Revalor-XS and Zilmax at 7.5 mg/kg diet DM for 20 of the final 23 days on feed.

Table 19. Least square means showing the effects of predicted tenderness on carcass traits.

	Predicted Tenderness			
Item	Low	High	SEM	Prob. > F
Fat Thickness (cm)	1.22	1.32	0.051	0.1912
Adjusted Fat Thick. (cm)	1.40	1.47	0.051	0.1649
Measured PYG	3.20	3.29	0.05	0.1912
Adjusted PYG	3.37	3.46	0.05	0.1649
Camera Adjusted PYG	3.20	3.27	0.05	0.1807
Grader REA (cm^2)	88.90	89.29	1.23	0.6706
Camera REA (cm^2)	91.55	91.68	2.26	0.9316
HCW (kg)	385.1	390.5	12.00	0.1194
KPH (%)	2.0	2.0	0.02	0.5355
Yield Grade	3.11	3.23	0.09	0.2161
Camera Yield Grade	2.78	2.90	0.07	0.2664
Grader Marbling Score[1]	447	454	10.20	0.3993
Camera Marb. Score[1]	465	472	7.17	0.4575
Lean Maturity[2]	161	158	1.35	0.0855
Skeletal Maturity[2]	165	165	2.95	0.9153
Overall Maturity[2]	163	162	2.10	0.6400
L*	32.04	32.90	0.22	0.0327
a*	10.07	9.94	0.10	0.3999
b*	11.57	11.71	0.11	0.3096
Dressing Percentage	64.37	64.19	0.18	0.4533
Liver Ab. Presence (%)	36.95	41.23	3.80	0.4278
WBSF	3.92	3.59	0.11	0.0209

[1]Marbling Score: 400 = Small[00]; 500 = Modest[00]
[2]Maturity: 100 = A[00]; 200 = B[00]

Table 20. Least square means showing the effects of predicted marbling on carcass traits.

Item	Predicted Marbling		SEM	Prob. > F
	Low	High		
Fat Thickness (cm)	1.17	1.37	0.05	0.0575
Adjusted Fat Thick. (cm)	1.35	1.52	0.05	0.0753
Measured PYG	3.15	3.34	0.06	0.0575
Adjusted PYG	3.53	3.50	0.05	0.0753
Camera Adjusted PYG	3.32	3.30	0.05	0.0961
Grader REA (cm^2)	88.84	89.42	1.23	0.5771
Camera REA (cm^2)	90.84	92.39	2.56	0.2701
HCW (kg)	381.5	394.2	12.00	0.0115
KPH (%)	2.0	2.0	0.02	0.2542
Yield Grade	3.04	3.30	0.10	0.0826
Camera Yield Grade	2.76	2.92	0.07	0.1989
Grader Marbling Score[1]	437	464	10.20	0.0226
Camera Marb Score[1]	451	485	8.10	0.0399
Lean Maturity[2]	160	159	1.35	0.4282
Skeletal Maturity[2]	166	164	2.70	0.4620
Overall Maturity[2]	164	162	2.04	0.3444
L*	32.25	32.68	0.22	0.1609
b*	11.45	11.84	0.11	0.0185
Dressing Percentage	64.42	64.14	0.17	0.1634
Liver Ab. Presence (%)	38.36	39.78	3.80	0.7923
WBSF	3.79	3.72	0.11	0.6092

[1]Marbling Score: 400 = $Small^{00}$; 500 = $Modest^{00}$
[2]Maturity: 100 = A^{00}; 200 = B^{00}

Table 21. Least square means showing the effects of growth promotion strategy on carcass traits.

Item	Growth promotion strategy		SEM	Prob. > F
	Moderate	Aggressive		
Fat Thickness (cm)	1.32	1.22	0.05	0.1695
Adjusted Fat Thick. (cm)	1.50	1.40	0.05	0.1293
Measured PYG	3.30	3.20	0.05	0.1695
Adjusted PYG	3.47	3.37	0.05	0.1293
Camera Adjusted PYG	3.29	3.19	0.05	0.0694
Grader REA (cm^2)	86.06	92.19	1.23	0.0022
Camera REA (cm^2)	88.32	94.90	2.26	0.0051
HCW (kg)	381.9	394.2	12.02	0.0171
KPH (%)	2.0	2.0	0.02	0.9458
Yield Grade	3.31	3.03	0.09	0.0278
Camera Yield Grade	3.01	2.67	0.07	0.0214
Grader Marbling Score[1]	448	454	10.49	0.5219
Camera Marb. Score[1]	464	473	7.17	0.3725
Lean Maturity[2]	157	162	1.61	0.1119
Skeletal Maturity[2]	165	164	2.73	0.6896
Overall Maturity[2]	162	163	2.18	0.7372
L*	32.89	32.04	0.25	0.0673
b*	12.11	11.18	0.11	0.0012
Dressing Percentage	63.67	64.89	0.18	0.0032
Liver Ab. Presence (%)	39.97	38.17	3.80	0.7387
WBSF	3.55	3.96	0.11	0.0054

[1]Marbling Score: 400 = $Small^{00}$; 500 = $Modest^{00}$
[2]Maturity: 100 = A^{00}; 200 = B^{00}

Table 22. LS Means for the marbling treatment * growth promotion management strategy interaction

	Aggressive Strategy				Moderate Strategy			
Carcass Trait	High Marbling	Low Marbling	SEM	*P*-value	High Marbling	Low Marbling	SEM	*P*-value
a*	9.74	9.13	0.14	0.0060	10.57	10.58	0.14	0.9965

Table 23. Percentage of carcasses by USDA grade separated by IGENITY tenderness genotype

USDA Grade	High Tenderness	SEM	Low Tenderness	SEM	*P*-value
USDA Quality Grade					
USDA Prime	2.91	1.25	0.00	-	0.6487
USDA Low Choice	47.67	3.85	48.46	3.95	0.9028
USDA Select	25.58	3.41	30.67	3.78	0.4739
USDA Standard	0.58	0.58	0.00	-	0.9455
USDA Yield Grade					
USDA Yield Grade 1	1.74	0.93	6.75	1.94	0.0357
USDA Yield Grade 2	38.37	3.83	38.65	4.01	0.8767
USDA Yield Grade 5	1.16	0.71	1.23	0.75	0.9510

Table 24. Percentage of carcasses by USDA grade separated by IGENITY marbling genotype

USDA Grade	High Marbling	SEM	Low Marbling	SEM	*P*-value
USDA Quality Grade					
USDA Prime	2.42	1.15	0.58	0.49	0.2037
USDA Low Choice	51.52	3.93	44.44	3.83	0.2025
USDA Select	20.00	3.17	35.67	3.75	0.0021
USDA Standard	0.0	-	0.58	0.58	0.9601
USDA Yield Grade					
USDA Yield Grade 1	2.42	1.06	5.85	1.75	0.1305
USDA Yield Grade 2	31.52	3.75	45.03	3.91	0.0111
USDA Yield Grade 5	2.42	1.01	0.00	-	0.7583

Table 25. Percentage of carcasses by USDA grade separated by growth promotion management strategy

USDA Grade	Aggressive Strategy	SEM	Moderate Strategy	SEM	*P*-value
USDA Quality Grade					
USDA Prime	1.18	0.66	1.80	0.86	0.6694
USDA High + Average Choice	24.26	3.44	20.36	3.19	0.4577
USDA Low Choice	44.38	3.86	51.50	3.90	0.1990
USDA Select	30.18	3.71	25.75	3.47	0.5505
USDA Standard	0.0	-	0.60	0.60	0.9862
USDA Yield Grade					
USDA Yield Grade 1	4.14	1.35	4.19	1.39	0.9310
USDA Yield Grade 2	46.75	3.92	29.94	3.65	0.0016
USDA Yield Grade 5	0.59	0.54	1.80	1.00	0.3401

Table 26. USDA quality grade percentages for the marbling * tenderness interaction

	High Tenderness				
USDA Grade	High Marbling	SEM	Low Marbling	SEM	*P*-value
USDA High + Average Choice	21.08	4.49	25.21	4.73	0.5273
	Low Tenderness				
USDA Grade	High Marbling	SEM	Low Marbling	SEM	*P*-value
USDA High + Average Choice	31.11	5.28	11.91	3.56	0.0043

Table 27. USDA yield grade percentages for the marbling treatment * tenderness treatment * growth promotion management strategy interaction

USDA Grade	HH*		HH		HL		HL		LH		LH		LL		LL		
	AGP	SEM	MGP	SEM	AGP	SEM	MGP	SEM	AGP	SEM	MGP	SEM	AGP	SEM	MGP	SEM	*P*-value
3	45.24^{abc}	7.78	62.80^{a}	7.46	44.18^{bc}	7.67	40.90^{bc}	7.51	52.50^{ab}	8.00	47.50^{abc}	8.00	29.54^{c}	6.95	50.00^{abc}	8.01	0.0342
4	9.51^{ab}	4.57	11.61^{ab}	4.94	4.65^{b}	3.22	15.88^{ab}	5.59	2.50^{b}	2.47	22.47^{a}	6.72	6.81^{ab}	3.82	5.00^{b}	3.46	0.0329

^{abc} LS Means in the same row without a common superscript differ (P < 0.05)

*HH-High Tenderness, High Marbling; HL-High Tenderness, Low Marbling; LH-Low Tenderness, High Marbling; LL-Low Tenderness, Low Marbling

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APPENDIX A:

Energy Recovery. Net energy values for each diet were calculated from estimates of energy expended for maintenance (EM, Mcal/d) and energy retained (EG, Mcal/d) derived from BW, actual growth performance data, and DMI using the following equations for large-framed yearling steers (NRC, 2000):

EM = 0.077 × mean shrunk $BW^{0.75}$ (kg), where mean shrunk BW (SBW) = full mean BW × 0.96;

EG = (0.0635 × ($EQEBW^{0.75}$) × ($EBG^{1.097}$)), where EQEBW = 0.891 * [SBW * (Standard Reference Weight/final shrunk body weight, kg)], Standard Reference Weight (SRW) at a Small degree of marbling = 478 kg, and EBG = 0.956 * daily shrunk weight gain (kg/d).

The NEm and NEg values of the diets were then calculated using the solution for the quadratic equation:

NEm (Mcal/kg DM) = ((-b + $\sqrt{(b^2-4ac)}$) / 2a), where

a = 0.877 × DMI,

b = (-0.877 × EM) - (0.41* DMI) - EG, and

c = 0.41 × EM

NEg (Mcal/kg DM) = 0.877 x NEm - 0.4

Appendix B. NCBA Means and standard errors for feedlot performance for each tenderness by marbling genotype group separated by growth promotion strategy.

	Low Tenderness and Low Marbling		Low Tenderness and High Marbling		High Tenderness and Low Marbling		High Tenderness and High Marbling	
Item[1]	M[2]	A[3]	M	A	M	A	M	A
Initial wt	374 ± 16	376 ± 18	385 ± 20	383 ± 21	381 ± 15	380 ± 18	390 ± 23	391 ± 23
D106	554 ± 20	545 ± 17	560 ± 22	567 ± 20	558 ± 15	558 ± 18	573 ± 22	577 ± 23
Final wt	581 ± 18	592 ± 20	606 ± 20	609 ± 22	594 ± 12	605 ± 18	616 ± 21	623 ± 24
ADG4	0.67 ± 0.02	1.21 ± 0.12	1.17 ± 0.12	1.12 ± 0.14	0.90 ± 0.09	1.17 ± 0.10	1.11 ± 0.11	1.16 ± 0.16
ADG	1.42 ± 0.05	1.48 ± 0.04	1.52 ± 0.05	1.56 ± 0.04	1.51 ± 0.02	1.54 ± 0.04	1.55 ± 0.03	1.59 ± 0.06
DMI4	18.32 ± 0.60	18.89 ± 1.18	20.67 ± 0.40	20.39 ± 1.28	19.79 ± 0.49	19.62 ± 0.57	23.60 ± 1.13	20.80 ± 1.30
DMI	20.50 ± 0.54	20.07 ± 0.71	20.95 ± 0.45	21.23 ± 0.90	21.29 ± 0.59	20.93 ± 0.56	23.36 ± 0.72	21.84 ± 1.04
FG4	12.5 ± 0.76	7.28 ± 0.64	8.31 ± 0.71	8.70 ± 0.94	10.53 ± 1.13	7.83 ± 0.70	9.91 ± 0.08	8.45 ± 0.71
FG	6.57 ± 0.20	6.13 ± 0.08	6.27 ± 0.15	6.18 ± 0.13	6.62 ± 0.17	6.17 ± 0.09	6.52 ± 0.17	6.22 ± 0.25
GF4	0.08 ± 0.005	0.14 ± 0.01	0.12 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.13 ± 0.01	0.10 ± 0.008	0.12 ± 0.01
GF	0.15 ± 0.004	0.16 ± 0.002	0.16 ± 0.004	0.16 ± 0.003	0.15 ± 0.003	0.16 ± 0.002	0.15 ± 0.004	0.16 ± 0.007
Cnem4	1.76 ± 0.06	2.20 ± 0.11	2.01 ± 0.09	1.99 ± 0.08	1.84 ± 0.09	2.11 ± 0.01	1.76 ± 0.06	2.01 ± 0.09
Cnem	2.00 ± 0.04	2.09 ± 0.02	2.05 ± 0.03	2.05 ± 0.03	1.97 ± 0.03	2.06 ± 0.02	1.97 ± 0.05	2.05 ± 0.05
Cneg4	1.13 ± 0.05	1.52 ± 0.10	1.35 ± 0.08	1.34 ± 0.07	1.20 ± 0.08	1.44 ± 0.07	1.14 ± 0.06	1.36 ± 0.07
Cneg	1.34 ± 0.04	1.42 ± 0.02	1.39 ± 0.02	1.39 ± 0.03	1.32 ± 0.03	1.40 ± 0.02	1.32 ± 0.04	1.38 ± 0.04

[1] ADG = Average daily gain, kg•head^{-1}•d^{-1}; DMI = Dry matter intake, kg•head^{-1}•d^{-1}; FG = Feed DM/gain, GF = Gain/feed DM, NEm = Net energy for maintenance, Mcal/kg DM; NEg = Net energy for gain, Mcal/kg DM; 4 = d107 – slaughter.
[2] M = Moderate growth management strategy of Revelor IS and no beta-agonist.
[3] A = Aggressive growth management strategy of Revelor XS and Zilmax at 6.8 g/ton diet DM for 20 of the final 23 days on feed.

Appendix C. NCBA Means and standard errors for carcass merit for each tenderness by marbling genotype group separated by growth promotion strategy.

	Low Tenderness and Low Marbling		Low Tenderness and High Marbling		High Tenderness and Low Marbling		High Tenderness and High Marbling	
Item[1]	M[2]	A[3]	M	A	M	A	M	A
HCW	373.0 ± 12.6	384.3 ± 10.7	385.8 ± 13.2	397.5 ± 13.0	377.2 ± 9.0	392.4 ± 12.3	390.8 ± 13.3	402.5 ± 15.0
DP	64.06 ± 0.28	65.04 ± 0.31	63.65 ± 0.16	64.71 ± 0.30	63.55 ± 0.36	65.05 ± 0.29	63.41 ± 0.28	64.77 ± 0.17
BF depth	1.30 ± 0.05	1.30 ± 0.08	1.63 ± 0.15	1.37 ± 0.08	1.42 ± 0.05	1.40 ± 0.03	1.60 ± 0.10	1.50 ± 0.10
LM area	86.71 ± 1.48	92.00 ± 1.10	85.74 ± 1.16	91.23 ± 1.87	84.45 ± 1.87	92.19 ± 1.55	87.35 ± 2.00	93.29 ± 1.87
KPH	1.97 ± 0.03	2.01 ± 0.04	2.02 ± 0.06	2.07 ± 0.05	2.08 ± 0.02	1.96 ± 0.04	2.03 ± 0.02	2.06 ± 0.02
Calc. YG	3.00 ± 0.06	2.86 ± 0.14	3.50 ± 0.29	3.08 ± 0.07	3.30 ± 0.08	3.01 ± 0.06	3.44 ± 0.15	3.17 ± 0.16
USDA YG								
YG 1	10.0	6.8	5.0	5.0	2.3	4.7	0.0	0
YG 2	35.0	56.8	20.0	40.0	40.9	46.5	23.3	42.9
YG 3	50.0	29.5	47.5	52.5	40.9	44.2	62.8	45.2
YG 4	5.0	6.8	22.5	2.5	15.9	4.7	11.6	9.5
YG 5	0.0	0.0	5.0	0	0	0	2.3	2.4
Marbling	433 ± 8.3	424 ± 9.9	453 ± 22.5	480 ± 11.6	443 ± 6.7	449 ± 18.2	461 ± 11.1	463 ± 14.9
Lean mat.	157 ± 2.9	167 ± 4.5	157 ± 2.4	162 ± 3.0	157 ± 1.7	159 ± 2.0	157 ± 0.7	160 ± 1.3
Skel. mat.	170 ± 6.0	161 ± 2.2	160 ± 1.6	164 ± 4.2	166 ± 3.3	166 ± 4.1	162 ± 2.5	166 ± 5.1
Maturity	166 ± 4.2	164 ± 2.8	161 ± 4.1	163 ± 3.7	163 ± 2.6	163 ± 2.9	160 ± 1.4	163 ± 3.9
USDA QG								
Prime	0.0	0.0	0.0	0.0	2.3	0.0	4.7	4.8
Choice^{+}	2.5	6.8	5.0	7.5	2.3	9.30	4.7	4.8
Choice^{o}	10.0	4.5	22.5	27.5	20.5	18.6	14.0	19.0
Choice^{-}	50.0	41.0	47.5	47.5	43.2	37.2	60.5	47.6
Select	32.5	47.8	22.5	12.5	29.5	30.2	16.3	19.0
Standard	5.0	0.0	2.5	5.0	2.3	4.65	0	4.8
Liver absc.	40.5	40.9	33.3	29.5	34.1	35.6	48.9	44.2

[1] HCW = hot carcass weight, kg; DP = dressing percentage; BF = 12th rib fat, cm; LM = Longissimus muscle, sq. cm; KPH = Kidney, pelvic, and hear fat, %; Calc. YG = Yield grade calculated from carcass measurements; USDA YG = USDA yield grade distribution; Marbling = marbling score, 400 = Small^{00}, 500 = Modest^{00}; Lean mat. = Lean maturity, 100 = A^{00}, 200 = B^{00}; Skel. mat. = skeletal maturity, 100 = A^{00}, 200 = B^{00}; Maturity = Overall maturity, 100 = A^{00}, 200 = B^{00}; USDA QG = USDA quality grade distribution; Liver absc. = prevalence of liver abscesses.

[2] M = moderate growth management strategy of Revelor IS and no beta-agonist.

[3] A = aggressive growth management strategy of Revalor-XS and Zilmax at 6.8 g/ton diet DM for 20 of the final 23 days on feed.