53RD ANNUAL

BEEF IMPROVEMENT FEDERATION
RESEARCH SYMPOSIUM & CONVENTION

BIF 2021

INNOVATION *to* APPLICATION

JUNE 22–25 | IOWA EVENTS CENTER | DES MOINES IOWA

IOWA STATE UNIVERSITY
Extension and Outreach
Iowa Beef Center

B I F

BIF 2021
INNOVATION to APPLICATION

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Welcome to Des Moines!

On behalf of the planning committee, we are excited to host the 2021 Beef Improvement Federation Symposium in person. The committee has planned an informative, thought-provoking event with plenty of opportunity for discussion and networking. The theme for this year's symposium is "Innovation to Application." Each topic revolves around cutting-edge technological developments, practical applications that can be implemented now, and information related to the future direction of the beef industry.

The meeting is being hosted at the Iowa Events Center in Des Moines, Iowa. Be sure and come early and attend the Young Producer Symposium on Tuesday afternoon. This session brings solid management and marketing information as well as a panel of experience producers. Wednesday evening will include a trip to the Hansen Student Agriculture Center on the campus of Iowa State University in Ames and feature beef prepared by the ISU Meat Lab. With a great atmosphere, great food, and great comradery, this will be an exciting event!

On Friday we have two tours packed with stops featuring several sectors of the beef value chain. One will go to Eastern Iowa and one to Western Iowa. We hope you will stay another day and see how Iowa beef is bred, produced, fed and marketed.

We look forward to seeing you in Des Moines June 22-25 and experience in person what "Iowa Nice" is all about.

Regards,

Dan Loy

University Professor of Animal Science, Iowa State University

Extension Beef Specialist, Iowa State University Extension and Outreach
Organizing Committee Chair, BIF 2021

Tuesday, June 22, 2021

8:00 a.m. **BIF Board of Directors Meeting** *Hilton Des Moines – Cloud Ballroom A*

11:00 **Registration open** *Iowa Events Center – Level 3, sponsored by Central Life Sciences*

YOUNG PRODUCER SYMPOSIUM—PROFITABILITY IN BALANCE *sponsored by Central Life Sciences, Iowa Events Center – Ballroom B, Level 4*

1:00 p.m. **Managing for Profitability** John Locke, instructor, Ranching for Profit instructor and manager – J.D. Hudgins Inc.

1:45 **Building a Brand** Rachel Cutrer, owner – Ranch House Designs

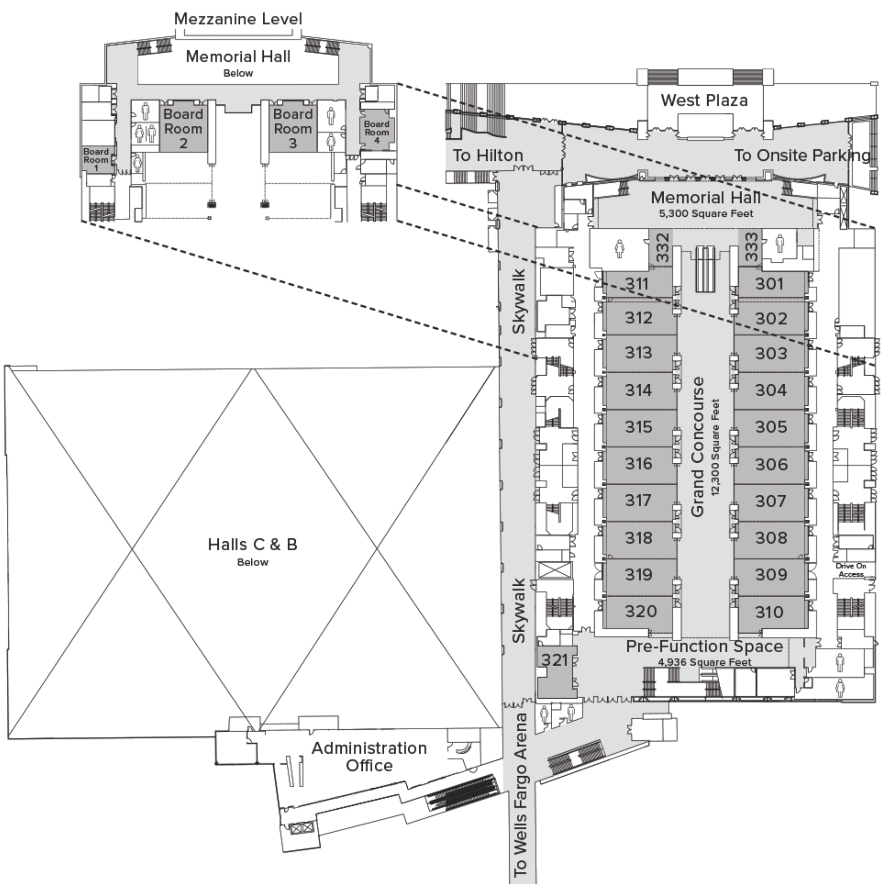
2:30 **BREAK**

3:00 **Breeding for Profitability: Keeping Balance for the Long Haul** Brian McCulloh, moderator – Wooldhill Farms
Producer panel: Steve Radakovich – Radakovich Cattle Company, Bart Jones – Red Hill Farms,
Mary Ann Kniebel – Kniebel Cattle Company

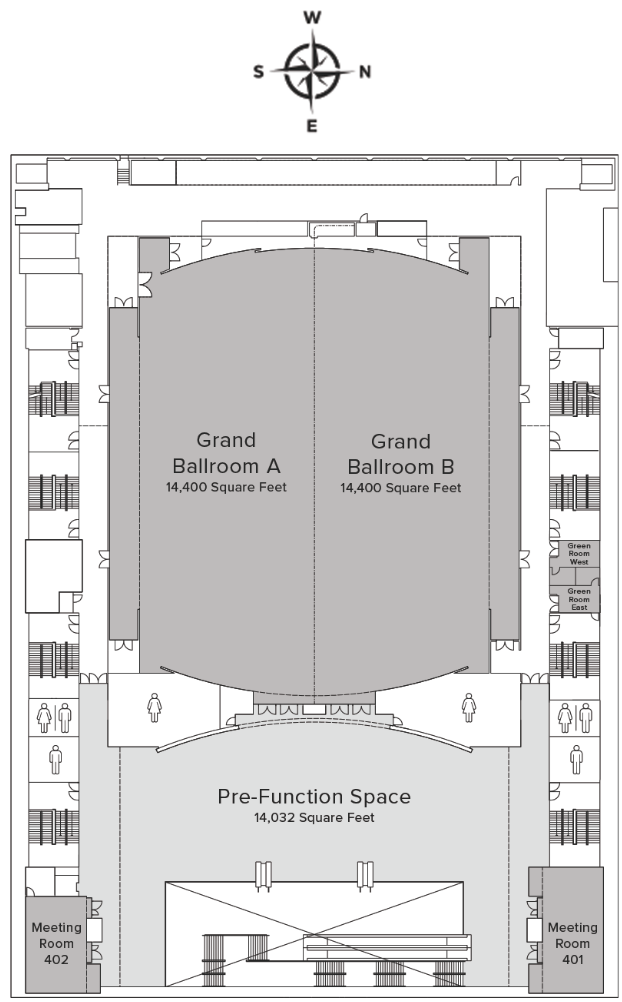
5:00 **Opening Reception** *sponsored by NEOGEN, Iowa Events Center – Ballroom A, Level 4*

7:00 p.m. **NATIONAL ASSOCIATION OF ANIMAL BREEDERS SYMPOSIUM: BEEF ON DAIRY What's Going On and Why?**
Sponsored by: National Association of Animal Breeders (NAAB), Iowa Events Center – Ballroom B, Level 4

The Changing AI Landscape Don Trimmer – Alta Genetics
Using Beef Genetics in a Modern Dairy Lynn Boadwine – Boadwine Farms Inc.
The Benefits of Beef on Dairy Randall Grimmius – Grimmius Cattle Company



LEVEL 3



LEVEL 4

Wednesday, June 23, 2021

7:30 a.m. **Registration open** – *Iowa Events Center – Level 3*
Continental breakfast *sponsored by Leachman Cattle of Colorado, Iowa Events Center –ballroom pre-luncheon space, Level 4*

GENERAL SESSION I—BEEF INDUSTRY: WHERE IS IT GOING? *sponsored by ZOETIS, Iowa Events Center – Ballroom B, Level 4*

8:00 **Opening Comments and Welcome** John Lawrence, vice president – Iowa State University Extension and Outreach

8:15 **Meat Consumer Purchasing Trends and Expectations** Michael Uetz, managing principal – Midan Marketing

9:00 **Lessons From Other Industries in Genetics** Jim Pillen, owner – Pillen Family Farms

9:45 **BREAK**

10:15 **We Can Sell More Beef** Dan Thomson, chair – Iowa State University Department of Animal Science

11:00 **What I Heard** Troy Marshall, Director of Commercial Industry Relations – American Angus Association

11:30 **Panel Discussion** Troy Marshall – moderator, featuring morning presenters

AWARDS LUNCHEON *Iowa Events Center – Ballroom A, Level 4*

12 p.m. Presenting BIF Commercial Producer • Continuing Service • Ambassador • Roy Wallace Scholarship

Technical Breakout Sessions

	Rooms 313-316, Level 3 **Advancements in** **GENOMICS AND GENETIC PREDICTION** Chair: Mark Thallman, Research Geneticist US Meat Animal Research Center	*Rooms 307-310, Level 3* **Advancements in** **PRODUCER APPLICATIONS** Chair: Darrh Bullock, professor University of Kentucky Extension	*Rooms 317-320, Level 3* **Advancements in** **EFFICIENCY AND ADAPTABILITY** Chair: Mark Enns, professor Colorado State University
2:00 p.m.	**Genomic Dissection and Prediction of Bull Fertility** Francisco Peñagaricano, assistant professor of quantitative genetics – University of Wisconsin	**Understanding the Value of Accuracy** Matt Spangler, professor and beef genetics specialist – University of Nebraska-Lincoln	**Calving Ease Cows: Optimal or Extreme?** Gary Bennett, supervisory research geneticist – US Meat Animal Research Center
2:45	**Proposed Guideline Revisions for Contemporary Groups** Mark Thallman, research geneticist – US Meat Animal Research Center; Matt Spangler, professor and beef genetics specialist – University of Nebraska-Lincoln	**Milk: Benefit or Burden** Ben Crites, Graduate Research Assistant – University of Kentucky	**An Introduction to the ARS Beef Grand Challenge Project** Larry Kuehn, research geneticist – US Meat Animal Research Center
3:20	**Break**	**Break**	**Break**
3:30	**Low-pass Sequencing Reveals Functional Genomics Affecting Cow Weight and Productivity** Warren Snelling, research geneticist – US Meat Animal Research Center	**Selecting for Dollars: Putting Selection Indices to Work** Troy Rowan, assistant professor – University of Tennessee	**A Piece of the Adaptability Puzzle: Multi-breed Hair-shedding Genetic Effects and EPDs** Jared Decker, associate professor – University of Missouri
4:15	**Developments in Research and Implementation Supporting Genomic Prediction for Australian Beef Cattle** Dr. David Johnston, Principal Scientist, Animal Genetics and Breeding Unit Staff – University of New England, Armidale, NSW, Australia	**Target Selection to Meet Consumer Demands** Jennifer Bormann, professor of beef breeding and genetics – Kansas State University	**Sire Differences Within Heart and Heart Fat Score in Beef Cattle** Isabella Kukor– Colorado State University

5:00 **Travel to Ames** Buses will load and depart from the west parking lot between 5-5:15pm: exit through the glass doors at the west end of the Community Choice Credit Union Convention Center, 300 level. Continue through the West Plaza until arriving on 5th Avenue where buses will be staged.

Driving to Ames? Stop by the conference desk and receive directions to the Iowa State University Hansen Agriculture Learning Center.

6:00 **Evening Social and Dinner at Iowa State University** *sponsored by Iowa State University, the Iowa Beef Council, Iowa Cattleman's Association and Iowa Premium- a National Beef Company*

7:30 p.m. **Program**
Welcome from Wendy Wintersteen, President – Iowa State University, and Dan Robison, Dean – ISU College of Agriculture and Life Sciences

Thursday, June 24, 2021

7:30 a.m. **Continental breakfast** *Iowa Events Center – Ballroom pre-luncheon space, Level 4*

GENERAL SESSION II—PRECISION LIVESTOCK TECHNOLOGY *sponsored by C-Lock, Iowa Events Center* **–** *Ballroom B, Level 4*

7:45 **Announcements**

8:00 **Gene Editing Today and in the Future** Alison Van Eenennaam, Animal Genomics and Biotechnology – University of California– Davis

8:45 **The Role of Technology in the Beef Industry** Justin Sexten, vice president of strategy – Precision Livestock Analytics

9:30 **BREAK**

10:00 **Applying Precision Technologies: Panel Discussion** Justin Sexten – moderator
Early implications of intelligent intake management on selection Pat Wall, extension specialist – Iowa State University Extension and Outreach
Our experience with behavior-monitoring ear tags Reiss Bruning, owner and operator – Bruning Farms
Our experience with virtual fencing systems Cody Jorgensen, owner and operator – Jorgensen Land and Livestock

11:00 **What I Heard** Scott Greiner, beef and sheep specialist – Virginia Tech University Extension

11:15 **BIF Board of Directors Caucuses and Elections** *Iowa Events Center* **–** *Ballroom A, Level 4*

12 p.m. **Awards Luncheon** *sponsored by American Angus Association*
Presenting BIF Pioneers • Seedstock Producer • Frank Baker and Larry Cundiff scholarship
• retiring president's comments • introduction of newly elected BIF Board of Directors • invitation to BIF 2022

Technical Breakout Sessions

	Rooms 313-316, Level 3 **Advancements in EMERGING TECHNOLOGY** **Chair: Megan Rolf, associate professor Kansas State University**	*Rooms 317-320, Level 3* **Advancements in END-PRODUCT IMPROVEMENT** **Chair: Tommy Perkins, associate professor West Texas A&M University**	*Rooms 307-310, Level 3* **Advancements in SELECTION DECISIONS** **Chair: Matt Spangler, professor University of Nebraska–Lincoln**
2:00 p.m.	**Multi-breed Genetic Evaluation: How Does It Work for Seedstock and Commercial Cattle?** Randie Culbertson, lead geneticist – American Simmental Association	**Ultrasound Guidelines Council Update** Patrick Wall, executive director – Ultrasound Guidelines Council	**An Update on and Demonstration of iGenDec** Matt Spangler, professor – University of Nebraska-Lincoln
2:45	**Gene-Edited Food Animals: The Path from Proof of Concept to Commercial Use** Tad Sonstegard, Chief Executive and Scientific Officer – Acceligen	**Impact of Ultrasound, Carcass, and Genomic Data on Body Composition Expected Progeny Differences** Kelli Retallick, director, Genetic and Genomic Program – American Angus Genetics Incorporated	**Examining the Impact of Situational Indexes on Selection Decisions** Bruce Golden, partner –Theta Solutions, LLC
3:20	**Break**	**Break**	**Break**
3:30	**Use of Advanced Reproductive Technologies and Inclusion of These Records in Genetic Evaluation** Mark Thallman and Alexandria Snider, research geneticists – US Meat Animal Research Center	**Use of New Generation Ultrasound Equipment to Collect Carcass Data** Tommy Perkins, associate professor – West Texas A&M University	**An Overview of Economic Selection Indexes Offered by American Breeds** John Genho, director, Genetic Prediction Group – Neogen
4:15	**Practical Examples of Machine Learning in Animal Breeding** Matt Spangler, professor – University of Nebraska–Lincoln	**Genomics Use in Improving Meat Quality in Cattle** Raluca Mateescu, professor – University of Florida	**Using Beef on Dairy Data to Increase the Accuracy of Selection Decisions for Carcass Traits** Bob Weaber, professor – Kansas State University

5:00 **Cocktail hour with the exhibitors**

6:00 p.m. **Dinner** on your own

Friday, June 25, 2021

POST-CONFERENCE TOURS

Tours depart at 7:30 a.m. / return by 6:00 p.m. • Both tours include lunch

Busses load and depart from the parking lot from the west parking lot of the event center. Exit through the glass doors at the west end of the Community Choice Credit Union Convention Center, 300 level. Continue through the West Plaza until arriving on 5th Avenue where buses will be staged.

Coming from the hotel? Take the skywalk to the convention center but do not enter the meeting area – turn left once in the convention center to exit into the West Plaza.

Eastern Iowa Tour

GRINNELL IOWA

Olympic Genetics Center Providing individual care and nutrition for client's donor cattle to achieve maximum potential in embryo collections and conception. They offer guidance and education to obtain optimum conception whether it be embryo transplant, artificial insemination, and/or other bovine reproductive services.

AMANA COLONIES IOWA

Amana Farms is made up of 26,000 acres with 8,500 acres of row crops, a 2,400 head cow/calf herd, a 4,000 head cattle feedlot, an anaerobic digester, and Iowa's largest privately held forest. A 1.6-million-gallon anaerobic digester was constructed here with secured funding from the Iowa Office of Energy Independence, and Amana Farms secured access to organic waste streams from nearby industrial partners which provided both a financial and environmental benefit. Waste product is used to produce energy and is applied to the fields as fertilizer without releasing methane gas into the atmosphere.

The Amana Society, Inc. is a one-of-a-kind legacy corporation located in the Amana Colonies. Established in 1932, businesses once a part of the original immigrant life style remain as thriving businesses within the Amana Society, Inc., reflecting a portrait of quality passed on from one generation to the next. These businesses continues to produce handcrafted furniture, unique woolens, authentic German foods, livestock, crops, energy production, forest products, and community services.

Exploring Amana will allow you to explore their local businesses such as the Amana General Store, Amana Meat Shop & Smokehouse, a woolen mill, or Millstream Brewing to name a few. Amana is famous for good things to eat and drink and many shops will offer a sample of the day from sausages to chocolate. Lunch will feature the historic, family-style dining Ronneburg Restaurant. Well-known for beloved specialties including sauerbraten, wiener schnitzel, jaeger schnitzel, and sausages.

Western Iowa Tour

DES MOINES IOWA

Hy-Vee, Incorporated is an employee-owned corporation operating 275+ retail stores across eight Midwestern states with sales of over $10 billion annually. The supermarket chain is synonymous with quality, variety, convenience, healthy lifestyles, culinary expertise, and superior customer service. Hy-Vee ranks in the Top 10 Most Trusted Brands and has been named one of America's Top 5 favorite grocery stores. The company's more than 85,000 employees provide "A Helpful Smile in Every Aisle" to customers every day. Hy-Vee is an innovator in beef retail and were the first to offer store-branded beef in Iowa, at that time featuring "Blue Ribbon Beef". As the beef industry evolved, Hy-Vee has been on the cutting-edge of heat-and-eat beef products, meal kits, and most recently e-commerce for beef. Tour their meat counter and question the beef managers about their vision for beef retail and tomorrow's consumer. For additional information, visit hy-vee.com.

LINDEN IOWA

Wilkerson Farms is the "poster family" for confined cow-calf housing, featuring the latest technology in hoop buildings. You will see how they manage cow-calf pairs in this type of facility, minimize the acreage required to run an Iowa cow-calf operation, and meet Iowa's environmental standards. Their operation is a satellite herd specializing in the development of recipients carrying embryos. Because of their experience in this type of operation, Wilkerson Farms been a feature stop at many previous field days.

MANNING IOWA

Wiese & Sons Herefords are long-time and nationally recognized breeders of Hereford seedstock. Starting with horned cattle in 1912, they have expanded into polled cattle and currently have the fifth generation of family members working within the cattle operation. The herd now consists of 450 purebred cows, and their goal has been to develop purebred Hereford cattle that will thrive in a variety of environments. They rotationally graze pastures, integrate annual forages into their cropping rotation, utilize synchronized AI, embryo transfer, EPD's and performance records into their breeding program. Environmental stewardship is a large focus with cattle being the main tool for land improvement.

EXIRA IOWA **Lauritsen Cattle Company** is a sixth-generation cattle feeding operation. The open feedlot houses 4000 head where the Lauritsen family provides cattle feeding services to customers across the country. The technologies used include individual animal identification, chute-side computers, CattleXpert record keeping, and individual carcass data collection. This year, Lauritsen Cattle Company is housing and feeding the 2020 Iowa Carcass Challenge steers, which is a program designed to help Iowa cow-calf producers gather performance and carcass data on calves in the finishing phase.

BIF President Joe Mushrush encourages producers to focus on producing efficient, sustainable beef.

Focusing on What Matters

"Right or wrong, there is going to be more emphasis on the sustainability of beef production," explains Kansas Cattleman Joe Mushrush. "We need to tell our story and explain how we produce beef in an efficient and sustainable manner."

Joe is currently serving as president of the Beef Improvement Federation (BIF), an organization dedicated to coordinating all segments of the beef industry – from researchers and producers to retailers – in an effort to improve the efficiency, profitability, and sustainability of beef production.

"Joe has been BIF president during one of the most trying times our society has experienced in the past few decades," says Bob Weaber, BIF executive director. "He took it all in stride and fulfilled the adage of 'When in doubt, lead.' BIF's impact and visibility in the industry has grown under Joe's leadership."

Joe and his wife of 41 years, Connie, have six adult children and enjoy spoiling their seven grandchildren. "One of the greatest rewards in life is when you raise kids and they want to do what you are doing with you," Joe says. Today back on the ranch working with Joe and Connie are their sons, Daniel and Chris.

The Ranch

Mushrush Ranches LLC is located in the picturesque Kansas Flint Hills near Strong City. The ranch is home to 800 registered Red Angus cows split into a fall- and spring-calving herd.

"Our focus is on the cows," Joe explains. "Our program has a strong maternal focus. We believe without the cow you don't have anything. Maternal traits will make you three times the money than growth and carcass traits."

The Mushrush breeding program includes an extensive artificial insemination (AI) program and the use of embryo transfer. The Mushrush family works with a cooperator herd to place about 120 to 150 embryos per year.

"We run our cows like they are commercial," Joe explains. "Our primary customer is the commercial cattleman, so we make sure we handle our cows in the same manner as our customers. Our breeding philosophy is based on a program, not individuals. Phenotypically, we select for moderate framed, easy fleshing individuals with a lot of natural thickness."

The family has high expectations of its cows and asks a lot of them. "Our cows calve unassisted in large pastures, raise a calf and maintain their breeding status in the herd all with minimal inputs," Joe adds. "Because of this, we put extra focus on calving ease, maintenance energy and stayability EPDs without sacrificing the carcass qualities that so many cattlemen need in today's grid-based markets."

The family hosts an annual bull sale in March offering 250 bulls. Joe says they also sell private-treaty bulls and groups of bred heifers. Each year the Mushrushes synchronize and AI about 600 commercial heifers. Many of these are sourced from bull buyers. Cull steers and heifers are fed out to obtain carcass data. The family also purchases some steers from customers to feed out.

Committed to total herd reporting, the Mushrush family collects and submits birth, weaning and yearling data, carcass, and ultrasound data to the Red Angus Association of America, in addition to mature cow weights, body condition scores, udder scores, foot scores and chute scores.

"Joe and his family are great role models and mentors of others in the performance cattle business," Weaber says. "They take their motto of 'All the data, all the time' seriously. Often, I would call Joe and catch them in the process of weighing or ultrasounding cattle. Mushrush Ranches has readily adopted new technologies utilized in genetic improvement and use that information to make sound breeding decisions."

They also DNA test all their calves. "Every cow on the place has been parent verified," Joe shares. "We strive to provide our customers with as much data as possible because this produces the most accurately described genetics possible," Joe says. "None of this is easy, but it is all done to give our customers confidence. We want to make sure that when you invest in Mushrush Ranches' genetics, you know exactly what you are going to get."

Along with focusing on producing the best genetics possible, the family is always looking for ways to improve its resources. They have implemented rotational grazing systems and other grass management strategies.

Joe says the ranch continues to be in an expansion mode as future generations consider making their home and livelihood part of Mushrush Ranches. They have leased land near Wakefield and are starting a red Sim-Angus herd at that location. He says the goal is to build that division to about 150 to 200 cows.

BIF involvement

Mushrush Red Angus was named BIF Seedstock Producer of the Year in 2011. "That really propelled my involvement in BIF," Joe explains. "I am very interested in cattle performance testing. One thing that drew me to the BIF organization, is the lack of politics. When the Board meets, we work to do what is best for the beef industry as a whole."

Joe was elected to the BIF Board in 2014 and served two terms before his presidency. "He's cool, quiet, efficient and effective," says Matt Perrier, 2020-21 BIF vice president. "Joe offered a level of steadiness to our Board during a year of uncertainty. I don't believe that he got to lead a single in-person meeting prior to the 2021 Symposium, yet he did a great job using technology to preside over our meetings via Zoom or phone."

Reflecting on his BIF Board tenure, Joe says he is proud of the efforts the organization made to remain effective during the pandemic including the shift to a virtual meeting in 2020. "We learned a lot from our shift to a virtual meeting," he says. "The virtual format allowed us more reach including international. It was exciting to see the amount of respect BIF has in the industry worldwide. The success of the 2020 Symposium has encouraged the Board to look at how we host the event in future years so we can continue to encourage international participation."

He is also excited about the move to the web-based Wiki format for the BIF guidelines. "The new format allows the guidelines to be continually updated to keep pace with the rapidly evolving field of objectively evaluating beef cattle," Joe explains.

"With all the 'pivots' and changes over the past year or two, Joe never seemed to waiver," Matt adds. "He knew our duties; he knew what our members expected, and he calmly led the organization forward to accomplish its mission."

Joe will pass the BIF reins to the next president on Thursday, June 24, but there's no doubt his passion and commitment to BIF's principles and goals will continue for years to come.

"The entire BIF team is excited to return to a 'face-to-face' format to better provide networking and educational opportunities for our members," Joe summarizes. "At the same time, we are equally excited to expand the opportunity for 'virtual participation' for those who are unable to make the journey to Iowa. As the beef industry continues to see new dynamics, I have no doubt that those who stay on the cutting edge by involvement with the BIF Symposium will be better poised for success."

SPEAKERS—Young Producers Symposium

Rachel Cutrer is co-owner of B.R. Cutrer, Inc. and president of Brahman Country Genetics, a global semen and embryo corporation. Internationally recognized as one of the most significant female Brahman breeders in history, she is also CEO of Ranch House Designs, Inc., an agricultural marketing agency, and oversees the Brahman Country Beef operation. Rachel holds a BS in Animal Science from Texas A&M University, where she was named the first ever Outstanding Young Alumni of Agriculture and Life Sciences. Rachel also earned her MS in Agricultural and Extension Education from Michigan State University and holds a prestigious Cornell University certification in women's leadership. The devoted wife of Brandon Cutrer and loving mother to their two beautiful daughters, Rachel takes the utmost care to honor her heritage while creating a new legacy for both the Brahman industry, and her family.

John Locke is a partner in the Locke Division of JD Hudgins, located in Hungerford, Texas. John grew up raising registered Brahman cattle and still is heavily involved in the family's business, but knew there was more to ranching than raising quality cattle. John and his family got involved in Ranching for Profit and were members of Executive Link for 6 years during which time John took on a larger leadership role in their business and has become a leader in regenerative grazing. John is passionate about the principles taught at Ranching for Profit and has experienced firsthand the transformation of the application of those principles can make in a ranching business.

SPEAKERS—General Session

Michael Uetz is a Managing Principal of Midan Marketing, meat marketing specialists since 2004. One of Michael's many roles at Midan is to drive the firm's consumer-focused research platform, giving him unique insight into how the demands of today's meat consumers are shaping retail trends from digital marketing to product branding. Recent proprietary research includes the impact of the COVID-19 pandemic on the meat industry and a first-of-its-kind Meat Consumer Segmentation Study. Michael's long-term connection with the meat industry started on his family's ranch in North Dakota and blossomed during his time at the National Cattlemen's Beef Association where he oversaw consumer research as well as retail and food service marketing programs. His understanding of the complete meat channel combined with his strategic approach to market research gives meat industry clients a competitive edge.

Jim Pillen grew up on a farm in Platte County, between Monroe and Platte Center and raised pigs with his father, Dale. Jim earned a BS in Animal Science from University of Nebraska-Lincoln and graduated from Kansas State as a doctor of veterinary medicine. In 1983 Jim returned to the area, opened a small animal practice, a swine vet consulting practice, and partnered with his dad with his 60-head sow farm.

As a second generation pork producer, Jim formed Pillen Family Farms in 1993. The business has grown into a premium pork producer with approximately 1,100 team members. In 2003 Pillen purchased a swine genetics supplier, currently known as DNA Genetics. The last fifteen years brought the addition of Jim's two oldest children, Sarah and Brock, into the Pillen Family Farms & DNA Genetics business, making them third generation pork producers.

Through the years, the Pillen business has evolved into grain merchandising with milling operations that purchase 14 million bushels of corn each year. The Pillen operation also includes a team of transportation drivers, hauling feed to farms and delivering animals to customers and to market. Most recently, the Pillen family became a partner in WholeStone Farms pork processing plant in Fremont, Nebraska, which completes the final piece of vertical integration for the business. Jim and wife Suzanne have four children: Sarah, Brock, Polly and Izic, and seven grandchildren.

Dan Thomson is a third generation bovine veterinarian from Clearfield, Iowa. Dr. Thomson received his BS in Animal Science and DVM from Iowa State University. He completed a MS in Ruminant Nutrition from South Dakota State University and a PhD in Ruminant Nutrition from Texas Tech University.

Thomson serves as the Chair of the Department of Animal Science Department at Iowa State University. He previously held the Jones Professor of Production Medicine and Epidemiology at Kansas State University's College of Veterinary Medicine. He created, founded, and directed the Beef Cattle Institute at Kansas State University. Thomson has served as the Global Co-leader for McDonald's Beef Health and Welfare Committee, sits on the YUM! Animal Welfare Council, chairs the Animal Welfare Committee of the National Cattlemen's Beef Association, and serves on the Animal Welfare Advisory Board of Tyson Fresh Meats.

He was an associate veterinarian with Veterinary Research and Consulting Services in Greeley, Colorado. He then served as the Director of Animal Health and Well-being for Cactus Feeders in Amarillo, Texas. Dr. Thomson still practices feedlot medicine in Nebraska, Kansas, Iowa, and Texas. He is an owner/partner in PAC veterinary and research services which oversees the veterinary care, health, and well-being for 20% of the US cattle of feed.

Thomson is recognized internationally as a leader in animal welfare, beef cattle production, and cattle health management. He is the founder and host of Doc Talk, a nationally aired beef cattle health veterinary show on television. He has hosted nearly 500 episodes of the show in its ninth season that reaches over 45 million homes world-wide. Dan is married to his wife Cindy and have four daughters: Kelly, Katelyn, Tory, and Sarah. They enjoy basketball, fishing in Southwest Iowa, and travelling together.

Justin Sexten is the strategic and product lead for Performance Livestock Analytics a part of Zoetis. His background helps bridge the customer success, sales and development teams, ensuring practical, innovative solutions for producers.

Prior to joining Performance Livestock Analytics, Sexten served as director of supply development for the Certified Angus Beef® brand, where he led the education and research efforts with cattle ranchers, academia, and allied industry. Prior to CAB, Justin was the State Extension Beef Nutrition Specialist at the University of Missouri with a research focus on forage-use efficiency. He continues to operate a small stocker operation and consulting nutrition business.

Raised on a diversified livestock and row-crop farm near Washington Court House, Ohio, Sexten earned his animal science degree from the University of Kentucky and his master's and doctorate degrees in ruminant nutrition from the University of Illinois. Justin, his wife, Julie, and three daughters reside in Columbia, Missouri.

Alison Van Eenennaam is a Cooperative Extension Specialist in the field of Animal Genomics and Biotechnology in the Department of Animal Science at University of California, Davis. She received a Bachelor of Agricultural Science from the University of Melbourne in Australia, and both an MS in Animal Science, and a PhD in Genetics from UC Davis. Her publicly-funded research and outreach program focuses on the use of animal genomics and biotechnology in livestock production systems. Her current research projects include the development of genome editing approaches for cattle. She serves as the bovine genome coordinator for the USDA National Animal Genome Research Program, and is an elected Fellow of the American Association for the Advancement of Science (AAAS). A passionate advocate of science, Dr. Van Eenennaam was the recipient of the Association of Public and Land-grant Universities (APLU) 2010 National Award for Excellence in Extension, American Society of Animal Science (ASAS) 2014 National Extension Award, the Council for Agricultural Science and Technology (CAST) 2014 Borlaug Communication Award, University of California – Davis 2019 James H. Meyer Distinguished Career Achievement Award, and ASAS 2019 Rockefeller Prentice Award in Animal Breeding and Genetics. Twitter: @BioBeef.

NOMINEES—Seedstock Producer of the Year

Cow Camp Ranch— Lost Springs, Kansas

Owners: The Brunner Family
Managers: Kent Brunner, Nolan Brunner

Cow Camp Ranch is located on the western edge of the Flint Hills near Lost Springs, Kansas, just off the old Santa Fe Trail. The Brunner family has been farming and ranching since the early 1890's and now is in its fifth generation of operation on some of the same land.

The registered cow herd was founded in 1969 by Kent Brunner, using some of the original Simmental genetics that were imported into the US Soon after, Cow Camp Ranch became an early member of the American Simmental Association (ASA). Today, the ranch is managed by Kent and his son, Nolan.

The cow herd consists of 800 registered Simmental, Sim-0Angus and Angus cows that are managed on native Flint Hills grass year-round. Crossbreeding is utilized to maximize the genetic potential of both the Simmental and Angus breeds. About 300 embryos are transferred every year, with the balance of the cow herd and replacement heifers artificially inseminated.

The Brunners market around 250 head of bulls each year, with the majority being sold through their annual spring bull sale held the first Friday in February. A select group of females are also marketed at the time, with the balance sold private treaty.

In addition to the seedstock operation, the Brunner family owns and operates a 9,000-head commercial feedyard, managed by Kent's brothers, Mark and Tracy Brunner. The entire Brunner family operation consists of 15,000 owned and leased acres, a large portion of which is native Flint Hills grazing lands. The remaining acres are devoted to hay and crop production.

Cow Camp Ranch was nominated by the Kansas Livestock Association.

Loving Farms Incorporated—Pawnee Rock, Kansas

Owners/Managers: Marty Loving, Scott Loving

What began as a small herd of multipurpose Shorthorns for Jack and Aletha Loving's family in 1950 has grown into one of the largest Shorthorn herds in the country and one of the most data driven, technologically advanced programs in the world. With more than 300 head of females active in the American Shorthorn Association, Marty Loving and his son, Scott, have emphasized the importance of accurate and comprehensive data collection and analysis.

From breeding and conception to calving ease and growth measurements through the feedout and harvest stage, nothing is overlooked or minimized in their drive to offer a complete commercial animal. Maternal traits are critically analyzed at every opportunity and is evidenced by Loving Farms' recognition of American Shorthorn Association Performance animals, of which they have had the most in the breed for six years running.

In 2017, they began testing all yearling bull prospects for feed efficiency utilizing the GrowSafe System. They have expanded that to all yearling replacement heifers. By feeding out their own calves they realized how economically important feed efficiency is to the bottom line and aim to improve these genetics and the profitability of the commercial producer as well as the sustainability of the industry.

The 6,500-acre diversified operation consists of dryland and irrigated corn, soybeans, wheat and grass pasture supporting nearly 300 cows. Loving Farms incorporates cover crops of rye and brassicas to minimize the amount of winter feed necessary. Loving Farms has also invested in a significant amount of surface drip irrigation to contribute to the sustainability of their farm and the industry.

The American Shorthorn Association nominated Loving Farms Inc.

Nextgen Cattle Company—Paxico, Kansas

Owners: Damon Thompson, Derek Thompson, Brad Lindstrom
Manager: Sam Myers

Nextgen Cattle Company is located in the Flint Hills of Kansas near Paxico. It was founded in 2015 with the goal of building a seedstock operation that will serve the needs of the commercial cattleman, as well as advancing the seedstock industry.

Nextgen raises both purebred Charolais and Beefmasters, and currently has 600 registered animals. These purebred cattle are produced using an extensive embryo transfer and artificial insemination program to quickly advance the quality of genetics.

Nextgen also manages a Beefmaster-influenced commercial cattle herd that is used as a testing herd for bulls and to create replacement females for the commercial cattleman. Nextgen Cattle operates two feed yards and a packing plant, making it a vertically integrated operation. Nextgen currently has two annual sales where they offer bulls and an elite set of females. The bulls that are offered have all been on a development test that includes feed efficiency testing and carcass ultrasound data. Calves sired by these bulls are eligible for a buyback program. Nextgen is continually striving to stay on the cutting edge and produce high-quality cattle that will serve the needs of commercial cow operations as well as improving seedstock operations.

The Beefmaster Breeders United nominated Nextgen Cattle Company.

Woodhill Farms— Viroqua, Wisconsin

Owners/Managers: Brian and Lori McCulloh, Dan and Anne Borgen

Started in 1984, Woodhill Farms originated with 35 registered Angus cows and 400 acres near Viroqua, Wisconsin. Today, the operation has grown to a nucleus cow herd of 280 registered Angus cows and 1,000 acres.

The Woodhill program commenced as EPDs were becoming available. The McCullohs and Borgens recognized their value and have incorporated them ever since. They have collected genomic DNA scans on all replacement heifers and bulls for the past nine years. As useful as “numbers” have been, consistent attention to physical traits has also been key to the Woodhill program success. The program was built on strong maternal traits. Adding carcass merit without compromising other traits has been accomplished over time.

The Woodhill team also works with three cooperator herds in Iowa where producers purchased a foundation unit of Woodhill females. They collectively discuss artificially insemination and natural service sire selections aligned with the Woodhill balanced-trait breeding objectives. Bull calves and data are evaluated at weaning. The top end is then selected and brought back to Wisconsin in preparation for the Woodhill bull sale, which has been hosted annually since 1991. Eighty females are also offered for sale each year.

The “Woodhill” prefix has also gained global brand awareness as the operation has marketed semen and embryos to five continents and has sold/leased more than 40 bulls to AI companies. Woodhill also received the Certified Angus Beef® Seedstock Producer “Commitment to Excellence” Award and the Wisconsin Beef Improvement Association “Seedstock Producer of the Year” Award.

Woodhill Farms was nominated by the American Angus Association and the Wisconsin Beef Improvement Association.

Past Seedstock Producers of the Year

2020	Your Family Farms	South Carolina
2019	Hinkson Angus Ranch	Kansas
2018	Van Newkirk Herefords	Nebraska
2017	Hunt Limousin Ranch	Nebraska
2016	Shaw Cattle Company	Idaho
2015	McCurry Angus Ranch	Kansas
2014	Schuler Red Angus	Nebraska
2013	Bradley 3 Ranch	Texas
2012	V8 Ranch	Texas
2011	Mushrush Red Angus	Kansas
2010	Sandhill Farms	Kansas
2009	Harrell Hereford Ranch	Oregon
2009	Champion Hill	Ohio
2008	TC Ranch	Nebraska
2007	Pelton Simmental Red Angus	Kansas
2006	Sauk Valley Angus	Ilinois
2005	Rishel Angus	Nebraska
2004	Camp Cooley Ranch	Texas
2003	Moser Ranch	Kansas
2002	Circle A Ranch	Missouri
2001	Sydenstricker Genetics	Missouri
2000	Fink Beef Genetics	Kansas
1999	Morven Farms	Virginia
1998	Knoll Crest Farms	Virginia
1998	Flying H Genetics	Nebraska
1997	Wehrmann Angus Ranch	Virginia
1997	Bob and Gloria Thomas	Oregon
1996	Frank Felton	Missouri
1995	Tom and Carolyn Perrier	Kansas
1994	Richard Janssen	Kansas
1993	R.A. “Rob” Brown	Texas
1993	J. David Nichols	Iowa
1992	Leonard Wulf & Sons	Minnesota
1991	Summitcrest Farms	Ohio
1990	Douglas and Molly Hoff	South Dakota
1989	Glynn Debter	Alabama
1988	W.T. “Bill” Bennett	Washington
1987	Henry Gardiner	Kansas
1986	Leonard Lodoen	North Dakota
1985	Ric Hoyt	Oregon
1984	Lee Nichols	Iowa
1983	Bill Borror	California
1982	A.F. “Frankie” Flint	New Mexico
1981	Bob Dickinson	Kansas
1980	Bill Wolfe	Oregon
1979	Jim Wolf	Nebraska
1978	James D. Bennett	Virginia
1977	Glenn Burrows	New Mexico
1976	Jorgenson Brothers	South Dakota
1975	Leslie J. Holden	Montana
1975	Jack Cooper	Montana
1974	Carlton Corbin	Oklahoma
1973	Mrs. R. W. Jones, Jr.	Georgia
1972	John Crowe	California

Arhart Farms—Alpena, South Dakota

Owners: Andrew and Missy Arhart, Jonathan and Joy Arhart
Managers: Andrew Arhart, Jonathan Arhart

Arhart Farms was founded in 1882 near Alpena, South Dakota. Focused primarily on commercial crossbreds at first, the farm transitioned to using purebred Simmental in the 1970s, followed by Angus and Angus x Simmental crosses. This change was driven by the progressive views of brothers LaVerne and Leroy Arhart, father and uncle of Andrew and Jonathan. Examples include being the first trained in and implementing artificial insemination (AI) techniques in their area, using irrigation to improve forage and pasture production, and using cover crops to extend fall grazing. Brothers Andrew and Jonathan are the fourth generation of their family to be in the cattle business.

The Arhart farm consists of 2,550 family-owned acres and roughly 3,500 rented acres. Of this land, roughly 1,500 acres are used for crops (corn, soybeans and forages), 1,000 acres are used for hay and alfalfa, leaving the rest as native pasture. In their current operation, the Arharts manage two distinct cow herds: a 200- to 300-head finishing feedlot, and a 10,000-pig finishing operation.

Their cow herds consist of 250 Angus and Angus-Simmental crosses ("black herd") and 350 Red Angus x Simmental crosses ("red herd"). Breeding in the black herd uses synchronized artificial insemination, breeding heifers to calve late January to early February, followed by cows in two cycles to calve February to March. Following AI, cleanup bulls are put with females for a 45-day window. The red herd utilizes only natural service breeding with a 45-day turnout window calving April to March. Across herds, they maintain a low open rate of 6-7%. From the calves produced, they provide replacement heifers (both herds), commercial seedstock bulls (black herd), and calves for finishing (both herds). The Arhart's utilize technology and innovative techniques to ensure sustainability and profitability of their operation.

Arhart Farms was nominated by North Dakota Beef Cattle Improvement Association.

Carter Cattle Company, LLC—Hope Hull, Alabama

Owners/Managers: Will and Monnie Carol Carter

A love for agriculture, hard work and lifelong learning are principles that define Carter Cattle Company. Located in central Alabama, along the Pintlala Creek, Carter Cattle Company is truly family-owned -and-operated, continuing a legacy of family farming since the 1820s.

Drs. Will and Monnie Carol Carter expanded the original land-base to 920 acres and established a cow herd consisting of 285 Sim-Angus and Brangus crossbred females. This Sim-Angus and Brangus cross provides an excellent balance of heterosis, growth, docility, maternal and carcass traits. The 90-day winter calving cow herd has been built using extensive performance data, strict selection criteria and Alabama BCIA proven genetics.
For heifers, thorough evaluation of consistent dam performance allows for strict selection to increase production longevity and a 60-day breeding season applying artificial insemination for genetically superior sires. The Alabama BCIA Commercial Record Keeping program with the Cattlemax system is pivotal for complete performance records in breeding, pregnancy percentage, actual and adjusted weaning weights, ratios, dam production history, gross sale income and extensive pasture management. A rotational grazing system is fully applied, grazing Bahiagrass in the summer and Ryegrass in the winter. Intensive rotational grazing has substantially decreased feed expense, improved soil health and pasture sustainability. A goal of Carter Cattle Company is to further advance grazing management by increasing number of paddocks, rotation frequency and decreasing paddock size. Focused analysis of all financial aspects is routinely assessed for operational efficiency, adjustments, and improvements. Carter Cattle Company continually strives to be sustainable and profitable for future generations.

Carter Cattle Company LLC was nominated byThe Alabama Beef Cattle Improvement Association.

MANCO Farms—Cascade, Iowa

Owners: Ralph, Dale, Brian Manternach and families
Managers: Dale and Sharon Manternach

MANCO is a family-owned corporation formed in 1984. Along with a cow-calf herd, the operation finishes cattle and hogs, raises corn, soybeans and hay, and has a trucking service. Ralph, his sons Dale and Brian and their wives, and now six grandsons all work together but Dale and his wife, Sharon, are primarily responsible for the cattle enterprise. They are located south of Cascade, Iowa, along the Maquoketa River in northern Jones County.

They currently manage about 260 commercial cows on roughly 500 acres of pasture, in a modified three-breed rotation, and also develop and sell bred heifers. The cow herd is predominantly Angus-based, with Angus-Gelbvieh Balancer maternal bulls and Charolais terminal sires. Heifers are estrus synchronized and artificially inseminated before exposing to a clean-up bull, while all cows are bull bred. Heifers start to calve in late-February and the mature cow herd calves in March and April. They practice a 75-day breeding season, so cows that do not fit their environment do not stay in the herd.
In addition to finishing out their own steers, they purchase mostly yearlings to finish in their open yards and confinement buildings. They are also partners in a sow farrowing unit which supplies feeder pigs for their finishing barns.

The majority of the crop land is in corn production to produce silage, high-moisture corn, and dry corn for cattle and hog feed, in addition to marketed grain. Their hay operation provides 100% of their hay needs, and some cover crops are utilized to provide additional forage.

MANCO Farms was nominated by Iowa State University.

Moore Cattle Company—Charleston, Arkansas

Owners/Managers: Jim and Missy Moore

Anything worth doing is worth doing right. Moore Cattle Company has had that mindset since it first started raising cattle. What started in the northwest corner of Arkansas in the 1920s as a multigenerational Hereford operation, is now a 275-head Angus herd on 1,200 acres of land.

Following college and a practical degree from two talented cattlemen, Jim and Missy Moore, took over the operation and really flipped the script for the success of the operation. The Moores went from raising a consistent commodity product to maximizing the genetic potential of their cattle after they realized the value they could earn from both sectors of the business: fed cattle and females.

A mindset shift took place after they figured they must be doing something right if people continued to come back and buy more cattle year after year. Instead of selling, the Moores focused on retaining ownership of their fed cattle and building a premiere cow herd without a single female purchased in more than 50 years.

Refining the herd for only the best was made easier for Moore Cattle Company with their forward-thinking mindset regarding data and technology. Whether it is improving the females or the fed cattle, they have used data to improve the product they are producing. They think it is their moral obligation to produce high-quality beef that makes people think they can't live without it.

Moore Cattle Company was nominated by The American Angus Association.

W & S Ranch Inc.—Smith Center, Kansas

Owners: Richard Weltmer, Kenton and Deborah Weltmer, Michael and Ladonna Weltmer, Philip and Jessica Weltmer

Manager: Philip Weltmer

After serving in the Korean War, Richard Weltmer and his wife, Avis (Sprague), put down roots southeast of Smith Center, Kansas, and founded Richard Weltmer Farms. They registered the W over S brand to represent Weltmer and Sprague and eventually Weltmer & Sons.

By 1977, both of their sons, Kenton and Mike, had returned to the ranch full time. In 1978, the operation's name transitioned to W & S Ranch, Inc. Philip, Richard's grandson, and his wife, Jessica, returned to the ranch full-time in 2003.

W & S Ranch encompasses more than 6,000 acres of owned and leased land on which the Weltmer family runs a commercial cow herd, a small registered Angus herd, a feedyard and a farming operation, where they raise corn, soybeans and wheat. The commercial and registered cow herds consist of a total of 180 cows. All females are bred through artificial insemination (AI) using Angus or Sim-Angus genetics and are followed with Angus cleanup bulls raised by the Weltmers. Cows calve between January 20 and March 1. AI and a tight calving window allow calves to be finished in the family's feedyard as a more uniform cohort, processed at 13 and a half months of age.

The cows rotationally graze on native and summer grasses from April 15 to October 1, then are placed on corn stalks. They have access to native grass during calving season and are provided supplemental feed from mid-January until breeding. W & S Ranch places an emphasis on improved genetics and profit-proven outcomes. With an openness to change, all segments of the business are continually evaluated to improve efficiency and effectiveness to maintain a viable operation for generations to come.

W & S Ranch Inc. was nominated by the Kansas Livestock Association.

Past BIF Commercial Producer of the Year

2020 Vest Ranches, Texas
2019 Mershon Cattle LLC, Missouri
2018 Woolfolk Ranch, Kansas
2017 Mundhenke Beef, Kansas
2016 Plum Thicket Farms, Nebraska
2015 Woodbury Farms, Kansas
2014 CB Farms Family Partnership, Kansas
2013 Darnall Ranch, Inc., Nebraska
2012 Maddux Cattle Company, Nebraska
2011 Quinn Cow Company, Nebraska
2010 Downey Ranch, Kansas
2009 JHL Ranch, Nebraska
2008 Kniebel Farms and Cattle Company, Kansas
2007 Broseco Ranch, Colorado
2006 Pitchfork Ranch, Illinois
2005 Prather Ranch, California
2004 Olsen Ranches, Inc., Nebraska
2003 Tailgate Ranch, Kansas
2002 Griffith Seedstock, Kansas
2001 Maxey Farms, Virginia
2000 Bill and Claudia Tucker, Virginia
1999 Mossy Creek Farm, Virginia
1999 Giles Family, Kansas
1998 Mike and Priscilla Kasten, Missouri
1998 Randy and Judy Mills, Kansas
1997 Merlin and Bonnie Anderson, Kansas
1996 Virgil and Mary Jo Huseman, Kansas
1995 Joe and Susan Thielen, Kansas
1994 Fran and Beth Dobitz, South Dakota
1993 Jon Ferguson, Kansas
1992 Kopp Family, Oregon
1991 Dave and Sandy Umbarger, Oregon
1990 Mike and Diana Hopper, Oregon
1989 Jerry Adamson, Nebraska
1988 Gary Johnson, Kansas
1987 Rodney G. Oliphant, Kansas
1986 Charles Fariss, Virginia
1985 Glenn Harvey, Oregon
1984 Bob and Sharon Beck, Oregon
1983 Al Smith, Virginia
1982 Sam Hands, Kansas
1981 Henry Gardiner, Kansas
1980 Jess Kilgore, Montana
1979 Bert Hawkins, Oregon
1978 Mose Tucker, Alabama
1977 Mary and Stephen Garst, Iowa
1976 Ron Baker, Oregon
1975 Gene Gates, Kansas
1974 Lloyd Nygard, North Dakota
1973 Pat Wilson, Florida
1972 Chan Cooper, Montana

Past BIF Pioneer Award Recipients

The Pioneer Award recognizes individuals who have made lasting contributions to the improvement of beef cattle, honoring those who have had a major role in acceptance of performance reporting and documentation as the primary means to make genetic change in beef cattle.

2020
Paul Bennett, Virginia
Craig Ludwig, posthumously
Charles McPeake, Georgia

2019
Jim Gibb, Colorado
Jerry Wulf, Minnesota

2018
Tim Holt, Colorado
Craig Huffhines, Texas
Mark Thallman, US Meat Animal Research Center, Nebraska

2017
Harvey Lemmon, posthumously, Lemmon Angus, Georgia
Dorian Garrick, Iowa State University

2016
Doug Hixon, University of Wyoming
Ronnie Green, University of Nebraska
Bill Rishel, Rishel Angus, Nebraska

2015
Paul Genho, Florida
Tom Woodward, Texas

2014
Merlyn Nielsen, Nebraska
Gary Bennett, Nebraska
Steve Radakovich, Iowa

2013
Keith Bertrand, Georgia
Ignacy Misztal, Georgia
Glenn Selk, Oklahoma

2012
Sally Buxkemper, Texas
Donald Franke, Louisiana
Leo McDonnell, Montana

2011
Mike Tess, Montana
Mike MacNeil, Montana
Jerry Lipsey, Montana

2010
Richard McClung, Virginia
John and Bettie Rotert, Missouri
Daryl Strohbehn, Iowa
Glen Klippenstein, Missouri

2009
Bruce Golden, California
Bruce Orvis, California
Roy McPhee, posthumously, California

2008
Donald Vaniman, Montana
Louis Latimer, Canada
Harry Haney, Canada
Bob Church, Canada

2007
Rob Brown, Texas
David and Emma Danciger, Colorado
Jim Gosey, Nebraska

2006
John Brethour, Kansas
Harlan and Dorotheann Rogers ,Mississippi
Dave Pingrey, Mississippi

2005
Jack and Gini Chase, Wyoming
Jack Cooper, Montana
Dale Davis, Montana
Les Holden, Montana
Don Kress, Montana

2004
Frank Felton, Missouri
Tom Jenkins, Nebraska
Joe Minyard, South Dakota

2003
George Chiga, Oklahoma
Burke Healey, Oklahoma
Keith Zoellner, Kansas

2002
H.H. “Hop” Dickenson, Kansas
Martin and Mary Jorgensen, South Dakota
L. Dale Van Vleck, Nebraska

2001
Larry Benyshek, Georgia
Minnie Lou Bradley, Texas
Tom Cartwright, Texas

2000
J. David Nichols, Iowa
Harlan Ritchie, Michigan
Robert R. Schalles, Kansas

1999
Joseph Graham, Virginia
John Pollak, New York
Richard Quaas, New York

1998
John Crouch, Missouri
Bob Dickinson, Kansas
Douglas MacKenzie Fraser, Canada

1997
Larry V. Cundiff, Nebraska
Henry Gardiner, Kansas
Jim Leachman, Montana

1996
A.L. “Ike” Eller, Virginia
Glynn Debter, Alabama

1995
James S. Brinks, Colorado
Robert E. Taylor, Colorado

1994
Tom Chrystal, Iowa
Robert C. DeBaca, Iowa
Roy A. Wallace, Ohio

1993
James D. Bennett, Virginia
M.K. “Curly” Cook, Georgia
O’Dell G. Daniel, Georgia
Hayes Gregory, North Carolina
Dixon Hubbard, Virginia
James W. “Pete” Patterson, North Dakota
Richard Willham, Iowa

1992
Frank Baker, Arkansas
Ron Baker, Oregon
Bill Borror, California
Walter Rowden, Arkansas

1991

Robert A. "Bob" Long, Texas

Bill Turner, Texas

1990

Donn and Sylvia Mitchell, Canada

Hoon Song, Canada

Jim Wilton, Canada

1989

Roy Beeby, Oklahoma

Will Butts, Tennessee

John W. Massey, Missouri

1988

Christian A. Dinkle, South Dakota

George F. and Mattie Ellis, New Mexico

A.F. "Frankie" Flint, New Mexico

1987

Glenn Burrows, New Mexico

Carlton Corbin, Oklahoma

Murray Corbin, Oklahoma

Max Deets, Kansas

1986

Charles R. Henderson, New York

Everett J. Warwick, Maryland

1985

Mick Crandell, South Dakota

Mel Kirkiede, North Dakota

1984

Bill Graham, Georgia

Max Hammond, Florida

Thomas J. Marlowe, Virginia

1983

Jim Elings, California

W. Dean Frischknecht, Oregon

Ben Kettle, Colorado

Jim Sanders, Nevada

Carroll O. Schoonover, Wyoming

1982

Gordon Dickerson, Nebraska

Mr. and Mrs. Percy Powers, Texas

1981

F.R. "Ferry" Carpenter, Colorado

Otha Grimes, Oklahoma

Milton England, Texas

L.A. Maddox, Jr., Texas

Charles Pratt, Oklahoma

Clyde Reed, Oklahoma

1980

Richard T. "Scotty" Clark, Colorado

Bryon L. Southwell, Georgia

1979

Robert Koch, Nebraska

Mr. and Mrs. Carl Roubicek, Arizona

Joseph J. Urick, Montana

1978

James B. Lingle, Maryland

R. Henry Mathiessen, Virginia

Bob Priode, Virginia

1977

Ralph Bogart, Oregon

Henry Holsman, South Dakota

Marvin Koger, Florida

John Lasley, Missouri

W. L. McCormick, Georgia

Paul Orcutt, Montana

J.P. Smith, Missouri

H.H. Stonaker, Colorado

1976

Forrest Bassford, Colorado

Doyle Chambers, Louisiana

Mrs. Waldo Emerson Forbes, Wyoming

C. Curtis Mast, Virginia

1975

Glenn Butts, Missouri

Keith Gregory, Nebraska

Braford Knapp, Jr., Montana

1974

Reuben Albaugh, California

Charles E. Bell, Jr., Virginia

John H. Knox, New Mexico

Paul Pattengale, Colorado

Fred Wilson, Montana

Ray Woodward, Montana

1973

Jay L. Lush, Iowa

Past BIF Continuing Service Award Recipients

Continuing Service Award winners have made major contributions to the BIF organization. This includes serving on the board of directors, speaking at BIF conventions, working on BIF guidelines and other behind-the-scenes activities. As BIF is a volunteer organization, it is this contribution of time and passion for the beef cattle industry that moves BIF forward.

2020

Donnell Brown—RA Brown Ranch, Texas

Frank David Kirkpatrick—University of Tennessee

2019

Craig Bieber—Bieber Red Angus, South Dakota

Scott Greiner—Virginia Tec University

Steve Munger—University of South Dakota

2018

Dan Moser—American Angus Association, Missouri

Lynn Pelton—Pelton Simmental/Red Angus, Kansas

Scott Speidel—Colorado State University

2017

Michelle Elmore—BCIA, Alabama

Shauna Hermel—Angus Journal, Missouri

Matthew Spangler—University of Nebraska–Lincoln

Kevin and Lydia Yon—Yon Family Farms, South Carolina

2016

John Pollakv—US Meat Animal Research Center, Nebraska

Alison Van Eenennaam—University of California, Davis

Alison Sunstrum—GrowSafe, Canada

Steve Kachman—University of Nebraska–Lincoln

2015

Joe Cassady—South Dakota State University

Andy Boston—Purdue University, Indiana

Lois Schreiner—Kansas State University

Chris Shivers—American Brahman Breeders Association, Texas

2014

Larry Kuehn—US Meat Animal Research Center, Nebraska

Wade Shafer—American Simmental Association, Montana

Warren Snelling—US Meat Animal Research Center, Nebraska

Susan Willmon—American Gelbvieh Association, Colorado

2013

Ben Eggers—Sydenstricker Genetic, Missouri

Brian House—Select Sires, Ohio

Lauren Hyde—American Simmental Association, Montana

Jerry Taylor—University of Missouri

Jack Ward—American Hereford Association, Missouri

2012

Tom Field, Nebraska

Stephen Hammack, Texas

Brian McCulloh, Wisconsin

Larry Olson, South Carolina

2011

Tommy Brown, Alabama

Mark Enns, Colorado

Joe Paschal, Texas

Marty Ropp, Montana

Bob Weaber, Missouri

2010

Bill Bowman, Missouri

Twig Marston, Nebraska

David Patterson, Missouri

Mike Tess, Montana

2009

Darrh Bullock, Kentucky

Dave Daley, California

Renee Lloyd, Iowa

Mark Thallman, Nebraska

2008

Doug Fee, Canada

Dale Kelly, Canada

Duncan Porteous, Canada

2007

Craig Huffhines, Missouri

Sally Northcutt, Missouri

2006

Jimmy Holliman, Alabama

Lisa Kriese-Anderson, Alabama

Dave Notter, Ohio

2005

Jerry Lipsey, Montana

Micheal MacNeil, Montana

Terry O'Neill, Montana

Robert Williams, Missouri

2004

Chris Christensen, South Dakota

Robert "Bob" Hough, Texas

Steven M. Kappes, Nebraska

Richard McClung, Virginia

2003

Sherry Doubet, Colorado

Ronnie Green, Virginia

Connee Quinn, Nebraska

Ronnie Silcox, Georgia

2002

S.R. Evans, Mississippi

Galen Fink, Kansas

Bill Hohenboken, Virginia

2001

William Altenburg, Colorado

Kent Andersen, Colorado

Don Boggs, South Dakota

2000

Ron BolzevKansas

Jed Dillard, Florida

1999

Bruce Golden, Colorado

John Hough, Georgia

Gary Johnson, Kansas

Norman Vincil, Virginia

1998

Keith Bertrand, Georgia

Richard Gilbert, Texas

Burke Healey, Oklahoma

1997

Glenn Brinkman, Texas

Russell Danielson, North Dakota

Gene Rouse, Iowa

1996

Doug L. Hixon, Wyoming

Harlan D. Ritchie, Michigan

1995
Paul Bennett, Virginia

Pat Gogginsv, Montana

Brian Pogue, Canada

1994
Bruce E. Cunningham, Montana

Loren Jackson, Texas

Marvin D. Nichols, Iowa

Steve Radakovich, Iowa

Doyle Wilson, Iowa

1993
Robert McGuire, Alabama

Charles McPeake, Georgia

Henry W. Webster, South Carolina

1992
Jack Chase, Wyoming

Leonard Wulf, Minnesota

1991
John Crouch, Missouri

1990
Robert Dickinson, Kansas

1989
Roger McCraw, North Carolina

1984
Bruce Howard, Canada

1987
Bill Borror, California

Jim Gibb, Missouri

Daryl Strohbehn, Iowa

1986
Larry Benyshek, Georgia

Ken W. Ellis, California

Earl Peterson, Montana

1985
Jim Glenn, IBIA

Dick Spader, Missouri

Roy Wallace, Ohio

1984
James Bennett, Virginia

M.K. Cook, Georgia

Craig Ludwig, Missouri

1983
Art Linton, Montana

1982
J.D. Mankin, Idaho

1981
Mark Keffeler, South Dakota

1980
Glenn Butts, PRI

Jim Gosey, Nebraska

1979
C.K. Allen, Missouri

William Durfey, NAAB

1978
James S. Brinks , Colorado

Martin Jorgensen, South Dakota

Paul D. Miller, Wisconsin

1977
Lloyd Schmitt, Montana

Don Vaniman, Montana

1976
A.L. Eller, Jr., Virginia

Ray Meyer, South Dakota

1975
Larry V. Cundiff, Nebraska

Dixon D. Hubbard, Washington, D.C.

J. David Nichols, Iowa

1974
Frank H. Baker, Oklahoma

D.D. Bennett, Oregon

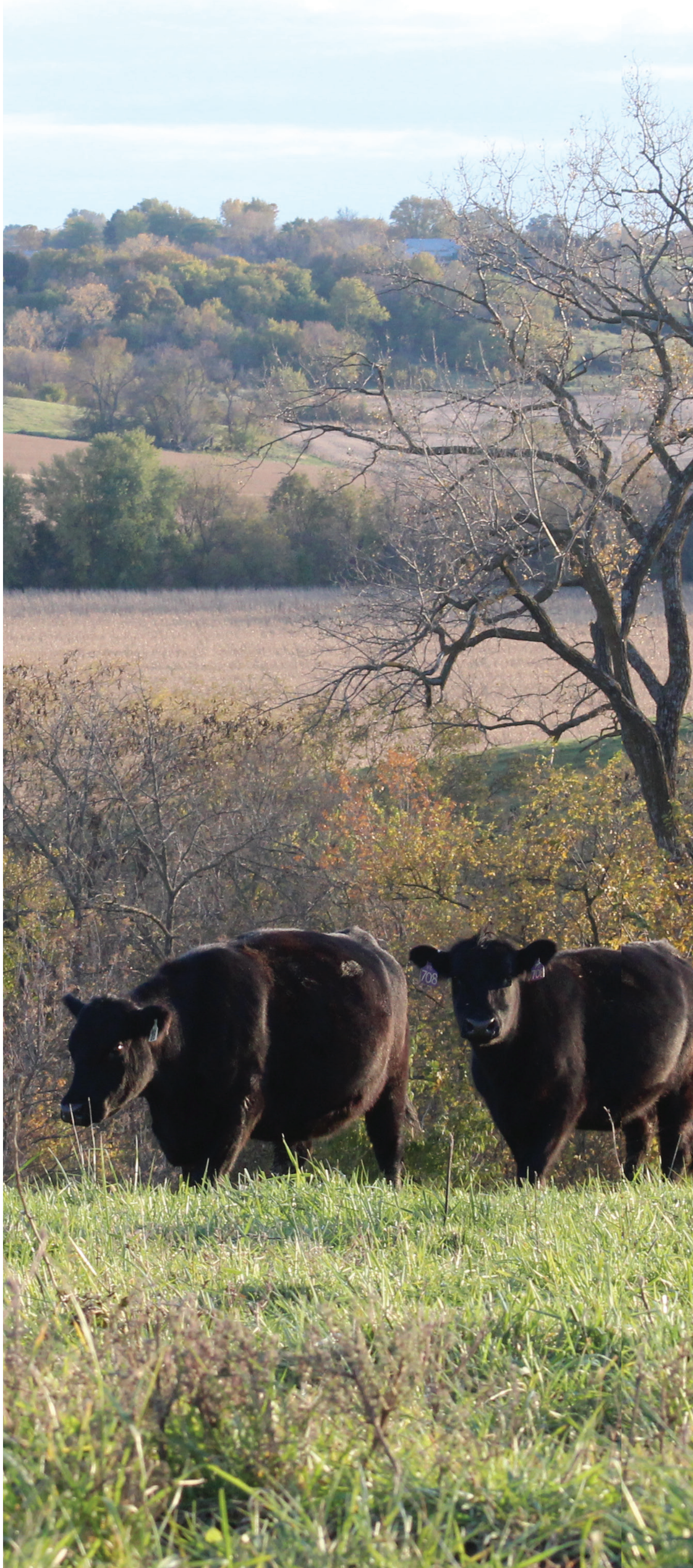
Richard Willham, Iowa

1973
F. R. Carpenter, Colorado

Robert DeBaca, Iowa

E.J. Warwick, Washington, D.C.

1972
Clarence Burch, Oklahoma



Past BIF Ambassador Award Recipients

The BIF Ambassador Award is given annually by BIF to a member of the media for his or her efforts in spreading the news of BIF and its principles to a larger audience.

2020 Becky Mills, Georgia—Freelance journalist

2019 Eric Grant, Missouri—Grant Company

2018 Pete Crow, Colorado—Western Livestock Journal

2017 Kevin Ochsner, Colorado—NCBA Cattlemen to Cattlemen

2016 Bob Hough, Colorado—Freelance writer

2015 E. C. Larkin, Texas—Gulf Coast Cattlemen

2014 John Maday, Colorado—Drovers CattleNetwork

2013 A.J. Smith, Oklahoma—Oklahoma Cowman Magazine

2012 Burt Rutherford, Texas—BEEF Magazine

2011 Jay Carlson, Kansas—BEEF Magazine

2010 Larry Atzenweiler, Andy Atzenweiler Missouri—Missouri Beef Cattlemen

2009 Kelli Toldeo, California—Cornerpost Publications

2008 Gren Winslow, Larry Thomas, Canada—Canadian Cattleman Magazine

2007 Angie Denton, Missouri—Hereford World

2006 Belinda Ary, Alabama—Cattle Today

2005 Steve Suther, Kansas—Certified Angus Beef LLC

2004 Kindra Gordon, South Dakota—Freelance Writer

2003 Troy Marshall, Missouri—Seedstock Digest

2002 Joe Roybal, Minnesota—BEEF Magazine

2001 Greg Hendersen, Kansas—Drovers

2000 Wes Ishmael, Texas—Clear Point Communications

1999 Shauna Rose Hermel, Missouri—Angus Journal and BEEF Magazine

1998 Keith Evans, Missouri—American Angus Association

1997 Bill Miller, Kansas—Beef Today

1996 Ed Bible, Missouri—Hereford World

1995 Nita Effertz, Idaho—Beef Today

1994 Hayes Walker III, Kansas—America's Beef Cattleman

1993 J.T. "Johnny" Jenkins, Georgia—Livestock Breeder Journal

1991 Dick Crow, Colorado—Western Livestock Journal

1990 Robert C. DeBaca, Iowa—The Ideal Beef Memo

1989 Forrest Bassford, Colorado—Western Livestock Journal

1988 Fred Knop, Kansas—Drovers Journal

1987 Chester Peterson, Kansas—Simmental Shield

1986 Warren Kester, Minnesota—BEEF Magazine

Past Baker/ Cundiff Award Recipients

The annual Frank Baker/Larry Cundiff Beef Improvement Essay Contest for graduate students provides an opportunity to recognize outstanding student research and competitive writing in honor of Frank Baker and Larry Cundiff. See page 51 for this year's Baker/Cundiff contest winning essay.

2021
Maci Mueller, University of California-Davis

2020
Johnna Baller, University of Nebraska-Lincoln
Kaitlyn Sarlo Davila, University of Florida
Katherine Upshaw, Kansas State University

2019
Madison Butler, Kansas State University

2018
Miranda Culbertson, Colorado State University
Jose Delgadillo Liberona, Texas A&M University

2017
Cashley Ahlberg, Kansas State University
Lindsay Upperman, University of California-Davis

2016
Kathleen Ochsner, University of Nebraska-Lincoln
Kashly Schweer, University of Nebraska-Lincoln

2015 and earlier: award was known as the Frank Baker Scholarship

2015
Justin Buchanan, Oklahoma State University
Jamie Parham, South Dakota State University

2014
Heather Bradford, Kansas State University
Xi Zeng, Colorado State University

2013
Heather Bradford, Kansas State University
Erika Downey, Texas A&M University

2012
Jeremy Howard, University of Nebraska-Lincoln
Kristina Weber, University of California-Davis

2011
Brian Brigham, Colorado State University
Megan Rolf, University of Missouri

2010
Kent A. Gray, North Carolina State University

2009
Lance Leachman, Virginia Polytechnic Institute & State University
Scott Speidel, Colorado State University

2008
Devori W. Beckman, Iowa State University
Kasey L. DeAtley, New Mexico State University

2007
Gabriela C. Márquez Betz, Colorado State University
Yuri Regis Montanholi, University of Guelph

2006
Amy Kelley, Montana State University
Jamie L. Williams, Colorado State University

2005
Matthew A. Cleveland, Colorado State University
David P. Kirschten, Cornell University

2004
Reynold Bergen, University of Guelph Angel Rios-Utrera, University of Nebraska

2003
Fernando F. Cardoso, Michigan State University
Charles Andrew McPeake, Michigan State University

2002
Katherina A. Donoghue, University of Georgia
Khathutshelo A. Nephawe, University of Nebraska

2001
Khathutshelo A. Nephawe, University of Nebraska
Janice M. Rumph, University of Nebraska

2000
Paul L. Charteris, Colorado State University
Katherine A. Donoghue, University of Georgia

1999
Janice M. Rumph, University of Nebraska
Bruce C. Shanks, Montana State University

1998
Patrick Doyle, Colorado State University
Shannon M. Schafer, Cornell University

1997
Rebecca K. Splan, University of Nebraska
Robert Williams, University of Georgia

1996
D.H. "Denny" Crews, Jr., Louisiana State University
Lowell S. Gould, University of Nebraska

1995
D. H. "Denny" Crews, Jr., Louisiana State University
Dan Moser, University of Georgia

1994
Kelly W. Bruns, Michigan State University
William Herring, University of Georgia

Roy A. Wallace Memorial Scholarship

The Roy A. Wallace Memorial Scholarship Fund was established to honor the life and career of Roy A. Wallace. Mr. Wallace worked for Select Sires for 40 years, serving as vice president of beef programs and devoted his life to beef cattle improvement. He became involved with BIF in its infancy and was the only person to attend each of the first 40 BIF conventions.Roy loved what BIF stood for: an organization that brings together purebred and commercial cattle breeders, academia and breed associations, all committed to improving beef cattle.

Wallace was honored with both the BIF Pioneer Award and BIF Continuing Service Award and co-authored the BIF 25-year history Ideas into Action.This scholarship was established to encourage young men and women interested in beef cattle improvement to pursue those interests as Mr. Wallace did—with dedication and passion.

Proceeds from the Roy A. Wallace Beef Improvement Federation Memorial Fund will be used to award scholarships to graduate and undergraduate students currently enrolled as fulltime students in pursuit of a degree related to the beef cattle industry. Criteria for selection will include demonstrated commitment and service to the beef cattle industry.

Preference will be given to students who have demonstrated a passion for the areas of beef breeding, genetics and reproduction. Additional considerations will include academic performance, personal character and service to the beef cattle industry.

Two scholarships will be offered in the amount of $1,250 each. One will be awarded to a student currently enrolled as an undergraduate and one will be awarded to a student currently enrolled in a master of science or doctoral program.

Past Scholarship Recipients—GRADUATE

2020 Lindsay Upperman, University of Nebraska-Lincoln

2019 Benjamin Crites, University of Kentucky

2018 Johnna Baller, University of Nebraska-Lincoln

2017 Dustin Aherin, Kansas State University

2016 Will Shaffer, Oklahoma State University

2015 Joshua Hasty, Colorado State University

2014 Heather Bradford, Kansas State University

2013 Loni Woolley, Texas Tech

2012 Ky Polher, University of Missouri

2011 Jessica Bussard, University of Kentucky

2010 Paige Johnson, Texas Tech University

Past Scholarship Recipients—UNDERGRADUATE

2020 Elle Moon, South Dakota State University

2019 Taylor Nikkel, Kansas State University

2018 Madison Butler, Oklahoma State University

2017 Tanner Aherin, Kansas State University

2016 Ryan Boldt, Colorado State University

2015 Matthew McIntosh, University of Connecticut

2014 Maci Lienemann, University of Nebraska- Lincoln

2013 Tyler Schultz, Kansas State University

2012 Natalie Laubner, Kansas State University

2011 Cassandra Kniebel, Kansas State University

2010 Sally Ruth Yon, Clemson University

Understanding Consumer Attitudes and Shopping Habits To Help Bolster Meat Case Activity—Michael Uetz, Principal, Midan Marketing

We've all heard and likely even used the phrase, "2020 will be a year like no other." While most did not shed a tear to see the year pass, the mark 2020 made on the meat industry and the meat buying consumer will have a long-term impact.

As the COVID-19 pandemic changed the way consumers were purchasing food, Midan Marketing surveyed meat consumers to get a better understanding of what was on their minds when making protein decisions.

One of the most significant changes we identified in our meat consumer research was the rise of e-commerce. According to data from IRI, grocery e-commerce dollar sales grew by 53% between October 2019 and October 2020. When looking solely at the refrigerated meats section, that number nearly doubles with 94% dollar sales growth from 2019. This increase also was reflected in our September research where we found that 53% of meat consumers purchased meat or chicken online during the pandemic. For about a quarter of these consumers, shopping for meat online was something they had never done. One-third of meat consumers say online shopping will be their primary method for purchasing meat in the future. As a result of this change, branding, packaging and online interfaces are areas retailers and processors will need to focus on to make the meat case adaptable to grocery pickup and delivery.

Other major shifts in consumer behavior came in the form of freezing meat, experimental cooking and even trying new cuts. Early in the pandemic, consumers were seeing headlines of meat plant closures and experiencing empty shelves at meat cases around the country. This caused a sense of panic and a behavioral change that may outlast the pandemic itself. From our September research, 53% of consumers reported they planned to freeze meat/chicken more often than normal. Shortages of protein products also caused consumers to purchase a wider variety of meat/chicken cuts than normal with 46% planning to do so. And, now that consumers are staying home more, 62% plan to experiment with different ways to cook the product and 44% are cooking larger servings to be used for multiple meals.

Health and wellness continue to be a priority for meat consumers. Our September report showed 62% of consumers were fearful for their own health and 77% said they were fearful for the health of others. Consumers took this concern to the meat case and 54% reported they were shopping for healthier types or cuts of meat and chicken. In December, we conducted a survey, targeting the natural and organic meat consumer and found that these shoppers are buying more claims-based meat since the pandemic began. When asked why they choose natural and organic products, the top response – with about 30% of respondents – is because they are looking for meat that is free from additives they perceive to be unhealthy. Secondarily, more than 20% of natural and organic meat shoppers say they purchase these products for reasons pertaining to better health and wellness.

Another area of the industry that was greatly impacted by the pandemic was foodservice. In October we asked consumers about their eating out habits. Only 50% of meat consumers said they had eaten inside a restaurant since the beginning of the pandemic. During the same time, 87% had placed an order for pickup/takeout. (And with the increase in COVID-19 cases and the closing of dining rooms, this number may be increasing.) To help fill the gap of what meat consumers are missing from restaurant dining – 84% say they regularly order meals with meat or poultry items and 41% say dishes they can't create at home – we have seen retailers develop unique partnerships with local/regional foodservice companies to ensure shoppers can continue to find their favorite restaurant menu items.

Consumer Segment Shifts

Historically, major cultural events such as the 2008 financial crisis have resulted in both short-term and long-term shopper behavior shifts and created new segments of consumers (i.e., Baby Boomers and Millennials). The COVID-19 pandemic has had similar implications for consumers. In September 2020, Midan Marketing revisited our groundbreaking Meat Consumer Segmentation 2.0 research, initially released in 2019. We wanted to see if the global health crisis affected the five meat and chicken consumer segments we identified in the previous year. A nationally representative sample of the meat-eating population was surveyed to determine if the distribution of segments had changed.

We learned the defining characteristics of each segment remained unchanged, but the number of consumers in certain segments did change, creating opportunity for the meat industry to identify and respond to the preferences of the meat-buying consumer.

Compared to the Segmentation 2.0 results from early 2019, there was a significant shift in four of the five consumer segments during the COVID-19 pandemic. The segment with the largest shift was Convenience Chasers which increased by 9 percentage points. This is the largest group of consumers and encompasses those who are time-pressed, shop for convenience first and are price-conscious. As of October, 24% of meat consumers reported a decrease in household income since the beginning of the pandemic. Combined with the number of ways consumers have been stretched during this global health crisis – remote working, providing teaching support, etc. – it makes sense that this group is looking toward convenience when preparing meat/poultry meals.

Other consumer segments that saw significant shifts included Protein Progressives, Aging Traditionalists and Wellness Divas. Another segment that increased was the Protein Progressives. This group likes to experiment and will increasingly replace meat and poultry with plant-based proteins. Aging Traditionalists, that group of consumers who keep meat at the center of their plate, decreased by 5 percentage points. It's important to keep reminding this group of meat's awesome nutritional profile.

When we revisited the Segmentation survey, we also asked consumers to indicate their level of agreement with a variety of statements. Among the statements, four increased by more than 10 percentage points and are highlights for the industry.

Likely due to the amount of at-home cooking that has taken place since the beginning of the pandemic, the number of consumers who noted they love to cook meat grew by 14 percentage points. That's great news for the industry. It seems that the number of YouTube videos, blogs and social media posts consumers watched for how-to instructions and recipe ideas showed them that meat wasn't so difficult to cook. Another statement found more favorable was that meat contains nutrients not found in any other foods (11 point increase). So, now they like to cook meat and they recognize it is packed with key nutrients.

If you carry a branded meat product in the meat case, consumers also agree that they look for a name-brand meat and believe it's worth the extra spend (11 point increase) and they recognize and look for meat that is USDA certified (up 11 points).

As you develop your marketing plans for your 2021 meat program, there's a lot of good news to talk about when it comes to the meat case. In order to be successful, you will need to understand who your target consumer is and what their particular preferences and needs are so you can keep them coming back.

NOTES

Lessons in Genetics from the Pork Industry—Jim Pillen

Introduction

Producing pork has been a passion of Pillen Family Farms since 1984 when I partnered with my father to raise 60 sows on dirt lots just northwest of Columbus, NE. We evolved into selling wean pigs and genetic multiplication in the 1990's, building our first 2500 sow farm in 1993 across the road from our home farm. Over the next two decades, we grew the business with two major goals in mind: create high quality jobs in rural Nebraska and sell 8 million lbs/sow/year. Today, Pillen Family Farms has grown to 75,000 sows farrow-to-finish. In 2018, we completed the final piece of vertical integration by purchasing the former Hormel packing plant in Fremont, Nebraska, via our ownership in Wholestone Farms. We take pride in the privilege and responsibility to feed 13 million people.

I became involved in the swine genetics business early in my career from two different avenues. From 1991 to 1996 I consulted as a veterinarian for a major genetic supplier within their nucleus operations located in Oklahoma. In addition, our production company became involved in the multiplication of gilts for sale to commercial pork producers. These experiences were extremely influential on my understanding of the value genetics can deliver, or not deliver, to a commercial producer. It became increasingly evident to me that a successful genetic program can have only one goal…to provide the genetic potential to achieve world-class performance for the pork producer. The belief I formulated then, and have retained to this day, is that a genetic program run by producers, for producers, is essential for the long-term success of the production businesses that compose our industry.

The opportunity to gain direct influence on the direction of a genetic program arrived in 2003 with the purchase of a small, local genetic supplier known then as Danbred North America. At the time, the company was tied to the Danish National Breeding program which was a producer-owned, producer-directed genetic program designed to purely serve the needs of the Danish producer. This approach to genetic improvement fit well with our beliefs about genetic suppliers and gave us the opportunity to gain influence on the product we were using every day in our commercial system and help U.S. producers gain access to world-class genetics. In 2012, our position was further solidified when we separated from Danbred and rebranded as DNA Genetics, also becoming an independent genetic supplier with complete control over the direction of the genetic program. Since the original purchase, DNA Genetics has grown to become the second largest genetic supplier in the U.S. and Canada with genetic influence on "2 out of 5 Strips of Bacon".

Today, I hope to share some lessons we've learned as pork producers that have driven us toward providing genetics that pork producers need to remain competitive.

The Best Pig Always Wins

It goes without saying that a genetic supplier needs to understand the end consumer and the product they desire. Pork must possess the quality attributes (taste, texture, tenderness, fat content, juiciness) that keep a consumer returning. However, to reach this end goal supply chain economics, particularly live production costs, are critical.

Over the last two decades, there has been a dramatic shift in terminal sires used at the commercial level. In 2003, we estimate that only about 30% of the pork produced in the U.S. was sired by a purebred Duroc boar. The remaining 70% of pigs were produced using Pietran and Hampshire-based terminal sires. This occurred because the industry made the shift to leaner pigs with higher cutability and the need for the producer to improve feed efficiency to better compete with poultry. The Pietran and Hampshire-based lines, at the time, delivered the carcass premiums and the cost of production demanded by the industry, whereas Duroc lagged. Producers essentially voted with their production costs on the type of sire line they would use.

The rise of the export market, and the profitability it represented, began a push for improved meat quality from packers and the Duroc could deliver this in a far superior way compared to the dominant sire lines at the time. The only thing holding the industry back from the switch was having a Duroc line that could deliver the production performance to compete, combined with the meat quality attributes the packers were pushing for. This is where the Duroc line available through DNA Genetics was on the forefront of driving the industry toward a Duroc sire. The focus on producer needs for performance in growth, feed conversion and carcass cutability had produced a Duroc line that could compete and win against the Pietran and Hampshire lines in these traits, but also brought superior pork quality.

Today we estimate that Duroc sires produce more than 80% of all market pigs and more than half of those (40-45%) are produced by the DNA Line 600 Duroc boar. The Duroc as a terminal sire has become the Angus of the pork industry. This transition would have never happened without identifying what the producer required to remain competitive. It was not meat quality that drove the change, it was the ability to produce the requested quality at the lowest possible cost throughout the supply chain that did. The lesson is to understand the true economics of your customer and center everything in the genetic program on making them successful.

Keep it Simple, but Do What it Takes

Creating competitive genetic progress is not a high-tech, difficult to understand formula. It is created by disciplined data collection on a large scale, accurate ranking of animals, selecting and retaining the best and culling based on data. There are no secrets in the genetics business. What differentiates suppliers is the discipline of implementing the fundamentals. Championship teams master the fundamentals and execute them every play. The same is true in a genetic program and one must believe this and stay focused. It is the fundamentals that create the opportunity for applying technology when it makes sense to do so. Not implementing the fundamentals 100% of the time results in second place, at best.

One reality of genetic improvement is that the larger the nucleus herd size, the more progress is possible. This is due to measuring more animals and the associated improvement in accuracy of breeding values along with lower inbreeding and preservation of genetic variation over the long-term. To achieve competitive progress, we reduced our product lines to be derived from three nucleus populations: purebred Duroc, Yorkshire and Landrace. Our commercial pig is a Duroc terminal sire produced from a F1 cross of the Yorkshire and Landrace. We do not make space or time for other sire lines or a range of female lines. Maintaining large populations of these three nucleus lines allowed us to focus our genetic program and maximize genetic improvement within each for the benefit of the commercial producer. We do not try to make a pig for every situation, but one that is the best for the core of our business, and that wins a lot of games.

Be In Front of the Industry

Genetic improvement takes a long time to move from its creation at the nucleus to a commercial environment. Five to 7 years in a swine genetic pyramid. As a producer, in addition to taking care of the daily events we all cope with, we must be looking ahead and be ready to change to remain competitive. There are two examples of how we have been able to do this with our genetic supply.

First, the sow we use in our commercial operations had become more productive over time. Genetics had improved for pigs born alive and we were getting more pigs than we ever had before. However, we were working harder than we ever did before to wean those pigs and move them through our system. This required more skilled labor, which is always in short supply. We did not see this type of genetic progress letting up and we knew we had to move toward a sow that is more self-reliant and able to be highly productive on her own. We talked with a large range of customers representing a broad swath of the industry and we know we are not alone in our assessment of what the sow of the future had to look like. This resulted in undertaking a complete change in our selection program which began over eight years ago.

We wanted a highly productive female that produced large litters of uniform and large pigs that thrived in the pre-weaning environment, and weaned at a heavy weight. Weight at birth and weight at weaning were key drivers of survival both pre-weaning and in the nursery post-weaning. After a lot of debate and discussion, we landed on a ‘keep it simple’ goal. We wanted a sow that produced and weaned 14, 14-pound pigs at 21 days of age…and we wanted the sow to do this on her own. This goal became known as 14:14:21 and has become the driver of the genetic program. Setting this as our target, we set about developing a selection program to hit that target. This included not only selecting for litter size, but forcing the additional pigs produced to be of higher quality by selecting sows that produce a larger pig at birth. Larger pigs have better pre-weaning survival rates. We implemented selection for teat count to improve the ability of a sow to nurse more pigs and began selection for sows that improved pre-weaning growth rate that resulted in a heavier pig at weaning.

Given what has been implemented, we can now predict from the genetic trend in each trait when we will hit our goal of 14:14:21. It is realistic that this will become our average sow in 8-10 years based on current genetic trends. A labor becomes more difficult, and more tools (like antibiotics) will be less available to us as an industry, the direction we are taking the sow line will leave us prepared as a producer to remain competitive in the industry of the future.

As a second example, our family decided in 2018 to forward integrate into the packing segment of the business through ownership in Wholestone Farms with their packing plant in Fremont, NE. This integration step was important for us to commit to, but is also a general viewpoint throughout the industry as the ties and ownership between production, packing and processing continue to become more coordinated. Being involved at this level of the pork chain provides insights that can be applied to our genetic program that will have a positive impact across the industry.

How this will impact the genetic program is still evolving, but we will clearly be moving from a program that is designed to ‘drop the pig at the dock’ to one that will involve the impact of genetics within the plant itself. This will likely include more emphasis on the yield of wholesale carcass cuts, meat quality and from a production standpoint, traceability of product. The value proposition will change which will in turn drive the genetic program we require to be successful.

Perhaps the lesson in both examples is the need to understand the direction of the industry, deeply understand the economics that are associated with a successful pork chain and to be bold enough to act so that the genetics required are available when the industry needs them

Conclusion

Producing food for the world is the noblest of professions. At a time when so much of what we believe in and do every day appears to be under attack, it is important that we persevere, educate and continue to produce food in a sustainable manner. Being involved in packing, production and genetics has been humbling, but also has given us a unique and comprehensive viewpoint to leverage and create value for the industry. At no time in our history of producing food have we produced so much abundance, with so small of input. Next year, we can all confidently make the same statement again. Genetics, world-class production and great people with great ideas will continue to keep this statement a reality.

Just remember, the best pig wins, keep it simple, but do what it takes, and keep looking ahead to stay in front.

We can sell more beef—Dan Thomson, PhD, DVM

Introduction: How Did We Get Here?
My title may sound like economics or the discovery of more markets for beef products. But, in reality, it is about sustainability in our beef industry and reclaiming market share we have lost in the US over the years. In my work with McDonalds Corporation, I have been lucky to work with Mr. Bruce Feinberg. One day he told me that I needed to quit thinking about consumer and retail demands on our industry as an audit, punishment, or criticism. But rather, start thinking that if we make continuous improvement in the field, our retailers have the messages to sell more beef.

I have been fortunate to be involved with agriculture and veterinary medicine my entire life. I lived through the 80's when we lost so many farms. We witnessed the consolidation of the swine industry from small herds to large integrators. While I was an undergraduate we focused on genetic improvement and as a graduate student we had the advent of metabolic modifiers.

In the 1990s food safety, E. coli, Jack in the box, and HACCP in packing plants were a focus, but until the big Conagra recall in 2001-2002 we did not see pre-harvest food safety action take place in the feedlots. Also during the early 2000s, the animal welfare era, factory farms, and animal rights groups kicked up. We experienced animal health and disease outbreak with BSE, FMD, avian influenza, porcine epidemic diarrhea and more. Over a decade or so, the natural/organic labeling and specialized grocers increased, bringing debate on technology in agriculture. GMO feed and antibiotic usage have been front and center as of late. Human resource issues and keeping rural America's mainstreets and schools open have been topics over the last 40 years. And now, traceability of beef products and plant-based proteins are challenging our industry.

All of these events had an impact on sustainability of livestock systems. They made us balance the issue at hand with all others in concert to figure out how to feed the world. Constant monitoring of all variables is imperative and we can not a let single agenda, mission, or issue to define sustainability.

What is Sustainability?
The dictionary says sustainability is the ability to be sustained, supported, upheld, or confirmed. It is mostly tied back to ecology, the planet's health, and environmental indicators. However, it means different things to different people depending on where you sit. Is it the sustainability of humankind? Is it the sustainability of the people in your country? Your individual commodity industry? Is it your corporation's sustainability? How about the sustainability of your household spendable income? Do you practice in your personal life what you represent in your professional life? Do you drive a hybrid, eat too much, have kid skip the YMCA league to be on a traveling basketball team? Sustainability of livestock production has individual, operation, local, state, national, and international definitions and for every complex problem there is a simple answer and it is wrong.

We must eat. Agriculture is necessary. Livestock systems are necessary. So, ag sustainability is important and necessary for humankind sustainability. Sustainability is measured by outcomes such as profit, performance, mortality, green houses gasses, food security etc. But, agriculture sustainability could be measured by human health as well.

Balance and Monitoring: Nothing Lasts Forever
"Life is like riding a bicycle. To keep your balance you must keep moving." Albert Einstein

Sustainability and industry evolution are balances. They never sit still and they are complex. Antibiotic usage, food safety, food security, environmental stewardship, animal health, human health and so much more must be measured constantly and kept in balance. Sustainability should not be audited as pass/fail but rather constantly tracked for continuous improvement of sustainability key performance indicators which are moving targets.

A quote from a paper from the National Academies of Science written by Mario Herrero and Phillip Thornton[1] says, "Recent global assessments have considered particular elements of livestock and livestock systems, but none addresses such systems and their considerable variations in a comprehensive, integrated way. This has led to inaccurate simplifications of the messages surrounding how to manage the livestock sector's growth in the future. The lack of a systems perspective has also curtailed explorations of more sustainable options for the sector's development. This needs to be rectified. Global change will have highly differentiated impacts on food, livelihoods, and ecosystem goods and services from livestock systems around the world."

The livestock industry must practice brutal honestly. In Wheeler's book[2] *Understanding Variation: The Key to Managing Chaos,* to change an outcome you must change the process, distort the process, or distort the data. What are the real time signals we can use to monitor our industry sustainability beyond supply and demand that help us understand where to improve to remain in business? In other words, which operations are utilizing the correct management practices with the right genetics to remain in business in the future. We can't quit learning. We can't quit improving.

The more I read about sustainability, globalization and climate change, more I am certain that the environment changes will have more impact on the production of livestock than livestock production will have on environmental change.

Sustainability could be a holistic view of production systems and technology adaptation. There are many examples of balancing sustainability indicators directly and indirectly related to livestock production. In turn, these indicators can be used by retail to market more beef to our consumers. Sustainability is a balance between playing defense and offense. Our industry has been too defensive minded for too long.

- Animal health and food safety
- Animal growth efficiency and animal welfare: animal housing, factory farming perception, slow growth
- Intensive agriculture and animal health: Bovine respiratory disease, liver abscess and bloat, water
- Extensive agriculture and animal health: Avian influenza, PED, prey
- Extensive agriculture and reliance on weather: drought, blizzard, etc.
- AB usage and human health/animal health: antibiotic usage, antibiotic resistance
- Food safety and security: safe, wholesome, nutritious, affordable, available

Marketing of Sustainability Indicators

Anthony Robins as self-help guru of the 1980s said, “The two things that drive people are fear and pleasure.” Today, we see human pharmaceutical companies market disease to get people to use their products, just ask your doctor for a free trial. Some ads sell drugs from the fear of dying or being in pain and others sell pleasure of better complexion or less pain.

Activists masquerading as consumers are convincing restaurants to market their activist “fear” agendas to sell our beef, poultry, dairy, and pork products. David AbiDaoud blogged[3], “Fear is an interesting emotion which affects the thought process and reaction of individuals. Therefore, fear can be used as a unique marketing tool to make consumers loyal. It may not be the safest tactic but if used correctly it can create huge impact.” Restaurants have fought over a captive 4% of personal income of people in the United States. Restaurants do not feed the poor. They feed those that can afford you to plan the meal, cook the meal, and do the dishes. Grocery stores feed the poor. They take food stamps and SNAP coupons. In the end, sustainability has many definitions that can fit many different marketing platforms.

The rich can afford to error on the side of safety and feel pleasure in saving the planet from buying organic food. The poor just need to eat. Retailers must have patience and use sustainability modeling prudently. Getting this right is so important. Most people literally can’t afford for us to get it wrong.

Food costs play a major factor in the determination of poverty in this country. Removal or discontinued use of technology or AB or management or housing without evidence-based or outcome-based decision will have lasting effects on society beyond next quarter or next year’s sales report. If food prices go up with no changes in incomes, poverty increases. Reliance on food stamps increases. The value of our tax dollar decreases. This is not just an agriculture sustainability issue, it is a societal sustainability issue. This is a human health issue.

We have forgotten how little money most people make and the decisions are being made by people that can afford almost any change. Based on data from USDA Economic Research Service[4], food insecurity in the US occurs at the same rate, around 15%, in urban, suburban, and rural areas. The rate of food insecurity is twice as high Latinos and African Americans than in Caucasian families in the US. We must feed our people. The highest rate of food insecurity occurs in homes where a single mom is raising children at 36%. Don’t show up on a Saturday to box a meal or to give a meal for so many dollars spent in your store then remove practices or technology that increases the price of food without proper due diligence.

Bill Gates was quoted to say, “If we can spend the early decades of the 21st century finding approaches that meet the needs of the poor in ways that generate profits and recognition for business, we will have found a sustainable way to reduce poverty in the world.”

Conclusion

Appropriate, honest sustainability studies are necessary for agriculture and livestock producers. Maybe there are changes a person can implement to improve their sustainability, or maybe they need to change what they raise? Global sustainability, humankind sustainability, national sustainability, local sustainability. We have to feed people. We have to keep food affordable. Sustainability always is tied to economics. Wealth = Food and Poverty = Starvation. It is hard for starving people in poverty to worry about 100 years from now when they are worried about eating tomorrow. Likewise, people who have abundance want to make sure it continues over time.

Our globe’s climate is going to change. Water availability is going to change. We will be able to grow crops in different areas of the world, and maybe in another world. New disease outbreaks will occur. Population centers of people are going to change. People’s tastes are going to change. Therefore, where and how food is produced is going to change over time and with that so will sustainability of agricultural products. In developing countries, sustainability studies are used to determine how, what, when, and where to best raise livestock to feed their people.

In our developed countries, our sustainability efforts are entwined with so many political agendas because we have an overabundance of food, unbelievably sustainable food production –and we can afford it. Local, national, and global distribution of food is our downfall but we are getting better. Globalization is here to stay. “Our” developing countries need the livestock systems and the developed countries need to focus more on the mission making sure everyone gets fed. The proper use of sustainability modelling will tell us how to feed the world. We must have humane leadership that makes sure we do not undo all the good that has been done for so many but look to the future for feeding the planet.

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NOTES

Gene editing: Today and in the Future—Alison Van Eenennaam, PhD

Take Home Messages

- Gene editing refers to the use of site directed nucleases (e.g. Zinc finger nucleases, TALENS, CRISPR/Cas9) to introduce targeted alterations into genomic DNA sequence.
- It offers a way to correct genetic defects, inactivate or knock-out undesirable genes, and/or move beneficial alleles and haplotypes between breeds in the absence of linkage drag.
- Gene editing would synergistically complement, not replace, traditional breeding programs.
- It has been used to introduce useful genetic variants impacting disease resistance, product quality, adaptability, and welfare (e.g. polled) traits in research settings.
- It could also be used to alter the sex ratio of offspring, and enable novel breeding schemes to accelerate the rate of genetic gain or reduce genetic lag in beef cattle breeding programs.
- The regulatory oversight of gene editing in animals varies by country; in 2017 the US Food and Drug Administration (FDA) released a regulatory guidance stating that it plans to treat "all intentional alterations" introduced into the genome of animals as new animal drugs.
- The USDA challenged this in 2021 by releasing a notice of proposed rule making claiming regulatory authority of certain livestock species, including cattle, developed using modern biotechnology that are intended for agricultural purposes such as human food and fiber.
- The FDA is opposed to sharing regulatory oversight of genetically engineered and genome edited animals with USDA, and as of May, 2021 it is unclear how this regulatory turf battle will play out; the outcome will likely determine whether it will be feasible to incorporate gene editing into US livestock genetic improvement programs.

Introduction

Gene editing involves using a site-specific nuclease (e.g. Zinc finger nuclease, TALENS, CRISPR/Cas9) to cut DNA and introduce a double-stranded break (DSB) at a targeted, specific sequence in the genomic DNA double helix. It is effectively a sophisticated pair of molecular scissors. The DSBs are then repaired by machinery in the cells using one of two mechanisms. One method is non-homologous end joining (NHEJ) where the two broken ends are brought alongside each other and are glued together. This method is error-prone and often results in small insertions and deletions (indels) at the target cleavage site due to inevitable mistakes in the repair process. These errors alter the nuclease target site and prevent further cleavage events. An alternative repair mechanism is homology-directed repair (HDR) using homologous DNA as a repair template. A DNA repair template can be added with desired modifications between regions of homology that match up either side of the DSB. This can be used to introduce a range of genome edits, from point mutations to whole-gene insertions.

Gene editing presents an approach to introduce targeted modifications into existing genes and regulatory elements within a breed or species, without necessarily introducing foreign DNA, potentially avoiding concerns regarding transgenesis. It offers a new opportunity to accelerate the rate of genetic gain in livestock by precisely introducing useful extant genetic variants into structured livestock breeding programs. These variants may repair genetic defects, inactivate or knock-out undesired genes, or involve the movement of beneficial alleles and haplotypes between breeds in the absence of linkage drag (genes introduced along with the beneficial gene during backcrossing.)

Introduction of Editing Components Into the Genome

Gene editing reagents can be delivered into target cells via physical methods or through the employment of vectors (viral or non-viral). Gene edited mammalian livestock have predominantly been produced using physical methods which include electroporation of somatic cells (typically fetal fibroblasts) and microinjection, or more recently electroporation, of zygotes (one-cell embryo). Electroporation uses high-voltage pulses to induce transient pore formation in the cell membrane. These pores allow the flow of gene editing components from the suspension liquid into the cell cytoplasm (Lin and Van Eenennaam, 2021). Although electroporation has traditionally been used to edit cultured cell lines, it is also effective on zygotes (Chen et al., 2016).

For a long time, cytoplasmic microinjection (CPI) has been the go-to technique for delivering gene editing components directly into livestock zygotes. Electroporation has only recently begun to show its potential for this purpose with effective introduction of indel mutations into zygotes of cattle (Wei et al., 2018a, Miao et al., 2019, Namula et al., 2019,

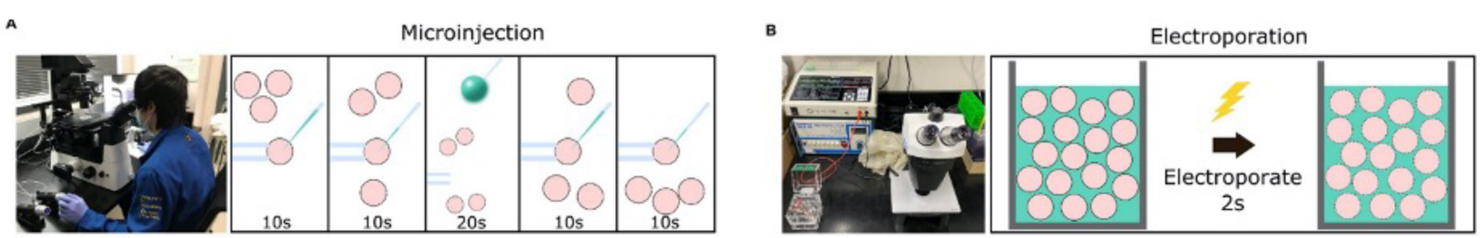

Figure 1. Graphical schematic of a comparison between setup and time necessary for the microinjection vs. electroporation of embryos. (A) The equipment necessary for the microinjection of embryos and the workflow involved to introduce editing reagents (green) into four presumptive zygotes (pink) using a holding needle (left) to stabilize the zygote before introducing the injection needle (right). (B) The equipment necessary for the electroporation of embryos and the workflow involved to introduce editing reagents into 30–100 presumptive zygotes via a cuvette. Image from Lin and Van Eenennaam (2021).

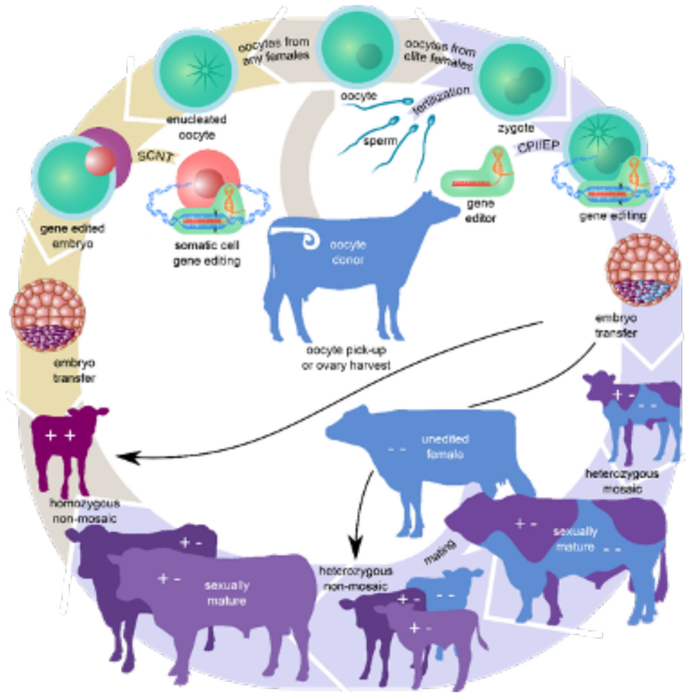

Figure 2. Steps for producing genome-edited livestock through somatic cell nuclear transfer (SCNT) or zygote editing. Schematic showing the steps involved to produce homozygous, non-mosaic livestock by either SCNT cloning of gene-edited and screened somatic cells (yellow arrows) or cytoplasmic injection (CPI)/electroporation (EP) of zygotes (purple arrows) with gene editing components. Image from Bishop and Van Eenennaam (2020).

Camargo et al., 2020). Unlike CPI, where a needle is used to deliver gene editing reagents into zygotes individually, electroporation allows the manipulation of zygotes en masse, reducing the time and expertise required (Figure 1).

Introducing gene editing reagents directly into zygotes using both methods has been a successful approach to achieve targeted knock-outs in embryos. However, issues still exist. Firstly mosaicism, meaning 2 or more genetically different sets of cells in an animal, is a common problem that can reduce the efficiency of producing a line of knock-out animals if the germ line (i.e. sperm and eggs) is derived from a subset of cells that were not gene edited. Second, inserting new genes is much more difficult than targeted knock-outs. Targeted whole-gene insertions relies on using the HDR pathway of repair which tends to only be active in dividing cells. As such it is difficult to achieve gene knock-ins in zygotes.

Gene Editing in Cattle Genetic Improvement

In animal breeding programs, germline transmission is the ultimate goal because edits must be passed on to the next generation to achieve genetic improvement. In mammalian livestock species, gene editing can be performed either in somatic cells and the edited cell line subsequently cloned by somatic cell nuclear transfer (SCNT), or in developing zygotes. Most targeted gene knock-outs in mammalian livestock, and a few targeted gene insertions, have been achieved by editing in cell culture, followed by SCNT (Tan et al., 2016). The use of SCNT to derive embryos from edited cells greatly reduces the efficiency of the method due to the low rate of birth of healthy cloned animals, particularly in cattle (Akagi et al., 2013, Keefer, 2015).

Delivery of gene editing components into the zygote avoids the shortcomings of SCNT, but has the drawback of significant rates of mosaicism when the editing event occurs at a multinuclear/multicellular stage, and unknown editing success prior to the birth of the calf, unless the embryo is biopsied prior to transfer. For mosaic animals, a breeding strategy must be employed to obtain homozygous, non-mosaic animals (Figure 2). Gene editing of zygotes also has the advantage of producing a diversity of foundation animals as each zygote will produce a genetically distinct animal, as opposed to animals derived from a clonal cell line.

Table 1. Publications using gene editing in cattle for agricultural applications. Modified from Mueller (2021).

Trait category	Goal	Genome target and function	Reference
Animal health/ welfare	Prevent horn growth	Horn/Poll	Tan et al. (2013); Carlson et al. (2016)
	Disease resistance: mastitis	CSN2 (Beta-casein): milk protein gene	Liu et al. (2013) Liu et al. (2014)
	Disease resistance: tuberculosis	Intergenic region between SFTPA1 and MAT1A	Wu et al. (2015)
	Intergenic region between FSCN1 and ACTB	Disease resistance: bovine respiratory disease (BRD) ITGB2 (integrin subunit beta 2): encodes the leukocyte signal peptide CD18	Shanthalingam et al. (2016)
	Disease resistance: bovine spongiform encephalopathy (BSE)	PRNP (prion protein): susceptibility to BSE	Bevacqua et al. (2016)
	Repair mutation: IARS syndrome	Isoleucyl-tRNA synthetase (IARS)	Ikeda et al. (2017); Ishino et al. (2018)
	Thermotolerance	PMEL (premelanosomal protein gene): coat color	Laible et al. (2020)
		PRLR (prolactin receptor): hair coat length	Rodriguez-Villamil et al. (2021)
Product yield or quality	Eliminate a milk allergen	PAEP (Beta lactoglobulin): whey protein gene	Yu et al. (2011) Wei et al. (2015) Wei et al. (2018b)
	Increase lean muscle yield	CSN2 (Beta-casein): milk protein gene	Su et al. (2018)
Reproduction and novel breeding schemes	Generate host for germ cell transfer	NANOS2 (Nanos C2HC-Type Zinc Finger 2): necessary for male germline development	Miao et al. (2019), Ciccarelli et al. (2020)
	All male offspring	Safe harbor loci, H11	Owen et al. (2021)

Gene editing research in cattle to date has focused primarily on monogenic (single gene) traits for animal health and welfare, or product yield and quality. There are also some applications that focus on reproduction and novel breeding schemes that may be of relevance to beef cattle breeding programs (Table 1).

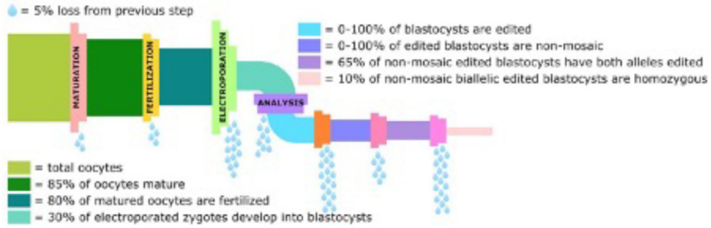

Figure 3. Graphical representation of the losses in the gene editing pipeline from collection of oocytes to the percentage of blastocysts that are non-mosaic homozygotes for the intended edit. Image from Lin and Van Eenennaam (2021).

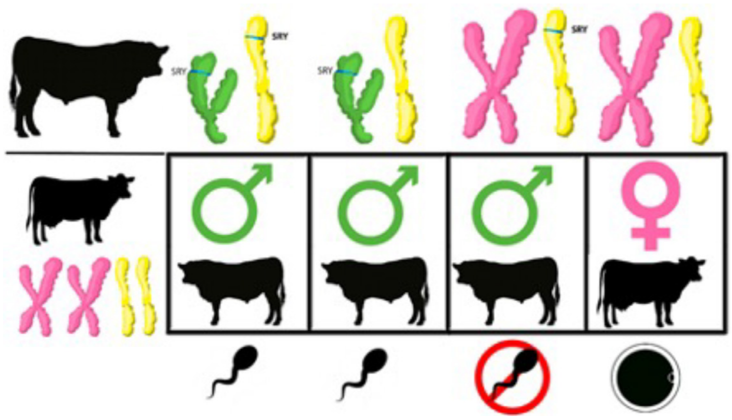

Figure 4. Cosmo will produce sperm carrying either an X (pink) or a Y (green) sex chromosome, and one copy of Chromosome 17. All Y-bearing sperm will produce a male calf, whereas only half of the X-bearing sperm will produce a female. The other half carrying the SRY gene on Chromosome 17 (yellow) are expected to produce a male-appearing XX individual. However, this animal would not be expected to be produce fertile sperm.

It should be emphasized that many of the processes involved in gene editing livestock are time consuming, and at present inefficient. There are a large number of procedural steps and unpredictable biological variables including gamete collection and maturation, introduction of the editing reagents, cloning and transfer of embryos into synchronized surrogate dams, all of which have their own limitations and constraints. Microinjection of zygotes that result in mosaic offspring, and then subsequently breeding to produce heterozygous and homozygous edited offspring is both time consuming and expensive when performed in large food animals. Many gene editing applications require homozygous modifications to ensure inheritance of one copy in the F1 generation, or for alleles with a recessive mode of inheritance. The complexity and inefficiencies associated with many of these processes makes the gene editing of livestock far from routine at the current time (Figure 3).

It is perhaps not obvious to those outside of this field, but a source of bovine oocytes for in vitro maturation and fertilization has to be readily available to perform zygote editing, often obtained from ovaries collected at a local slaughter facility, unless specific female genetics is required, in which case ovum pick-up may be used. To produce viable mammalian offspring, it is also necessary to have a ready supply of synchronized recipient or surrogate cows. This is not an inexpensive undertaking in the case of large livestock species, and due to seasonal breeding and other climatic factors, it is almost impossible to conduct this work during certain times of the year.

Future Applications of Gene Editing

Skewing of sex ratios

In mammals, sex determination is typically dependent on the inheritance of the sex chromosomes, X and Y. Individuals with two X chromosomes are genetically female and individuals with one X chromosome and one Y chromosome are genetically male. Dairy farmers often use "X-sorted" semen in artificial insemination as it contains only sperm carrying an X chromosome and will result in all female calves.

It is actually only a single gene on the Y chromosome that determines whether an embryo develops as a male or female. This gene is known as the sex-determining region of the Y chromosome or "SRY" for short. SRY expresses a protein in early embryogenesis that initiates male sexual differentiation by triggering a cascade of factors necessary for male gonadal development and shutting down formation of the female gonad.

In 2020 we generated a gene edited calf, Cosmo, who carries an extra copy of SRY on one of his non-sex chromosomes (Owen et al., 2021). Cosmo is expected to produce 75% male offspring: 50% of which will be XY males; 25% of which will be XX females; and 25% of which are expected to be XX individuals that appear male due to the inheritance of the chromosome 17 carrying the SRY gene. These XX males are not expected to produce viable sperm as that requires the expression products of additional genes located on the Y chromosome (Figure 4).

Cosmo turned one year of age in April 2021, and he will be bred to study if inheriting the SRY gene on Chromosome 17 is sufficient to trigger the male developmental pathway in XX embryos. Such bulls could produce a higher proportion of male market calves. However, at this time the project is still in the research stage and is highly regulated by the Food and Drug Administration, meaning Cosmo and his offspring are not allowed to be marketed, enter the food supply, or even be rendered.

Bulls and cows carrying gametes belonging to a different animal

There is a lag in the genetic improvement between the elite nucleus seedstock sector and commercial animals. One way to decrease this lag would be to make germline copies of elite animals. This aim could be achieved through the use of surrogate sires (Gottardo et al., 2019) which involves replacing the germline of inferior males (e.g. herd sires) with the germline of genetically elite males (e.g. AI sires) by introducing germ cells derived from the elite sires into the testes of the herd sires.

Recently, gene editing has been used to knock out genes necessary for an animal's own germ cell production (Ideta et al., 2016, Park et al., 2017, Taylor et al., 2017). These germline knock-out animals make ideal hosts for elite donor-derived germ cell production. In germline knock-out mice, pigs and goats, transplantation of donor spermatogonial stem cells (Ciccarelli et al., 2020), or embryonic stem cells (Miura et al., 2021) resulted in donor-derived sperm production in the otherwise sterile testes. Additionally, donor-derived oocytes have been generated in sterile ovaries of germline knock-out heifers (Ideta et al., 2016).

In vitro breeding: New advances in vitro with germ cell and gamete development from mouse ESCs have led to recent interest in the potential for in vitro breeding in livestock (Goszczynski et al., 2018). The advantage of this proposed method would be that it could effectively remove the wait required for animals to reach sexual maturity prior to meiosis and conception. This has the potential to dramatically decrease the generation interval component of the breeders' equation. If both in vitro gametogenesis and fertilization could be successfully accomplished in a petri dish, this offers the possibility of maintaining an entire breeding population of large animals in a laboratory (Figure 6). Gene editing could be included at the ESC stage to introduce useful genetic variation in the selected cell line.

Figure 6. In vitro breeding (IVB). Diagram of the strategy, estimated times, and possible alternatives for its implementation in animal production systems. NT: nuclear transfer. IVF: In vitro fertilization. ESCs: Embryonic Stem Cells. Image from Goszczynski et al. (2018).

Regulations

As with earlier genetic engineering approaches, whether breeders will be able to employ gene editing in cattle genetic improvement programs will very much depend upon global decisions around regulatory frameworks and governance of gene editing for food animals. Argentina was the first country to publish its proposed regulatory approach for gene editing and other new breeding techniques (Whelan and Lema, 2015). The Argentine approach is that if there is no "new combination of genetic material", and if the final product is free of "transgenes", then that product will not be subject to regulation as a genetically modified organism (GMO). In this system, no distinction is drawn between gene edited plants and animals. In 2018, a gene edited line of tilapia, which did not contain any foreign DNA or a new combination of genetic material, received regulatory exemption by Argentina's National Advisory Commission on Agricultural Biotechnology. Similarly, Brazil ruled that the intraspecies polled allele substitution that results in hornless cattle would not be regulated as a GMO.

In 2020, the United States Department of Agriculture (USDA) published its SECURE (Sustainable, Ecological, Consistent, Uniform, Responsible, Efficient) rule which confirmed that the "USDA does not regulate or have any plans to regulate plants that could otherwise have been produced through traditional breeding techniques."

However, the United States Food and Drug Administration (FDA) has taken a very different approach for edited animals, and in a 2017 draft guidance announced that "all intentional alterations" in the genome of animals would be regulated as new animal drugs (FDA, 2017; Maxmen, 2017). The guidance elaborates that each alteration would need to go through a mandatory premarket multigenerational safety and efficacy review, irrespective of whether that alteration already exists in the target species or could have been achieved using conventional breeding. It should be noted that only two genetically engineered animals for agricultural purposes (fast-growing AquAdvantage salmon, and the GalSafe pig) have ever been approved using this regulatory approach, whereas numerous genetically engineered crops, and even a couple of gene edited crop varieties are commercially available.

Unapproved animal drugs are not allowed to enter the food or rendering chain, requiring incineration or burial following euthanasia of experimental gene-edited food animals. This added expense is inhibitory for gene editing research into food animal species. Typically, the income derived from marketing surplus animals, and the milk, meat and eggs produced by both university and USDA (e.g. MARC) herds and flocks, used in both research and teaching, is an integral offset to the sizable costs associated with large animal research. Categorizing all gene edits as drugs, irrespective of novelty, eliminates saleable products from edited livestock, and increases the costs associated with this research considerably. It also dramatically increases the developmental costs associated with commercializing gene edited livestock. A US 2019 petition calling for regulations that are proportionate to unique product risks, and the harmonization of regulations for gene edited plants and animals was supported by hundreds of scientists (Van Eenennaam et al., 2019)

On January 19, 2021, the USDA announced the finalization of a Memorandum of Understanding (MOU) with the US Department of Health and Human Services outlining regulatory responsibilities over certain animals developed using genetic engineering that are intended for agricultural purposes (such as human food, fiber, and labor). However, the FDA is opposed to losing their regulatory oversight of genetically engineered and gene edited livestock for food purposes. A public comment period on the USDA proposal closed in May 2021, and as of writing this paper it is unclear how this regulatory turf battle will play out.

Meanwhile in Europe, the Court of Justice of the European Union (ECJ) ruled in 2018 that gene-edited crops should be subject to the same stringent regulations as conventional GMOs (Callaway, 2018). This will likely hinder both the use of gene editing by both plant and animal researchers in the EU, and the adoption of this technology in European agriculture.

Conclusions

Gene editing is a tool that is well-suited for modifying qualitative, single-gene traits at comparatively rapid rates and which could be used in conjunction with conventional selection approaches to address issues such as disease resistance, improved product yield or quality, and animal welfare traits. It could also be used to introduce traits that skew the sex ratio of offspring, and enable novel breeding schemes to accelerate the rate of genetic gain. The availability of this technology for use by industry likely hinges on the regulatory framework imposed, which varies dramatically by country. From a risk-based perspective, it makes little sense to regulate gene edited animals carrying the same allelic DNA at the targeted locus as conventionally bred animals differently, solely because the former was produced using gene editing. Regulations should be fit-for-purpose, proportionate to novel product risks, if any, and agnostic to method, rather than being triggered and predicated on the use of an arbitrarily defined subset of breeding methods.

Acknowledgements

The author acknowledges having received funding support from Revive and Restore, the Foundation for Food and Agricultural Research, Select Sires, and the USDA National Institute of Food and Agriculture, including the Biotechnology Risk Assessment Grant program, under award numbers 2015-33522-24106, 2017-33522-27097, 2018-67030-28360, 2020-67015-31536, and 2020-70410-32899.

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The Future of Precision Livestock for the Cattle Industry—Justin Sexten

Introduction to Precision Livestock Farming

Precision agriculture is not a new idea. Diverse farming and ranching operations have already seen exponential advancement in precision ag within the row crop space. Technology moved us from farm level planning to sub-acre management. Precision livestock farming (PLF) is a more recent application of this similar technological approach to the livestock enterprise.

How one defines PLF will differ depending on the source. Some suggest PLF is the application of process engineering principles to animals (Wathes et al., 2008). In this model animals are monitored continuously by sensors and/or cameras and predictions are made using behavior or trait deviations from normal. Monitoring for deviations from a normal individual's baseline are similar to how equipment manufacturers monitor machines to initiate preventative maintenance. In the livestock space these prediction models tend to focus around event detection, such as estrus, calving, lameness or illness.

A good veterinary friend once told me he has been using a similar model to train future veterinarians. Attempting to learn every disease symptom can be overwhelming, whereas a solid understanding of the normal animal provides a baseline to detect early disease indicators ultimately signaling the need for intervention or further diagnosis.

Another vision of PLF is using technology to automate and simplify data capture to inform production decisions. This model is built on a similar premise to event prediction, informed by massive amounts of sensor data collected around the clock (Berckmans 2017). Machine learning and artificial intelligence continuously evaluate the data to generate an algorithm to make predictions around health, performance and welfare.

This model has greater focus on understanding intervention points around growth and efficiency. Predicting terminal endpoints, making genetic predictions, and automated sorting are outcome examples derived from digitally gathered phenotypes.

The two definitions are not largely different in execution as each incorporates data from the Internet of Things (IoT) using sensor technology coupled with machine learning and AI analysis enabled by cloud-based connectivity. Regardless of the output, PLF is focused on addressing a common challenge: feeding a growing demand for meat and milk products using fewer resources.

Efficient natural resource use is a key metric of operational and financial sustainability. In many areas of agriculture simply increasing operational scale can provide the most effective path to efficiency. As herd and flock sizes increase infrastructure and fixed costs are diluted offering greater margin opportunities. The availability or cost of skilled labor to manage these growing operations often drives producers to increasingly look to technology to curtail any scale related labor and management challenges.

The binary nature of event-based data (estrus, calving, illness) coupled with their labor saving opportunities led to the development of sensor-based solutions for individual animals. Success of these solutions may also be attributed to the limited time the solution is needed, the relative confinement during these periods and the high cost of missing the event. This event focused approach will guide the emerging technology of group management.

Resource Optimization

Berckmans (2017) suggested managing livestock in concert with the animal's genetic potential offers a significant path to environmental sustainability. With that backdrop a question to consider, what percentage of livestock are managed in a way to optimize their genetic potential. Does your answer differ by species? Where is the greatest opportunity to improve? Increase the average genetic potential or provide an environment that optimizes expression?

Innovators will continue to provide point solutions, sensors and algorithms as discussed above. Technology limitations and use will certainly vary across the supply chain as solutions for the ranch will differ widely from that of the feedyard. However the functional challenge to the beef industry as well as the average ranch is finding ways to optimize individual animal performance within a group without sacrificing animal welfare.

No single animal reflects the average of a group (Berckmans, 2017), an example of the paradox of average management. Remove the technology aspect for a moment and consider PLF at the core as managing animals as individuals rather than a group. Group management by rule of math results in half the cattle managed under their potential while half are wasting resources they don't have the potential to fulfill. Rosa (2021) highlighted this individualized approach to optimize future productivity while moving away from traditional management that "pen-alyzes" high production animals fed in a pen.

Precision feeding practices are not a unique approach. Swine and dairy producers implemented phased feeding long ago, grouping animals by nutrient demand. Precision feeding addresses inefficiency in both nutrient supply and demand (Pomar, C. and A. Remus. 2019). By narrowing the window of ingredient supply and animal demand the variation associated with time is reduced. Diet formulations can be changed to narrow the nutrient supply with potential to reduce cost as well unnecessary over formulations and safety margins.

There are few gaps in the knowledge of the average individual animal's nutrient requirements, the gap lies in application of these individual requirements within a dynamic group of animals. If PLF is primarily managing to the individual level future success gets more challenging as operations get larger. Is the average feedlot pen sized to optimize animal production per head? An economy of scale designed to optimize marketing and logistical challenges may impair true enhancements in efficiency. Can precision feeding systems offset the advantages of large group management? Pen size need not limit the ability to apply precision feeding systems if individual animal variation can be minimized.

The use of artificial insemination and estrus synchronization are prime examples where the beef industry solved this challenge. To optimize genetic merit individual matings are carefully considered by seedstock breeders for each cow. PLF solutions emerged to accomplish estrus monitoring that range from chalk to electronics. One may argue detection may still limit technology adoption as estrus synchronization was needed to optimize labor, limiting individual "variation" in estrus timing.

Execution logistics often present the greatest barrier to implementation of good ideas. Breeding cows by appointment continues to improve the uniformity and genetic merit of calf crops across the nation. With a host of options to manage the variation of a cows' reproductive cycle with a high degree of precision producers are able to select the option that addresses their greatest need, ranging from maximum pregnancy rate to most labor efficient.

Another area where logistical challenges can hamper PLF implementation is genetic potential. The ability to quantify genetic potential is well developed for purebred and crossbred cattle. Communicating this potential at logical intervention points is the gap where technology offers possible solutions.

Long generation intervals continue to drive investments in genetic testing by seedstock and progressive commercial breeders. The value of time and need for continual progress will continue to drive genetic PLF solutions. Purebred and commercial cattlemen want to understand the genetic potential of an animal early in life. The value proposition for this technology is clearly defined for those making long-term selection and mating decisions.

For the short-term manager of the products of genetic improvement the communication of performance potential downstream is largely unrealized. Breeders have established a currency of communication amongst themselves using EPD's and genomic results yet the conversion of these results to other aspects of the supply chain are limited to group level badges and certifications. The goal of implementing precision feeding systems appears unattainable when genetic potential cannot be communicated to the next owner.

An equal challenge is communicating genetic potential so that managers can act on the information. Whether at purchase or initial processing the need for technology solutions to enable real-time communication across operations. If individual animal management is the goal for optimal resource use, then communication of individual data must evolve beyond current industry practices.

Currently precision management beyond the ranch is limited to biometric sorting as well as strategic implant and feed additive use. These solutions are valid PLF management approaches applied to imperfect groups. The ability to deploy technology at an animal level is limited by group size or chute sessions. If group size is determined by logistics and marketing then solutions should seek opportunities for prescriptive management at chute intervention points. Pen monitoring and algorithm predictions, while useful, ultimately require additional operator intervention. Processing cattle using real-time information is a first step to PLF implementation.

Chute sightings provide key opportunities for passive phenotypes collection that remain a premium in powering PLF predictions. The digital capture of visual phenotypes was first used in carcass evaluation (Fernandes et al., 2020) with increasing use in dairy and swine systems. The evolution of computer vision systems with integration into PLF ecosystems offer opportunities to provide data to the market and production segments. Use cases where both production and marketing needs are met can lead to wide-scale adoption.

Future Considerations

Technological

Connectivity is a key enabler of PLF solutions. The ability to move data across devices, operations and people is key. What good is data locked in a single device or platform? Data management challenges are not a unique problem to PLF. In areas of poor or slow connectivity, data transfer challenges are exacerbated. Berckmans (2017) suggested PLF applications should use local algorithm development to minimize the need to manage data and the associated energy and transactions costs. This factor is increasingly important in developing regions where infrastructure may lag (Rosa 2021).

Connectivity offers reduced deployment costs when enabled by agnostic on-farm sensors and processors provide infrastructure to deploy technology. How many are using a high cost or outdated system due to the high cost of switching? Switching costs are expressed in many forms. The first and most painful is data entry, for many getting data into systems the first time is bad enough making re-entry worse.

Real-time updates enabled by connectivity provide frictionless software deployment from basic operations to farm level algorithms. Technology providers are well served to ensure components are agnostic to current upgrades or amenable to the new components to promote early adoption. Early adopters provide key feedback to the marketplace and developers. While rapid product evolution and iterations are key to product improvement, early adopters should not be punished with outdated prototypes.

Optionality is a key to the success of technology adoption. We have no idea how devices, hardware or service providers will change and adapt over time so consider platforms where data portability is a core focus. John Deere® provides a row-crop example where they actively promote across company development to ensure system compatibility. https://developer-portal.deere.com/#/. If history provides an example, those solutions focused on keeping producers or data locked into a program or offer limited integration opportunities will be challenged by open source or flexible platform models.

Production

Limiting individual and group disruptions to normal behavior is a key barrier to address (Rosa, 2021). For beef production systems where most management occurs in extensive environments the application of spatial sensors, video cameras and other monitoring technologies are limited. The nature of converting large areas of unimproved forage to beef mandates the need for off-line or intermittent communication solutions.

For those systems that are successful in these environments, battery life and size becomes the next barrier to overcome. While battery technology will continue to advance, passive technology offers the greatest solution in the near term. Sensor activation near key gathering points (water, mineral, or gates) will provide check in opportunities to capture and sync data.

Several sensing technologies have clearly demonstrated predictable outcomes overcoming the barriers above, however, they require a timely sensor application. These solutions will remain a point solution (solve a singular problem) or incorporate within a long term sensor. Here is where the cow's ears proves to be a key asset to PLF applications.

Any discussion of future applications of PLF that ignores data privacy issues would be incomplete. Producers increasingly understand the value of their data. Data in exchange for value has been a swap people are willing to make thus far. Whether auto insurance, family genetic history or soil productivity, consumers continue to share data in exchange for improved solutions. Data is the currency of PLF, effective consumer protections that incorporate across operation sharing will provide additional value beyond performance predictions.

Ethical considerations related to PLF pose a unique challenge. PLF solves for the growing list of sustainability metrics suppliers increasingly demand. Yet the consumers may view the solution as compromising welfare and converting the care and monitoring of animals over to the machines (Wathes et al., 2008). Consumers seek technological solutions in every aspect of life yet the food system is increasingly pressured to maintain the historical context of red barns and upright silos.

While PLF systems offer an increasingly wide range of monitoring and predictive management opportunities, the most useful aspect of PLF may lie in the primary requirement for execution, individual identification in a connected ecosystem. The ability to provide digital, on-line practice verification across the supply chain may be the most valuable by-product of precision livestock management.

PLF offers the beef industry the opportunity to improve animal productivity, and address growing labor issues while fulfilling consumer demand for increased food system traceability and sustainability. The technology to accomplish the production goals exists in a number of current solutions. When the marketplace is willing to pay for adoption, producers will rapidly solve for the execution barriers.

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Use of Advanced Reproductive Technologies and Inclusion of these Records in Genetic Evaluation—R. Mark Thallman and Alexandria Snider

Introduction

Most of the performance records of the millions of seedstock cattle produced by embryo transfer over the past 50 years have been excluded from national cattle evaluation (NCE). A topic entitled "Embryo Transfer (ET): Data Collection and Utilization" was recently added to the BIF Guidelines to provide recommendations on the utilization in genetic evaluation of records of cattle produced by embryo transfer.

Here, we provide background information on the use of embryo transfer in cattle breeding, various forms of ET and terminology used to describe them, and their relative advantages and disadvantages. Based on this background, we explain the rationale behind the recommendations in the current BIF Guidelines. We also discuss a few topics related to ET, but not addressed in the current Guidelines and propose actions that could allow records of additional ET cattle to be included in future genetic evaluations.

Embryo Transfer

Embryo Transfer refers collectively to a set of reproductive technologies to increase the reproductive rate of cows. Embryo transfer was commercialized in the 1970s and has contributed substantially to the genetic improvement of beef cattle since the 1980s. Selection of donors and service sires for ET should follow the principles of the BIF Guidelines.

Roughly 100,000 beef seedstock calves are produced annually in the U.S. through ET. Although this represents a minority of beef seedstock calves, they are disproportionately influential because a large proportion of AI sires, as well as other sires used in seedstock herds and donor females, are themselves produced through ET. Therefore, it is important that these influential parents be selected from the pool of candidates as accurately as possible. Furthermore, ET calves are more likely to be measured for expensive traits such as individual feed intake.

Embryos are placed (usually at day 7 of development) into cows (the recipients) that carry the fetuses and raise the calves. The recipient cows are typically not related to the embryos. To be a viable recipient, a cow must be "in synchrony" with the embryo, which usually means she was in estrus 7 days prior to transfer. More calves can be obtained from cows of superior breeding value by these techniques. Embryo transfer (ET) can improve selection response through increasing selection intensity, reducing generation interval, and increasing the accuracy of dams.

Most variations in ET are related to the source and/or processing of the embryos, which are described below.

Multiple Ovulation Embryo Transfer (MOET)

Historically, most embryos for ET have been produced through MOET. The embryos are typically flushed from the uterus of their genetic dam (the donor) 7 days after AI; the donor is usually superovulated by injection with follicle stimulating hormone (FSH) prior to AI so that multiple embryos are collected. The number of transferable embryos per collection is highly variable[3] and influenced by many factors but averages about 7. The donor cow must be open and cycling to produce embryos through MOET. Donor cows can be collected multiple times between pregnancies, usually about 45-60 days between collections. Pubertal heifers can be collected; they usually produce fewer transferable embryos than cows.

MOET is sometimes referred to in industry as "conventional ET" or "in vivo production" of embryos. The process of collecting embryos in MOET is referred to as "flushing" because the embryos are literally flushed from the donor's uterus in a special collection fluid. Consequently, the MOET technique is sometimes referred to as "flushing" to distinguish it from in vitro production (see below).

In Vitro Fertilization (IVF)

Alternatively, embryos can be produced by IVF, which makes it possible for donors to be collected for most of the year while keeping them in an annual calving season. It can also allow production of multiple progeny per straw of semen[3].

In IVF, unfertilized oocytes are collected from the donor cow's ovaries by transvaginal, ultrasound-guided needle aspiration of multiple follicles per ovary. This process is referred to as ovum pickup (OPU). Because most of these follicles would not have ovulated naturally, they must undergo in vitro maturation (IVM), then in vitro fertilization with bull sperm, followed by in vitro culture (IVC) in a laboratory until being ready for transfer into recipient cows at the blastocyst stage (about day 7).

Technically, the entire process is referred to as in vitro production (IVP) and IVF refers specifically to the fertilization aspect of the process. In industry, the entire IVP process is more commonly referred to as "IVF" and that use of the term is adopted in the remainder of this document. Methods of collection are sometimes distinguished as in vivo (MOET) versus in vitro (IVF).

In 2019, 96,887 IVF beef embryos were transferred in the U.S., up from 41,993 in 2015[4]. This increase is partially at the expense of MOET embryos. In 2019, 109,218 MOET beef embryos were transferred in the U.S., down from a high of 156,506 in 2015[4].

The increase in use of IVF is likely due to the opportunity to collect donors without disrupting their normal calving season as well as the opportunity for greater (and perhaps more uniform) annual embryo production per donor. In IVF, the donor need not be in estrus and even pregnant cows can be collected via OPU. Donors are typically collected every 2 weeks and produce approximately 8[4] transferable embryos per collection.

Donors for IVF can be treated with FSH prior to OPU, or not. Using FSH increased average viable embryos per OPU from 5.0 to 8.4 but may have long-term effects on donor cows and unknown effects on resulting progeny. In 2019, 170,924 viable IVF embryos were produced by companies that predominantly use FSH and 23,146 were produced by companies that predominantly don't use FSH[4].

Juvenile In Vitro Embryo Transfer (JIVET)

Prepubertal heifers can be collected (with decreasing success at younger ages); this form of IVF is known as juvenile in vitro embryo transfer (JIVET). In principle, JIVET could decrease generation interval on the female side of the pedigree to one year; this could make it a very useful tool for cattle breeders. The IVM step in JIVET is more technically demanding than in IVF from pubertal donors.

Calves produced through IVF may be subject to Large Offspring Syndrome (see below). It seems plausible that JIVET may accentuate large offspring syndrome relative to pubertal IVF, but this appears to have not yet been evaluated. Combined with genomic selection, the reduced generation interval made possible by JIVET could substantially increase response to selection. It could also cut approximately in half the minimum time required to introgress a rare allele into a more useful genetic background.

Nuclear Transfer (NT)

Nuclear transfer, commonly referred to as "cloning", can be used to produce groups of genetically identical individuals. Somatic cell nuclear transfer can be used to produce animals genetically identical to existing animals, including those that have been neutered, become infertile or unhealthy, or that have died (provided an appropriate tissue sample is collected and handled properly soon enough postmortem).

In nuclear transfer, embryos are produced by fusing the nucleus of a donor cell with an oocyte from which the nucleus has been removed, resulting in a cell very roughly equivalent developmentally to a fertilized one-cell embryo. These embryos are then cultured in vitro (similar to IVF) to the blastocyst stage prior to being transferred or frozen. Donor cells can be relatively undifferentiated cells in embryos or somatic cells of live cattle of any age or sex (including steers). The latter process, referred to as somatic cell nuclear transfer (SCNT) was used to produce "Dolly" the famous sheep and a few years later 8 cloned calves. The somatic cells are often cultured from skin cells from ear notches. The oocytes to which donor cells are fused are typically collected from ovaries recovered in large numbers from cow harvesting facilities; little is typically known about the oocyte donors other than whether they are heifers or cows and whether they are beef or Holstein. Cattle produced by NT are (for practical purposes) genetically identical to the donor; in principle, large numbers of genetically identical progeny could be produced. A variation on SCNT referred to as "handmade cloning" is reported to be easier to perform and more efficient than SCNT. Because of currently high cost per pregnancy, use of NT is generally limited to reproducing highly valuable individuals that have died or become infertile; it has been used to clone extremely desirable (e.g. Prime YG1) carcasses identified on the grading rail [10]. Perhaps the most common current use of SCNT is to facilitate gene editing. Calves produced through NT may be subject to Large Offspring Syndrome and Abnormal Clone Syndrome (see below). Van der Berg et al. (2019) is an excellent review of technical, safety, ethical, and regulatory aspects of SCNT as well as a review of companies commercially engaged in SCNT.

Freezing

Embryos can be cryopreserved (frozen in liquid nitrogen) to be transferred at a more convenient time. This allows donors to be collected throughout the year, potentially generating a large number of candidate embryos, while the recipient cows calve during the optimal calving season. Having an inventory of frozen embryos also ensures that a high-quality embryo is available to transfer to each recipient cow and that transfers are timed optimally relative to estrus of the recipients.

Transfers of embryos that have not been frozen are referred to as "fresh" transfers. Frozen embryos may be referred to as "vitrified". In 2019, 70% of beef MOET transfers and 67% of beef IVF transfers were of frozen embryos[4]. Pregnancy rates are approximately 60-70% for MOET fresh and 50-60% for MOET frozen transfers and about 10% lower for IVF transfers. Freezing is used more widely in beef than in dairy cattle[4] because it facilitates seasonal calving. Freezing also facilitates more precise synchrony of the embryo with the recipient.

Calves resulting from frozen embryos had greater gestation length and were heavier at birth than those from fresh transfers in some circumstances, but not in others. Differences in phenotype between calves resulting from fresh or frozen transfers are not widely recognized but may exist. In humans, children born from frozen IVF embryos had greater birth weight than those born from fresh IVF embryos.

Sex Determination and Genotyping

The opportunity to preselect embryos offers the potential to greatly increase selection intensity with relatively little increase in cost. The current impediment to widespread adoption is genotyping cost per calf if intensive selection is applied to embryos.

One or a few cells can be removed from an embryo prior to transfer or freezing to be used for DNA analysis. Applications include sex determination, genotyping, and low-pass sequencing. Although this could be feasible without freezing the embryos, it is more practical in conjunction with freezing.

Large Offspring Syndrome

Calves produced through NT or IVF may be subject to Large Offspring Syndrome (LOS), resulting in increased gestation length, birth weight, dystocia, abortion, higher postnatal mortality rate and a wide variety of congenital abnormalities[31]. Large offspring syndrome in cattle is sometimes referred to as "large calf syndrome".

Large Offspring Syndrome is primarily associated with gestation length, birth weight, dystocia, and neonatal characteristics, but although effects on phenotypes measured later in life may be relatively smaller, they should not be assumed negligible. Large offspring syndrome is the result of major disruptions in embryonic and fetal development and its effects should be expected to persist throughout life.

Birth weight of IVF calves can vary depending on the type of culture media used[34] and other conditions (e.g., oxygen tension), and the in vitro maturation (IVM) conditions and it's duration.

Much has been learned about potential causes of LOS, so the severity and/or frequency of it may currently be considerably less than in the past. Hopefully, IVC techniques can be modified sufficiently that LOS is no longer an issue.

Abnormal Clone Syndrome

Extremely high birth weights, prolonged gestation, failure to initiate parturition, and many other abnormalities were first recognized in calves cloned from embryonic cells in the 1980s. It later came to be known as Large Calf Syndrome, or more commonly, LOS to refer also to sheep and other species. For a long time, it was thought that SCNT calves suffered a more severe or frequently occurring[25] form of LOS than IVF calves. More recently, it has been recognized that, in addition to LOS, there is a separate set of abnormalities, primarily fetal and placental abnormalities, that can occur in calves produced by NT that do not typically occur with IVF[25]. This is referred to here as abnormal clone syndrome (ACS), but there does not seem to be a consensus in the literature on how to refer to it.

The list of abnormalities in NT, but not IVF calves is not well defined but seems to include failure to initiate parturition, enlarged umbilical cord that required clamping and sometimes urachus surgery, respiratory problems[46], lethargy[46], contracted flexor tendons[46], and other congenital abnormalities.

These additional abnormalities are thought to be due to incomplete reprogramming of the DNA in the fusion of the donor and enucleated oocyte cells to the epigenetic state of a fertilized one-cell embryo. This is a major challenge in NT that is not required by IVF. The characteristics of LOS common to IVF and NT are assumed due to in vitro oocyte maturation and in vitro embryo culture, which encompasses most of the duration of development in both processes.

Calves produced by NT vary greatly in the extent to which they are affected by LOS and ACS, with some appearing completely normal while the most severely affected may be twice the weight of a normal calf.

Progeny of SCNT cattle generally seem to be relatively unaffected by LOS and ACS[36].

It seems reasonable to assume that abnormalities observed in IVF calves also occur in NT, but it does not seem reasonable to assume that abnormalities observed in NT calves also occur in IVF calves, even if the assumption is that the frequency or severity is lower in IVF.

The prospects for modifying IVC techniques such that LOS is eliminated from IVF are far better than the prospects that modifying SCNT techniques will eliminate ACS. The ongoing process of improving IVM and IVC techniques is a matter of making the culture environment more like the natural environment and much progress has already been made. In contrast, the epigenetic reprogramming required for NT is much more challenging because it is a process that does not occur in nature. The more we know about SCNT, the more astonishing it is that it works at all.

Modelling Records of ET Animals in Genetic Evaluation

Throughout the history of genetic evaluation of beef cattle, many cattle have been selected for use as sires and donors in seedstock herds based on EPDs that did not reflect their individual performance. The aim of this Guideline is to reduce that effect to the extent possible.

Seedstock animals resulting from ET are potentially influential and reflect additional investment to achieve genetic progress. Therefore, maximizing the accuracy of genetic predictions early in the animals' lives by using the animals' own observations has increased importance. But, for maternally influenced traits such as weaning weight, the genetic evaluation model must be modified slightly to account separately for the donor's contribution to the calves' genetics and the recipient cows' contributions to maternal environment.

Methods for modelling the effects of recipient dams are in the literature and can be easily incorporated in genetic evaluations. Specifically, both the maternal additive genetic effect and the permanent maternal environment effect should be associated with the recipient dam instead of the donor dam.

Recipient Effects in Genetic Evaluation

Effects on the phenotype due to the dam of the animal are present in traits measured up to weaning, but generally not seen on phenotypes measured post-weaning. For animals produced using ET, these maternal influences are primarily due to the recipient dam, rather than the embryo donor dam. Ideally, pedigree information on the recipient would be included but it is not always available, as recipients are often commercial females. Both age of the recipient dam and its breed composition affect maternally influenced traits - i.e. birth weight, calving ease, and weaning weight. Therefore, if recipients of mixed breed composition or parity group (1st, 2nd, or later) produce calves contemporaneously, the differences in breed and/or parity among recipients should also be reported to the breed association and accounted for in genetic evaluation models.

Suitability of MOET Records for Genetic Evaluation

It has been reported[43] that calves produced by MOET are substantially heavier at birth than non-ET calves due to the time outside the cow between collection and transfer, although the data structure was far from ideal for estimating such effect due to separate management of MOET and non-ET progeny (both reports are from different analyses of different subsets of the same population). Based on knowledge gained through studying LOS, it seems plausible that the transfer medium, exposure to atmospheric oxygen, etc. for the few hours between collection and transfer (or freezing) could alter embryonic and/or placental development, resulting in increased birth weight. Consequently, the prudent assumption (until disproven) is that mean differences exist between MOET and non-ET phenotypes for all traits. There likely is ample data (limited by the co-occurrence of both types in the same contemporary group and code) to evaluate this assumption in existing field data; this would be a very useful exercise. Until this is done, the following recommendations are based on the more cautious approach.

Nonetheless, the data structure in [51] was well-suited for estimation of heritability in subsets of the data. Heritability of birth weight of non-ET calves, and MOET calves with Holstein, beef crossbred, or unknown breed recipients was 41.4±4.3, 28.4±3.1, 32.4±3.8, and 32.5±3.4%, respectively[51]. The MOET calves resulted from transfers of mixtures of fresh and frozen, sexed and un-sexed embryos and probably countless other variations in MOET processes, none of which were available for the analysis. This missing information probably contributed to the lower heritability of MOET calves compared with non-ET calves. Thus, birth weight records from calves produced by MOET are suitable for use in genetic evaluation even with little or no information on the recipient breed and age (excluding heifers) or the variations of MOET techniques performed. In such cases, it would be preferable to fit additional residual and/or permanent environment variance to the model for such records. Nonetheless, it is far preferable to have as much information as possible on the recipient cows, and where feasible, to use registered recipients that have several previous recorded calves. Furthermore, it would be useful to record whether MOET calves were produced from fresh or frozen transfers, were biopsied for sex determination and/or genotyping, and whether any other substantial variations in ET technique were performed.

Suitability of IVF Records for Genetic Evaluation

The commercial use of IVF by seedstock producers is increasing rapidly for the reasons discussed above. Unfortunately, innumerable reports in the literature suggest that LOS makes phenotypes of IVF unsuitable for inclusion in genetic evaluation. Much has been learned about causes of LOS and techniques have been modified to reduce its impact. Anecdotal information suggests the prevalence and/or severity of LOS has decreased substantially since the early days of IVF. Nonetheless, sufficient evidence to warrant inclusion of IVF phenotypes in genetic evaluation is not currently evident.

Because of the importance of IVF to genetic improvement, efforts should be made to utilize those phenotypes as soon as it becomes feasible. A first step could be to estimate heritabilities and genetic correlations to the same traits in non-ET calves using IVF and MOET field data as it currently exists. At least one breed association currently records whether ET calves were produced by MOET or IVF. For associations that do not already record it, this information should be available to the breeder, at least if the breeder owned the donor at the time of collection, so it could be obtained retrospectively, if there was sufficient motivation to do so. The analysis required to directly quantify the effects of both MOET and IVF on phenotypes of traits in NCE from field data would not be trivial but appears feasible.

It should be expected that heritabilities of ET records would improve if more details on the techniques used to produce each calf were available for inclusion in the analysis but this would require additional transfer of information from ET provider to breeder to breed association to genetic evaluation provider. Accomplishing this transfer of information is not trivial, but it could greatly accelerate the incorporation of IVF phenotypes in evaluations and could also provide feedback to ET providers on which techniques are most effective in reducing or eliminating LOS.

The DNA of calves affected by LOS tend to have some characteristic epigenetic marks. It is possible that these or other biomarkers could predict the degree to which individuals are affected by LOS. If so, phenotypes of the most severely afflicted calves could be eliminated and those of many calves could potentially be used in genetic evaluation, perhaps adjusting for degree of affliction. This would require collection of tissues samples for specialized DNA analysis that is different from routine genotyping, but it might be a feasible way to utilize records of IVF calves.

Suitability of NT Records for Genetic Evaluation

Current evidence suggests that the effects of ACS and LOS are too frequently severe to consider including NT records in genetic evaluation in the near future. Hopefully, that situation will eventually change.

Genetically Identical Animals

Although NT records are not used in most genetic evaluations, groups of genetically identical animals (often resulting from NT) do appear in the pedigrees of genetic evaluations. Breed associations differ in how they handle genetic identicals in the pedigree.

Some treat them as different individuals with the same parents, i.e., as full sibs. This approach results in identicals that have produced progeny having different EPDS. If we don’t believe that clones are identical, this approach allows us to compare their EPDS. However, quantifying the degree to which EPDs of a pair of identicals fit as full sibs differ from each other due to chance, conditional on their accuracies is not a trivial task, and even if we completed it, far too few such pairs exist in current field data to reach a valid conclusion from them.

To understand some disadvantages of this approach, consider the following example: a popular, influential, and high accuracy bull dies, leaving no semen. His EPDs are considerably better than his parents' EPDs. Semen from his clone has just hit the market and you are deciding whether to use it. Which EPDs do you use: the progenitor's or the clone's? You know the progenitor's EPDs reflect the clone's genetic merit, so you try a few straws. However, most breeders recognized that the clone's EPDs (currently equal to the progenitor's mid-parent EPDs) are what will influence his progeny's EPDs, so they decide to wait until the clone's EPDs have improved. The clone produces 20 progeny in his first year and you sell your bulls knowing their EPDs are lower than if they had been sired by the progenitor. Your only consolation is that the EPDs of the daughters you kept will eventually rise if the clone produces enough progeny for his EPDs to converge to the progenitors'.

To be theoretically correct and avoid the problems in the example, some genetic service providers fit clones as genetic identicals. There is a complicated way to fit this directly, but there is a very simple way to achieve the same result: within the genetic evaluation, assign all identical individuals the same ID (i.e., that of the progenitor), as if all the records and progeny of the clones were produced by the progenitor. In taking this approach it is recommended that clones retain their unique identities within the registration system so that, if we ever have enough data to make it feasible to estimate the degree, if any, to which clones differ in breeding value, we will have the information needed to estimate it.

It has been pointed out that, if all identicals are genotyped, the problem described above almost vanishes with current genomic evaluation procedures. Nonetheless, assigning all identical individuals a common ID for genetic evaluation will still be simpler and more accurate. The example above assumed the clone was not genotyped to illustrate the point.

The above discussion is the basis for a recent addition to the BIF Guidelines[1]:

"There are instances where genetically identical animals are in the pedigree (i.e. identical twins and clones). BIF recommends that, where genetically identical animals exist in the pedigree, for purposes of routine genetic evaluation, each set of genetically identical individuals is assigned a common identifier, so they have identical EPDs. Periodic test runs with the genetic identicals individually identified and the differences between them evaluated would be prudent. BIF recommends that genetically identical individuals should be assigned different permanent identification numbers." which appears in the section on "Expected Progeny Differences".

Gene Edited Animals

Gene editing is a process that allows specific modifications to be made to the genomic sequence of embryos or gametes resulting in animals that can transmit the desired modifications to their descendants. It is mentioned here because most approaches to gene editing involve manipulation and transfer of the embryo, but we leave description of the details and variations of it to others. [24]

Currently, most, if not all, gene edited cattle are produced by either IVF or NT. Consequently, their records are implicitly excluded from genetic evaluations.

However, eventually descendants of gene edited animals will enter genetic evaluations. If gene editing only introduced the polled mutation into a breed that is mostly horned, it would probably have no effect on genetic evaluation. At the other extreme, using gene editing to inactivate the myostatin gene could wreak havoc on genetic evaluations of close relatives on both sides of the gene editing event for most traits currently evaluated. Other uses of gene editing would likely fall along a continuum between these extremes.

Gene editing directly violates fundamental assumptions of traditional (non-genomic) genetic evaluation. Fortunately, it is probably much easier to accommodate in genomic evaluation models. However, there are many different genomic models and the ways in which they could accommodate gene editing are likely to differ. This may be a challenging problem when it eventually materializes as a problem.

Records Produced by AI or Natural Service Progeny of Donors Subsequent to Superovulation

Non-ET (AI or natural service) calves whose dams had been previously superovulated weighed 2.2±0.4 lb more at birth than non-ET calves whose dams had not been previously superovulated[51], although many of those donors had been superovulated numerous times. Superovulating donors repeatedly predisposes them to obesity and may raise their tailhead, thicken their crest and make them appear generally "coarse" (Thallman, personal observation). The effect of superovulating a cow only once is less. Whether, and/or under what circumstances, records of natural calves produced subsequent to superovulation are suitable for inclusion in genetic evaluation requires further investigation. Records for reproductive traits collected subsequent to superovulation are not suitable for use in genetic evaluation.

Maternal Effect of Donor Cow

Previous models[47][48][49][50][51] to include MOET records for maternal traits in genetic analysis have been based on the over-simplified assumption that the recipient is the sole source of maternal effects. This approach is clearly superior to assigning the maternal effect solely to the donor, but it may be suboptimal. A better approach is likely to be to separately estimate the variances of the maternal effect of the recipient and the (presumably much smaller) maternal effect of the donor from appropriate field data. There are several reasons for this assertion:

It is not implausible that the early oviductal and uterine environment of the donor affects the subsequent development and phenotypes of the resulting animal, given the discussion about LOS and abnormal clone syndrome (ACS). Furthermore, the ovum cytoplasm is filled with mRNA transcribed from the maternal genome that guides the embryo through the first several cell divisions and may have effects beyond that.

Effects of gametic imprinting and X-chromosomes are not fit in current genetic evaluations of beef cattle. To the extent that they are important for a trait, these mechanisms are accounted for by the direct additive, maternal additive, and residual effects in the model. Based on similarity of design and relationship matrices, the majority of these mechanisms may be allocated to the maternal effect. Gametic imprinting captured by the maternal effect (because of imprinting not being fit in the model) has been proposed as a potential contribution to the negative genetic correlation that has long perplexed animal breeders. These effects are genetic, so in MOET, that would be the maternal effect of the donor, not of the recipient. In Brangus and Simbrah, gametic imprinting was estimated to account for 4.7 and 6.9% of phenotypic variance for birth weight in male and female calves, respectively[51].

Consequently, an improvement to the above model for MOET records may be to allocate the maternal effect between the recipient and donor, with the proportions estimated from field data. Nonetheless, challenges in implementing this refinement should not impede implementation of the current recommendations.

Recommendations of Current BIF Guidelines on Embryo Transfer

Please see http://guidelines.beefimprovement.org/index.php/Embryo_Transfer_(ET):_Data_Collection_And_Utilization for recommendations that reflect future updates. The recommendations in effect at the time of this presentation are:

"BIF recommends that observations from animals resulting from MOET, for traits that do not have maternal effects, be used in genetic evaluations provided any preferential treatment, if given, is accounted for by assigning an appropriate contemporary group code.

BIF recommends that observations from animals resulting from MOET, for traits that have maternal effects, be used in genetic evaluations as long as the recipient dams' ages (heifer, 1st parity, or multiparity) and approximate breed compositions are available, and any preferential treatment, if given, is accounted for by contemporary grouping.

BIF recommends use of recipient cows with known pedigrees well-tied to the genetic evaluation as being preferable to recipients with unknown pedigree and no previous calves with records in the genetic evaluation. Where this is not practical, each recipient dam should be assigned a unique identifier so occurrences of multiple ET calves with the same recipient are properly accounted for.

BIF recommends that embryo stage (1-9) and grade (1-3) [55] and whether frozen, split, sexed, or genotyped be recorded and submitted to breed association or other recording organization. BIF recommends that, when sufficient information becomes available, genetic evaluation models for MOET calves include effects of fresh versus frozen and of biopsied (sexed and/or genotyped) or not.

BIF recommends that records of animals produced by MOET should have separate contemporary group effects in the genetic evaluation from records of animals produced by AI or natural service. However, animals produced by MOET should be included in the same management code (as determined by the breeder) as animals not produced by MOET (including AI or natural service calves) that were managed identically in the same group so their common environmental effect can be accounted for in future genetic evaluations. Major differences in age, breed, origin, etc. among recipients should also be accounted for in genetic evaluation models.

BIF recommends to not use phenotypic observations in genetic evaluation from animals resulting from In vitro Fertilization (IVF), Nuclear Transfer, or that are not explicitly known to have resulted from natural service, AI, or MOET in genetic evaluations. BIF recommends that observations on ET calves be recorded and submitted to breed association or other recording organization, along with the form of technology (as listed above or others not listed) used to produce the ET calves.

BIF recommends that for genetic evaluations of traits with maternal effects, that direct effects (breeding value, genomic effects, breed composition, heterosis, etc.) be assigned to the donor or natural dam, and maternal effects (breeding value, genomic effects, breed composition, heterosis, permanent environment, etc.) with the recipient dam.

BIF recommends that records for reproductive traits collected subsequent to superovulation not be used in genetic evaluation."

Conclusions

Embryo transfer is a valuable tool in the genetic improvement of beef cattle. Calves produced by ET comprise a disproportionately large share of ancestors of seedstock animals. Unfortunately, many ET cattle have been selected based on EPDs with unnecessarily low accuracy because their own records were excluded from the genetic evaluation. The Beef Improvement Federation recently adopted Guidelines recommending that records of most cattle produced by multiple ovulation embryo transfer be included in genetic evaluation. Unfortunately, despite important advantages leading to its rapidly increasing use, in vitro fertilization can cause large offspring syndrome, which renders records of cattle produced by it unsuitable for inclusion in genetic evaluations using current models. Actions by breeders, breed associations, and ET service providers that could potentially allow records of in vitro fertilized cattle to be included in future genetic evaluations are proposed.

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NOTES

Gene Editing as a Tool for genetic Improvement of Beef Cattle—Maci Mueller, University of California-Davis

INTRODUCTION

Gene editing is a suite of molecular tools that allow livestock breeders to precisely add, delete, or replace letters in the genetic code in order to influence a specific trait of interest (e.g., disease resistance), in as little as one generation. Several studies have produced gene edited livestock embryos and live animals, including cattle, for a multitude of traits. However, gene editing has not yet been applied on a commercial scale in livestock, so studies related to incorporating gene editing into livestock breeding programs have been limited. Moreover, the beef industry, which primarily raises animals in extensive grazing systems has several unique considerations compared to other more intensively managed industries (e.g., dairy). Therefore, this review aims to summarize gene editing research related to beef cattle improvement and to discuss strategies for disseminating traits improved via gene editing in extensive beef cattle grazing systems.

REVIEW OF LITERATURE

What is gene editing?

Genome or gene editing refers to the use of site-directed nucleases (i.e., nucleic acid cleaving enzymes) to precisely introduce double-stranded breaks (DSB) at predetermined locations in the genome [1]. Cells have evolved two primary pathways to repair DSBs: non-homologous end joining (NHEJ) and homology-directed repair (HDR). The underlying principle of both pathways is that the cell's endogenous repair factors will identify and congregate at the site of the DSB to repair the DNA in an efficient manner.

When using the NHEJ pathway, the cell attempts to fuse the broken DNA ends back together through blunt-end ligation. NHEJ is referred to as "non-homologous" because the ligation occurs without the use of a homologous template (e.g., sister chromatid) [2]. Consequently, this pathway is error-prone and often introduces variable-length insertion and deletion mutations (indels) at the DSB site [3]. In other words, the NHEJ pathway allows for the efficient disruption or knockout of a gene by targeting breaks to the coding region of the gene, where indels can result in frameshift or nonsense mutations.

On the other hand, the cell can use the HDR pathway if a nucleic acid template is provided. HDR templates can be designed to include desired modifications between regions of homology to either side of the DSB and templates are generally provided to the cell in the form of single-stranded or double-stranded DNA. The cell's repair enzymes can use the template as a model for precise repair by homologous recombination. The HDR pathway can be used to introduce, or knock-in, a range of gene edits, from point mutations to allelic substitutions, to entire transgenes [3].

There are currently three primary site-directed nucleases used for gene editing in livestock: 1) zinc finger nucleases (ZFN); 2) transcription activator-like effector nucleases (TALENs); and 3) clustered regularly interspersed short palindromic repeats (CRISPR)-associated protein 9 (Cas9) (Table 1). Since 2012, all three editing systems have been used to perform both gene knockouts and knock-ins in livestock cells and zygotes [4-6].

How can gene editing be applied for genetic improvement of beef cattle?

Regardless of the gene editing system used, the experiments in cattle have primarily focused on three main areas of improvement 1) animal health and welfare, 2) product yield or quality, and 3) reproduction or novel breeding schemes (Table 1). All three of these areas are highly aligned with the goals of conventional breeding programs [4, 7, 8].

In particular, a highly anticipated application of gene editing in livestock is to enable breeders to tackle specific animal health and welfare issues at a genetic level that through conventional breeding alone would either not be possible or likely result in decreased production efficiency. For example, gene editing enabled Wu et al. [9] and Gao et al. [10] to precisely insert genes from other species (mouse SP110 and human NRAMP1, respectively) into an intergenic region of the bovine genome to decrease susceptibility to tuberculosis. This scientific feat would not have been possible through conventional breeding methods alone. Gene editing has also enabled researchers to replicate a beneficial mutation in the prolactin receptor (PRLR) gene, first found in Senepol cattle and hypothesized to result in a SLICK phenotype (i.e., short, sleek hair coat), in Angus cattle to increase thermotolerance [11]. Although the Senepol PRLR mutation could be introgressed into another breed, such as Angus, through conventional breeding methods alone, the process would require multiple generations of backcrossing to restore genetic merit to pre-introgression levels, due to linkage drag [12]. In a species like cattle, with a long generation interval, backcrossing is a time-consuming and expensive process [13, 14]. Additionally, it is important to note that genetic solutions for animal health and welfare issues are often more sustainable and less work for livestock producers than chemical or mechanical methods [15, 16].

Overall, the potential for gene editing to improve livestock sustainability is evident. For instance, the 2018 National Academies of Sciences, Engineering, and Medicine (NASEM) study, Science Breakthroughs 2030: A Strategy for Food and Agricultural Research, identified "the ability to carry out routine gene editing of agriculturally important organisms," as one of the five most promising scientific breakthroughs that are possible to achieve in the next decade to increase the U.S. food and agriculture system's sustainability, competitiveness, and resilience

[17]. However, strategies for effectively incorporating gene editing into existing animal breeding programs, especially for species with long-generation intervals, such as cattle, are less obvious.

How can gene editing be integrated into beef cattle breeding programs?

In order for gene editing to be an important factor for genetic change, it must integrate smoothly into conventional cattle breeding programs and reliably edit the germline of breeding stock [6]. Therefore, the potential of gene editing cannot fully be realized without being used in conjunction with genomic selection (GS) and assisted reproductive technologies (ART) to accelerate genetic gain by simultaneously altering components of the breeder's equation [7, 18, 19].

GS, which has been advanced by the development of high-throughput genotyping of single nucleotide polymorphisms (SNPs), is used to predict the genetic merit of an animal based on its DNA data [20]. In livestock, GS has been used to improve the accuracy of selection and to provide useful information on traits that would otherwise be difficult to measure [21-23]. Concurrently, ART, such as artificial insemination (AI), multiple ovulation embryo transfer (MOET), and more recently ovum-pick up with in vitro embryo production (OPU-IVP), have been incorporated into cattle breeding schemes to increase selection intensity. Moreover, the benefits of each of these tools (i.e., GS and ART) can be maximized when used synergistically to accurately select young animals, which can drastically reduce the generation interval and ultimately accelerate genetic gain [24].

For example, GS can be used to accurately select high-genetic-merit young donor females for MOET or OPU and bulls for semen collection. Therefore, embryos produced from these matings will also have high genetic merit [24]. However, due to Mendelian sampling variance, not all full-sibling embryos will have the same genetic merit and there is a large cost and natural resource drain in gestating embryo transfer (ET) calves of unknown genetic merit to later cull [25].

An additional strategy is genomic screening of embryos (GSE), sometimes referred to as embryo genotyping, which is the genotyping of cells biopsied from preimplantation embryos (i.e., before ET into a recipient female). GSE can be used to predict an embryo's genetic merit so that only the embryos with the highest genetic merit are used for ET. Moreover, since a larger number of embryos can be in vitro produced (IVP) compared to live-born animals, GSE can be used to select a small number of animals from a large pool of candidates (in their embryo stage), which will further increase the selection intensity [24, 26, 27]. Although GSE holds great potential, there are currently several technical limitations to overcome.

There is an inverse relationship between the viability of a biopsied embryo and the ability to obtain enough DNA sufficient for genotyping [28]. DNA extracted from embryo biopsies can be used for genetic diagnosis (i.e., genotyping of a few specific loci via polymerase chain reaction (PCR)), for GS, or a combination of both). DNA from one to several biopsied cells has been used successfully for genetic diagnosis (primarily, sex identification) of preimplantation bovine embryos [28-31]. Moreover, de Sousa et al. [29] took biopsies of a limited number of cells (10-20 blastomeres) from the trophectoderm of both in vivo derived and IVP bovine embryos on day 7 of development and demonstrated that the biopsies were sufficient for embryo sexing via PCR and that there was no significant ($P > 0.05$) difference on day 60 pregnancy rates of fresh transfer, biopsied embryos compared to control, non-biopsied embryos. It is important to note that this study did not investigate pregnancy rates of biopsied and cryopreserved embryos. Due to the limited amount of time between being able to biopsy an embryo and needing to transfer the fresh embryo (i.e., both on day 7 of in vitro culture), the ability to cryopreserve biopsied embryos will likely be a critical process for applying GSE on a commercial scale.

While embryo biopsies for sex determination have been routinely used in ET programs [28, 32, 33], GS of embryos has been limited since a much larger number of cells (minimum of 30-40 cells) must be biopsied and genotyped to make accurate selection decisions [27, 28]. Although taking a biopsy of more than ~20 cells will drastically decrease embryo viability, alternatives to generate a sufficient amount of DNA for GS from only a small number of biopsied cells have been investigated, such as growing biopsied cells in culture [34, 35], and using whole genome amplification of biopsied cells in combination with imputation from known parental and population genotypes [35-37].

An adaption to traditional GSE was developed by Kasinathan et al. (2015) to genomically screen unborn bovine fetuses rather than embryos. Their strategy utilized multiple ET's and subsequent embryo flushing (21-26 day fetuses) to generate fetal fibroblast lines. DNA was extracted from the fibroblast lines for GS and the resulting genomic breeding values (U.S. dairy, Lifetime Net Merit index (NM$)) were used to select the line with the highest genetic merit. Cells from the selected elite fibroblast line were used as donor cells for somatic cell nuclear transfer (SCNT) cloning. Following ET of the cloned embryos, five healthy calves with elite dairy genetics were born [38]. This scheme does overcome the challenges of taking embryo biopsies for GS but still relies on the inefficient process of SCNT cloning to produce live offspring.

Similar challenges also exist for producing live, homozygous gene edited offspring. Currently, there are two primary methods to generate gene edited bovine embryos and each has associated tradeoffs (Figure 1). One option is to introduce the gene editing reagents (e.g., CRISPR/Cas9) into a somatic cell line and subsequently clone the cell line by SCNT to produce embryos. To date, this has been the primary method for gene edited livestock production because the clonal colony growth of cell lines provides large amounts of DNA that can be genomically sequenced to confirm and isolate cells with the desired edit in order to only produce animals with intended edits. However, due to faulty or incomplete epigenetic reprogramming of the donor cell genome, SCNT cloning often results in high rates of pregnancy loss and can also negatively affect the viability of live-born calves [39, 40]. Additionally, unless a scheme similar to Kasinathan et al. [38] is used, adult somatic cloning increases the generation interval by one generation (equivalent to two years in cattle), compared to ET of in vivo derived or IVP embryos.

Alternatively, gene editing reagents can be introduced directly into the cytoplasm of an IVP zygote (i.e., single-cell embryo), typically via microinjection (Figure 2) or more recently, via electroporation. Gene editing of zygotes is an attractive option because it avoids the inefficiencies associated with SCNT cloning, allows for the production of a diversity of foundation animals as each zygote will produce a genetically distinct animal, as opposed to animals derived from a clonal cell line, and does not increase the generation interval because the editing process is occurring in the next generation of animals. However, characterizing gene edited zygotes is difficult due to the challenges of GSE discussed above. Specifically, a major challenge associated with gene editing of zygotes is the production of mosaic animals [6, 19, 41]. Mosaicism arises from mutations that occur after DNA replication [42], resulting in one individual having two or more different genotypes. It is important to keep in mind that many livestock gene editing applications require homozygous modifications (i.e., two copies) to ensure inheritance of one copy in the F1 generation [6]. Therefore, mosaic gene edited animals will require subsequent breeding to produce homozygous edited offspring (Figure 1). Regardless of the method used to generate gene edited bovine embryos, ET into synchronized recipient females is a crucial step in producing live gene edited offspring (Figure 1).

Due to the fact that gene editing has not yet been applied on a commercial scale in livestock, strategies for incorporating gene editing into livestock breeding programs have primarily been modeled via computer simulation. One of the first simulation studies to explore the potential of combining gene editing with GS in a livestock breeding program was by Jenko et al. [18]. They modeled a breeding scheme called promotion of alleles by genome editing (PAGE) to improve quantitative traits, by selecting and gene editing the best animals based on their breeding values and then compared this scheme to GS alone. Jenko et al. [18] found that when gene editing was combined with GS the rate of genetic gain could be doubled as compared with GS alone. It is important to note that this simulation assumed a quantitative trait that had 10,000 known quantitative trait nucleotides (QTN), but identifying such QTN is not a trivial exercise and to date relatively few QTN with large effects on quantitative traits have been identified [43].

Bastiaansen et al. [44] modeled gene editing of a monogenic trait at the zygote stage in a generic livestock population combined with GS for a polygenic trait (i.e., index-based selection). In this simulation, zygotes from either 0, 10, or 100% of matings from genomically-selected elite parents were gene edited for the desired monogenic trait. Additionally, due to the low efficiencies of gene editing reported in the literature (Tan et al., 2016), they modeled various gene editing success and embryo survival rates. When they modeled 100% gene editing efficiency and embryo survival, they observed a strong favorable impact of gene editing on decreasing the time to fixation for the desired allele (four-fold faster), compared to GS alone. However, when they modeled a 4% gene editing efficiency, this had a major impact on the number of editing procedures needed (increased by 72%) and increased by eight-fold the loss in selection response for the polygenic trait, compared to the 100% efficiency model [44]. As discussed above, gene editing of zygotes is typically not 100% and mosaic animals are common [19, 41]. Therefore, in a commercial setting gene edited embryos will likely need to be biopsied to confirm the desired change before ET and avoid transferring non-edited embryos. Moreover, the current technical limitations of taking embryo biopsies for GS will need to be overcome to not only identify embryos with the intended edit(s) but also to select embryos with superior genetic merit in order to improve selection intensity.

Van Eenennaam [7] proposed a scheme where gene editing could be incorporated as an added step to the Kasinathan et al. [38] elite cattle production system (Figure 3). This approach was modeled to introduce a beneficial, monogenic, dominant allele (i.e., POLLED) into the U.S. dairy cattle [45] and northern Australian beef cattle populations [46]. In these simulations, fetal tissue from the next generation of yet-to-be-born bulls was genomically screened and selected, gene edited, and then successfully cloned such that this production system added 3–5 months to produce a homozygous gene edited, bull (Figure 3).

In the U.S. dairy population, Mueller et al. [45] found that the use of gene editing was the most effective way to increase the frequency of the desired allele while minimizing detrimental effects on inbreeding and genetic merit based on an economic selection index (i.e., NM$). The addition of gene editing only the top 1% of genetic merit bull calves per year to mating schemes that placed moderate selection pressure on polled was sufficient to maintain the same or better rate of genetic gain compared to conventional selection on genetic merit alone, while significantly increasing POLLED allele frequency to greater than 90% [45]. Additionally, both Bastiaansen et al. [44] and Mueller et al. [45] found that gene editing reduced long-term inbreeding levels in scenarios that placed moderate to strong selection emphasis on the monogenic trait of interest (e.g., polled) compared to conventional breeding alone. Importantly, Mueller et al. [45] modeled breeding to represent the widespread use of AI in the U.S. dairy population (i.e., maximum of 5,000 (5%) matings/bull/year) [23, 47-49], so a single dairy sire was able to have an immense impact on the whole population. Therefore, only a small number of elite dairy sires needed to be gene edited to see population-level results [45].

In contrast, AI is not widely used in northern Australian breeding herds [50], thus Mueller et al. [46] modeled all matings via natural service (i.e., maximum of 35 matings/bull/year). The natural mating limits prevented individual gene edited beef bulls from having an extensive impact on the whole population. Consequently, gene editing only the top 1% of seedstock beef bull calves per year in mating schemes that placed moderate to strong selection on polled resulted in significantly slower rates of genetic gain compared to conventional selection on genetic merit alone. However, they did find that if the proportion of gene edited animals was increased to the top 10% of seedstock beef bull calves per year in similar polled mating schemes then similar rates of genetic gain could be achieved compared to conventional selection on genetic merit alone. In all scenarios, regardless of if gene editing was applied, the population inbreeding level never exceeded 1%, which is well below the acceptable level [51]. This simulation study modeled solely natural mating because currently reproductive tools are scarcely used in this population [50]. However, the authors explain that, "this is unlikely to be the situation with valuable gene edited bulls. It is more probable that a high-genetic-merit homozygous polled sire would be used for AI or in vitro embryo production followed by ET, in the seedstock sector. This system would amplify the reach of each gene edited bull using well-proven advanced reproductive technologies and enable these bulls to produce hundreds or even thousands of progeny, and thus have a greater impact on the whole population."

Although Mueller et al. [46] modeled a northern Australian beef cattle population, many findings are also applicable to the U.S. beef industry [52]. Presently, only 12% of U.S. beef producers use AI, and even fewer (7%) use estrus synchronization. In 2017, this resulted in less than 10% of all females being bred via AI. A larger portion of heifers (19%) were bred via AI compared to only 7% of cows. Additionally, the majority of females bred via AI were also exposed to a clean-up bull (>80%). Interestingly, more operations in the U.S. Central region (22%) reported using AI compared to either the East or West regions (~8% each). Overall, AI is not currently widely practiced on U.S. beef operations largely due to the logistical challenges and additional labor required to identify females in estrus and constrain them to perform AI [52]. Therefore, a large number of gene edited natural service bulls will be needed to broadly disseminate gene edited traits in the U.S. beef industry.

A potential alternative to AI is the use of surrogate sires. Surrogate sires are host bulls that carry germ cells from more genetically elite donor sires, and they will be able to pass on these desirable donor genetics through natural mating to improve beef production efficiency [53]. Additionally, surrogate sire technology could potentially provide an efficient means for the distribution of traits that have been improved through gene editing [54].

It is anticipated that surrogate sire technology can be realized through germline complementation, which consists of using donor cells from one genetic background to complement or replace the germline of an otherwise sterile host of a different genetic background [55, 56]. Germline complementation requires two components: 1) hosts that lack their own germlines, but otherwise have normal gonadal development (e.g., intact seminiferous tubules and somatic support cell populations), and 2) donor cells that are capable of becoming gametes (Figure 4).

One method to generate germline-deficient hosts is via treatment with chemotoxic drugs (e.g., busulfan) or local irradiation, but these methods are not efficient in livestock because they either fail to completely eliminate the endogenous germline, or the treatment has undesirable side effects on animal health [55]. A promising alternative is to use gene editing to knockout a gene (e.g., NANOS2 or DAZL) in a zygote that is necessary for an animal's own germ cell production [57-61].

Donor cells can be blastomeres (i.e., embryo cells) or stem cells, as reviewed by Bishop and Van Eenennaam [6] and McLean et al. [19]. Stem cells provide several advantages over blastomeres. An embryo has a limited number of blastomeres and therefore a limited amount of genomic screening and multiplication potential [19]. In contrast, stem cells are self-replicating so they can provide a potentially unlimited supply of donor cells. Additionally, stem cells could be gene edited in culture, possibly multiple times sequentially, and then DNA could be extracted without harming the viability of the remaining stem cells to both confirm the intended gene edit was made and use GS to determine the genetic merit of each line. This scheme would be especially useful when applied to embryonic stem cells (ESCs) to overcome the current challenges associated with GSE and to avoid the mosaicism issues currently associated with zygote gene editing.

One source of germline competent stem cells is spermatogonial stem cells (SSCs), which can be isolated from mature or juvenile testes [55, 59]. Another potential source of donor cells is ESCs, which are derived from the inner cell mass (i.e., the tight cluster of cells inside a 7-day old embryo that will eventually give rise to the definitive structures of the fetus) of a preimplantation embryo [62]. Alternatively, induced pluripotent stem cells (iPSC) can be derived from somatic cells. Additionally, ESCs or iPSCs can be induced in culture to become primordial germ cell-like cells (PGCLCs) and subsequently induced to form sperm [63].

The process of germline complementation (i.e., combing donor cells with a host) can occur at different stages of a host animal's development, depending on the donor cell source (Figure 4). If the donor cells are SSCs or PGCLCs then they can be injected into a juvenile or adult host's germline-deficient gonad (Figure 4A). SSCs transfer has been demonstrated in pigs and goats and represents germline cloning of the current generation of sires [57, 59]. On the other hand, PGCLCs derived from ESCs would represent germline cloning of the next generation since the donor cells originated from an unborn 7-day old embryo. Alternatively, donor blastomeres or ESCs, which both represent the next generation could be combined with the host at the developing embryo stage (Figure 4B) [19, 64].

Irrespective of the production method, surrogate sires could unlock an opportunity to both accelerate genetic improvement of beef cattle and widely distribute traits improved via gene editing. The selection of only elite males for donor cells would increase selection intensity. Additionally, since the use of surrogate sires will not require any additional labor for commercial producers, there could be widespread adoption of this technology, which would dramatically reduce the lag in genetic merit that typically exists between the seedstock sector and the commercial sector. Gottardo et al. [53] performed simulations to develop and test a strategy for exploiting surrogate sire technology in pig breeding programs. Their model projected that using surrogate sire technology would significantly increase the genetic merit of commercial sires, by as much as 6.5 to 9.2 years' worth of genetic gain as compared to a conventional breeding program. An important question that should be addressed in future research is how to best accommodate both surrogate sires and their progeny and gene edited animals and their products into genetic evaluations.

Conclusions and Implications to Genetic Improvement of Beef Cattle

The ability of gene editing to inactivate targeted gene function (i.e., knockout genes), knock-in genes from other species, and/or achieve intraspecies allele introgression in the absence of undesired linkage drag, offers promising opportunities to introduce useful genetic variation into livestock breeding programs. Specifically, gene editing is well-suited for modifying qualitative, single-gene traits, at a much more rapid pace than conventional selection alone. Moreover, if gene editing is synergistically combined with GS and ART, genetic gain can be accelerated by simultaneously altering multiple components of the breeder's equation. It also offers the opportunity to improve currently elusive traits, such as disease resistance and improved animal welfare. Although the potential for gene editing to improve livestock sustainability is evident, strategies for effectively incorporating gene editing into existing animal breeding programs are less apparent. Several gene editing schemes have been modeled for livestock populations, and the most efficient schemes have relied heavily on widespread adoption of ART, especially commercial sector use of AI. Considering the currently limited adoption of AI in the U.S. commercial beef industry, novel breeding schemes, such as gene editing applied to surrogate sire production (i.e., host bulls that carry germ cells from more genetically elite donor sires), will be required to widely disseminate desired traits improved via gene editing. Furthermore, this system could have the added benefit of reducing the genetic lag that typically exists between the seedstock sector and the commercial sector in beef cattle breeding programs.

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