Action Plan
National Program 101
Food Animal Production
2022-2027

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Vision, Mission, and Mapping

This Action Plan defines the research that scientists in the USDA Agricultural Research Service (ARS) National Program 101 will perform in accordance with the mission of the agency. The Action Plan was developed following multiple types of information gathering sessions with stakeholders and includes the problems that will be addressed, the goals of the research, potential products from the research, and the ARS locations that will perform the research.

Vision Statement

National Program 101 "Food Animal Production" (NP 101) is a research program that delivers scientific information and solutions that ensure sustainable (efficient and profitable), environmentally responsible animal agriculture, appropriate care and well-being of food animals, (e.g. aquaculture, beef and dairy cattle, goats, insects, pigs, poultry, sheep) and a high quality, safe supply of animal-products for U.S. consumers.

Mission Statement

Conduct research to improve food animal production efficiency, animal and food industry sustainability, animal welfare, and product quality and nutritional value, while safeguarding animal genetic resources and conserving environmental resources.

Mapping

This Action Plan aligns with the mission of the USDA that is described in its Strategic Plan, with the priorities outlined in the USDA Science Blueprint, and with the goals of the ARS Strategic Plan by performing research that will increase the productivity of U.S. food animal producers and the quality of their products. Specific information on these topics can be found in the following directives.

Relationship of NP 101 to the USDA Strategic Plan

The National Program for Food Animal Production outlines research that supports the following goals and objectives in the USDA Strategic Plan for FY 2018-2022[1]:

- *Strategic Goal 2*: Maximize the Ability of American Agricultural Producers To Prosper by Feeding and Clothing the World
    - Objective 2.2 Increase Agricultural Opportunities and Support Economic Growth by Creating New Markets and Supporting a Competitive Agricultural System
- *Strategic Goal 5*: Strengthen the Stewardship of Private Lands Through Technology and Research
    - Objective 5.1 Enhance Conservation Planning with Science-Based Tools and Information

Relationship of this National Program to the USDA Science Blueprint

This National Program supports Theme 1: Sustainable Ag Intensification, from the USDA Science Blueprint 2020 to 2025.

Relationship of this National Program to the ARS Strategic Plan

This Action Plan outlines research that supports the 2018-2020 ARS Strategic Plan[2], Strategic Goal Area 4, Animal Production and Protection, Strategic goal 4.1. Improve food animal production efficiency, industry sustainability, animal welfare, product quality, and nutritional value while safeguarding animal genetic resources. The National Program for Food Animal Production participates in the following ARS

[1] https://www.usda.gov/sites/default/files/documents/usda-strategic-plan-2018-2022.pdf
[2] https://www.ars.usda.gov/ARSUserFiles/00000000/Plans/2018-2020 ARS Strategic Plan.pdf

Grand Challenge Synergies and other Initiatives:

- **The Beef Grand Challenge** research will identify the interactions between genomics and the production environment on beef cattle systems at distinct production stages to increase the efficiency and productivity of this industry.
- **The Dairy Grand Challenge** research investigates the interrelationships between soil, forage, dairy cow, and characteristics of milk that influence the nutrition and health of humans resulting in improvements in product quality and dairy industry efficiency.
- **The Antimicrobial Resistance Initiative** research identifies alternatives to antibiotics for growth promotion of livestock and implements their use.
- **The Climate Change Initiative** investigations include life cycle assessments of livestock production which indicated that primary contributions of livestock production to climate change are those associated with livestock feed (all livestock) and methane production (primarily ruminants). Therefore, this program works to improve feed and production efficiency, which will reduce greenhouse gas production associated with livestock feed and mitigate methane production in ruminants.
- **The Microbiome Initiative** addresses the role of the microbiome in production efficiency (primarily nutritional efficiency) and animal welfare (primarily disease mitigation).

National Program 101 interacts with other National Programs within ARS such as with the Animal Health (NP 103), Veterinary, Medical, and Urban Entomology (NP 104), Aquaculture (NP 106), Food Safety (NP 108), and Grass Forage and Rangeland Agroecosystems (NP 215) programs.

- NP 103 connections are primarily related to the production and welfare consequences of disease and genomic analyses for disease tolerance/resistance.
- Collaborations with NP 104 focus on solutions to mitigate disease, pests, and parasites that affect livestock productivity.
- Interaction with NP 106 encompasses genome to phenome collaborative research.
- Collaborative research with NP 108 ensures that our food supply is safe and includes research topics like systems biology, alternatives to antibiotics, and antimicrobial resistance.
- Research with NP 215 considers the interaction of the animal with its forage, pasture, and rangeland to develop healthy, prolific animal production environments and systems.

Introduction

Food animal production and product consumption will continue to increase due to: a growing world population, income growth, increased demand for animal products by developing nations, and growing demands for better nutrition (higher quality and more nutrient dense sources of protein, iron, and other vital nutrients) at a lower cost. This trend will continue as the world's population continues to grow and as animal production systems increase efficiencies across varied environments and production systems. Animal production systems fit a unique and valuable niche in global food production by utilizing feeds and forages that are not suitable for human consumption. Animal production, in environmentally sustainable food production systems, will continue to serve this vital role in response to increasing demands for nutritious protein sources according to the International Food Security Assessment, 2020-2030[3]).

The United States is a significant source of quality animal products and is a world leader in related technological development and adoption. These advances enabled the United States to develop one of the world's most prolific animal production systems[4] and ARS serves a vital role in that achievement.

[3] https://www.ers.usda.gov/webdocs/outlooks/99088/gfa-31.pdf?v=1003.6
[4] http://www.fao.org/faostat/en/#rankings/commodities_by_country

Pressure to feed a projected nine billion people by 2050 makes the role of ARS critically important. To provide responsible global leadership during a time when extraordinary growth in animal production systems around the world is required, the United States must focus on increasing animal production efficiencies through the development and adoption of sound scientific technologies that facilitate effective stewardship of the planet's resources. Moreover, improvements in production efficiency must promote responsible animal care and welfare. ARS researchers that implement this Action Plan will identify and apply new genomics tools, and make advances in biotechnology, metagenomics (gut health and the microbiome), reproductive physiology, nutrition, and molecular biology. At the same time, ARS scientists will improve the quality of animal health, welfare, and ecosystem conservation to advance the global economic competitiveness and sustainability of U.S. food animal production. The products of this Action Plan will advance animal production systems through the adoption of science-based strategies that harness animal biology in sustainable ways, while maximizing profits, securing supply, increasing market competitiveness, promoting small and mid-sized producers, conserving natural resources, and maintaining genetic diversity and consumer confidence.

Stakeholder Engagement

A retrospective presentation of the USDA ARS National Program 101 Food Animal Production Program research was presented for the period from 2015 - 2020 by the Office of National Programs in December 2020. An external panel of industry members and academic scientists evaluated the scientific value of the accomplishments, identified unmet potential, and assessed the value of this national research program. Information from this session can be found in the Panel report[5].

In addition, in 2021, representatives of the USDA ARS National Program for Food Animal Production and the Animal Production Division of the National Institute of Food and Agriculture (NIFA) co-hosted a series of listening sessions to engage members of the academic communities, producers, allied stakeholders, and other government agencies to provide information about our collective research, education, and extension programs and to solicit direction and guidance for the next 5-10 years. Specifically, ARS researchers solicited guidance and direction to:

- Facilitate development of USDA research, education, and extension programs to effectively address existing and emerging commodity/discipline-specific, and cross-cutting issues in food animal production.
- Identify emerging food animal production issues impacting the food animal industries over the next 5-10 years.
- Explore opportunities for collaboration among ARS, NIFA, allied food animal industry and academia to maximize research capability and performance by leveraging funding, physical resources, and scientific talent.
- Develop ideas to facilitate technology development, and transfer to industry.

This Action Plan identifies the priorities from these listening sessions that ARS has the expertise and resources to address. The Action Plan serves as a strategic plan to define the scope of our programs and which are consistent with our Vision and Mission. Additional information and the results of these listening sessions can be found in Appendix 1.

Stakeholders identified additional priorities that ARS does not have the capacity to conduct research on, but may be addressed by other USDA programs or federal agencies, including:

- Equine health, nutrition, performance, safety, and reproductive physiology;
- Assessing the technological capabilities of rural America;

[5] https://www.ars.usda.gov/animal-production-and-protection/food-animal-production/docs/retrospective-assessment/

- Use of non-livestock species as models in growth and development studies; and
- Alternative protein sources to meat for human consumption - a broad category encompassing plant-based meat alternatives, fermentation derived proteins, laboratory grown cells and tissues that can be formed to make meat-like products.

Research Component Overview

The NP 101 Food Animal Production Action Plan contains general strategies and specific actions within the following organizational hierarchy:

1) Components that are general categories of agriculturally useful research areas that ARS will undertake, identified with the help of stakeholders;
2) Problem Statements that indicate the specific nature and scope of problems to be solved;
3) Research Focus for each Problem Statement that will be addressed by ARS in order to achieve a successful resolution of the problem;
4) Anticipated Products of research activities; and
5) Potential Benefits that describe the valuable outcomes of the proposed research for consumers and the food production industries.

Two overarching components of this Action Plan are climate change adaptation and environmental stewardship in accordance with the USDA Climate Change Adaptation Plan[6]. That plan states that, when applicable, actions by a USDA agency will "identify potential impacts of climate change on their area of responsibility, prioritize, implement, and integrate response actions into their operation, contingent on the availability of resources, continuously assess and improve the capacity to adapt to current and future changes in the climate, and incorporate climate-resilience into our decision-making." Therefore, the application of that mandate has been incorporated, where appropriate, within the research of this Action Plan. The components and associated problem statements for this Action Plan include:

Component 1: Increase Food Animal Production Efficiencies, Food Animal Well-Being, and Adaptation of Food Animals to Diverse Production Systems

Problem Statement 1A: Improve the Efficiency of Food Animal Growth and Nutrient Utilization
Problem Statement 1B: Improve Food Animal Reproductive Efficiency
Problem Statement 1C: Enhance Food Animal Well-Being and Reduce Stress in the Production System

Component 2: Understanding, Improving, and Effectively Using Food Animal Genetic and Genomic Resources

Problem Statement 2A: Develop Bioinformatic and other Required Capacities for Research in Genomics and Metagenomics
Problem Statement 2B: Characterize Functional Genomic Pathways and their Interactions
Problem Statement 2C: Preserve, Characterize and Curate Food Animal Genetic Resources
Problem Statement 2D: Develop and Implement Genetic Improvement Programs using Genomic Tools
Problem Statement 2E: Develop Techniques for Genetic Modification and Genetic Engineering of Food Animals and Evaluate their Efficacy

Component 3: Measuring and Enhancing Product Quality and Enhancing the Healthfulness of Meat Animal Products

Problem Statement 3A: Enhance Systems to Improve Product Quality and Healthfulness and Reduce Variation in Meat Animal Products

[6] https://www.usda.gov/sites/default/files/documents/DR1070_001USDAPolicyStatement_062015.pdf

Research Approach

The following section describes the research that will be performed. It is divided into the three components that were just presented and provides reasons and rationale for the research by topic. In addition, the products and benefits of these efforts are also described to provide an understanding of the utility of the research.

Component 1: Increase Food Animal Production Efficiencies, Food Animal Well-Being, and Adaptation of Food Animals to Diverse Production Systems

U.S. food animal agriculture is at a unique and critical juncture. Globally, food prices are increasing to record levels, as demand for animal products increase and standards of living improve around the world. More consumers seek higher quality, more nutrient-dense animal-derived foods. For these reasons, food animal production must continue to increase, particularly across the vast areas of marginal lands around the world that are not suitable for grain or other food production. In fact, USDA projects that food animal production will need to increase by 70 to 100 percent by 2050 to meet the demands of a growing world population[7] . This leaves U.S. food animal producers with several challenges and opportunities including some of the items listed below:

- *Competition:* Global food animal production systems are growing at unprecedented rates and are in direct competition with U.S. producers. Therefore, U.S. food animal managers must increase production levels and efficiencies to remain profitable in the face of greater international competition and the increasing need to produce high quality animal products for human consumption.
- *Feed costs*: Historically, 50 to 60 percent of the total costs of producing a unit of meat or milk have been attributed to feed costs. This high percentage of the cost of production has driven the need for improvements in the efficiency of nutrient utilization to reduce feed costs. Basic and applied research will improve the efficiency of nutrient utilization to reduce the amount of feed required per unit of production, to increase livestock growth and product yield, and to explore the use of non-traditional feeds.
- *Breeding population maintenance*: An additional primary cost of production in the livestock industry is maintenance of the breeding stock. This includes:
  - Reproductive rates which includes the maturation rate of animals as well as number of offspring produced;
  - Longevity of breeding females, which includes the expenses associated with raising replacement animals for the breeding population, reproductive failure, and other factors that affect longevity (e.g. environmental constraints, animal adaptation, and well-being);
  - Feed efficiency of breeding animals which would increase the efficiency of overall production.

These factors are related to production and production efficiencies in the food animal industries.

- *Reproduction*: As a result of research by ARS and others, much is known about the factors that affect reproduction and production efficiency, yet many questions about their interactions remain unexplored and warrant further research. Numerous factors reduce reproductive success and contribute to decreased breeding longevity. For example,
  - Embryonic mortality and factors affecting early embryonic mortality;
  - The antagonism between production efficiency and reproductive efficiency for many food animal production systems (e.g. improvements in dairy cattle milk production and growth rates in livestock and poultry occurred with simultaneous reductions in fertility even though our current understanding (genetics, genomics, and physiology) indicates that the biological limits of these traits are significantly higher than current production levels).

[7] https://www.usda.gov/topics/food-and-nutrition/food-security

- *Feeding and nutrition*: Because feed efficiency relates to nearly all aspects of economic and environmental sustainability, it is imperative that solutions be found to improve nutrient utilization efficiency for conversion to livestock and poultry products. Consequently, research will be proposed that will:
  - Explore the basic biological and physiological mechanisms controlling energy metabolism and growth to inform the development of strategies to improve feed efficiencies;
  - Understand the relationships between animal stress, immune system activation, gastrointestinal function, and energy utilization;
  - Produce food animal products while balancing growth, feed consumption, and management of manure and nutrient by-products.
- *Food animal production systems*: Proper matching of animal genotype and management system to the production-marketing environment is critical for sustainable and profitable production to limit the negative impacts on animal health, production efficiency and welfare, and to meet consumer demands regarding animal welfare. This Action Plan proposes research that will:
  - Develop a comprehensive understanding of factors that affect animal adaptability to production systems, functionality, welfare, production, and efficiency;
  - Develop and interpret scientific measures of animal stress and welfare;
  - Create an understanding of the stress caused by social, nutritional, environmental factors and their interactions.

Problem Statement 1A: Improve the Efficiency of Food Animal Growth and Nutrient Utilization

Enhance production and efficiencies: The largest production costs of food animal production are from feed inputs. Improvement of production and production efficiencies by ARS for food animal production systems can be accomplished by improving growth performance and the efficiency of nutrient utilization. These increased efficiencies must be achieved while prioritizing sustainability of the natural resource base.

Develop strategies to improve growth, yield, feed conversion, reproduction, production efficiency, and well-being: In general, an improved understanding of nutrient and energy requirements, gastrointestinal function, and host-microbe interactions of livestock during various stressful situations and during an immune challenge will improve the efficiency, productivity and overall well-being of livestock in production environments. To improve our understanding, ARS scientists will develop strategies to predict and improve growth, milk and egg yield, as well as feed conversion, reproduction, production efficiency and overall well-being.

Identify nutrient requirements, functional microbiology of utilization, and opportunities to optimize feeding systems: Because growth rate, milk and egg yield, and feed efficiency are heritable traits and because of the selection pressure utilized in livestock improvement programs, the genetic merit for production (e.g. rate of growth and yield of meat, milk, and eggs) is perpetually changing. Therefore, ARS scientists will identify and validate nutrient requirements, the functional microbiology associated with nutrient utilization, improved gastrointestinal functioning, and optimized feeding systems so that higher levels of genetic potential can be realized. ARS scientists will develop a comprehensive understanding of the metabolic or physiological functions that determine production potential to achieve this goal.

Improve food animal genome sequences and annotation, with next generation sequencing capabilities. ARS scientists will enhance their understanding and develop opportunities for functional genomic analysis of tissues for production traits. ARS scientists will better understand the regulation of genes and gene complexes that affect production. Moreover, ARS scientists will develop production systems that utilize genetic selection for growth efficiency and performance parameters to identify animals that are immunologically competent while simultaneously efficient in diverse environments. ARS

scientists will use new techniques in mass spectrometry to conduct comprehensive analyses of proteins and metabolites that contribute to nutrient utilization and growth and their application.

Understand the interactions between the host and gut biome: The microorganisms that inhabit the digestive tract of food animals contribute to growth and developmental performance, nutrient utilization, gastrointestinal function (GI), and health of the animal. However, the digestive system is complex and contains many microorganisms that compete with other organisms in these environments and may partially explain the recognized growth promotion effects of antibiotics in food animal species. A healthy interaction between the host and the gut microbiome is key for maintaining homeostasis and for proper nutrient utilization as animals rely heavily on microbes for digestion of complex nutrients. Recent changes limiting the use of antibiotics in livestock increase the importance of understanding the interactions that occur within livestock microbiota, including the development of antibiotic resistance. To better understand this complicated system, ARS scientists will use modern high throughput sequencing technologies to characterize the organisms present in the digestive tract of all food animal species, test the value of genomic and other strategies to beneficially alter the organisms present to improve growth performance and nutrient utilization efficiency, and characterize the prevalence of antibiotic resistance or metal tolerance genes. This will result in the development of alternative strategies by ARS scientists to improve growth performance, milk and egg yield and feed efficiency by replacing the beneficial growth effects of antibiotics through the development of methods to make modifications in the digestive tract microbiome and/or animal metabolism. In addition, certain commensal microorganisms in the gastrointestinal tract of livestock are opportunistic pathogens that may initiate disease, may manifest during periods of stress and can reduce the efficiency of nutrient utilization, alter the function of the gastrointestinal tract, negatively impact the rate of gain, exacerbate disease due to other pathogens and increase production costs due to disease outbreaks requiring antibiotics. ARS scientists will develop alternative strategies to reduce or protect against opportunistic pathogens on the farm which will decrease the use of antibiotics for disease treatment and limit production losses.

Simultaneously, development of alternative management strategies to antimicrobials by ARS should limit unintended consequences to the environment such as the accumulation of harmful chemical compounds in agricultural settings or selection for resistance to antimicrobials in pathogens.

Explore pasture-based animal food production systems, forage consumption, and alternative feed sources: In recent years, there have been growing trends toward development of pasture-based dairy and beef production systems. Additionally, there is a growing number of food animal production operations in the United States that already rely on forage-based systems, and a desire to explore alternatives to traditional feed sources. Therefore, ARS scientists will investigate the following concepts:

- Effective utilization of forages and alternative feed sources by livestock to provide appreciation of rumen and monogastric digestion of forages and alternative feeds in mixed diets;
- The characteristics of forage plants that alter nutrient digestibility;
- Toxicosis problems associated with certain forages;
- Methodology for evaluating feed consumption, characteristics and digestibility for ruminants and monogastric species;
- The role and interaction of diverse forages and alternative feeds on animal production and animal nutrient utilization efficiency;
- The influences of forage/feed type and utility on animal manure characteristics, soil health, and fertility for the evaluation of the fate of carbon and nitrogen in integrated dairy and animal production systems;
- Means to improve nitrogen use efficiencies in animal systems which have direct implications for forage crop and animal production system capacity and efficiency as well as environmental sustainability of food animal systems;
- The effects of climate change on forage-based and alternative feed systems.

Research Focus

Growth and development: Defining the factors that predict and influence growth and developmental performance and the utilization of nutrients by livestock is essential for increasing U.S. agricultural productivity and efficiency. Included in these factors are genetic/genomic and basic cellular and metabolic biological systems that influence growth, development, production and reproduction efficiency, product yield, quality and healthfulness, animal well-being, and the generation of manure and emissions from animal production systems. ARS scientists will develop comprehensive systems research strategies to optimize feed inputs and production efficiencies in economically diverse and environmentally sustainable production systems and to ensure that greater levels of production can be achieved.

Genetics and genomics: ARS scientists will develop a greater understanding of poultry, cattle, swine, sheep, and goat genome sequences, that includes elucidating the genetic diversity within and between breeds, as well as comprehensive and accurate annotation to increase our understanding of the genes that influence traits and how they function. Analyses of proteins and metabolites will be performed by ARS scientists to enhance our understanding of nutrient utilization processes, and to develop biomarkers that could be used as indicators of high and low efficiency livestock. Developing a better understanding of metabolic syndromes in cattle through this approach will also be performed by ARS. Feed intake in poultry, cattle, sheep, and swine will also be investigated by ARS and include identification of genes and gene products that affect feed intake and regulation. Knowledge gaps exist in the interaction of poultry, cattle, sheep, goat, and swine feed efficiency and the genetic effects that modulate this process and will be researched by ARS. Means of increasing the efficiency of nitrogen utilization in poultry, cattle, sheep, goat, and swine will be explored by ARS to provide tools to reduce the environmental impact of livestock. Bioinformatics capacity to manage and analyze data sets from these research projects will be expanded and implemented by ARS scientists.

Microbiome: Characterization and manipulation of the functional microbiology and microbiome of food animals will be performed by ARS to improve growth and production performance, maintain a healthy gastrointestinal tract, and optimize the efficiency of nutrient utilization. Additional goals of microbiome research that will be performed by ARS are to:

- Reduce emissions (methane and other greenhouse gases);
- Develop opportunities to identify and implement alternatives to antibiotics for growth promotion;
- Develop research infrastructure to effectively utilize high throughput sequencing of the metagenome of livestock species, including bioinformatics capabilities to store and manipulate the data generated;
- Understand host-microbial interactions, including metabolite production;
- Develop interventions to decrease opportunistic pathogens in the gastrointestinal tract that reduce the rate of gain and predispose animals and poultry to infectious diseases;
- Create management tools to protect animals and poultry against facultative pathogens that require antibiotic administration to control acute disease outbreaks;
- Develop alternatives to antibiotics and alternative strategies for antibiotic administration for improved immunotolerance and suppression of opportunistic pathogens to limit production losses and curtail the development of antimicrobial resistance and metal (ionophore) tolerance;
- Test the implementation of these strategies on nutrient utilization and availability, feed efficiency, growth, development, promote better use of feed components etc.

Feeds and feeding: ARS scientists will identify opportunities to optimize forage use and characterize alternative feeds for ruminant and monogastric livestock production systems. ARS scientists will also identify alternatives to commonly fed ingredients as sources for energy and amino acids for livestock, including non-traditional feeds or feed components. Gaps exist in all aspects of our understanding of and ability to optimally utilize traditional feeds, forages, and alternative feeds in systems. Research by ARS will also better characterize forage and feed intake by livestock to improve nutrient utilization efficiencies, as well as improve rangeland health and sustainability. In addition to these considerations,

efforts to address climate smart feeds, for example feeds that reduce methanogenesis (like seaweeds) and feeds that maximize nutrient (e.g. nitrogen) retention to reduce manure and manure emissions of greenhouse gases, will also be investigated by ARS scientists.

Stress and Immune function: Non-antibiotic supplements can provide immunological protection and reduce the negative impacts associated with stress responses without diverting nutrients and energy away from economically important production characteristics like animal growth and development, milk production, and meat quality. ARS scientists will explore and acquire an understanding of how changes in metabolism modulate the stress response and immune function in livestock.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Elucidation of the genes, causative genetic variants, metabolic pathways, and biological markers that contribute to growth and production performance (food and/or fiber), gastrointestinal function, and nutrient utilization efficiency of livestock, and identification of strategies and improved management practices for their use. (See also Component 2A Anticipated Product 5).
2. Comprehensive characterization of the microbiota in livestock species, including organism presence and prevalence throughout production, identification of species correlated with improved performance, nutrient utilization, gastrointestinal function, or reduced environmental impact.
3. Identification of alternative feedstuffs and precision feeding systems for livestock that can be used to provide optimal nutrients for maintaining production, production efficiencies, and meat quality while minimizing nutrient loss to the environment and maximizing carbon sequestration.
4. Development of management strategies and optimized year-round forage-based systems, including the use of crop residues, cover crops and summer/fall annuals, to improve grazing land health, sustainability, and conservation/return of natural ecosystem services.
5. Identification of alternatives to antibiotics including the role of pre-, pro-, post- and para-biotics, for improving growth performance, decreasing pathogen susceptibility of livestock, reducing disease severity and microbial carriage of antimicrobial resistance and metal tolerance genes.
6. Determination of current nutrient and energy needs of livestock based on current genetics and management strategies, for traditional and non-traditional feedstuffs, during stressful situations, during/after a health challenge, in the presence of alternatives to antibiotics, and to meet livestock growth, gastrointestinal function, and microbial nutrient needs.

Potential Benefits

Research in this area will:

- Improve the development and growth rates of food animals and preserve product yield and quality.
- Ensure animal well-being and improve economic sustainability and conserve environmental resources.
- Enable optimal use of nutrient inputs in both intensive and extensive production environments.
- Improve our understanding of the digestive system, digestibility of feeds, host-microbial interaction, and functional microbiology thus increasing productivity, growth rate and feed efficiency of food animals.
- Reduce pathogen susceptibility and the need for antibiotics for growth promotion and feed efficiency.
- Identify biological markers that can predict growth rate and feed efficiency.
- Optimize forage use and alternative feeds which will reduce the amount of necessary nutrients from grain and other concentrated feed sources and their associated costs.
- Create a better understanding of genetic regulation of growth rate and feed efficiency leading to increased growth performance and efficiency of nutrient use.
- Improve use of natural resources and the economic and environmental sustainability of livestock species.
- Develop and improve forage-based and less-conventional production systems.

Problem Statement 1B: Improve Food Animal Reproductive Efficiency

Improving reproductive performance and efficiency in food animals represents the single most critical challenge to efficient food animal production and is a primary factor contributing to producer profitability and competitiveness. The challenges to improving this aspect of production are diverse and complex and include such things as reproductive capacity and reproductive longevity, environmental factors including temperature, humidity, photoperiod, and plane of nutrition, neuro-endocrine regulatory mechanisms, gonadal and uterine function, conceptus-dam interactions throughout gestation and into the neonatal period, managerial factors that may contribute to epigenetic influences on reproduction, prepubertal development, seasonally reduced gamete production, pregnancy maintenance, postpartum anestrous, aging, and the genetic and phenotypic antagonism that exists between production and reproductive efficiency. Collectively, significant improvement of reproductive efficiency will require a true "systems biology" approach including integration of all relevant genetic, physiological, and environmental factors. These improvements will result in increased profitability and competitiveness of producers and improve the economic and environmental sustainability of the food animal industries.

Research Focus

Production and reproduction: Studies in numerous food animal species indicate that nutrition, metabolism, pre- and postnatal growth, previous reproductive status, and lactation all affect reproductive capacity, but we have an incomplete understanding of the actions and interactions of the genetic, physiologic, metabolic, and other pathways that result in these antagonisms. Antagonistic effects of these factors on puberty, postpartum anestrus, ovulation rate, embryonic, fetal, and neonatal survival, and lifetime productivity have all been described, but problems with each component still occur in various livestock species and therefore, effective strategies and remedies are needed. For example, basic research of the process of embryo implantation is needed to mitigate the observed decline in conception rate per service in dairy cattle. Research by ARS scientists will elucidate and remediate the physiological factors that create antagonism between these aspects of food animal production systems. Physiological and metabolic factors underlying lowered longevity of breeding females will be explained by ARS to address this issue in cattle and swine. Functional genomic analyses including transcriptomic, proteomic and metabolomic analyses of various reproductive tissues will be performed by ARS scientists to provide a comprehensive analysis of factors that affect fertility. The use of functional genomic analyses for growth and feed efficiency data analysis will also be developed by ARS to enhance the generation of knowledge from these types of experiments.

Assisted reproductive technologies (ARTS): Improvements to ARTs, including in vitro oocyte maturation, fertilization, and embryo production, semen, oocyte, and embryo cryopreservation (vitrification), and sexing semen for several livestock species, which result in greater fertility must be pursued by ARS. In addition, many breeds of sheep and goats are obligate seasonal breeders and ARS scientists will improve the utilization of these animals in production systems by developing methods to overcome the seasonal production variation in an inexpensive, cost-effective manner. Swine, despite being capable of breeding year-round, also display seasonal variation in fertility that is problematic in intensive swine production and this will likewise be addressed by ARS. Consequently, research by ARS will identify the physiology underlying seasonal infertility for these species.

Reproductive efficiency: Even under ideal conditions, significant inefficiencies in fertility exist in all species that are not associated with level of production or seasonality. Both the male and female contribute to pregnancy failure. Research in the male will be performed by ARS to discover sperm biomarkers of fertility for the optimal production, evaluation, and use of semen in various species. Research in the female by ARS will focus on attainment of puberty; follicle development, ovulation of optimally fertile oocytes, and elucidation of the oocyte contribution to reproductive success; oocyte and uterine biomarkers of receptivity and fertility; factors contributing to embryo, fetal and neonatal survival and development; and efficient return of animals to breeding readiness after parturition. Factors

associated with lactation efficiency are not well understood and will be explored by ARS to enhance the survival, growth, and development of neonatal animals. The information obtained from these efforts by ARS will collectively result in strategies to maximize reproductive efficiency of livestock species.

Environmental stressors: Gamete production, fertilization, and pregnancy resulting in live births in all livestock species is modulated by environmental stressors. Research by ARS will determine the effects of environmental factors such as air quality, housing, heat stress, and social interactions on reproductive function. In addition, maternal epigenetic and behavioral effects on neonatal survival will be investigated by ARS scientists.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Strategies that break the antagonistic relationship between production and reproductive efficiency, allowing both to be simultaneously improved.
2. Characterization of the mechanism of implantation to mitigate embryonic losses, and identification of other physiological or biological markers, and management factors that modulate fertility/infertility in livestock.
3. Development of assisted reproductive technologies resulting in greater fertility.
4. Data to facilitate matching the genetic potential of breeding animals with environmental stressors and managerial interventions to optimize reproduction.
5. Strategies based on dietary and epigenetic inheritance that increase longevity and lifetime productivity of breeding females in livestock systems.
6. Strategies that contribute to increased success with assisted reproductive technologies such as in vitro embryo production, gamete cryopreservation and sexed semen, especially in small ruminants and poultry.

Potential Benefits

Research in this area will:

- Increase reproductive capacity, efficiency and longevity of the nation's breeding herds of livestock leading to a more stable and profitable animal agriculture sector by ensuring reproductive success and reducing production risks and losses. Reproductive efficiency is the single most critical factor in livestock production and economic sustainability for the livestock industries. Improvements in reproductive efficiency will enhance the profitability and competitiveness of the livestock industries and contribute to improved environmental sustainability and rural development.
- Facilitate a continual improvement in production efficiencies by reducing the number of breeding animals required to maintain livestock production. By decreasing production costs associated with breeding herd maintenance coupled with greater output per individual, production efficiency and profitability are concurrently increased.
- Characterize the biological process of embryo implantation in livestock species which will contribute to improved genetic selection and epigenetic manipulation for enhanced fertility. This will further lead to enhanced production and profitability for livestock producers working to solve worldwide hunger. Optimize management and environmental resources for the genetic potential of breeding animals which has the greatest potential payoff in animal production systems in this arena.

Problem Statement 1C: Enhance Food Animal Well-Being and Reduce Stress in the Production System

Concern among the American public regarding animal welfare in food production systems continues to grow. Some members of the private sector have embraced more stringent criteria for animal welfare and have marketed this as a value-added component of their products to consumers. Public concerns have also resulted in regulations and supply system requirements in many states governing the treatment of

animals in local and regional production systems and the perception that increased production efficiency may negatively impact animal welfare. These and future regulations and production criteria should be science-based and sustainable in terms of their effect on animal welfare because they often add costs to production, and in some cases decrease production capacity and efficiency. As the demand for food animal products grow, increasing production and production efficiencies will be critical to the continued viability of the U.S. livestock industries. Techniques must be developed by ARS that maintain or increase efficiency without detrimental effects on livestock welfare. For these reasons, research to quantify the relationship between animal welfare, production, and economic factors including: genetics, behavior, housing, health, nutrition, management, level of performance, profitability, production efficiencies, and food safety must be performed by ARS. Specific objective criteria will also be developed by ARS to assess animal comfort and care in typical U.S. production systems to optimize animal production with respect to cost-effectiveness, while ensuring animal health, performance, and welfare.

The Farm Animal Welfare Council identified Five Freedoms of animal welfare[8]. These tenets have been successfully used to direct the scientific assessment of animal welfare and are applicable for animal welfare focused ARS research.

1. Freedom from thirst, hunger, and malnutrition – by ready access to fresh water and a diet to maintain full health and vigor.
2. Freedom from discomfort – by providing a suitable environment including shelter and a comfortable resting area.
3. Freedom from pain, injury, or disease – by prevention or rapid diagnosis and treatment.
4. Freedom to express normal behavior – by providing sufficient space, proper facilities, and company of the animal's own kind.
5. Freedom from fear and distress – by ensuring conditions and treatment which avoid mental suffering.

As scientifically validated measures become available, research in production environments aimed at ameliorating possible negative effects of the production environment or management practices on welfare will be needed. Development of such criteria by ARS will require an improved understanding of stress physiology and animal behavior (ethology) related to overall production efficiencies. Animal stress can originate from exposure to various natural and/or management stressors (e.g., environment, predators, illness/injury, social interaction, climate change induced temperature/humidity variability, and housing systems) and ultimately leads to production inefficiencies, compromised animal well-being, increased animal morbidity and mortality, and loss of profits. For example, heat stress alone resulted in annual economic losses exceeding $1.2 billion for the United States[9] dairy industry and it is estimated that this is 53 to 64% of the total losses for this stressor[10].

In modern production systems, management of stress relies on two main factors: 1) identifying the source of stress, and 2) timely management interventions to minimize or alleviate the adverse effects on individual or groups of animals. However, many stressors are difficult or impossible to detect with current production system protocols, including daily visual inspection. Consequently, development of criteria that indicate that animals are not adequately coping with stress will require an integrated research approach by ARS to understand the animal physiology and behaviors associated with various stressors in modern livestock systems. Furthermore, stress reduces production efficiency by diverting energy and nutrients, obtained through intake of feed and energy stores in the body, towards survival mechanisms

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[8] Farm Animal Welfare Council: http://webarchive.nationalarchives.gov.uk/20121007104210/http:/www.fawc.org.uk/freedoms.htm

[9] https://www.ers.usda.gov/publications/pub-details/?pubid=45282

[10] St-Pierre, N.R., Cobanov, B., Schnitkey, G. 2003. Economic losses from heat stress by US livestock industries. Journal of Dairy Science, 86 (SUPPL. 1): E52-E77. https://doi.org/10.3168/jds.S0022-0302(03)74040-5

and away from growth and production. Stress has also been associated with subclinical disease and the redistribution of energy and nutrients to the immune system, which further reduces performance. Consequently, identification of valid indicators of stress in food animals by ARS will provide the information needed to make informed, science-based decisions regarding cost-effective modifications to management practices and production systems to enhance animal welfare while ensuring economic sustainability for producers.

The role of ARS regarding animal welfare research is to safeguard the well-being of animals in economically viable and sustainable production systems while addressing animal industry priorities and supporting domestic and international food security. Consequently, the role of ARS research is not to develop systems and practices/protocols that maximize the welfare state of individual animals, absent the requirements of modern production systems, but rather to develop strategies and practices/protocols that ensure appropriate animal welfare standards can be, and are, implemented while maintaining or improving the economic viability of animal production systems.

Research Focus

A more complete understanding of the physiological, immunological, microbial, and behavioral responses of all food animals to stressors present in our production systems will be obtained by ARS scientists to improve animal welfare and implement strategies to reduce morbidity and mortality, lessen production risk, and ensure economic sustainability. Specific ARS research programs will address industry and social priorities in animal welfare, including:

Effects of the production environment: Development of objective measures of animal welfare under various production and housing systems, thermal environments, immunological, and physiological states using scientifically validated behavioral, physiological, and performance measures to sustainably mitigate animal welfare issues (addresses Farm Animal Welfare Council Freedom (FAWCF) 1, 2, 3, 4, 5.)

Pain management: Evaluation of pain management in animal agriculture and the use of analgesia (addresses FAWCF 2, 3).

Nutrition: Assessment of the effects of nutrition on animal stress and welfare as it relates to feed ingredient management, nutrient and energy utilization, and nutritionally based strategies that improve animal welfare (addresses FAWCF 1).

Transportation: Determination of the effects of transportation on animal stress, immune function and welfare and developing strategies that improve animal stress, health and welfare outcomes during and after transportation (addresses FAWCF 1, 2, 4, 5).

Precision livestock farming: Understanding how stress can be reduced and animal welfare improved through precision livestock farming (addresses FAWCF 1, 2, 3, 4, 5).

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Comprehensive production systems best management strategies and practices (e.g., time of animal processing and vaccination, pain management, nutritional supplements, etc.) that sustainably reduce animal stress, enhancing immune function, and improving animal welfare.
2. Objective, science-based criteria for assessing animal stress and welfare in production systems in response to various management techniques, environmental stressors, or common production practices.
3. Enhanced understanding of genetic, physiological, immunological, microbial and behavioral responses of food animals to management and environmental stressors.
4. Species-specific, cost-competitive strategies to mitigate animal stress and improve animal welfare and longevity in production systems.
5. Improved precision animal management/production systems to better identify compromised animal

welfare in production systems.

Potential Benefits

Research in this area will:

- Research results to make informed, science-based decisions regarding animal production practices and their relationship to animal stress and welfare.
- Strategies which improve animal welfare in production systems and are cost effective, thus improving public perception and support of the animal industries.
- Animal stress and welfare research that will benefit animals, producers, and ultimately consumers, by identifying means for reducing animal health costs and improving food animal production efficiencies will be performed.
- Identification of economic and societal goals which will help maintain and increase demand for food animal products both domestically and internationally, particularly regarding rapidly changing international requirements for animal welfare and production practices.
- Collectively, improved animal production capability and production efficiencies which improve economic sustainability for the food animal industries while improving animal welfare.

Component Resources

The following ARS locations have research projects addressing Problem Statements identified under Component 1:

- Ames, Iowa
- Beltsville, Maryland
- Clay Center, Nebraska
- Dubois, Idaho
- El Reno, Oklahoma
- Fort Collins, Colorado
- Lexington, Kentucky
- Lubbock, Texas
- Madison, Wisconsin
- Miles City, Montana
- Mississippi State, Mississippi
- Stoneville, Mississippi
- West Lafayette, Indiana

Component 2: Understanding, Improving, and Effectively Using Food Animal Genetic and Genomic Resources

Understanding the relationships between the phenotype and the genotype of food animals is critical to associating their genetic makeup with economically important production or performance traits. These associations provide effective methods to modify the traits through genetic marker-assisted selection and related technologies. In addition, these associations can be used for marker-assisted management. Although significant utility of genomic associations with economically important traits can be realized without knowing the genes involved, obtaining the maximum benefit from the vast information now being generated through genome sequencing and related genomic technologies will only be possible when we understand more about roles of genes and gene polymorphisms on traits of interest. Maximum value of research in genetics and genomics will be realized when economically important phenotypes are accurately predicted from individual animal genotypes, and we understand the functions of a gene, or genes, with respect to traits of interest.

Modern genetic science is challenged with determining the effects of DNA variants in the diverse production systems and environments to optimize genetic progress for the food animal industries.

Consequently, comprehensive knowledge of the genome and its interactions with management systems and the environment are critical to leverage our current understanding of the biological basis of all food animal science disciplines. Because of the complexity of production traits, a "systems biology" approach for research will be critical to the development of improved genomic tools and technologies to increase genetic progress across a large range of production systems. Access to state-of-the-art tools and technologies requires that ARS remain intimately involved in the development of these critical resources. Unfettered access to these tools will result in application of economically feasible management tools for livestock producers and will spur genetic and genomic technology development for food animal industries.

Genetic improvement of food animal populations by ARS is critical for increasing the efficient production of animal products. However, the rate of genetic improvement is hindered in many animal populations by a variety of constraints. These limitations include: a lack of phenotypic data on many economically important traits; incorporation of precision management tools in the collection of phenotypic data; inadequate understanding of genetic architecture underlying traits; sub-optimal methods for evaluating candidates for selection; and inefficient or non-existent strategies to incorporate genomic data into breeding programs. In addition, problems and inconsistencies with the current livestock genomes create difficulties in understanding the role of specific genes in traits of interest, and a significant effort is required to resolve these problems through new sequencing and annotation efforts.

Genetic engineering, particularly gene editing technologies of food animals, is a rapidly evolving area of research that offers opportunity for rapid improvement in disease/parasite resistance as well as animal production efficiency. Initial goals for implementation of these technologies by ARS may include improved animal health and welfare while simultaneously demonstrating the wholesomeness and safety of meat products. Other applications of the technologies by ARS may include gene editing to increase swine production, exploration of sequence modifications, and methods for genetic modification of poultry.

Finally, a wide variety of food animal breeds and unique populations around the world are at elevated risk because of inadequate genetic characterization. This lack of description of these resources results in a failure to recognize their value in genetic diversity. Hundreds of breeds of livestock have been lost around the world, and, on average, one additional breed is lost to extinction each month. As production systems evolve and consumer preferences or feed resources change, genetic resources that are not widely used in today's production systems may become economically important. Likewise, the breeds and lines that are desirable today may be improved or changed through selection pressures which necessitates preservation of the current genetics/foundational genetics for future utilization. Unique genetic variation may also be needed to respond to emerging disease threats and for environmental adaptability. These genetic resources provide producers with options that could be tailored to meet current and future demands. For these reasons, preservation of unique genetic resources (minor and commercial breeds and lines) by ARS is critical to the future of the food animal industries.

Problem Statement 2A: Develop Bioinformatic and other Required Capacities for Research in Genomics and Metagenomics

Advances in genome sequencing technologies have created tremendous opportunity in animal agriculture. Most food animal species now have a foundational reference genome sequence. However, these reference sequences must continue to be improved by ARS through additional sequence information inclusive of broad genetic diversity and gene annotation efforts to be used to their fullest potential impact. Additionally, structural variation among lines or breeds within species may be a significant contributor to genomic variation and should be characterized. Sequencing technologies are now also being applied to the microbiome of the gastrointestinal tract for food animals to better understand the symbiotic, commensal, and pathogenic relationships between gut microflora and food animal hosts. Technological advances now make practices such as individual genome sequencing, genotyping with low coverage

sequencing, metagenomic sequencing, and high-density genome association studies cost effective for research and, in many cases, application. However, development and application of these and other advanced technologies by ARS are limited by the size and scope of the data sets being generated. High-throughput proteomics and metabolomics have also vastly increased our ability to generate phenotypes for genomic associations. These technologies are also very data intensive, and bioinformatics research by ARS is required to obtain the full value of these new tools.

Research Focus

Analytical infrastructure: ARS research will develop bioinformatic expertise, tools, and resources to expand its capacities for research in food animal production. These tools include the development and adaption of analytical tools for large data sets and data analysis. Enhanced bioinformatic resources will be developed by ARS to expand the annotation of food animal genomes. Programs in extensive phenomics will also be developed by ARS to create comprehensive phenotypes for novel or expensive traits and traits that are difficult to measure, but are highly relevant to important biological functions in food animals as well as programs to develop the intensive phenomics to better characterize the genetic components for traditional food animal production traits. Advanced bioinformatic tools, such as machine learning to integrate and summarize large multivariate data sets, to exploit proteomic, metabolomic, metagenomic and genomic sequence information and related genetic information for the development of improved genetic evaluation tools to increase the rate of genetic progress for economically important traits in the food animal industries will be investigated and implemented by ARS.

Data and data management: ARS will also improve data pipelines to better facilitate data movement, access, genome alignment curation, annotation, and analysis. Improvements specifically for data arising from high density panels, genomic imputation, genotype calling from low coverage sequence reads, and sequence information used in genomic and metagenomic studies will be developed and implemented by ARS. Additional bioinformatic resources and programming to develop database management infrastructure and technologies will likewise be created and deployed by ARS.

Application of resources: To increase utility of these resources, ARS will develop and disseminate educational materials and information for these bioinformatic resources.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Improved bioinformatic and database tools for data movement, access, curation, annotation, and analysis of large genotypic, sequence, and phenotypic data sets.
2. Better integration of expertise, infrastructure, and genetic and genomic technologies within ARS, industry, and academic partners to facilitate development of database tools, and technologies to exploit shared resources.
3. Development of comprehensive intensive and extensive phenomic and analytical tools to relate genomic and phenotypic data for development of improved genome-based estimates of genetic merit (see also Component 2B Anticipated Product).
4. Improved annotation of genome sequence assemblies for food animals, including health or growth-promoting microbes, to elucidate the genes behind improved animal production. Will also include participation in the Functional Annotation of Animal Genomes Consortium and consortiums to evaluate structural variation among genomes within species (see also Component 2B Anticipated Product 2).
5. Greater understanding of the association of individual genes, genetic, genomic, phenotypic, and epigenetic effects, and their subsequent protein and metabolomic products, with economically important traits in food and fiber animals.
6. Enhanced metagenomic characterization and analysis of microbiomes related to health, feed efficiency, productivity, and environmental impact of food animals.

Potential Benefits

Research in this area will:

- Improved bioinformatic resources and infrastructure will facilitate the management and analysis of large proteomic, metabolomic, metagenomic, and genomic sequence data sets and will provide the tools and technologies to develop large phenotypic data sets for genome annotation and genome wide association studies. These tools will increase our understanding of the genes responsible for various economically important traits, providing opportunity to develop improved genetic strategies to increase genetic progress.
- Leveraged expertise and technologies through collaboration in and out of ARS will increase the efficiency of metagenomic and genetic and genomic research increasing the impact of ARS public research for industry stakeholders.
- Improved bioinformatic, metagenomic, genetic and genomic resources will facilitate development of advanced genetic and genomic evaluation and selection technologies that will increase genetic progress for economically important traits in food animals.

Problem Statement 2B: Characterize Functional Genomic Pathways and their Interactions

A better understanding of the functional genomics of food animals will better relate genetic expression with phenotypes for economically important traits, including novel and emerging traits and traits that are difficult to measure. These relationships increase in complexity as the heritability for traits decrease (i.e., complex traits such as health, disease resistance, reproduction, and nutrient utilization) and as environmental influences grow, increasing the value and critical need for functional genomic studies. A better understanding of the relationship between genotype and phenotype is needed so that ARS can develop genetic models to improve genetic progress in these and all traits of economic importance in the food animal industries. In addition, complex traits such as reproduction and nutrient utilization are influenced by non-additive genetic effects such as dominance and epistasis, which are not well understood. Transcriptomic, proteomic and metabolomic efforts by ARS will help inform the connections between the genotype and phenotype of an animal and the interaction of these factors will enable realization of the full value of research in genetics and genomics to promote sustainability.

Research Focus

Genotype to phenotype: Additional sequencing and sophisticated genome annotation along with high resolution mapping efforts to associate genes responsible for variation in phenotypes will be performed by ARS scientists. Considerable research effort in intensive phenomics to establish the connection between genotype and relevant phenotypes for components contributing to complex traits such as efficiency of nutrient utilization, reproductive efficiency and longevity, health, disease resistance, animal well-being and resistance to stress, product yield and quality, healthfulness and other traits will be explored by ARS. Genes impacting these traits and their interactions, along with an understanding of their genetic and epigenetic regulation to improve genetic analysis and prediction technologies will be identified by ARS. This identification will enable ARS scientists to improve the prediction of phenotype from genotype, contribute to our understanding of how phenotypes are generated from the genotype, significantly increase the rate of genetic progress, and improve profitability and competitiveness of the food animal industries.

Environmental effects: Research by ARS scientists to better understand the effect of epigenetic modifications due to environmental effects that alter phenotypic expression will be performed.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Standardized intensive and extensive phenomic activities for determination of genetic and phenotypic variation for economically important traits in food and fiber animals (see also Component 2A

Anticipated Product 3).

2. Improved annotation of genome sequence assemblies for food animals, including health or growth-promoting microbes, to elucidate the genes behind improved animal production. ARS scientist participation in the Functional Annotation of Animal Genomes Consortium and consortiums to evaluate structural variation among genomes within species (see also Component 2A Anticipated Product 4).
3. Gene targets and development of additional strategies to beneficially manipulate the environment of the food and fiber animal to improve economic traits.

Potential Benefits

Enhanced functional genomic research by ARS will significantly improve genetic progress in food animals through the continued development of molecularly enhanced genetic evaluations and will ultimately enable the improved prediction of phenotypes from genotypes. Functional genomics data generated by ARS will serve as the cornerstone to enable systems biology research to optimize economic and environmental sustainability. Development of a more complete understanding of the biological systems underpinning food animal performance by ARS will lead to precision food animal selection and production management models to improve food animal health, production, and efficiencies. Ultimately, the impact of this research performed by ARS will be to enhance profitability, economic competitiveness and sustainability of U.S. livestock and poultry producers.

Problem Statement 2C: Preserve, Characterize and Curate Food Animal Genetic Resources

Maintenance of genetic diversity in food animal populations is critical to the long-term competitiveness, and the economic and environmental sustainability of animal agriculture. Considering the trends of the past several decades toward increased consolidation and integration of production, along with employment of breeding systems that accumulate inbreeding within breeds and lines resulting in the loss of genetic diversity within heritage and commercial livestock breeds, this need has risen to highest priority. Furthermore, due to increased concentration of food animals, and continued increase in the easy and rapid movement of animals, the need exists to be able to respond to repopulation of animal and poultry systems in the event of a widespread disease outbreak or other catastrophe that would threaten the genetic resource base of animal agriculture. In addition, as climate change influences agriculture and food animal production, genomic and phenotypic traits related to animal adaptation (i.e., heat tolerance, pest resistance, etc.) may become more important, many of which may no longer exist or segregate in conventional production system populations.

Research Focus

Repository practices: Germplasm (semen (sexed and non-sex sorted), oocytes, embryos, DNA, tissues, organs, cells) collection and management requires a suite of tools to facilitate genetic analysis, cryopreservation of samples, capture of animal/sample information in a database, and potential release of samples. ARS scientists will develop new and improve existing technologies to ensure a high-quality collection of animal genetic resources is established and maintained in perpetuity.

Collection analysis and documentation: Selection of specific germplasm to be preserved requires phenotypic and genetic characterization for a wide variety of phenotypic characteristics measured within the appropriate production environments and systems for each livestock species. Therefore, genetic diversity characterization of individuals within breeds and lines will be performed by ARS using a suite of tools, which may include quantitative approaches that utilize pedigrees, carefully designed genomic evaluations using genotypes based on single nucleotide polymorphisms or sequence information, functional genomics, or a combination of techniques. This process will poise the collection toward greater utilization by ARS and U.S. producers and ensure complete coverage of genetic diversity within a breed, line, and species within the collection.

Assisted reproductive technologies: Considerable gaps exist in the ability to preserve gametes and embryos of the various livestock and poultry species, with the need for improved cryopreservation technologies being most critical in poultry. Therefore, ARS scientists will create or improve assisted reproductive technologies to enhance our ability to cryopreserve germplasm.

Collection development: Due to the broad and vibrant nature of the livestock sector, ARS scientists will collaborate with private and corporate producers, federal laboratories, universities, and international partners to facilitate collection development and assist in quantifying the genetic diversity present in the collection.

Anticipated Products

ARS scientists in this area expected to generate the following products from this research:

1. A collection of viable, and well documented, livestock and poultry germplasm that represents a broad spectrum of genetic diversity not currently included in the repository, which can be used for assisted reproductive technologies, research, and as a reference resource for genomic studies such as gene editing.
2. A publicly available database providing information about the germplasm collection to industry and the research community.
3. Acquisition of additional high-quality, comprehensive characterization, evaluation, and gene bank curatorial data that describes the animals included in the database.
4. Genetically diverse germplasm samples which are ensured via quantitative and, or molecular technologies for selection of individuals to be preserved.
5. Successful and efficient germplasm cryopreservation technologies and methods for livestock and poultry species.

Potential Benefits

Careful strategic planning for and successful implementation of genetic resource management projects by ARS will provide industry users with a more dependable and more diverse source of high-quality livestock and poultry genetic resources. Vulnerable or threatened genetic resources will be better preserved and more secure. The ARS National Animal Germplasm Program will be a repository of the alleles being elucidated in the post-genome sequencing era so that they may be available for long-term use by the animal agriculture industry in responding to the needs of the future. Readily available access to comprehensive and curated germplasm characterization information maintained by ARS will allow strategic use of livestock and poultry genetic resources in fulfilling the demands for animal products in the future and to adapt to changing production priorities and criteria domestically and internationally.

Problem Statement 2D: Develop and Implement Genetic Improvement Programs using Genomic Tools

Application of quantitative genetics theory to populations of livestock and poultry has resulted in significant genetic improvement for economically important trait complexes. This has been accomplished primarily from the use of field data recorded in both public and private national genetic evaluation programs. Much of this improvement was facilitated by advances in statistical methodology coupled with increased scope and power of computing platforms that could be applied to large-scale pedigreed phenotypic data sets. Genetic evaluation and improvement programs have advanced for several livestock species with the development of high-density DNA marker panels and statistical methodology developed to integrate genome information with current genetic evaluation technologies. These technologies can be further developed by ARS to take advantage of new sources of genomic markers (low pass sequencing, genomic imputation), improved genomic annotation to characterize function variation, and incorporation of precision phenotypes and phenomic data sets. Additionally, utilization of routine data by ARS that is obtained from commercial livestock production could dramatically increase selection accuracy for traits that are most economically important to production if automated collection systems are integrated with

new genomic tools to tie these populations to nucleus germplasm sources.

Additional technologies to genetically evaluate health traits, heat tolerance, and structural soundness will add significant value to the current portfolio of traits being evaluated by ARS in all livestock industries. Additionally, the focus of ARS genetic improvement programs is now shifting to support production models that increase production efficiencies while ensuring economic and environmental sustainability on a global scale. Finally, development of cost-effective strategies for precise data collection and progeny testing for optimized genetic evaluation systems by ARS will improve the value and return on investment of genetic evaluation and genomic technologies for food animal producers.

Research Focus

Valuable traits: The current traits included in genetic evaluation programs will be expanded by ARS to include all food animals and will include such traits as efficiency of nutrient utilization, reproductive capacity and longevity, product yield and quality, healthfulness, animal behavior, health and disease resistance, longevity, heat tolerance, product quality, structural soundness, and resistance to stress. In addition, biological traits that are correlated with production traits will be developed by ARS scientists that allow for improved selection of complex traits. Research on this expanded set of traits will be performed by ARS on a variety of parameters related to genetic evaluations that include breed effects, heterosis, heritability, and genetic correlations. As new traits continue to be defined and added to the genetic evaluation pipelines, ARS will continue to research the breeding objectives that incorporate multiple traits under various markets.

Functional genomics: Research to increase the accuracy of the genetic evaluation estimates created for new and traditional production traits will be performed by ARS. Functional genomic research by ARS may yield diagnostics for measuring new traits and produce new methods to select for production traits. Functional genomic analyses performed by ARS scientists may also lead to tools that better define specific genes and complex genetic mechanisms including non-additive and epigenetic effects. This new molecular information will be incorporated into genetic evaluation and prediction frameworks by ARS to maximize genetic improvement.

Genotype and phenotype sampling: Additional studies to determine the most cost effective strategies to collect genotypic and phenotypic data, including data from non-traditional sources such as commercial or terminal livestock populations, and to refine and improve progeny testing in the field to optimize the value of genetic evaluation programs will be performed by ARS.

Genetic and genomic tool development: New methods developed by ARS scientists to increase genotyping efficiency such as low-pass sequencing and improved bioinformatic imputation algorithms will increase the utility of genomic information in selection candidates and provide tools for genetic management of commercial and terminal populations. Additionally, new approaches to better use comprehensive genome and haplotype information will be investigated by ARS to improve genome selection and mating programs.

Data analytics: The complexity of the new types of information becoming available for genetic evaluation will require significant advances in bioinformatic research and infrastructure, statistical methodology, and software to be developed by ARS to exploit these data in a commercial setting.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Multi-breed genetic prediction tools and breeding system designs that utilize genomic and traditional genetic prediction tools in varied domestic and international production systems to maximize productivity and sustainability.
2. Development of tools and software to provide genotypic information for genomic-enhanced selection and management tools to use in centralized genetic evaluation and improvement systems, particularly

for novel traits.
3. Improved genetic evaluation, genetic selection programs and strategies, and whole-genome prediction techniques to increase accuracy of these tools for the food and fiber animal industries.
4. Elucidating environment, management practices, and genetic interaction effects on performance in livestock, for traditional and novel production traits.
5. Improvement of precision management tools to collect and utilize data from non-traditional sources such as commercial or terminal operations.

Potential Benefits

ARS genetic improvement programs will be enhanced by adding traits that enable producers to better match genetic potential to the production resource base and consumer and societal demands. This enhancement will lead to a more profitable and sustainable animal agriculture. Genomic-level information generated by ARS will allow complex and novel traits previously excluded from genetic improvement to be evaluated, including traits essential to production system profitability. Identification and utilization of elite genetic seed stock at younger ages with higher levels of accuracy will empower ARS scientists to improve the rate of genetic progress for the food animal industries. Enhanced value of public research investments in animal genomics and bioinformatics will be realized through "genome-enabled" genetic improvement programs resulting from this ARS research. Global food security will be enhanced by ARS through adaptation of genome-aided selection methods to meet challenges of production in systems lacking infrastructure or utilizing marginal environments.

Problem Statement 2E: Develop Techniques for Genetic Modification and Genetic Engineering of Food Animals and Evaluate their Efficacy

As the "genomic revolution" starts to deliver a tangible impact on the breeding strategies in livestock industries, the next generation of genomic tools is now being developed by ARS scientists for application to animal production systems. Various forms of genetic engineering involving the use of genetic material to alter (improve) the livestock genome may have relevance to improving food animal production. Historically, a genetically engineered organism is produced by isolating the genetic material of interest using molecular cloning methods to generate a DNA sequence containing the required genetic elements for desired expression, and is then inserted into the animal's DNA through a variety of available methods. Methods include adding a gene (transgenic), gene specific targeting, and/or knocking out specific genes and these can be accomplished using technologies such as Transcription Activator-Like Effector Nucleases (TALENs) and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technologies.

Using these technologies, specific modifications to genes can be made that are indistinguishable from the natural polymorphisms that occur in nature. If this is done with stem cells or somatic cells, nuclear transfer technologies allow the generation of livestock with the directed DNA change. Thus, if one knows or suspects that a particular DNA modification is the cause of a particular phenotype, it has now become possible to make that DNA modification without making any other nonspecific changes in the genome. Thus, genetic modification offers the possibility of rationally designing beneficial gene modifications that are not necessarily found in nature. This effect will be realized by evaluating the impact of a specific allele on an animal's phenotype and then transferring the superior allele into the genome of elite breeding stock, thus facilitating the fixation of the superior allele in the genotype of the population. For example, an elite allele for growth rate or reproduction could be isolated, and then introduced and evaluated in elite animals of interest. If the allelic exchange was positive, it could then be fixed in the population very quickly and efficiently. This practice is "hypothesis driven animal breeding" or the "ability to evaluate an isolated genetic effect in a well-defined genetic background and environment" which is not possible using conventional animal breeding techniques. Despite current regulatory uncertainties, research by ARS is needed to explore and advance the huge potential of this technology for improvement of animal performance and well-being. However, as the technology matures, more extensive and more sophisticated

modifications will be used by ARS to improve livestock species. Moreover, information will be provided by ARS delineating the wholesomeness, quality, and safety of genetically modified animal products along with ensuring the well-being of genetically modified animals, which will be critical to the consumer acceptance of these products.

Research Focus

Site specific technologies: Research performed by ARS will develop improved genetic modification and engineering strategies, using technologies such as TALENs or CRISPR, to support regulatory agencies in the decision-making process, and to characterize the attributes of products derived from genetically modified meat animals.

Animal health tools: Identification of specific disease targets (e.g., cellular viral targets) by ARS that can be positively impacted by genetic modifications and engineering will be elucidated.

Gene editing exploration: Genetic modifications and engineering in livestock species will be pursued by ARS for identification of functional variants using gene editing and exploration of sequence modifications. Other applications of these technologies include addressing animal well-being concerns in production agriculture, improving the sustainability of livestock production systems which include improved adaptation and decreased environmental impacts, and for precision livestock farming to improve animal productivity, health, and well-being by ARS.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Programs to evaluate specific DNA modification techniques (i.e., gene editing) to determine the effects of natural mutations and rationally designed modifications on economically important traits in food and fiber animals and exploit their benefits to enhance animal production systems.
2. Strategies to elucidate the genetic, protein and metabolic pathways that translate genotypes into phenotypes in food and fiber animals to inform gene modification design.
3. Scientific data for use in the decision-making process regarding the nutritional value, healthfulness, and animal well-being impact of genetically modified animals in meat animal production systems.

Potential Benefits

Genetic engineering strategies promise to increase our understanding of genetic effects that link genotype with phenotype. Strategies developed by ARS to test specific allelic effects will increase the rate of genetic progress for important phenotypic traits that have both an economic, animal health, and animal well-being benefit. Information generated by ARS scientists will be available upon which to make science-based decisions regarding the utility and regulation of food animal products from genetically modified meat animals.

Component Resources

The following ARS locations have research projects addressing Problem Statements identified under Component 2:

- Athens, Georgia
- Beltsville, Maryland
- Columbia, Missouri
- Clay Center, Nebraska
- Dubois, Idaho
- El Reno, Oklahoma
- Fort Collins, Colorado
- Madison, Wisconsin
- Miles City, Montana

Component 3: Measuring and Enhancing Product Quality and Enhancing the Healthfulness of Meat Animal Products

Consumer demands are consistently evolving, and meat animal producers must understand these trends and adopt production systems accordingly. Product changes like increased body weight and lean carcass yield created many associated effects on the meat animal production industries. As meat animals grew larger and leaner, feed efficiency increased, and product demand was maintained or was significantly increased. Larger carcasses altered chilling dynamics, resulting in profound impacts on the conversion of muscle to meat, which drastically influences meat quality attributes. Concerns developed regarding the eating quality of many meat products as lean percentages increased and tenderness, flavor and eating satisfaction decreased. These changes are ongoing and require research by ARS to delineate both their scope and remediation. And while much work is yet to be done, all these issues are being dealt with by the industry through long-term basic and applied research in the areas of health, nutrition, animal well-being, and product quality. These challenges clearly illustrate the importance and influence of consumers on meat animal production.

Marketing of "branded" meat products differentiated by meat quality attributes, production system, genetics, or other factors have increased industry focus on consumer demands. Lean color is the primary factor influencing consumer purchase decisions. Thus, products with color not meeting consumer expectations are excluded from these programs. Products with insufficient color stability are severely discounted and eventually discarded which can result in a significant loss for the industry. Palatability (i.e. tenderness, flavor, and juiciness) determine repeat purchase decisions and failure to meet consumer expectations for these traits result in lost demand.

Consumers are now adding to their demands and expectation for meat animal products by focusing on nutritional value or the "healthfulness" of meat animal products. While many of the concerns regarding meat animal products such as saturated fats are not as critical as they have been in recent history, consumers are more interested in foods and meat products that promote health and vitality and limit concerns about health issues such as metabolic diseases and cancer.

Ensuring sustainability of meat production is of critical importance to the industry. Thus, examination of all aspects of animal production and processing by ARS to ensure efficient utilization of resources is warranted. In addition, a growing sector of the consuming public is demanding animal products from less intensive and non-conventional production systems including grazing dairy and beef finishing systems and natural or organic animal production systems. Product consistency and quality from these systems is relatively poorly characterized.

Today, consumers have a wide array of readily available food products, resulting in stiff competition among the sectors of the food industry. Added information generated by ARS is continually needed to provide meat animal producers with the tools to continue to address evolving consumer preferences while preserving profitability and competitiveness for the meat animal industries.

Problem Statement 3A: Systems to Improve Product Quality and Healthfulness and Reduce Variation in Meat Animal Products

Product consistency and quality continues to be a major concern for the livestock industry. Product quality issues such as flavor, tenderness, color, and consistency of these attributes continue to create concerns in the meat animal production and processing sectors due to their negative effect on consumer demand. Many of these challenges are difficult, if not impossible, to directly measure or predict on the farms making programs to improve product quality through proactive genetic selection or management impossible. Many knowledge gaps exist in the understanding of the biological regulation of variation in these traits, and interrelationships among these traits are poorly defined. Moreover, consumers are becoming more cognizant of the relative nutritional value of foods for human health. Meat products are no exception. Saturated fats have been associated with increased risk of obesity, cancer, heart disease and

metabolic disorders. While current research demonstrates that these associations may not be accurate, there is a critical need for ARS to demonstrate the relative healthfulness of meat products and to develop interventions and production practices to improve the nutritional value of meat products. Meat animal producers need better technologies to predict product quality, healthfulness, and consistency. Processors need non-invasive, non-destructive testing procedures to identify defects and measure product yield and quality characteristics. Objective measures and systems for determining product value characteristics should be developed by ARS to allow processors to communicate value differences more effectively to producers and give producers greater incentive to improve product quality and consistency. Such "value feedback" will facilitate the development of coordinated supply chains which effectively apply all available known tools to improve product quality and consistency.

Research Focus

Valuable traits: Identification of technologies for measuring and predicting important traits relating to meat product quality, healthfulness, and consistency as well as the biological mechanisms that control these traits will be developed by ARS. Programs to best determine the impact of changes in target traits relating to healthfulness of meat animal products on human health will also be created by ARS.

Meat quality: ARS scientists will elucidate the biological basis for lean color, color stability, tenderness, flavor, juiciness and other important organoleptic properties of meat across all muscle cuts in meat animals, including the interaction between meat processing procedures and biochemical changes in meat. ARS will also develop technologies to facilitate prediction of important meat quality and healthfulness traits including genetic and biological markers and physical data collection systems and to increase efficiency of meat production. Research to develop techniques and instrumentation for the measurement and prediction of product healthfulness, yield, and quality under commercial meat industry conditions will also be performed by ARS scientists. Product variation introduced by various animal stressors has begun to be described ARS and additional research by these scientists will be performed.

Anticipated Products

ARS scientists in this area are expected to generate the following products from this research:

1. Development of cost-effective technologies to better predict and evaluate meat quality attributes on farm and during processing. Validated methodologies and instrumentation for on-line commercial industry use to determine product quality and yield.
2. Identification of supply chain critical control points which can be targeted for increasing product quality and yield; and reducing waste.
3. Identification of strategies for improving nutritional composition of meat products that will result in positive impact on human health.
4. Scientific characterization of variability of healthfulness traits and the biological mechanisms that control and influence product quality, color stability and consistency of red meat products.
5. Documentation of the nutritional value and healthfulness of meat products resulting from traditional and non-traditional production systems and how these profiles are affected by production system environmental and management factors.

Potential Benefits

This research by ARS will facilitate the further development of technologies to better assess and predict meat product quality, healthfulness, and consistency. This research by ARS will support development of value-based supply chains for the livestock industry and increase profitability and competitiveness for producers. Better understanding of the biological basis for meat quality, healthfulness, and consistency attributes provided by ARS scientists will lead to improved selection, management and processing practices which will further increase demand for meat products, increasing profitability for producers. Increased nutritive value and healthfulness generated by ARS research will increase demand for meat products increasing the profitability and competitiveness of the meat animal industries. Implementation of

research products from ARS should improve consumer satisfaction, enhance consumer health, and increase sustainability of meat production.

Component Resources

The following ARS locations have research projects addressing Problem Statements identified under Component 3:

- Clay Center, Nebraska
- El Reno, Oklahoma
- Lexington, Kentucky

Conclusions

Completion of the proposed research by ARS scientists will provide the U.S. food animal producers with improved methods to produce high quality, nutritious products for domestic and international markets. Moreover, as this science progresses, these goods will be produced under improved animal welfare conditions and in production systems that are more environmentally, meaning less greenhouse gases will be produced while simultaneously improving the health and quality of our soils, forages, and animal feeds. The end result will be a U.S. production system that is more efficient and healthier for the planet, the animals, and the consumer.

Appendix 1: Summary of ARS and NIFA Stakeholder Survey and Webinar Listening Sessions

Stakeholder Input

Stakeholder input was obtained in collaboration with National Program Leaders from the National Institute of Food and Agriculture using a three pronged approach (1) National survey, (2) National webinars and (3) ARS location specific focus groups (The U.S. Meat Animal Research Center, Clay Center, NE, and the Beltsville Agricultural Research Center, Beltsville, MD). Brief summaries of each effort follow.

National Survey Results

A National Survey was initiated by the USDA ARS Office of National Programs NP 101 to obtain input on the importance of various research topics addressing animal production, and to enlist feedback on the impact of research in various disciplines that influence animal production. In addition, research topics related to sustainability and precision livestock management were also included. Finally, each topic included open ended responses to provide feedback on research topics that were not included in the survey.

Results of any survey depend on participation of various interested parties, and an initial question divided respondents into (1) Allied livestock companies (pharmaceutical, nutrition, breeding), 43 responses; (2) Commodity association, 24 responses; (3) Consultant, 11 responses; (4) Government agency (including ARS respondents), 15 responses; (5) Producer or farmer, 84 responses (6); Scientific association other than commodity, 9 responses; (7) University, 355 responses; (8) Other, 20 responses; and (9) no response to the question, 11 responses; for a total of 572 participants.

Priority Research Topics

In the first part of the survey, participants were asked to rate the importance of a variety of research topics dealing with nutrition, reproduction, animal welfare, genetics, animal production, meat quality and healthfulness, sustainability, and precision management. Ratings were from 1= very important to 5= not important. Average responses to the research topics presented are in Figure 1. Overall ratings of topics ranged from 1.88 for automated disease detection technologies to 3.09 for seasonality research, indicating that all the research topics within the survey received some support. However, overall responses tracked closely with University scientist responses, which is likely a consequence of the large number of University scientist participants. Producer ratings of research topics ranged from 1.59 for healthfulness of meat products to 3.17 for negative social interactions among animals, once again indicating support for all the research topics, but with some differences compared to the overall ratings.

Figure 1: The frequency of responses by topic from the National Survey on Priority Research Topics. Responses ranged from 1 = large impact to 5 = no impact.

The five highest priority research topics overall were automated disease detection technologies,

understanding gene function including epigenetics, alternatives to antibiotics, nutrient use efficiency and measuring stress. However, the top five research topics for producers were healthfulness of meat products, longevity in the breeding herd, pregnancy rate, tenderness and predicting and improving quality grade preslaughter. Lowest rated (highest score) research topics overall were seasonality, euthanasia techniques, GPS localization of animals in pens, pastures, rangelands, negative social interactions among groups and refining requirements of nutrients. Producers lowest rated research topics were similar and were GPS localization of animals in pens, pastures, rangelands, negative social interactions among groups, thermal imaging to detect cold/heat stress, euthanasia techniques and automated feed intake measurement.

Also, the impact of research (Figure 1) of different research categories varied from 2.26 for genetics to 3.04 for precision management. For producers, impact of research topics varied from 2.63 for genetics to 3.14 for precision management, and ratings were uniformly lower from producers compared to overall. These results suggest that livestock research, depending on the type of research, had between large impact and some impact.

Open ended questions were used to capture important research topics that were not presented on the survey. Responses to open ended questions were categorized into topics and responses within each topic were counted to gauge the priority of that topic. For animal nutrition, nutrition and health and nutrients in manure were the top two topics. Both are covered in other programs within ARS (NP 103 and NP 212), but there may be a need for manure research as it addresses sustainability (see below). For reproduction, programming (fetal, nutritional), cryopreservation for poultry, and advanced reproductive technologies (in vitro fertilization, embryo transfer, sexed semen) were topics mentioned by several respondents. For animal welfare, parasites and biting insects, and production system effects on welfare were listed by several respondents. For meat quality and healthfulness, muscle myopathies in poultry and meat shelf life (presumably beyond color stability) was listed by several participants. For sustainability, water and air research were mentioned (these are likely to fit into other ARS programs (NP 211 and NP 212). A popular comment for this question was that solutions were needed that fit production. For precision management, the two top research topics suggested by respondents were automated estrus detection and automated behavior analysis. Consideration for these topics will be made when developing the NP 101 Action Plan.

NP 101 Program Impact

The second part of the survey (Figure 2) was designed to obtain feedback on the impact of the NP 101 Food Animal Production program overall, and the impact of various components of that research. Respondents were asked to provide responses ranging from 1 = large impact to 5= no impact. The second figure below provides average responses to these questions broken out into an overall average, and then averages for the same subcategories of respondents as previously described for research topics. For the overall program, the average impact rating was 2.4, which is between some and large impact. For research disciplines with the NP 101 program, impact ratings ranged from 2.26 for genetics to 3.04 for precision management. Precision management is a new focus for the NP 101 program, so it is not surprising that it has not had a large impact. It is also instructive to assess ratings from the different categories of respondents. For the different categories of respondents, the impact of the overall NP 101 program ranged from 1.93 for government agencies (that likely includes ARS scientist responses), to 3.29 for scientific associations that are not commodity groups. Interestingly, producers rated the program at 2.93, which is essentially a rating of some impact. Across respondent categories, genomics research was clearly rated as having the highest impact of the different research disciplines, ranging from 1.73 for government respondents to 3 for scientific associations not commodity groups. Producers rated this topic at 2.63. Similar to research topic importance, University scientist responses and overall responses were similar, likely due to the overrepresentation of this group in the responses. Finally, Producers rated the impact of research disciplines in the following order (1) genetics (2.63), (2) meat quality and healthfulness (2.75), (3) reproduction (2.84), (4) nutrition (2.86), (5) animal welfare (2.91), sustainability (2.92) and (6)

precision management (3.14).

Open ended questions were also used to elaborate on the impact of the NP 101 program, and for different research topics within the NP 101 program. For the open ended question addressing the impact of the whole NP 101 program, top responses included that the genetic component of the program has had a large impact (which agrees with the responses for this part of the program), there needs to be more emphasis on poultry production research, and there needs to be more emphasis on applied production research. Regarding nutrition research, there were not many comments offered, suggesting that the research topics provided in the survey covered this topic well. For reproduction research, the top comment was that the reproduction program required more production-oriented research. For animal welfare research, comments suggested a general unfamiliarity with welfare research performed within the program, suggesting that more effort in raising the profile of this research is needed. For genetics research, the need to provide genomics technologies to sheep and poultry was indicated. Like nutrition research, few comments were offered regarding meat research.

Finally, open ended questions were asked regarding what to continue and discontinue, and any further comments. Regarding what to continue within the program, genomics received the greatest number of comments, which is consistent with other portions of the survey. Sustainability research was second. All other research disciplines within the program received some support for continuation. Regarding research to discontinue, organic production research, animal welfare and sustainability were the top responses. Organic production is not a specific focus of the NP 101 program, and many comments suggested that this was more a marketing exercise rather than true research. That sustainability and animal welfare should be high on the discontinue list is surprising, considering that many more comments were received to continue this research than to discontinue it. These responses likely address the controversial nature of these two topics and how they are often applied as negatives to animal production research. From this survey, there is clear evidence that not everyone believes that sustainability and animal welfare are important topics in animal production research, even though the positive response to these two topics was substantial.

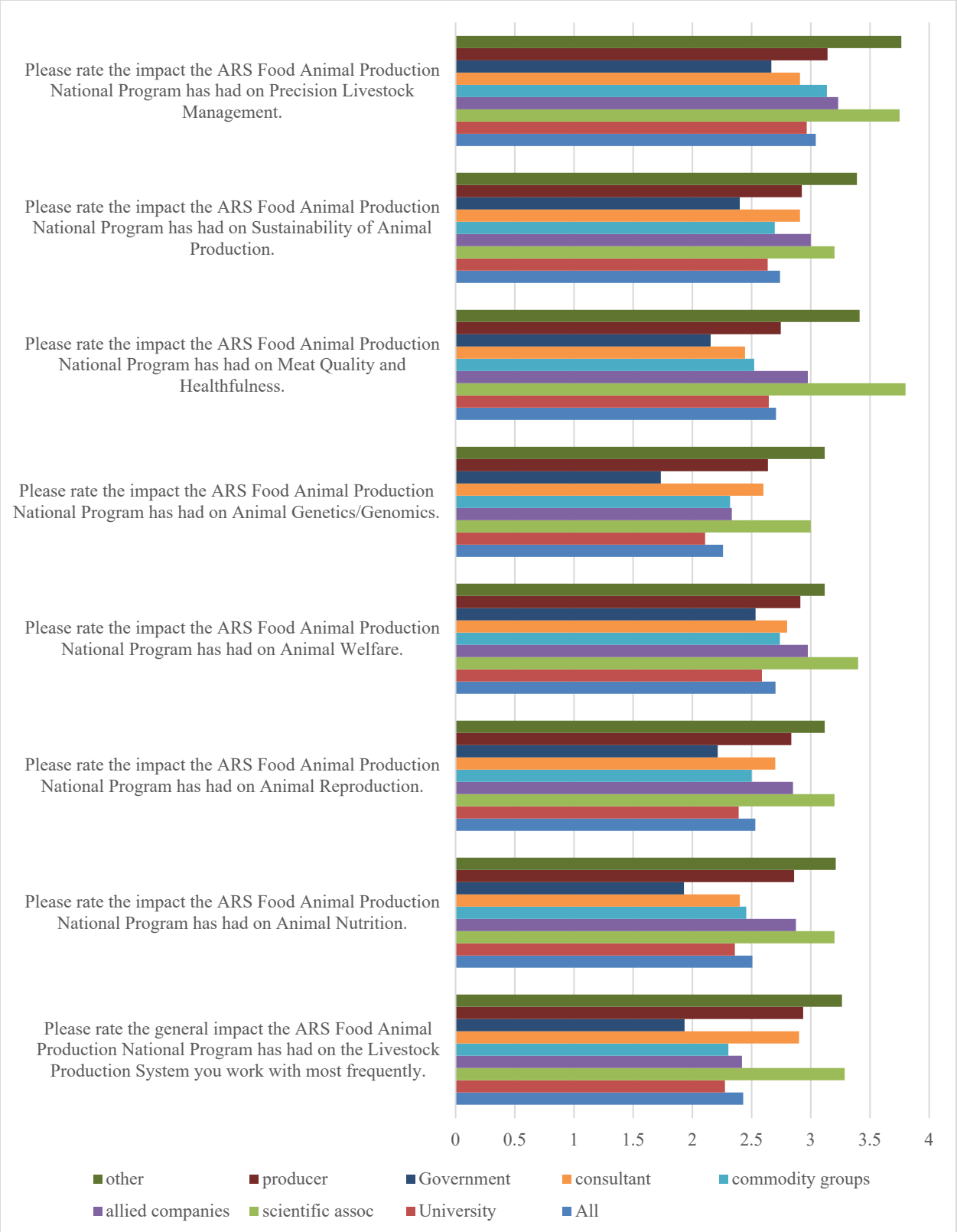


Figure 2: The Perception of the Impact of NP 101 by Research Topic and Respondent during the National Webinars. Responses ranged from 1 = large impact to 5 = no impact.

Ten, one hour webinars were held covering (Figure 3) Animal Genetics, Genomics and Bioinformatics; (Figure 4) Applications of Biotechnology to Animal Production; (Figure 5) Animal Well-Being, Stress and Production; (Figure 6) Animal Reproductive Biology; (Figure 7) Quality, Nutritional Value and Healthfulness of Animal Products; (Figure 8) Sustainable Intensification; (Figure 9) Animal Growth Biology; (Figure 10) Antimicrobial Resistance, Alternatives to Antimicrobials for Growth Promotion; (Figure 11) Reducing Environmental Impacts of Animal Production; and (Figure 12) Lactation Biology and Nutritional Efficiency of Animals including Forage Use. The format for each webinar was a brief introduction from ARS and NIFA, followed by 35 minutes of discussion of research topics within each broad topic area, which were recorded in real time. Then, the chat function was used so that participants could rank their top 4 research priority areas among those listed for that topic. The figures, below, shows the percentage of responses for each webinar in each respondent category (higher scores indicate more responses).

The top three overall research topics identified during the Genetics webinar were (1) improved genomic evaluation of crossbred animals, (2) deeper investigation of G x E analyses, and (3) understanding gene function within the genomes Figure 3). Commodity group priorities were slightly different and were (1) improved genomic evaluation of crossbred animals, (2) novel quantitative methods for genetic evaluations and (3) genomics of semen quality. University scientists top three priorities were (1) more multiomics data, consolidation and analysis of multiple data, (2) deeper investigation of G x E analysis, and (3) improved genomic evaluation of crossbred animals.

Figure 4 presents the results from the Biotechnology webinar where participants identified the top three overall research topics as (1) disease targets for gene editing, (2) gene editing in poultry, sheep and other species, (3) identification of functional variants. Commodity group priorities were (1) disease targets for gene editing, (2) building data to demonstrate risk/safety, and (3) focus on welfare traits. University scientists priorities were (1) Gene editing in poultry, sheep and other species, (2) identification of functional variants and (3) disease targets for gene editing.

Participants in the Animal Welfare webinar, Figure 5, identified their top three research topics overall were (1) objective measures of animal well-being, (2) pain management in the US, drugs to manage pain, (3) Nutritional interventions on welfare. Commodity group priorities were (1) pain management in the US, drugs to manage pain, (2) objective measures of animal well-being and (3) transportation effects on animal welfare. University scientist's priorities were (1) nutritional interventions on welfare, (2) objective measures of animal well-being and (3) improved management through precision technologies (cameras sound etc.).

The consensus from the Reproductive Biology webinar, Figure 6, was that the top three research topics overall were (1) environmental stressors on reproductive success, heat, fescue and other toxicants, cold etc., including climate change effects, (2) assisted reproductive technologies, freezing oocytes and semen, sexed semen, small ruminants and (3) early embryonic loss. Commodity group priorities were (1) precision reproductive methodologies, (2) review fertility rankings of semen that are currently in use and (3) environmental stressors on reproductive success, heat, fescue, and other toxicants, cold etc., including climate change effects. University scientists priorities were (1) fundamental mechanisms of maintenance of pregnancy, ovarian and implantation, (2) environmental stressors on reproductive success, heat, fescue and other toxicants, cold, etc., including climate change effects and (3) assisted reproductive technologies, freezing oocytes and semen, sexed semen, small ruminants.

Figure 3. Animal Genetics, Genomics and Bioinformatics

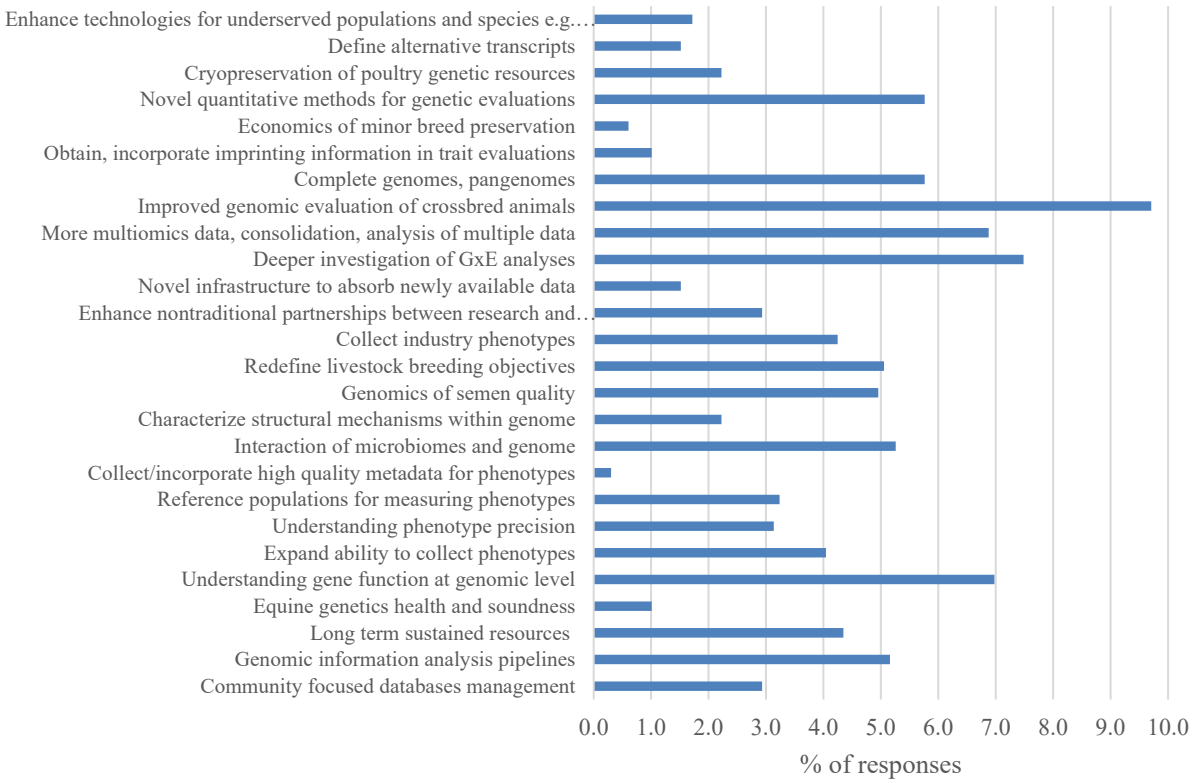


Figure 4. Applications of Biotechnology to Animal Production

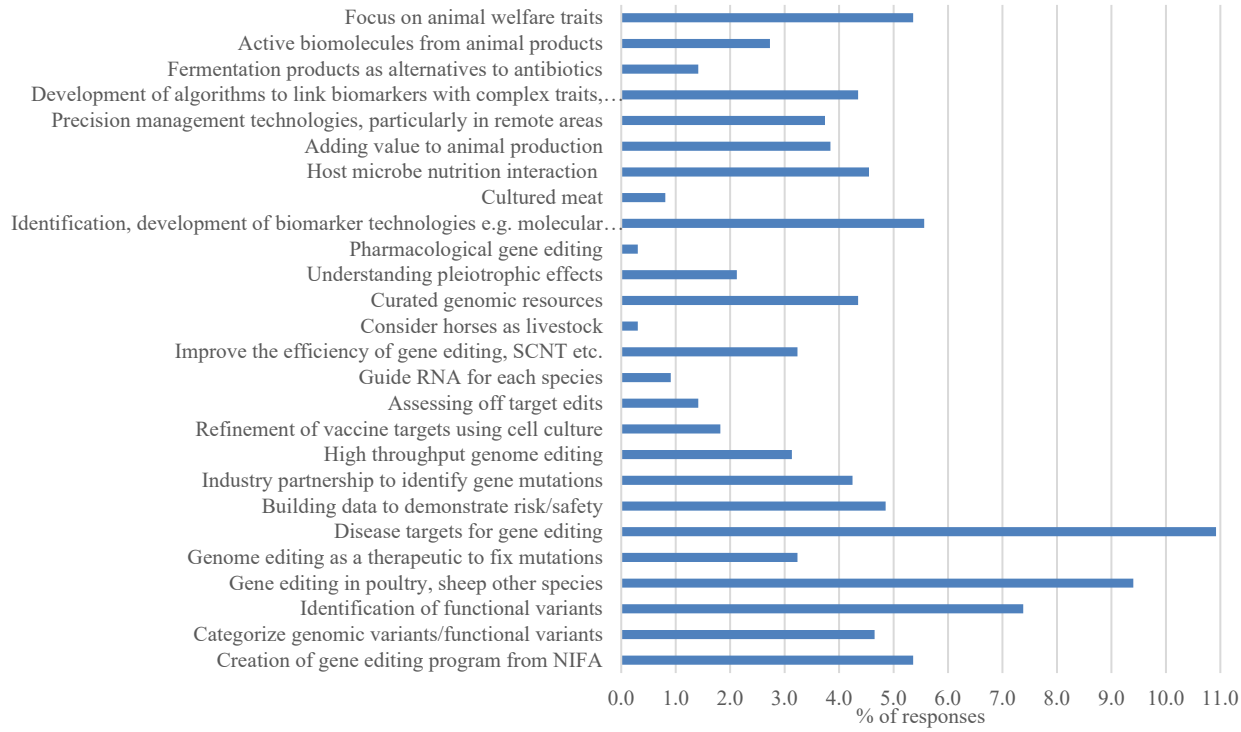


Figure 5. Animal Well-being, Stress and Production

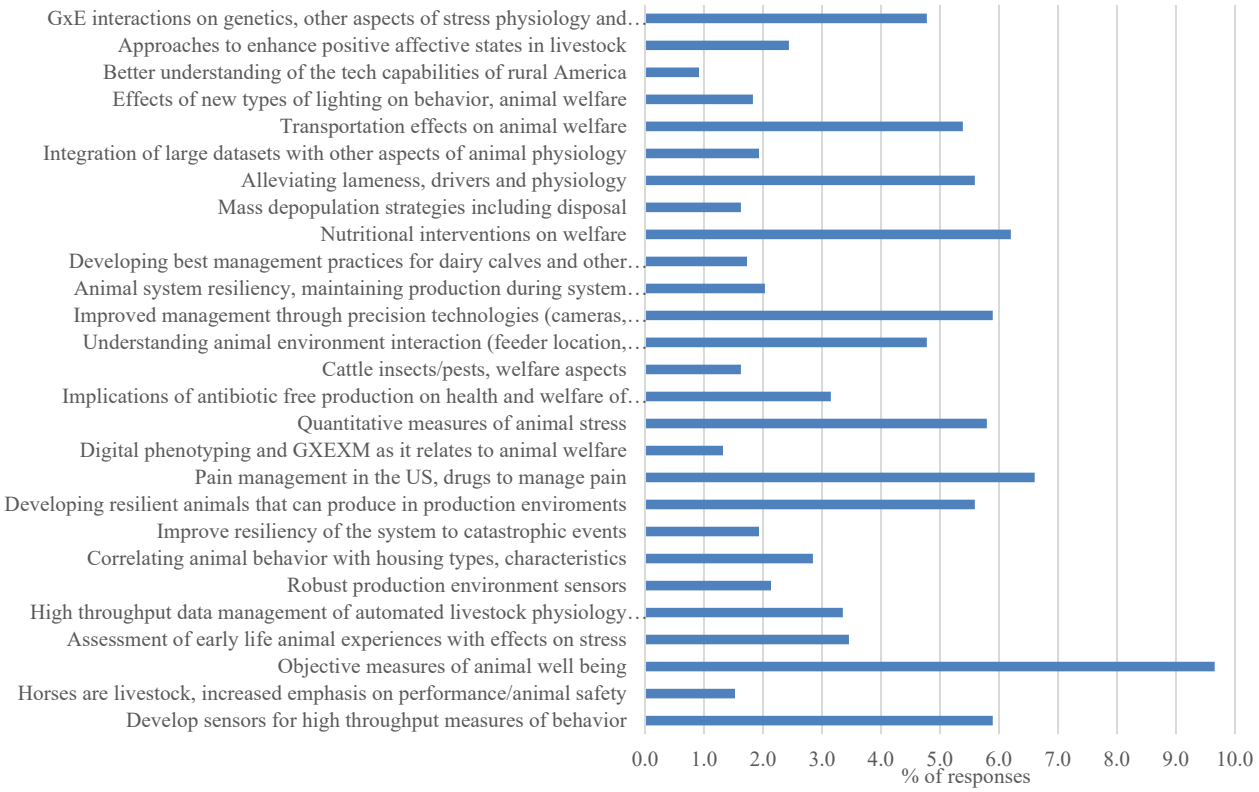
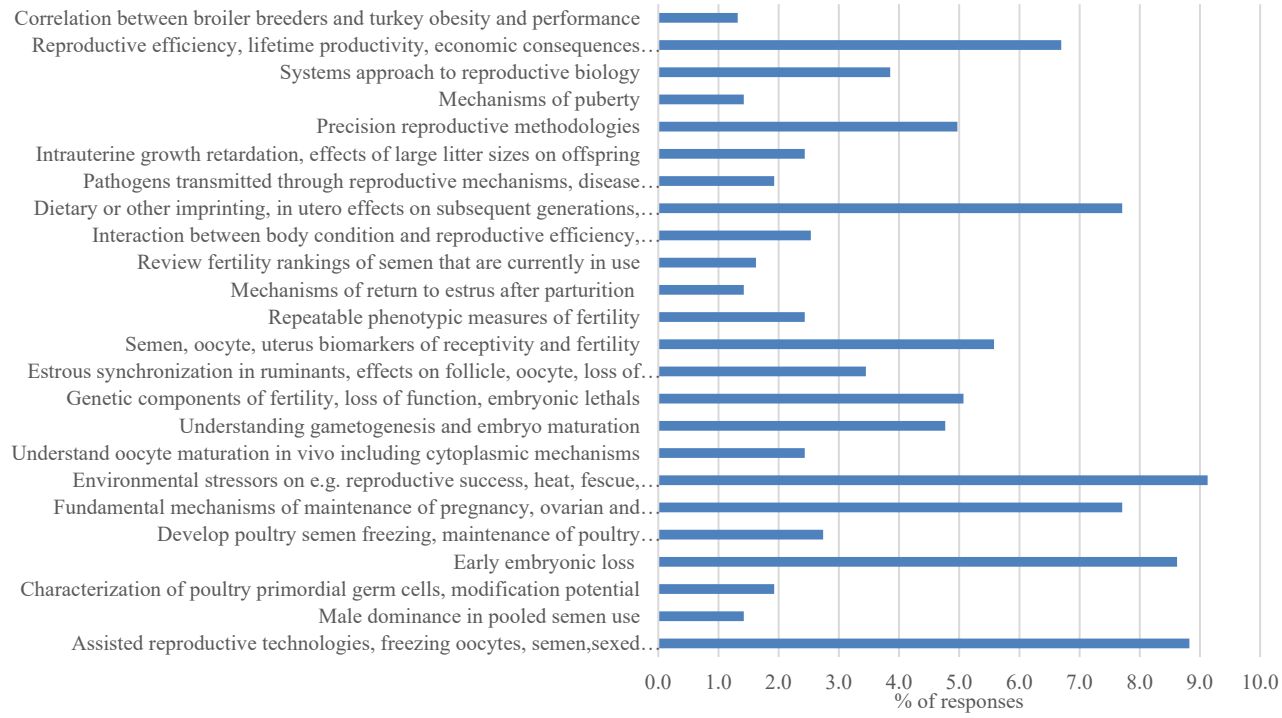


Figure 6. Animal Reproductive Biology



Contributors to the Animal Product Quality and Healthfulness webinar, Figure 7, identified the top three overall research priorities as (1) management and genetics and genomics of meat, eggs and milk quality, healthfulness and human health effects, (2) integration of feed characteristics with the quality and healthfulness of the final product and (3) developing a data pipeline and use big data analytic tools for prediction of product quality, composition and nutrient value. Commodity group top research priorities were (1) integration of feed characteristics with the quality and healthfulness of the final product, (2) small farm production practices effect on meat, eggs and milk quality and (3) development of automated sensors for meat, egg and milk quality and healthfulness. University scientists top research priorities were (1) recognition of the effects of product oxidation affects quality and nutrient availability, (2) management and genetics and genomics of meat, eggs and milk quality, healthfulness and human health effects and (3) integration of feed characteristics with the quality and healthfulness of the final product.

During the Sustainable Intensification webinar, Figure 8, the top three overall priorities identified were (1) genetic selection for increased heat tolerance and other climate induced stresses, (2) growth enhancing and feed efficiency technologies and (3) sustainable manure management. Commodity group priorities were (1) livestock and biodiversity, (2) contributions of livestock to energy and environment and (3) genetic selection for increased heat tolerance and other climate induced stresses. University scientist's priorities were (1) sustainable manure management, (2) sustainable air emissions measurement and remediation and (3) nitrogen cycling in the production system, form, and fate of nitrogen.

Figure 9 illustrates the top three overall research priorities identified during the webinar for Animal Growth Biology which are (1) developmental programming including perinatal effect of growth and impacts on subsequent generations, (2) understand how differences in growth, health or environmental challenges change nutrient requirements and nutritional efficiency and (3) influence of animal growth on animal product quality. Commodity group priorities were (1) what are the characteristics of a healthy gut and how does that affect production, (2) replacements for growth promotants and (3) manipulation of the microbiome, host microbiome interactions. University scientists priorities were (1) developmental programming including perinatal effect of growth and impacts on subsequent generations, (2) specific nutrient needs of growing muscle, minerals and other micronutrients and (3) better understanding of feed intake under a variety of production conditions.

Figure 7. Quality, Nutritional Value and Healthfulness of Animal Products

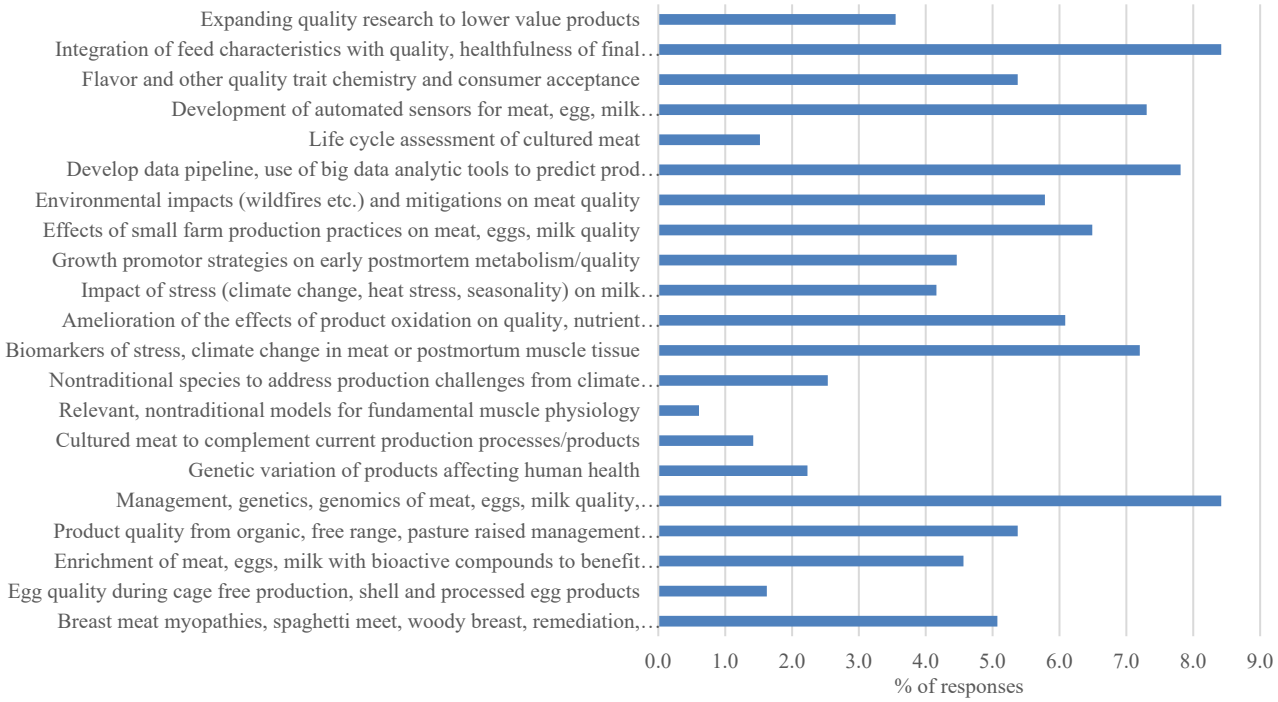


Figure 8. Sustainable intensification

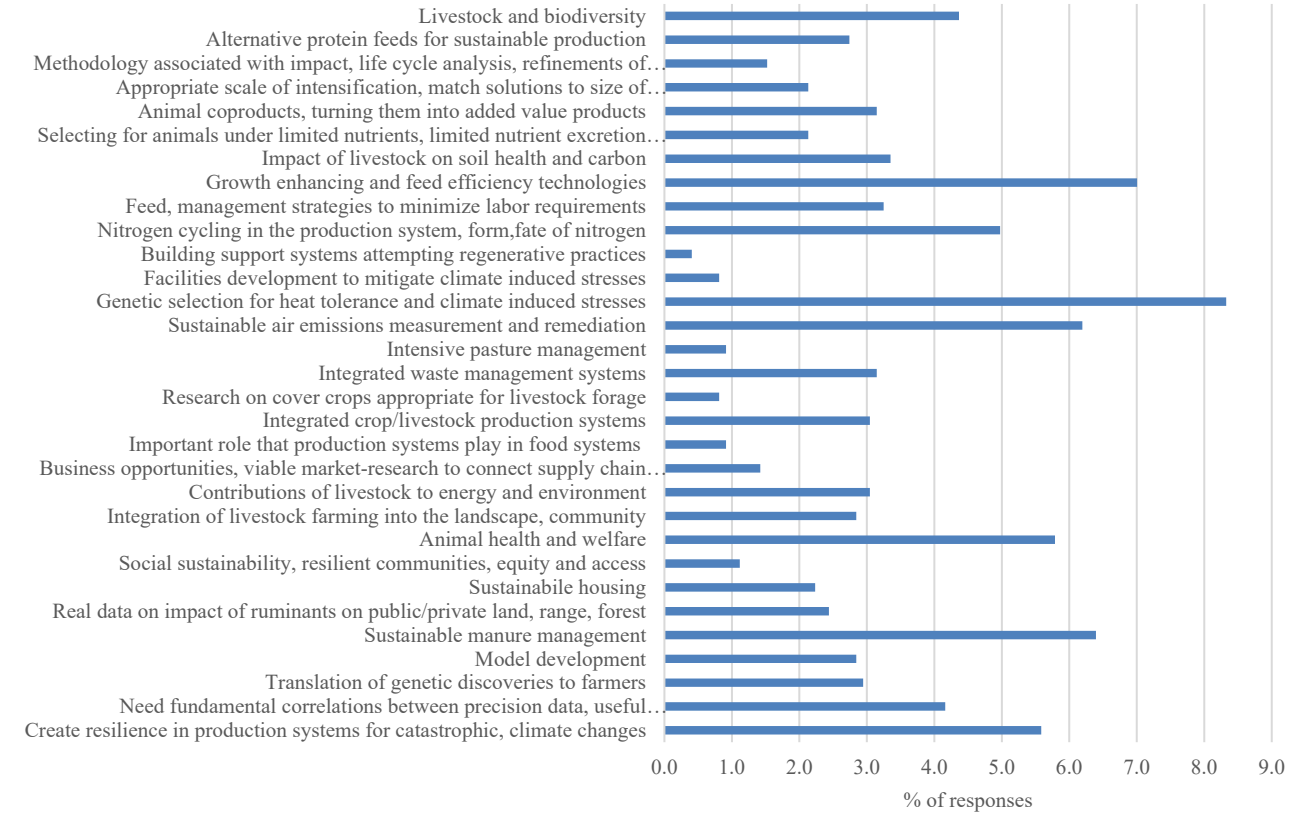
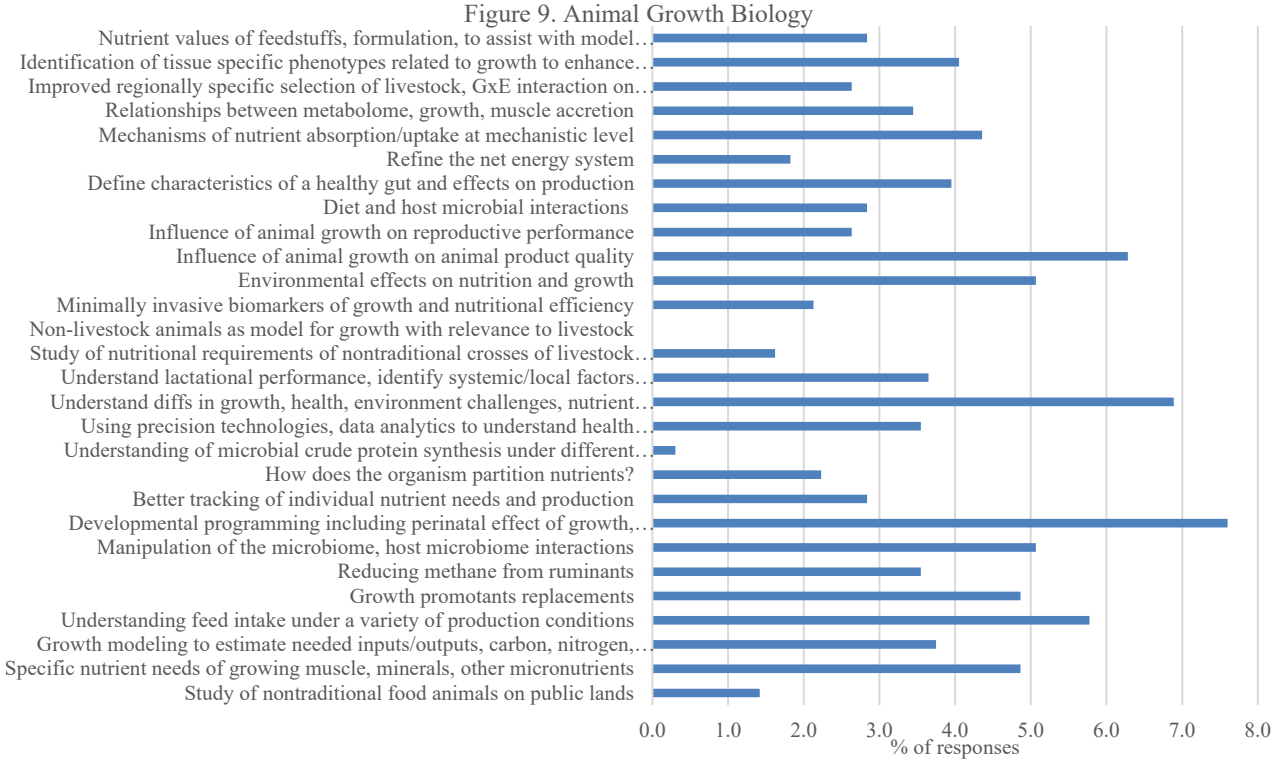
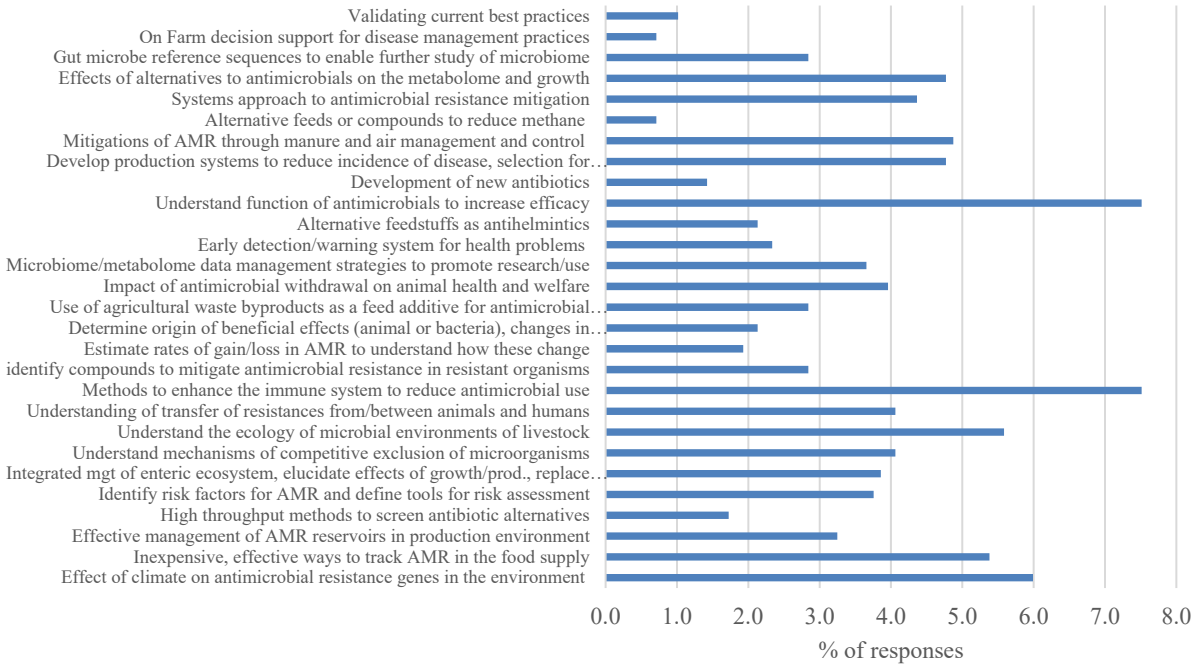


Figure 9. Animal Growth Biology



In discussions on Antimicrobial Resistance and Alternatives to Antimicrobials, Figure 10, the top three overall priorities identified during the webinar were (1) methods to enhance the immune system to reduce the need for antimicrobials, (2) understand how antimicrobial alternatives work so that they function more consistently and (3) effect of climate on reservoirs of antimicrobial resistance genes in the environment. Commodity group priorities were (1) methods to enhance the immune system to reduce the need for antimicrobials, (2) integrated management of the enteric ecosystem as it affects growth and production, to replace the effects of antimicrobials and (3) better understanding of transfer of resistances from/between animals and humans. University scientists priorities were (1) understand how antimicrobial alternatives work so that they function more consistently, (2) mitigations of antimicrobial resistance through manure and air management and control and (3) effect of climate on reservoirs of antimicrobial resistance genes in the environment.

Figure 10. Antimicrobial Resistance, Alternatives to Antimicrobials for Growth Promotion



During the webinar on Reducing Environmental Impacts of Animal Production, Figure 11, the participants identified the top three overall priorities as (1) life cycle assessments of different livestock production systems, including how different animal sectors affect each other, (2) update emission data on which current standards are based, including the use of currently employed housing and manure management systems and (3) connecting nutrition to manure composition, including updating information to modern genetics and housing, and modern feed processing. Commodity group priorities were (1) life cycle assessments of different livestock production systems, including how different animal sectors affect each other, (2) update emission data on which current standards are based, including the use of currently employed housing and manure management systems and (3) manipulation of the microbiome to reduce methane emissions. University scientists priorities were (1) use of precision technologies to measure the impact of livestock on the environment, (2) life cycle assessments of different livestock production systems, including how different animal sectors effect each other and (3) update emission data on which current standards are based, including the use of currently employed housing and manure management systems.

Lastly, during the Lactation Biology and Nutritional Biology webinar, Figure 12, the top three research priorities identified were (1) nutritional requirements of livestock under stress conditions, (2) interactions of gut microbiota and nutrients and their effect on nutrient utilization and whole animal biology, physiology and health and (3) understand environment by nutritional needs interactions. There were only two respondents in the commodity group, but their priorities were (1) more research on the maintenance requirements and other nutrient needs of the modern livestock due to changes in the animals through selection, (2) interaction of nutrition, metabolism and immunity on health and well-being including nutraceuticals and (3) how has nutrition changed as we maintain egg production for longer and other changes to poultry production. University scientists priorities were (1) interactions of gut microbiota and nutrients and their effect on nutrient utilization and whole animal biology, physiology and health, (2) integrate cell physiology with the broader organismal physiology in a systems approach to lactation, nutrition and (3) Precision nutrition management for individual animals, genomics and other mechanisms affecting efficiency of animals.

Figure 11. Reducing Environmental Impacts of Animal Production

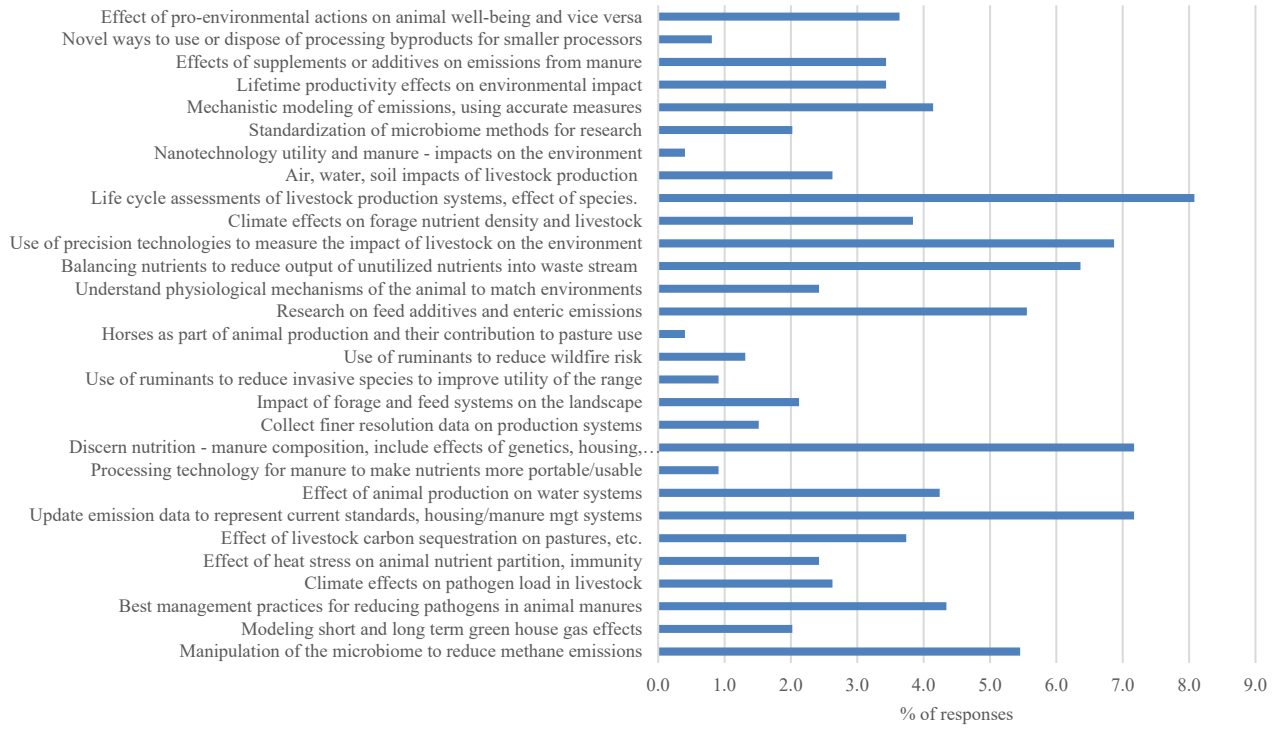


Figure 12. Lactation Biology and Nutritional Efficiency of Animals Including Forage Use

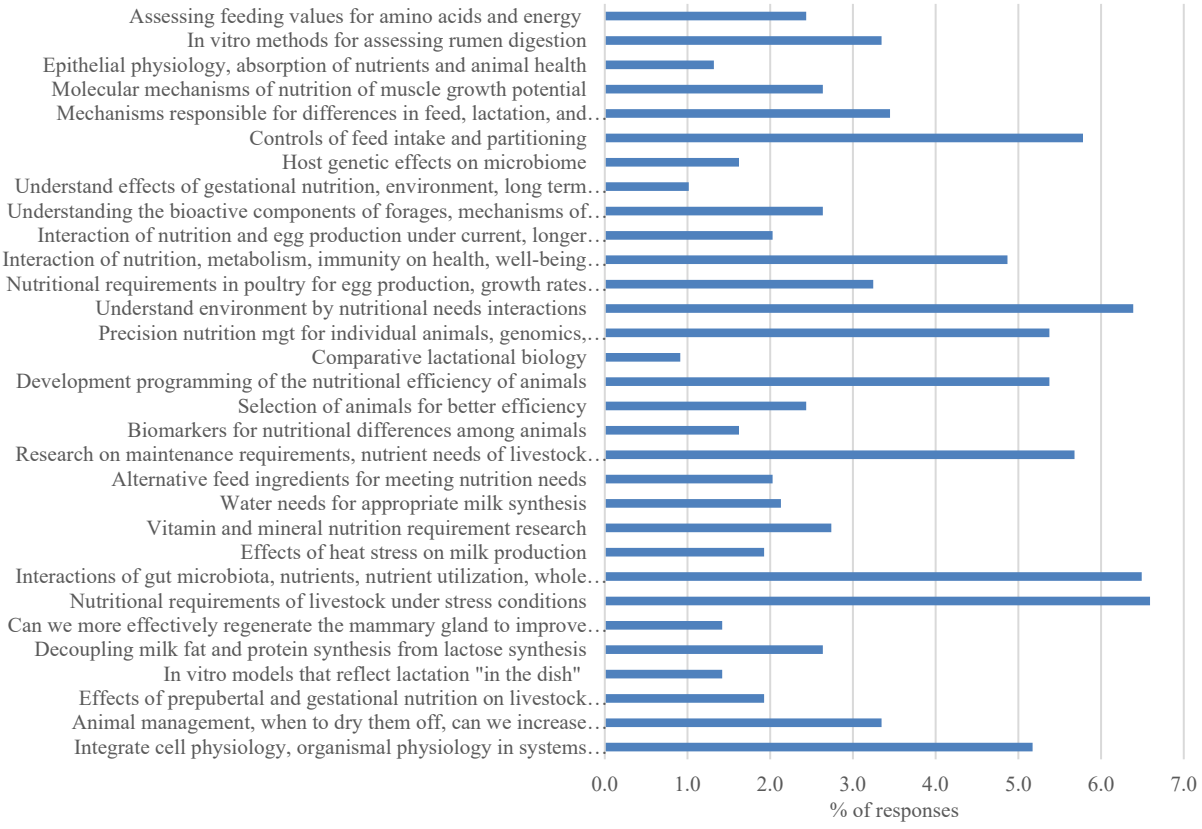


Table 1: Demographics of the respondents for each webinar.

	Respondent			
Topic	**ARS**	**Commodity**	**University**	**Unknown**
Animal Genetics, Genomics and Bioinformatics	15	23	39	5
Applications of Biotechnology to Animal Production	11	18	41	5
Animal Well-Being, Stress and Production	9	18	74	6
Animal Reproductive Biology	10	11	57	4
Quality, Nutrition Value, Healthfulness of Anim. Prod	6	10	30	3
Sustainable Intensification	6	12	35	3
Animal Growth Biology	7	11	45	3
Antimicrob. Resist., Alt. to Antimicrob. -Growth Promo	7	8	34	6
Reducing Environmental Impacts of Animal Production	8	6	38	2
Lactation Bio., Nutrition., Efficiency, Forage Use	9	2	35	4
Total	**88**	**119**	**428**	**41**

As with the survey, University scientists were the greatest number of participants. Participation fell during the webinars, and commodity group participation was very low for the last three webinars.