USDA

United States Department of Agriculture

## Agricultural Research Service

2019 ANNUAL REPORT

# ARS REPORT ON SCIENCE

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# INTRODUCTION

# LEADERSHIP IN AGRICULTURAL DISCOVERIES THROUGH SCIENTIFIC EXCELLENCE

The USDA Agricultural Research Service (ARS) delivers scientific solutions to national and global agricultural challenges. Through scientific excellence, innovation, and integrity, ARS supports the nourishment and well-being of all people, sustains America's agroecosystems, and ensures the economic competitiveness and excellence of American agriculture.

The ARS Office of National Programs coordinates and empowers the approximately 2,000 scientists conducting research on 660 projects across the agency. ARS engages its partners and stakeholders to identify research priorities in the following areas:

- Animal Production and Protection: improving the health, well-being, and efficiency of livestock, poultry, and aquatic food animals to ensure a productive and safe food supply;
- Crop Production and Protection: delivering science-based information, genetic resources, and technologies for increased crop productivity, economically and environmentally sustainable methods of crop production, and crop protection from diseases and pests;
- Natural Resources and Sustainable Agricultural Systems: developing technologies and strategies that help farmers, ranchers, and other managers effectively steward the diverse agricultural mosaic spread across the Nation; and
- Nutrition, Food Safety, and Quality: maintaining a healthy and safe food supply while improving the economic viability and competitiveness of American agriculture by enhancing the quality and utilization of agricultural products for the benefit of producers and consumers.

Additionally, ARS fosters research synergies that cut across the continuum of science to achieve breakthrough innovations. These synergistic projects harness the energy of diverse scientific teams to address complex problems of high national importance. For example, the Dairy Agriculture for People and Planet team cuts across animal, climate, nutrition, and information science to develop agronomic and animal management practices that deliver healthy products with lower environmental impacts.

The ARS Office of Technology Transfer, Office of International Research Engagement and Cooperation, and National Agricultural Library all support ARS in achieving its mission. These Research units move ARS research discoveries to the marketplace, facilitate mutually beneficial international research engagements, and provide public access to agricultural data.

Looking ahead, ARS prioritizes the development of precision agricultural management decision tools, labor-saving automation, and enhanced data management capabilities across its programs. These new tools and technologies will benefit crop and livestock systems while increasing the quality and safety of our food supply. ARS seeks to couple these technologies with artificial intelligence innovations for agricultural production and processing that would enable, for example, early detection of sickness or disease in livestock and aquaculture, fruit-specific harvesting for optimal readiness in specialty crop industries, virtual fencing in rangeland management systems, and precision watering and treatments of plants. ARS also prioritizes the use of artificial intelligence and nanotechnologies to develop new food processing and packaging systems to reduce food loss and waste. Furthermore, ARS envisions an integrated, multidisciplinary precision agriculture research effort to develop a network of models to forecast water availability and quantify soil erosion; conduct dam and levee risk assessments; and evaluate opportunities for aquifer recharge. Collectively, these efforts will enhance profitability and sustainability across the food supply and distribution chain.

# ARS AT A GLANCE

## Our Mission
Deliver scientific solutions to national and global agricultural challenges.

## What We Envision
Global leadership in agricultural discoveries through scientific excellence.

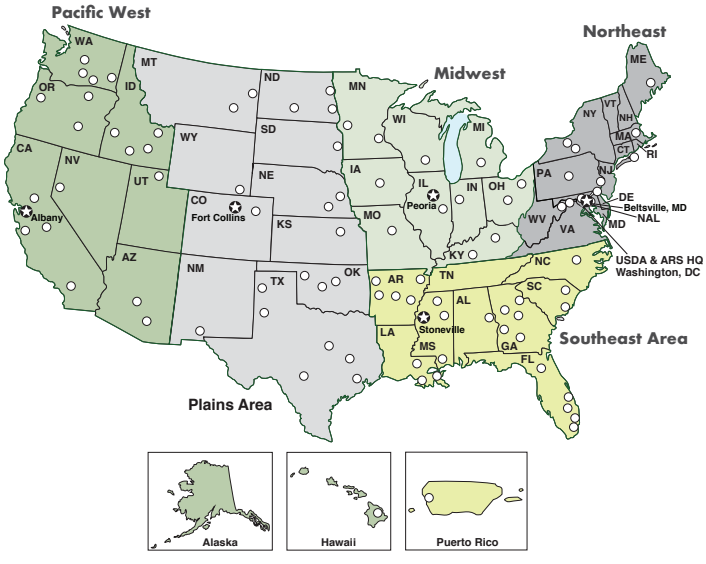
## Core Values
Scientific excellence, creativity, innovation, integrity, leadership, collaboration, accountability, transparency, diversity, respect, inclusiveness, and public service

These values underpin ARS's commitment to delivering cutting-edge, scientific tools and innovative solutions for American farmers, producers, industry, and communities to support the nourishment and well-being of all people; sustain our Nation's agroecosystems and natural resources; and ensure the economic competitiveness and excellence of our agriculture.

## Our Focus
- Animal Production and Protection
- Crop Production and Protection
- Natural Resources and Sustainable Agricultural Systems
- Nutrition, Food Safety, and Quality

## How We Get It Done
- 660 research projects
- 8,000 employees
- 90+ research locations
- $1.4 billion budget
- 1,535 international collaborations between ARS and foreign collaborators

## FY 2019 Outputs
- 3,816 peer-reviewed journal articles
- 85 new patent applications filed
- 65 new patents issued
- 51 new licenses



# SPECIALIZED INFRASTRUCTURE AND CAPABILITIES

## More than 90 research locations, featuring state-of-the-art facilities and resources such as:

- Four Overseas Biological Control Laboratories *(https://www.ars.usda.gov/office-of-international-research-programs/overseas-biological-control-laboratories)*
- U.S. National Arboretum (*https://www.usna.usda.gov/*)
- National Agricultural Library (*https://www.nal.usda.gov/main/*)
- National Bio and Agro-Defense Facility (under construction) (*https://www.usda.gov/nbaf*)

## Special Collections, including:

- ARS Culture Collection (*https://nrrl.ncaur.usda.gov/*)
- ARS National Rhizobium Germplasm Resource Collection (*https://data.nal.usda.gov/dataset/usda-ars-national-rhizobium-germplasm-collection*)
- National Animal Germplasm Program (*https://agrin.ars.usda.gov/*)
- National Invertebrate Genetic Resources (*https://data.nal.usda.gov/dataset/national-invertebrate-genetic-resources*)
- National Plant Germplasm System (*https://npgsweb.ars-grin.gov/gringlobal/search.aspx*)
- USDA Nematode Collection (*https://nt.ars-grin.gov/nematodes/search.cfm*)
- U.S. National Arboretum Herbarium (*https://usna.usda.gov/science/herbarium/*)
- U.S. National Fungus Collections (*https://nt.arsgrin.gov/fungaldatabases/specimens/specimens.cfm*)

## Premier Networks of Scientific Expertise, including:

- Long-Term Agroecosystem Research Network, for developing national strategies for the sustainable intensification of agriculture (*https://ltar.ars.usda.gov/*)
- USDA Climate Hubs, for providing region-specific, climate-informed assistance to agricultural and natural resource managers (*https://www.climatehubs.usda.gov/*)
- Greenhouse gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet), for promoting sustainability through reduced soil emissions of greenhouse gases (*https://www.ars.usda.gov/anrds/gracenet/gracenet-home/*)
- Resilient Economic Agricultural Practices (REAP), program for improving soil health and resiliency through improved management practices (*https://www.ars.usda.gov/anrds/reap/reap-home/*)
- Partnerships for Data Innovations project, for developing precision field monitoring systems and managing big data in agriculture
- Breeding Insight Platform, for accelerating small breeding programs through the combination of modern breeding approaches, genomics, and informatics (*https://www.breedinginsight.org/*)

# PROGRAM OVERVIEWS

## PROGRAM KEY

Animal Production and Protection

Crop Production and Protection

Natural Resources and Sustainable Agricultural Systems

Nutrition, Food Safety, and Quality Research

Office of International Research Engagement and Cooperation

National Agricultural Library

ARS Office of Technology Transfer

FOR MORE INFORMATION: https://www.ars.usda.gov/animal-production-and-protection/

# ANIMAL PRODUCTION AND PROTECTION RESEARCH

The ARS national programs in Animal Production and Protection improve the health, well-being, and efficiency of livestock, poultry, and aquatic food animals to ensure a productive and safe food supply. These research programs provide the scientific information and tools to support U.S. food animal industries as they supply the nutritional animal products required by the Nation, compete successfully in worldwide trade, and contribute toward global food security. The program also addresses the many veterinary problems created by zoonotic diseases and arthropod pests and vectors, producing solutions to protect the health and well-being of American citizens.

To achieve these goals, ARS conducts research that:

- Improves food animal production efficiency, industry sustainability, animal welfare, product quality, and nutritional value while safeguarding animal genetic resources;
- Protects and ensures the safety of the Nation's agriculture and food supply through improved disease detection, prevention, and control;
- Improves domestic aquaculture production efficiency and product quality while minimizing impacts on natural resources; and
- Eliminates arthropod vectors and the diseases that they transmit to livestock, humans, and other animals and nullifies their economic impact.

ARS is also working with the U.S. Department of Homeland Security to bring online a new National Bio and Agro-Defense Facility (NBAF) in Manhattan, Kansas. This state-of-the-art facility will be the first maximum biocontainment laboratory (BSL-4) in the United States to study high-consequence zoonotic diseases affecting large livestock. This facility will enhance existing research programs and expertise in foot-and-mouth disease, African swine fever, Japanese encephalitis, and Rift Valley fever; initiate new research and expertise in zoonotic disease agents and new arthropod-borne diseases; and conduct research gap analyses and risk analyses for diseases of interest to ensure research alignment. NBAF construction activities are underway, facility commissioning will be completed in May 2021, and the facility will be fully operational in December 2022.

In FY 2019, ARS Animal Production and Protection researchers developed the first-ever candidate vaccines to protect the swine industry against African swine fever and made numerous other advances to address antimicrobial resistance and develop alternatives to antibiotics. ARS National Program leaders took the lead in publishing a new Genome Blueprint (*https://www.frontiersin.org/articles/10.3389/fgene.2019.00327/full*), an industry-wide 10-year strategic vision that prioritizes and facilitates coordinated research efforts in animal genome research.

Looking ahead, ARS prioritizes the development of precision agricultural management decision tools, labor-saving automation, and data management for small- and medium-scale beef and lamb production systems. These technologies will detect and manage environmental stress, estrus, disease, and behavior. ARS seeks to couple these technologies with artificial intelligence innovations for agricultural production and processing that would enable, for example, early sickness or disease detection in livestock and aquaculture. Collectively, these resources will help producers manage production efficiency, weather-associated risks, and market variability using intensive automated data collection from their own farms and ranches in real-time.

FOR MORE INFORMATION: https://www.ars.usda.gov/crop-production-and-protection/

# CROP PRODUCTION AND PROTECTION RESEARCH

The ARS national programs in Crop Production and Protection deliver science-based information, genetic resources, and technologies for increased crop productivity, economically and environmentally sustainable methods of crop production, and research on crop protection from diseases and pests. Research conducted under these programs meet producers' needs for increased crop productivity and value; consumers' demands for a ready supply of high-quality, safe, affordable, and nutritious food; workers' needs for a safe working environment; the public's desire to protect the environment; and the global community's need for food security.

To meet these needs, ARS conducts research that:

- Harnesses the genetic potential of plants to transform U.S. agriculture;
- Enhances U.S. agricultural crop productivity, efficiency, and sustainability, and ensures a high-quality and safe supply of food, fiber, feed, ornamental, and industrial crops for the Nation;
- Improves and expands our knowledge of existing and emerging plant diseases and develops effective and sustainable disease management strategies that are safe to humans and the environment; and
- Provides technology to manage pest populations below economically damaging thresholds through the integration of environmentally compatible strategies that are based on increased understanding of the biology and ecology of insect, mite, and weed pests.

ARS is steward to important national agricultural resources for protecting U.S. agriculture, including the National Plant Germplasm System (distributed over 19 locations), Overseas Biological Control Laboratories (four locations), and the U.S. National Arboretum. ARS also oversees important targeted programs, including the National Sclerotinia Initiative, the National Plant Disease Recovery System, the Pulse Crop Health Initiative, and the AgBioData consortium.

ARS is accelerating and transforming small breeding programs through the Breeding Insight Platform (breedinginsight.org), which provides breeders with direct access to customized tools, informatics, and database technologies to adopt modern genomics strategies to their programs. Breeding Insight leverages investments in open-source tools by ARS, Cornell University, the National Science Foundation, the Consultative Group on International Agricultural Research, the U.S. Agency for International Development, and the Bill & Melinda Gates Foundation. The platform currently supports grape, blueberry, sweet potato, alfalfa, and trout breeding and will expand its portfolio to more than 60 specialty breeding programs over the next 5 years.

Looking ahead, ARS prioritizes investment in precision agriculture technologies and labor-saving automation to aid in the breeding and production of tree fruit crops, small fruits, and vegetables that traditionally rely on manual labor. These technologies include computational analyses of crop traits and performance in the field, low-cost robotic data measurement and analytics, and improved spray technologies. ARS seeks to couple these technologies while advancing artificial intelligence innovations for agricultural production and processing, developing systems for watering and treating individual plants, minimizing product loss, and developing decision tools for maximizing profits based on near real-time crop quality information and current market opportunities. Collectively, these technologies will address current labor shortages and enhance the profitability of U.S. specialty crop industries.

FOR MORE INFORMATION: https://www.ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/

# NATURAL RESOURCES AND SUSTAINABLE AGRICULTURAL SYSTEMS RESEARCH

The ARS national programs in Natural Resources and Sustainable Agricultural Systems (NRSAS) develop technologies and strategies that help farmers, ranchers, and other managers effectively steward the diverse agricultural mosaic spread across the Nation, from livestock grazing the expansive natural western rangelands, to crops grown in the fertile Midwestern Heartland and Southern States, to the high-value produce cultivated in the coastal valleys and plains. These diverse landscapes generate more than $200 billion in goods and services that are the basis of a strong rural economy.

ARS's NRSAS research programs investigate and develop tools and methods for:

- Effectively and safely managing water resources to sustain and increase agricultural production and water use efficiency while protecting the environment and human and animal health;
- Enhancing and protecting soil resources; managing nutrients and emissions from agricultural soils, livestock production systems, and byproducts; and improving production from agroecosystems to be resilient to changing climates;
- Improving management decisions and enhancing the function and performance of rangelands, pastures, forage, and turf agroecosystems while enhancing ecosystem services; and
- Integrated solutions for agriculture enabling greater productivity, profitability, and natural resource enhancement.

To achieve these goals, ARS coordinates the Long-Term Agroecosystem Research (LTAR) Network, a premier partnership of 18 Federal and university agricultural research sites that represent most of the agricultural production regions in the United States. Additionally, ARS partners with the U.S. Forest Service to direct the USDA Climate Hubs, which develop science-based, region-specific information and technologies that provide climate-informed decision-making and assistance to agricultural and natural resource managers. The recently completed 5-year review of the Climate Hubs made clear the high demand for the hubs and their strengths in convening, leveraging funds, and expanding climate adaptation practices. ARS is also home of the Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), the Resilient Economic Agricultural Practices (REAP) program, and the Partnerships for Data Innovations project.

Looking ahead, ARS prioritizes research, infrastructure, and interagency collaboration to manage excess water and control erosion on agricultural landscapes. These efforts will result in water availability and soil erosion forecasts, dam and levee risk assessments, and opportunities for aquifer recharge to maximize production and minimize water needs and soil losses. ARS also prioritizes the development of precision agricultural management decision tools, labor-saving automation, data management, and artificial intelligence innovations for U.S. cattle production and rangeland management. Collectively, these resources will help producers manage production efficiency, weather-associated risks, and market variability while employing practices that conserve air quality and improve nutrient management.

FOR MORE INFORMATION: https://www.ars.usda.gov/nutrition-food-safetyquality/

# NUTRITION, FOOD SAFETY, AND QUALITY RESEARCH

The ARS national programs in Nutrition, Food Safety, and Quality exist to maintain a healthy and safe food supply while improving the economic viability and competitiveness of American agriculture by enhancing the quality and utilization of agricultural products for the benefit of producers and consumers.

To achieve these goals, ARS conducts research that:

- Defines the role of food and its components in optimizing health throughout the life cycle for all Americans;
- Protects food from pathogens, toxins, and chemical contamination during production, processing, and preparation; and
- Improves postharvest quality of foods and clothing fibers, develops new uses of agricultural-based foods and fibers, and develops renewable fuels and new products through biorefining of agricultural feedstocks.

One of the defining features of these programs is an emphasis on food-based approaches to improve human health. The ARS Human Nutrition research program hosts the capacity of six internationally-recognized Human Nutrition Research Centers with the core capability for long-term, multidisciplinary, translational research in high-priority areas and the availability of premier scientists and state-of-the-science equipment and facilities for human nutrition research across the life cycle. This program leverages unique national resources, including the National Nutrient Data Laboratory, the Food Surveys Research Group (which conducts the What We Eat in America survey), and a laboratory that develops and improves methods for food analysis.

The ARS Food Safety program provides a research-based means to ensure that the food supply is safe for consumers and that food and feed meet foreign and domestic regulatory requirements. Current research efforts focus on whole genome sequencing and metagenomics, water safety in fresh produce production, guidelines at the interface between animal and produce operations, climate change and mycotoxin contamination, food adulteration and fraud, reduction of foodborne pathogens during animal production and food processing, and contamination of ready-to-eat foods. Food safety is a global issue, and therefore the program involves both national and international collaborations through formal and informal partnerships.

Looking ahead, ARS prioritizes development of precision agriculture technologies, data management and tool development, and labor-saving automation to improve preharvest and postharvest processing; enable nondestructive quality assessment and grading; detect microbial, chemical, and biological contaminants in agricultural products and in the field; determine water safety and quality for agricultural commodities; and develop biobased fuels and high-value products that enhance rural economies. ARS also seeks to advance artificial intelligence innovations that would enable fruit-specific harvesting for optimal readiness and minimize food and agricultural processing waste. Collectively, these technologies will address current labor shortages and help producers manage production efficiency, weather-associated risks, and market variability using intensive automated and real-time data collection from their own farms, ranches, and food distribution systems.

FOR MORE INFORMATION: https://www.ars.usda.gov/office-of-international-research-engagement-and-cooperation/

# THE ARS OFFICE OF INTERNATIONAL RESEARCH ENGAGEMENT AND COOPERATION

The ARS Office of International Research Engagement and Cooperation (OIREC) enhances the productivity, effectiveness, and impact of ARS research through mutually beneficial international research projects. USDA international research cooperation provides solutions to current and future agricultural productivity and sustainability challenges beyond what can be achieved through purely domestic research. OIREC supports ARS leadership in global science and technology engagements so that ARS can identify emerging ideas and solutions wherever they arise, increase the impact of research and development spending, and deliver new knowledge and technologies.

OIREC, which celebrated its 20th anniversary in October 2019, is the main contact for international activities in ARS. OIREC regional international affairs specialists work closely with the ARS Office of National Programs to cultivate strategic international partnerships that can enhance ARS national programs and further the goals of the U.S. Government.

OIREC works within ARS and partners with other USDA and Federal research entities to:

- Catalyze and manage domestic and international partnerships that enhance the agency's national programs to address critical needs of U.S. agriculture;
- Manage the ARS Overseas Biological Control Laboratories that identify and collect natural enemies of invasive species in the United States; and
- Network with other U.S. government agencies and the international community to promote the agency's interests.

OIREC coordinates and oversees efforts by the ARS Overseas Biological Control Laboratories. These four strategically located research laboratories enable ARS to study and partner with countries where invasive plants originated, supporting the future mitigation of these threats in the United States. These laboratories include:

- The European Biological Control Laboratory (EBCL) in Montpellier, France, which also operates a satellite laboratory in Thessaloniki, Greece. ARS owns and operates EBCL. In 2019, EBCL celebrated its 100th anniversary.
- The Australian Biological Control Laboratory in Brisbane, Australia, which operates through a cooperative agreement with Australia's Federal research body, CSIRO.
- The Foundation for the Study of Invasive Species (FuEDEI) in Hurlingham, Argentina, which operates as a nonprofit research organization partnering with ARS.
- The Sino-American Biocontrol Laboratory in Beijing, China, which operates through a cooperative agreement with the China Academy of Agricultural Sciences.

FOR MORE INFORMATION: https://www.nal.usda.gov/main/

# THE NATIONAL AGRICULTURAL LIBRARY

The National Agricultural Library (NAL) sustains the American agricultural enterprise through public access and effective stewardship of agricultural data, literature, and other information resources. Housing more than 8 million physical items, NAL is the world's largest collection of agricultural information.

As one of five national libraries and the library of the USDA, NAL manages the NAL website (https://nal.usda.gov/), the entry point to all its online resources, including:

- AGRICOLA (https://agricola.nal.usda.gov/), USDA's online catalog and index to the agricultural literature;
- PubAg (https://pubag.nal.usda.gov/) and Ag Data Commons (https://data.nal.usda.gov/), USDA's "one-stop-shop" for public access to scholarly literature and data funded by the Department;
- NAL Digital Collections (https://naldc.nal.usda.gov/), including digitized content from NAL's Special Collections; and
- DigiTop (https://digitop.nal.usda.gov/), the online resource for USDA staff that provides 24/7/365 access to licensed electronic resources such as journals, databases, newspapers, and e-books.

By investing in these resources, providing top-notch expertise in library and information science, and collaborating with partner and stakeholder resources, NAL:

- Supports USDA's strategic goals for fact-based, data-driven decision-making through NAL's information products and services;
- Delivers unified, easy-to-use, convenient 24/7/365 digital services that are customer-focused and meet customers' expectations and needs;
- Works efficiently and effectively, with integrity and customer-focus; and
- Provides leadership in agricultural and research library communities to build capacity for effective stewardship of information resources and improving access to agricultural information, supporting the USDA mission to "do right and feed everyone."

NAL is a leader in scientific data management, benefiting researchers everywhere. Today's research studies in agriculture are data-intensive—and publishing that data fosters trust and drives innovation in agricultural research. NAL updated Ag Data Commons with a fresh design for ease of use and access to data. Ag Data Commons curators help researchers prepare high-quality data management plans ensuring that dollars spent on research have the largest possible impact.

In FY 2019, NAL greatly increased access to journal articles and other publications, special collections, and rare materials. For example, the library put together onsite and online exhibits showcasing rare Smokey Bear artwork and artifacts to celebrate the 75th anniversary of the wildfire-prevention mascot. There is something new for the consumer, too: FoodData Central, an integrated data system that provides expanded nutrient profile data and links to related agricultural and experimental research.

FOR MORE INFORMATION: https://www.ars.usda.gov/office-of-technology-transfer/

# ARS OFFICE OF TECHNOLOGY TRANSFER

The ARS Office of Technology Transfer encourages, promotes, and facilitates the adoption and commercialization of technology resulting from ARS research, helping to move USDA research discoveries to the marketplace. Although research results are sometimes transferred directly from ARS to end users, the private sector more often serves as the essential delivery mechanism and intermediary between ARS research and the realization of public benefit. Private sector partners facilitate technology transfer by providing the complementary assets needed for the adoption of research outcomes. Such assets may include unique research and manufacturing expertise, capabilities, and facilities; marketing and distribution expertise and capacity; product registration and/or regulation expertise; and investment capital. By providing these assets, private sector partners make investments to increase the impact of ARS research by ensuring research outcomes are widely available.

Because the ARS mission is to transfer technologies for broad public use by the most effective mechanism, ARS pursues patents and licensing principally to incentivize commercialization and to facilitate technology transfer to the marketplace. This is usually the case when complementary investment by the private sector is necessary to commercialize a product, and patent protection is required to protect this investment. In licensing practices, ARS reserves the right to allow use of any intellectual property-protected technology for research purposes (noncommercial).

To facilitate technology transfer at ARS, the Office of Technology Transfer:

- Creates a culture that understands and fosters entrepreneurship and innovation.
- Maintains intellectual property policies and technology transfer mechanisms.
- Ensures an understanding and awareness of technology transfer policies and best practices.
- Communicates the strategic value of technology transfer internally and externally.
- Judiciously uses intellectual property rights to enhance adoption of research outcomes.
- Develops and maintains flexible technology transfer mechanisms that correspond to scientific needs.
- Leads and engages in the Agricultural Research Partnerships (ARP) Network.
- Supports small businesses by coupling funds and technologies in collaboration with the Small Business Innovation Research Program of the USDA National Institute of Food and Agriculture.
- Recognizes and incentivizes participation in technology transfer activities.
- Stays current on Federal policies and best practices in technology transfer.
- Encourage the implementation of innovative methods of conducting technology transfer.

ARS has been delegated authority by USDA to administer the patent and license programs for all USDA agencies. As part of this departmental leadership, ARS publishes an annual report on technology transfer that reports on the technology transfer of all USDA agencies, including ARS.

# FY 2019 RESEARCH ACCOMPLISHMENTS

## PART I: INCREASING THE RESILIENCE OF THE AGRICULTURAL ENTERPRISE

FOR MORE INFORMATION: https://ars.usda.gov/Advancing Sustainable Livestock and Poultry Production/

# ADVANCING SUSTAINABLE LIVESTOCK AND POULTRY PRODUCTION

The ARS food animal production research program improves food animal production efficiency, sustainability, animal welfare, and product quality while safeguarding animal genetic resources. Animal production is a critical component of the U.S. economy, yielding $440.7 billion in economic output, with $76.7 billion in earnings, $19.6 billion in income taxes, and $7.4 billion in property taxes in 2014. The following accomplishments highlight ARS advances in animal production research in FY 2019.

**Increases in pork carcass weight will improve tenderness of pork loin chops.** Historical trends indicate the size of U.S. hogs will likely continue to increase. ARS scientists in Clay Center, Nebraska, and University of Illinois and Kansas State University collaborators found that the heaviest group of carcasses weighed 36 percent more than the industry average. This group represents the expected average carcass weight by 2050. The increased carcass weight resulted in loin chops that were juicier and tenderer and had minimal effect on other pork quality traits, improving overall eating quality.

**Characterization of the porcine mycobiome (fungal microbiome).** ARS scientists in Beltsville, Maryland, performed the first in-depth analysis of the gastrointestinal tract mycobiome of piglets between birth and postweaning transition. These scientists reported a dynamic shift in the fungal mycobiome at the time of weaning, suggesting that milk may suppress gut fungi and may be important for preweaned piglet health. Likewise, if the same factors are present in cow's milk and are not damaged by pasteurization, they could provide health benefits to humans. In addition, postweaning diarrhea in piglets is a common production problem, which may be influenced by this shift in the mycobiome.

**New method improves genome assembly.** ARS researchers in Clay Center, Nebraska, and Beltsville, Maryland, and collaborators at the National Institutes of Health, University of Nebraska, and University of Kentucky pioneered a method for improving the assembly of genetic sequence data and developed the most complete and correctly ordered genome sequence to date for Yak and Scottish Highland cattle. The assembly is of equal or better quality than any existing mammalian genome assembly, including human. This strategy would rapidly improve the quality of other livestock and plant genome assemblies.

**National genomic evaluations for crossbred dairy cattle.** ARS researchers in Beltsville, Maryland, collaborated with the Council on Dairy Cattle Breeding (CDCB) and São Paulo State University in Brazil to develop the first genomic evaluations for crossbred dairy cattle. CDCB adopted the new evaluation methodology, and genomic evaluations for crossbreds were released to the dairy industry for the first time in April 2019. This new evaluation methodology will help dairy producers who have turned to crossbreeding to counter decreases in fertility associated with purebred dairy cows.

**New model to predict illness using swine feeding behavior.** ARS scientists in Clay Center, Nebraska, with South Dakota State University collaborators developed a model to predict swine feeding behavior based on temperature and time of day and observed large deviations between predicted and observed behaviors before and after a pneumonia outbreak. This provides the groundwork for developing software using real-time feeding behavior as an early predictor of illness and stress in individual animals.

FOR MORE INFORMATION: https://ars.usda.gov/Advancing Sustainable Aquaculture Production

# ADVANCING SUSTAINABLE AQUACULTURE PRODUCTION

The ARS aquaculture research program delivers new knowledge and technologies that improve domestic aquaculture production efficiency and product quality while minimizing impacts on natural resources. This work advances the efforts of more than 2,900 aquaculture farmers producing more than $1.5 billion worth of goods annually to meet the potential market demand generated by 300 million U.S. consumers. Aquaculture production is growing because demands for healthy seafood products are increasing even as stocks of wild-caught seafood are dwindling from overfishing and other stressors. Developing technologies that reduce production costs and maintain or improve product quality will help U.S. aquaculture producers meet that increasing demand. Ultimately, the ARS aquaculture research program will ensure that a healthy, competitive, and sustainable aquaculture sector is able to produce an abundant, safe, and affordable supply of seafood products. The following accomplishments highlight ARS FY 2019 advances in catfish, salmon, trout, and oyster production.

**ARS advances blue catfish breeding.** Over the last 15 years, U.S. catfish production has been shifting from purebred channel catfish to hybrids of channel and blue catfish. ARS scientists in Stoneville, Mississippi, found that the Rio Grande strain of blue catfish shows superior growth and meat yield relative to other blue catfish strains. ARS will release approximately 10,000 4- to 6-year-olds, 20,000 2-year-olds, and 100,000 fingerlings of the Rio Grande strain to farmers during FY 2020. These scientists, in cooperation with Louisiana State University and ARS scientists in Fort Collins, Colorado, have also established a collection of cryopreserved blue catfish sperm from multiple strains of approximately 300 blue catfish males. This collection is crucial for developing hybrid blue catfish germplasm since blue male catfish must otherwise be sacrificed to obtain sperm for hybrid production.

**Improved North American Atlantic salmon germplasm.** Commercial salmon farming in the United States is expected to increase fivefold over the next 3 years, which will require support from an Atlantic salmon breeding program. ARS researchers in Franklin, Maine, bred an improved salmon strain and provided eggs to industry. This new strain with increased growth, enhanced processing characteristics, and improved resistance to sea lice will improve the industry's production efficiency and sustainability.

**Superior ARS trout germplasm now used commercially.** ARS researchers in Aberdeen, Idaho, developed rainbow trout germplasm noted for growth on feeds containing plant protein ingredients. The second largest commercial rainbow trout egg retailer in the United States, Riverence, obtained this germplasm and is now selling eggs from these lines. The company is expressly marketing these eggs for their hardiness and improved growth rates.

**The pathogen *Yersinia ruckeri* can sense its host.** ARS researchers in Leetown, West Virginia, demonstrated that the pathogen *Yersinia ruckeri* shuts off production of its flagellum when it senses its rainbow trout host. Absence of the flagellum during infection is critical for the bacteria to avoid recognition and subsequent destruction by the fish's immune system. These insights will guide development of new vaccines for disease control.

**Sequencing the eastern oyster genome.** In collaboration with the Eastern Oyster Genome Consortium, ARS researchers produced a high-quality, chromosome-level genome assembly for the eastern oyster. The genomic resources developed through these efforts will speed selective breeding strategies that can keep pace with industry priorities and consumer demands.

FOR MORE INFORMATION:https://ars.usda.gov/Improving Pasture and Rangeland Management

# IMPROVING PASTURE AND RANGELAND MANAGEMENT

The ARS pasture and rangeland management research program enhances the utility, function, and performance of rangelands, pastures, forage, and turf agroecosystems while providing ecosystem services. ARS research helps producers improve management decisions and ultimately achieve healthy and productive pastures and rangelands that support rural prosperity, food security, and healthy agroecosystems, as illustrated by the following FY 2019 accomplishments.

**Low-cost precision technology helps with peak rangeland production.** ARS scientists in Reno, Nevada, and Las Cruces, New Mexico, determined that inexpensive, land-based, plant phenology cameras can quantify changes in mixed shrub-grasslands and meadow ecosystems. These plant "phenocams" offer producers a powerful way to improve their ability to decide when grazing time is at its peak, the best time to apply herbicides, and when to reduce vegetative fuel loads that increase the risk of wildfires.

**Online decision support tool provides county-level forecasts of rangeland vegetation.** ARS scientists from Fort Collins, Colorado, the USDA Northern Plains Climate Hub, and collaborators developed the online Grassland Productivity Forecast (Grass-Cast; grasscast.unl.edu) based on recent weather patterns and 30 years of historical forage productivity. Grass-cast originally focused on the Northern Great Plains when it launched in May 2018, and its maps and projections now cover all of New Mexico and Arizona. Between May 2019 and March 2020, more than 1,800 unique visitors accessed Grass-cast nearly 3,000 times, with time spent on the home page averaging 5 minutes and 35 seconds.

**Mineral supplementation increases productivity and profitability of cattle grazing wheat.** Many producers who graze their cattle on wheat do not supplement cattle diets with mineral mixtures even though wheat herbage is calcium deficient. ARS scientists in Woodward, Oklahoma, demonstrated that providing high-calcium and trace mineral mixtures to cattle grazing in a winter-wheat pasture resulted in cattle with a 43 percent faster average daily body weight gain. At the end of the grazing period, supplemented cattle weighed as much as 6 percent more than cattle that did not receive supplements.

**New cool-season grass cultivars for the southern Great Plains.** An ARS researcher in El Reno, Oklahoma, and collaborators developed two improved grasses: 'Artillery' smooth bromegrass and 'Ammo' orchardgrass. These grasses function under hot, dry growing conditions and on lower amounts of fertilizer than existing grasses in North America or Europe. 'Artillery' was registered for sale in Canada, and ARS has applied for Plant Variety Protection for 'Ammo.'

**Building climate-resilient landscapes and communities in the Southwest.** ARS scientists at the USDA Southwest Climate Hub in Las Cruces, New Mexico, completed the launch of two online decision support tools, the AgRisk Viewer (*https://www.climatehubs.usda.gov/hubs/southwest/tools/agrisk-viewer*) and the Climate Smart Restoration Tool (*https://climaterestorationtool.org/csrt/*). These tools will help farmers, ranchers, foresters, and other land managers in the Southwest strategically adapt to the impacts of extreme weather and climate change.

FOR MORE INFORMATION: https://ars.usda.gov/Crop Breeding for Trait Enhancement and Disease Resistance

# CROP BREEDING FOR TRAIT ENHANCEMENT AND DISEASE RESISTANCE

ARS advances multiple crop industries by developing new crop varieties with disease resistance and other trait enhancements and providing new tools and approaches that will support future breeding efforts. In addition to supporting major commodities, ARS breeding programs advance specialty crops, which alone have a U.S. farm gate value of $87.7 billion. The following accomplishments are examples of ARS advances in crop breeding for disease resistance and trait enhancement in FY 2019.

**New tomato flavor gene discovered.** Tomatoes are the most valuable fruit crop in the world, and Americans consume an average of 70 pounds of tomatoes per person annually. ARS researchers in Ithaca, New York, identified a rare version of the TomLoxC gene that contributes to tomato flavor by catalyzing the synthesis of aromatic compounds that consumers prefer. This trait is of great interest to breeders attempting to address consumer demands for more flavorful tomatoes.

**World's first red leaf spinach.** ARS researchers in Salinas, California, developed 'USDA Red', the world's first spinach variety with red color on the surface of the leaves. In field trials conducted between 2015 and 2018, 'USDA Red' on average had 65 percent higher betacyanin content and 53 percent higher antioxidant capacity than red-veined spinach cultivars. The betacyanin adds another punch to a plant already loaded with phytonutrients, making red leaf spinach a true "super food." The red spinach may bring some excitement to the spinach market and attract consumers to the colorful new product.

**A new table grape.** ARS researchers in Parlier, California, have released a new early season, black-skinned seedless table grape named 'Solbrio' that has large, fully-colored berries and crisp and crunchy flesh. Growers are very pleased with the new variety, which is both easy and inexpensive to grow.

**New seedling screening method for *Phomopsis* seed decay in soybean.** ARS researchers in Stoneville, Mississippi, developed a new method to rapidly screen soybean seedlings for resistance to *Phomopsis* fungi. *Phomopsis* causes seed decay and can result in both seed yield and quality losses. Unlike previous methods, this new assay can identify resistance to *Phomopsis* without waiting an entire growing season. Public soybean breeders and laboratories in the United States and in China have adopted this method.

**More efficient method for analyzing genetic data for tree breeding.** DNA analyses of trees at the seedling stage can increase the efficiency and reduce the costs of tree breeding. ARS researchers in Miami, Florida, and collaborators developed a more efficient method of analyzing DNA data for mango and avocado that can distinguish specific cultivars of interest, identify traits to remove from breeding stocks, and optimize breeding efficiency.

FOR MORE INFORMATION: https://ars.usda.gov/Advancing Alfalfa Breeding and Production Research

# ADVANCING ALFALFA BREEDING AND PRODUCTION RESEARCH

ARS prioritizes improved alfalfa production and use for producer success and environmental quality. Alfalfa is the fourth largest U.S. crop commodity, contributing more than $10 billion annually to the U.S. farm economy. Dairy and beef producers feed alfalfa to their cattle for its high protein and energy content. Alfalfa fixes approximately 300 pounds of nitrogen per acre per year, disrupts pest cycles, is a major nectar source for honeybees, and can grow well under dry conditions, making it valuable in crop rotations. The following accomplishments highlight ARS advances in alfalfa research in FY 2019.

**Alternative fungicide for protecting alfalfa seeds.** Almost all alfalfa seed is treated with mefenoxam. However, this fungicide is not active against the pathogen causing *Aphanomyces* root rot, a lethal widespread disease of alfalfa, nor against fungal seed rot pathogens. ARS researchers in St. Paul, Minnesota, developed a commercial fungicide mixture effective against all alfalfa seed rot and damping off pathogens, now providing alfalfa growers with much needed relief.

**Planting alfalfa in corn grown for silage protects soil and water resources.** ARS researchers in Madison, Wisconsin, found that alfalfa planted among corn rows reduced the loss of soil and nutrients from cropland by 40 to 80 percent compared with a conventional system in which alfalfa was planted in the spring, 7 months after corn harvest. Intercropping alfalfa with corn was also effective in reducing the risk of nitrate leaching into groundwater. Consequently, intercropping alfalfa with corn holds promise for improving farm profitability and protecting the environment.

**Alfalfa cyst nematode found in North America identified and characterized.** ARS scientists from Beltsville, Maryland, along with researchers from Idaho, Kansas, and Nebraska, have discovered the first evidence of alfalfa cyst nematode in North America. Plant-parasitic nematodes such as alfalfa cyst nematode cause nearly $10 billion in crop losses annually in the United States. Plant pest management specialists and regulatory officials will now use the evidence of this potentially emerging threat to the alfalfa industry to contain the nematode and prevent inadvertent movement to additional areas.

**Condensed tannins play an important role in alfalfa resistance to root lesion nematode.** Alfalfa usage for grazing beef cattle has been limited due to its propensity to cause pasture bloat, a potentially lethal condition in cattle. ARS researchers in Beltsville, Maryland, have been working for years to produce tannins in the leaves and stems of alfalfa, which can beneficially impact digestion to prevent pasture bloat in ruminants. Recently, these researchers discovered that alfalfa roots produce tannins as a defense mechanism against root lesion nematode infection. ARS researchers can now leverage knowledge of this mechanism to develop alfalfa cultivars with tannin-rich leaves.

**New DNA markers for drought resistance and salt tolerance in alfalfa.** Drought resistance and salt resistance are important for enhancing alfalfa productivity in arid and semiarid regions. An ARS scientist in Prosser, Washington, identified genetic markers associated with these traits and developed eight drought-tolerant and salt-resistant alfalfa lines. ARS has transferred these lines to Alforex Seed Company to breed alfalfa cultivars with increased drought resistance, salt tolerance, and water use efficiency.

# FY 2019 RESEARCH ACCOMPLISHMENTS

## PART II: ENHANCING THE SUSTAINABILITY OF AGRICULTURE THROUGH ENVIRONMENTAL STEWARDSHIP AND HEALTHY PLANTS AND ANIMALS

FOR MORE INFORMATION: https://ars.usda.gov/Increasing the Sustainability of Agricultural Systems

# INCREASING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS

ARS builds the science-based foundations for future farming systems that satisfy human food and fiber needs, sustain the economic viability of agriculture, enhance environmental stewardship, and improve quality of life. Through transdisciplinary research approaches that integrate information and technology, ARS provides producers with several options for increasing the sustainability of their production systems. The following FY 2019 accomplishments highlight ARS advances in farming for carbon capture, improving the sustainability of organic cropping systems, and optimizing water use.

**Intercropping bioenergy crops with trees captures and stores atmospheric carbon in soil.** ARS researchers in Temple, Texas, and collaborators at Washington State University and Texas AgriLife Extension determined that intercropping switchgrass among poplar trees increased soil organic carbon by 16 percent at depths of 0 to 15 cm. These results show that intercropping switchgrass with poplar can give foresters greater economic returns from biofuel production while also promoting ecosystem services such as improved water use, nutrient cycling, and carbon sequestration.

**Innovative method for cover crop termination using engine exhaust heat.** ARS researchers in Auburn, Alabama, prototyped an innovative method to control weeds and terminate cover crops: instead of using herbicides, the team developed a mechanical pusher that uses exhaust heat from a walk-behind tractor's gasoline-based engine. The prototype demonstrated that exhaust heat (otherwise lost to the environment) can be an effective and economical means of terminating cover crops.

**Novel planter developed for small-seeded plants.** Precisely planting small seeds can be difficult with standard planters. Small seeds are often pelleted so they can be planted with precision, but this process is expensive. An ARS researcher in Salinas, California, developed a simple planter, called the Slide Hammer Seeder, for precision hand-seeding of unpelleted, small-seeded species. The planter works well for seeding a variety of small-seeded herbs and vegetables.

**Making decisions easier with Irrigator Pro.** ARS researchers in Dawson, Georgia, and collaborators have developed the Irrigator Pro decision support for corn, cotton, and peanut irrigation scheduling. The tool has proven helpful for peanut growers, with documented increases in peanut yield and grade by 400 pounds per acre. These increases equate to increased net revenue of $60.25 per acre, which then equates to $5.5 million per year increased revenue in Georgia alone. In FY 2019, the team deployed the Irrigator Pro website and an app for smart phones and tablets.

**Toolkit for monitoring daily water use in California Central Valley vineyards.** Persistent and extreme drought has plagued California in the last decade with enormous implications on surface and groundwater resources for agriculture. ARS scientists in Beltsville, Maryland, have led the Grape Remote Sensing Atmospheric profile & Evapotranspiration eXperiment (GRAPEX) project with the goal of, for the first time, gaining accurate estimates of daily water use and stress from field to regional scales for high-valued perennial crops. This will inform more efficient irrigation management in the face of drought.

FOR MORE INFORMATION: https://ars.usda.gov/Protecting Soil and Air Quality

# PROTECTING SOIL AND AIR QUALITY

The ARS soil and air research program protects soil resources essential for U.S. agricultural production, optimizes management of crop nutrients and greenhouse gas emissions from agricultural soils and byproducts, and enhances production management in the face of global climate change. Farms face the challenge of increasing production for a growing population while maintaining profitability, preserving and enhancing natural resources, and instilling public trust. The following FY 2019 highlights demonstrate how ARS helps farmers meet these challenges through research-based practices.

**Innovative manure treatment reduces nutrient pollution and creates commercial products.** Excess phosphorous found in some manure applied as crop fertilizer can contaminate rivers, lakes, and bays through runoff. ARS researchers in Florence, South Carolina, developed a new biorefinery process that recovers value-added phosphorus, proteins, amino acids, and leftover solids from manures. Their innovation lowers treatment costs and extracts nearly all of the phosphorus from the manure, which can be used as a recycled material to replace commercial phosphate fertilizers.

**Perennial living mulch systems increase sustainability of corn production.** Perennial living mulches, such as kura clover, provide the environmental benefits of cover crops without the need to replant each year. ARS scientists in St. Paul, Minnesota, have optimized management systems that incorporate kura clover. They developed a rotary zone tillage system that widens rows to eliminate early-season kura clover and therefore reduces corn competition for resources. The net economic return in the kura-corn system averaged over two seasons was $138 per hectare more than conventional corn production.

**Reducing phosphorus problems by intensive investigation of best management practices.** ARS scientists in Fayetteville and Booneville, Arkansas, and University of Arkansas research partners conducted a 15-year study on 15 watersheds and found that buffer strips and converted pastures to hayfields can effectively reduce phosphorus runoff in southeastern U.S. pastures: unfertilized buffer strips reduced phosphorus runoff 36 percent; fenced, unfertilized riparian buffers reduced phosphorus runoff 60 percent; and converting pastures to hayfields reduced phosphorus runoff 49 percent.

**Inexpensive vegetative buffers around poultry facilities reduce air pollution.** ARS researchers in Iowa, Maryland, South Carolina, and Texas collaborated with university colleagues to document that a vegetative environmental buffer surrounding a poultry house removed 22 percent of ammonia and reduced net downwind ammonia dispersion 51 percent. The Natural Resources Conservation Service is using these results to define the mitigation potential and limitations of the vegetative buffers.

**Adapting anaerobic soil disinfestation (ASD) for commercial production systems.** The loss of methyl bromide for soilborne pest control left few registered soil fumigants, and these fumigants are not effective for the array of pests previously controlled using methyl bromide. ARS researchers in Fort Pierce, Florida, and their cooperators found that ASD succeeded in achieving yields equivalent to or higher than those attained from chemical fumigation, translating to profits for growers.

FOR MORE INFORMATION: https://ars.usda.gov/Protecting Agricultural Watersheds

# PROTECTING AGRICULTURAL WATERSHEDS

ARS promotes stewardship of water resources to support agricultural production while protecting environmental, human, and animal health. Agricultural watersheds cover more than 70 percent of the continental United States. Operating a national network of experimental watersheds and long-term agroecosystem research sites, ARS is uniquely situated to develop integrated watershed management strategies for agriculture across broad regions of the continental United States. The following accomplishments highlight ARS advances in watershed protection research in FY 2019.

**New bank stability assessment technology protects rivers and streams.** Current bank erosion prediction technology does not account for spatial and temporal variability, making it difficult to accurately predict bank erosion. ARS researchers in Oxford, Mississippi, developed a new way of predicting bank erosion by incorporating new parameters into ARS's widely used Bank Stability and Toe Erosion Model (BSTEM). The Sacramento District of the U.S. Army Corps of Engineers is using the new technology to prevent levee failure around the city of Sacramento, California.

**Mulch and gypsum reduce nutrient export into rivers.** ARS researchers in Oxford, Mississippi, found that adding inexpensive organic sources such as hardwood mulch to ditches or other edge-of-field systems can reduce the impact of nitrogen pollution on surrounding waterways. Mulch and mulch-gypsum amendments removed 65 to 69 percent of the load in the system, and including gypsum significantly decreased phosphorus runoff.

**Design and demonstration of the construction of a phosphorus removal structure.** ARS scientists in West Lafayette, Indiana, designed an underground tile drain phosphorus filter on a large swine farm near Holland, Michigan, using 60 tons of slag—the largest tile drain filter ever constructed using tanks. An American Society of Agronomy journalist filmed and documented the process for future use in training modules. Increased adoption of phosphorus removal structures will reduce dissolved phosphorus runoff and protect bodies of water.

**Oilseed cover crops reduce unwanted soil nitrogen loss.** Contamination of water from the leaching and runoff of soil nitrogen and phosphorus from corn-soybean cropping systems is a major concern. Winter annual cover crops can use leftover nitrogen and phosphorus from the previous crop and reduce runoff. ARS researchers from Morris, Minnesota, in collaboration with University of Minnesota scientists, demonstrated that winter camelina and pennycress grown as cover crops can reduce nitrogen losses by 84 percent and 91 percent compared to typical no-till and conventional till systems, respectively.

**Cover crops reduce nitrate leaching.** ARS scientists in Beltsville, Maryland, conducted a meta-analysis of literature to understand how well cover crops reduce nitrate leaching from agroecosystems. Compared to no cover crop controls, cover crops reduced nitrate leaching by 56 percent. Soil type, planting and termination dates, shoot biomass, and climate each influenced the extent to which cover crops reduced nitrate leaching. These findings indicate that cover crops are an effective way to reduce nitrate leaching and should be integrated into existing cropping systems for water quality benefits.

FOR MORE INFORMATION: https://ars.usda.gov/Protecting Animal Health through Disease Detection Prevention and Control

# PROTECTING ANIMAL HEALTH THROUGH DISEASE DETECTION, PREVENTION, AND CONTROL

The ARS animal health research program protects and ensures the safety of the nation's agriculture and food supply through improved disease detection, prevention, and control. These research-based programs discover and develop diagnostics, vaccines, biotherapeutics, disease management systems, and farm biosecurity measures to control animal diseases. The following accomplishments highlight ARS advances in animal health research in FY 2019.

**African swine fever candidate vaccines transferred to industry.** In 2019, ARS scientists in Orient Point, New York, developed the first-ever African swine fever candidate vaccines and transferred them to five pharmaceutical companies. African swine fever infects domestic pigs, causes fever and hemorrhages, is often fatal, and threatens the U.S. swine industry. The virus originated in sub-Saharan Africa, spread across Europe and Asia and, in 2018, reached China. Without a vaccine for African swine fever, disease control is strictly dependent on animal quarantine, biosecurity measures, and slaughter.

**Study reveals pigs can transmit foot-and-mouth disease (FMD) before showing signs of sickness.** ARS scientists in Orient Point, New York, discovered that pigs infected with FMD can infect other pigs just 24 hours after infection, long before showing clinical signs of FMD. This means that outbreaks can be 40 percent greater than previously thought. Failure to account for this new information could make the difference between preparing for a limited, well-controlled U.S. FMD outbreak costing $3 million over 2 months and a catastrophic nationwide epidemic costing $20 billion over 1 year.

**A new United States swine pathogen database (*https://swinepathogendb.org*).** Several deadly viral swine diseases have recently emerged in the United States causing hundreds of millions of dollars in economic damage. ARS scientists in Ames, Iowa, have created a database of viral genetic sequences to accelerate response efforts to these diseases. The database's suite of web-based tools will aid swine pathogen control efforts across the research community.

**Creating the next generation of biodefense researchers.** In 2019, ARS established agreements with Auburn University, University of Connecticut, and University of Minnesota as part of a new NBAF workforce development program. This program will provide a cadre of qualified scientists in immunology/vaccinology, epidemiology, and disease pathogenesis who can compete for NBAF positions when they become available. Seven trainees are currently in place.

**ARS to conduct international African swine fever workshop in 2020.** With the help of the ARS Office of International Research Engagement and Cooperation, ARS applied for and received USDA Foreign Agricultural Service funding to conduct an international African swine fever workshop with China in 2020. The workshop will identify knowledge gaps and tools to control and eradicate African swine fever. ARS scientists have entered into an agreement with collaborators at the U.S.-China Center for Animal Health at Kansas State University to implement this workshop.

FOR MORE INFORMATION: https://ars.usda.gov/Mitigating Impacts of Vector-Borne Diseases

# MITIGATING IMPACTS OF VECTOR-BORNE DISEASES

The ARS veterinary, medical, and urban entomology research program mitigates the health and economic impacts of arthropod vectors and the diseases that they transmit to livestock, humans, and other animals. ARS collaborates across the human, animal, and environmental health communities to achieve sustained health outcomes for both animals and people. Economic losses from arthropod damage exceed $100 billion annually. The following FY 2019 accomplishments illustrate ARS efforts to eliminate arthropod vectors and nullify their impacts.

**New tick-borne disease diagnostic assay.** ARS scientists in Kerrville, Texas, and collaborators at Texas A&M University in College Station developed the TickPath Layerplex to aid in the quick diagnosis of human and animal tick-borne diseases. This innovative assay detects several groups of tick-borne pathogens in a sample, identifies the type of tick-borne pathogen, and guides decisions for rapid and appropriate treatments.

**Easily deployed spatial repellent provides protection from disease vectors.** ARS scientists in Gainesville, Florida, and collaborators developed a way for the U.S. military to rapidly create shelters from biting and disease-vectoring insects. Transluthrin is a spatial repellent that emits vapors to deter insects. By applying transluthrin to strips of camouflage netting attachable to perimeters and structures, the research team successfully reduced the number of mosquitoes, sand flies, and other biting flies within the perimeter without having to wait for intervention by mosquito- and vector-control units.

**Salivary proteins of biting midges associated with virus transmission in livestock.** ARS scientists in Manhattan, Kansas, discovered that when virus-infected midges bite, they transmit the virus and 45 proteins in their saliva that are critical for successful acquisition of a bloodmeal. The salivary proteins also promote rapid infection and systemic dissemination of midge-transmitted viruses via the lymph system, and saliva-induced blood vessel dilation encourages virus replication and dissemination via the circulatory system. These discoveries will guide new methods to impede virus transmission in livestock.

**Improved diagnostic kit in commercial development for all quarantined fire ant species.** ARS scientists in Gainesville, Florida, with APHIS scientists in Biloxi, Mississippi, developed a simple-to-use and portable kit that can identify imported fire ants from all other ants in a single, 10-minute test. Unlike previous tests, this kit is capable of distinguishing black imported fire ants, a quarantined species. The speed of the test curtails extended delays at inspection stations by eliminating the need to send off samples for identification. Agida Inc. has acquired the license for this new technology for commercial development.

**Surveillance of pesticide resistance in southern cattle fever tick.** The southern cattle fever tick threatens the U.S. beef and dairy industries, and intensive pesticide use has driven pesticide-resistant tick populations. ARS scientists in Kerrville, Texas, developed a rapid molecular test to identify DNA variants in southern cattle fever ticks associated with resistance to a class of pesticides commonly used against ticks. This will inform rapid surveillance efforts and tick management strategies.

**Development and validation of CRISPR-Cas9 for gene knockout in screwworms.** The continual release of sterile screwworms is essential to the successful eradication of this economically important pest of livestock and wildlife in Central and South America. ARS scientists in Kerrville, Texas, and collaborators developed and validated methods for using genome editing to alter specific genes in screwworm. Their work holds promise for advancing sterile screwworm release as part of screwworm control efforts.

FOR MORE INFORMATION: https://ars.usda.gov/Protecting Pollinators and Crops from Pests

# PROTECTING POLLINATORS AND CROPS FROM PESTS

ARS promotes sustainable crop production by protecting crops and pollinators from pests that threaten their health and consequently reduce crop yields. More than 4,500 invasive pests damage crops, costing U.S. agriculture an estimated $30 billion annually. In addition, the risks posed to bees by invasive mites, beetles, and disease is equivalent to $15 billion in lost pollination services for fruit, nut (almond), and legume crops. The following FY 2019 accomplishments highlight several ARS advances in pollinator health and pest management research.

**Mite blood-feeding dogma overturned: Varroa mite feeds instead on bee fat body.** Varroa mite is the greatest factor in honey bee mortality. ARS researchers in Beltsville, Maryland, along with University of Maryland cooperators, discovered that varroa mites feed on honey bees' fat bodies, overturning decades of previous literature suggesting that varroa mites feed on honey bee blood (hemolymph). This has important implications for developing mite control strategies.

**Small hive beetle genome sequenced.** The small hive beetle is a worldwide parasite of social bee colonies. ARS scientists in Beltsville, Maryland, sequenced and characterized the beetle genome and characterized the proteins the beetles use to identify each other and honey bee colonies by smell. The study provides new insights into the genomic basis for local adaption and invasiveness in the beetle and a blueprint for control strategies that target this pest without harming their honey bee hosts.

**Protecting sorghum from sugarcane aphid.** Sugarcane aphid is a new invasive pest of sorghum, costing $742.7 million in production losses in 2015 alone. ARS scientists in Stillwater, Oklahoma, developed sugarcane aphid infestation monitoring methods based on multispectral imagery obtained from an aerial platform. This innovative system can delineate spatially variable infestations and differentiate between aphid damage and other crop stress events such as drought. These data can reduce the number of improperly timed or unnecessary insecticide applications. ARS scientists in Stillwater also released two sorghum breeding lines: 'STARS 1801S', which has genetic resistance to both sugarcane aphid and greenbug, and 'STARS 1802S', which has resistance to sugarcane aphid and head smut disease. These new resistant sources are already available to the sorghum community to safeguard their crops from this pest.

**ARS facilitates registration of chemical pesticides for specialty crops.** The Interregional Research Project Number 4 (IR-4 Project) facilitates registrations of conventional pesticides and biopesticides for specialty crops in the United States. In collaboration with the national IR-4 Project and cooperating universities and industries, ARS researchers in eight locations conducted 55 field trials for food crops, 96 field trials for ornamentals, and pesticide residue analysis on 40 sample sets of food crops. In 2018, ARS data supported the registration of four fungicides and one herbicide now available to specialty crop growers.

**New precision sprayer for specialty crops.** ARS scientists in Wooster, Ohio, developed an innovative sprayer to help specialty crop growers apply precise amounts of agrochemicals. Smart Guided Systems LLC in Indianapolis, Indiana, in April 2019 licensed and then commercialized the technology for use on citrus, apple, pear, pecan, and hazelnut crops. The Intelligent Spray Control system reduces spray application by up to 90 percent, depending on the crop type and age of tree. The World Ag Expo listed the system in its 2020 Top 10 New Products.

FOR MORE INFORMATION: https://ars.usda.gov/Combating Citrus Greening Disease

# COMBATING CITRUS GREENING DISEASE

ARS combats citrus greening disease (also known as Huanglongbing, or HLB) through disease detection, prevention, and mitigation research. Citrus greening represents the greatest threat to the $3.35 billion U.S. citrus industry. It is caused by a bacterial pathogen, *Candidatus* Liberibacter asiaticus (CLas), which is spread by the Asian citrus psyllid. Since the psyllid's discovery in Florida in 1998, the industry has lost 60 percent of acreage and closed about 80 percent of juice plants and packinghouses. The disease has spread to Texas, California, Georgia, Arizona, and Louisiana. The following advancements in FY 2019 highlight ARS's ongoing citrus greening response efforts.

**Canine detection of citrus greening in California to mitigate an impending statewide epidemic.** The key to mitigating citrus greening is early detection and rapid response. ARS researchers in Fort Pierce, Florida, have trained 20 dogs to detect citrus greening within 2 to 4 weeks after infection and with 99 percent accuracy. This surpasses the prior molecular-based methods that could detect citrus greening only months after infection and with 30 to 35 percent accuracy. The California Department of Food and Agriculture is now deploying the canines for early response and tree removal efforts.

**New citrus trees for U.S. growers.** ARS researchers in Fort Pierce, Florida, released three citrus greening-tolerant citrus rootstocks that produced sweet orange trees with improved health, fruit yield, and fruit quality over multiple years where citrus greening is endemic. ARS researchers have also released the first scion cultivar with tolerance to citrus greening, 'US SunDragon', for niche fruit and home-owner plantings. Initial tests of juice quality show promise for 'US SunDragon' in orange juice blends.

**New treatment for citrus greening.** Many bacterial pathogens in plants protect themselves with biofilms. ARS scientists in Fort Pierce, Florida, discovered that a novel set of molecules can penetrate the biofilms protecting CLas and subsequently kill the bacterium. This strategy, which also worked in potato against zebra chip disease, is now patented by ARS and represents a new means to protect fruit, nut trees, and vegetables from numerous important plant diseases.

**Improved protocol for detecting citrus greening infections.** Early detection of CLas in citrus trees is critical for disease management. However, detection of CLas in citrus trees is prone to false negatives. ARS scientists in Fort Pierce, Florida, developed a sampling strategy that reduces the probability of false negative diagnoses of CLas and is capable of detecting CLas infections within 24 hours after infection. These results will help APHIS improve official protocols for monitoring CLas in citrus groves.

**A new sensitive method to detect low concentration samples of CLas.** ARS researchers in Parlier, California, along with a scientist in the Central California Tristeza Eradication Agency, developed a new DNA-based test capable of detecting the HLB pathogen at even low concentrations and with increased accuracy. This new test can be used to confirm otherwise questionable results obtained through the standard regulatory industry protocols.

**Citrus greening strains in southern California have different origins.** Citrus greening has been detected in more than 1,400 citrus trees in urban southern California. ARS researchers in Parlier, California, along with scientists from the California Department of Food and Agriculture, APHIS, and South China Agricultural University, discovered that the CLas strains found in California were more closely related to the strains in Asia rather than Florida, indicating multiple introductions of the pathogen. This information is important for formulating citrus greening management strategies.

FOR MORE INFORMATION: https://ars.usda.gov/Managing the Spread of Invasive Weeds

# MANAGING THE SPREAD OF INVASIVE WEEDS

ARS is a global leader in limiting the spread of invasive species, with more than 12 laboratories in the United States and overseas facilitating the discovery and safety testing of new biological control agents. Globally, invasive weeds are the single largest and most damaging group of invasive species, costing an estimated $137 billion per year. On western Federal lands alone, the spread of invasive weeds is estimated at 2,300 acres per day. The following FY 2019 accomplishments illustrate ARS successes in limiting and recovering from the spread of invasive species.

**New biological control agent for Brazilian pepper tree.** Brazilian pepper tree originated in South America and then became one of the most widespread and destructive invasive species in the Florida Everglades. In July 2019, ARS scientists in Fort Lauderdale, Florida, released the first biological control agent for Brazilian pepper tree in the continental United States. It is a leaf-feeding thrips that reduces the growth and reproduction of this noxious weed. Research has shown that thrips fed under greenhouse conditions can reduce Brazilian pepper seedling growth by 80 percent. Since 2005, researchers at the Foundation for the Study of Invasive Species (FuEDEI) have collaborated on the project by conducting exploratory surveys and host range studies of the thrips in South America.

**Reducing an invasive weed in the cattle fever tick quarantine zone.** The giant reed is an invasive weed in the cattle fever tick Permanent Quarantine Zone, where it clogs portions of the Rio Grande River, reduces border visibility, and provides ideal habitat for southern cattle fever ticks. Two biological control agents of the giant reed, the arundo wasp and the arundo scale, were released in 2009 and 2010, respectively. Nine years after the release of the scale, ARS scientists in Kerrville, Texas, documented 55 percent less aboveground biomass of giant reed stands in areas where both the arundo wasp and scale were used as a biocontrol agent compared with areas where the wasp alone was used.

**Kudzu invasion and impact will expand northward with climate change.** Kudzu, an invasive group of vines, currently infests nearly 8 million acres in the United States, much of that in commercially owned forests. Treatment costs often exceed the economic value of the timber harvest. Kudzu is a carrier of Asian soybean rust, a fungus that can damage soybeans. ARS scientists in Beltsville, Maryland, and university partners found that kudzu has a greater potential to migrate northward as temperatures rise, and that it has not yet reached its biological northward limit.

**New transplanting and seeding methods help restore native rangelands.** Degradation of rangelands from wildfires has led to millions of acres of native rangelands being dominated by cheatgrass. This invasive and exotic annual grass has caused significant loss of critical browsing plants, such as antelope bitterbrush, for wildlife and livestock. In a study investigating effective methods of antelope bitterbrush reestablishment after an extensive wildfire, ARS scientists in Reno, Nevada, found that transplanting resulted in an initial establishment of more than 100 new antelope bitterbrush per acre while seeding had initial establishment of more than 15,000 antelope bitterbrush seedlings per acre.

# FY 2019 RESEARCH ACCOMPLISHMENTS

## PART III: DELIVERING SAFE, HEALTHY, AND HIGH-QUALITY PRODUCTS TO CONSUMERS AND PARTNERS IN RESEARCH

FOR MORE INFORMATION: https://ars.usda.gov/Safeguarding the Food Supply

# SAFEGUARDING THE FOOD SUPPLY

The ARS food safety research program ensures a safe food supply that meets foreign and domestic regulatory requirements. Emerging research areas focus on metagenomics, climate change and mycotoxin contamination, food adulteration and fraud, reduction of foodborne pathogens during animal and produce production and food processing, and contamination of ready-to-eat foods. The following accomplishments highlight ARS advances in food safety research in FY 2019.

***E. coli* transmission by cattle pest flies in leafy greens.** Leafy greens are a leading source of the *Escherichia coli* bacteria that cause human foodborne illness. Cattle pest flies can carry this pathogen and may transmit it to leafy greens and other fresh produce. ARS scientists in Clay Center, Nebraska, determined that flies carrying the pathogenic *E. coli* strain can transmit it from a cattle feedlot to leafy greens planted 600 feet away. This work has informed new industry recommendations to increase the setback distance between leafy greens fields and concentrated animal feeding operations.

**Imagery from drones for microbial water quality assessment in irrigation ponds.** ARS scientists from Beltsville, Maryland, proposed and tested a method of using drone-based imagery and artificial intelligence to obtain representative water samples for *E. coli* enumeration across irrigation ponds. Results of this work provide the knowledge base for efficient microbial water quality sampling and indicate a new direction for monitoring microbial water quality, thus improving food safety.

**New metagenomics pipeline for pathogen detection.** ARS scientists in Albany, California, in collaboration with scientists at the Georgia Institute of Technology, developed and validated an approach called imGLAD (in-silico-metagenomics for genome low-abundance detection) to detect human foodborne pathogens in mixed DNA samples extracted from the environment. Metagenomics-based detection of pathogens is much faster than current culture-based methods and can be used for source-tracking foodborne outbreaks.

**Global and regional contributors to mycotoxin contamination of wheat and barley.** Fusarium head blight (FHB) is a destructive disease of cereal crops worldwide that can contaminate grain with toxins, a major food safety concern. ARS scientists in Peoria, Illinois, collaborated with scientists in Brazil and Uruguay to characterize FHB pathogens from their countries. The most common FHB pathogen of wheat and barley in Brazil, Uruguay, and the United States is *Fusarium graminearum*, which can make a form of vomitoxin. A new species, *F.subtropicale*, was found in Brazil that produces a related mycotoxin with greater toxicity for humans and animals. These results will inform mycotoxin control programs.

**Factors affecting pathogen survival in manure-amended soils.** ARS researchers in Beltsville, Maryland, and university collaborators showed that site, year, and season affect survival durations of *E. coli* in manure-amended soils more than weather, manure type, depth of application, or organic vs. conventional management. These results will inform the U.S. Food and Drug Administration's food safety standards for controlling bacterial contamination of fresh produce from soil.

FOR MORE INFORMATION: https://ars.usda.gov/Combating Antimicrobial Resistance

# COMBATING ANTIMICROBIAL RESISTANCE (AMR)

ARS research elucidates the factors associated with antimicrobial resistance (AMR) in agricultural settings and develops tools and alternatives to antibiotics that mitigate AMR for the benefit of human, animal, and ecosystem health. Antimicrobials such as antibiotics will remain an essential tool for treating animal and human diseases, though the growing prevalence of resistant bacteria has garnered global concerns over the prudent use of antibiotics in animals. The following FY 2019 accomplishments highlight ARS advances in optimizing the use of and reducing the need for antibiotics in agriculture.

**Restoring effectiveness of antibiotics.** Tunicamycin is a powerful antibiotic that can be combined with penicillins to restore their effectiveness against otherwise resistant bacterial strains. However, tunicamycin's toxicity in humans and animals has limited its use. ARS scientists in Peoria, Illinois, developed a technology to modify tunicamycin into less harmful derivatives while still retaining the ability to enhance penicillins. This technology holds promise for reducing the use of traditional antibiotics to treat livestock and reinstituting shelved antibiotics that were once rendered ineffective due to AMR.

**Investigating susceptibility of foodborne pathogens to commercial and household biocides.** Biocides are a type of antimicrobial used to reduce bacterial contamination during retail meat processing. In a study of 17 common household and commercial biocides, ARS researchers in Athens, Georgia, identified several biocides that were ineffective against antibiotic-resistant Salmonella isolates. However, they did not find an overall correlation between resistance of Salmonella to the biocides and antibiotics.

**AMR distribution differs among methicillin-resistant Staphylococcus aureus (MRSA) isolates from healthcare and agricultural sources.** ARS researchers in Ames, Iowa, found that swine-associated MRSA isolates harbored resistance to fewer antibiotics than clinical MRSA isolates from humans who had no swine contact. The two sets of samples had little overlap in AMR genes. These results suggest that swine do not play a major role in maintaining a MRSA reservoir for humans.

**Developing tools to combat AMR in a postharvest fungus of apples.** ARS researchers in Beltsville, Maryland, in collaboration with Cornell University, developed a sensitivity assay to identify fungicide-resistant strains of blue mold that can form during apple storage and produce a mycotoxin. Extension professionals now use this assay to monitor fungicide resistance to maintain the efficacy of current postharvest chemicals against this postharvest fungus of apples.

**Low-cost anaerobic digester reduces antibiotics in farm waste.** ARS scientists in Beltsville, Maryland, in collaboration with University of Maryland scientists, demonstrated that an on-farm anaerobic digestion system for reducing antibiotic compounds in farm waste removed 70 percent of the antibiotic monensin, a widely used antibiotic in animal husbandry. Anaerobic digestion systems such as this would reduce point source pollution runoff from farms into important watersheds.

FOR MORE INFORMATION: https://ars.usda.gov/Advancing Human Nutrition Research

# ADVANCING HUMAN NUTRITION RESEARCH

The ARS human nutrition research program enhances the quality of the American diet and improves health through research. Obesity is estimated to cost $190 billion annually, and as its prevalence has increased over recent decades, ARS scientists have researched innovative ways of reversing that trend. Since agriculture primarily produces food for human consumption, integrating human nutrition research into ARS is critical for solving the biggest problems facing producers and consumers. The following accomplishments highlight ARS advances human nutrition research in FY 2019.

**A healthy microbiome in infants predicts better vaccine response.** ARS scientists in Davis, California, found that infants with microbiomes colonized with more beneficial bacteria (*Bifidobacterium infantis*) had better responses to four vaccines (tuberculosis, polio, hepatitis B, and tetanus) given in early infancy. This study is the first to demonstrate that bifidobacteria, which are abundant in the infant gut as a result of breastfeeding, may lead to long-term enhancement of the immune system.

**Evening snacking generally involves less healthy choices.** Almost two-thirds of Americans eat or drink something after 8:00 p.m., which concerns researchers and policymakers because most people generally have consumed enough daily calories by the end of their evening meals. ARS researchers in Beltsville, Maryland, found that one in five adults obtained 30 percent or more of their total daily calories from late-evening consumption of foods and beverages. Those who ate late at night took in about 15 percent more calories than nonsnackers. Behavioral interventions for weight control or healthier diets could focus on this vulnerable time during which fewer calories and healthier choices could be selected.

**Improving USDA food composition databases and launching FoodData Central.** ARS scientists in Beltsville, Maryland, and the National Agricultural Library created and publicly released FoodData Central, which provides access to all USDA food composition information in a single location. These online, publicly available sites provide information on more than 560,000 different foods with more than 8.6 million food nutrient entries. Combined, these data products generated more than 30 million page views via 4 million user sessions.

**Brain activation in children with obesity differs from that in normal-weight children.** Research by ARS-supported scientists in Little Rock, Arkansas, suggests that normal-weight and obese children process high-calorie food stimuli differently, exhibiting different levels of brain activation when presented with images of high-calorie food. Understanding how normal-weight and obese young children process high-calorie food stimuli may provide ways to alter unhealthy eating behaviors.

**Diet, gut bacteria, and chronic diarrhea.** ARS researchers in Davis, California, in collaboration with University of California-Davis scientists, discovered that gut microbes in animals with inflammatory bowel disease consume more of the protective mucin layer produced by intestinal cells compared with microbes in nondiseased animals. These discoveries will enable new strategies to prevent chronic gastrointestinal diseases such as ulcerative colitis in humans.

**Newly created atlas of epigenetic variation in humans.** Most diseases still cannot be predicted on DNA sequences alone, leading researchers to explore the role of epigenetics in disease. ARS-supported scientists in Houston, Texas, performed deep sequencing of genomic DNA and identified regions that vary in DNA methylation (a type of epigenetic marking). These data will inform a basic understanding of disease processes from an epigenetic perspective.

FOR MORE INFORMATION: https://ars.usda.gov/Mitigating Food Loss and Waste

# MITIGATING FOOD LOSS AND WASTE

ARS research reduces food loss and waste and transforms food waste into new marketable products for consumers. The USDA Economic Research Service determined that annually 31 percent of the 430 billion pounds of U.S. food supplies at retail and consumer levels goes uneaten and is otherwise wasted. In 2015, USDA joined with the U.S. Environmental Protection Agency to set a goal for the Nation to cut its food loss and waste by 50 percent by the year 2030. The following FY 2019 accomplishments illustrate ARS efforts to achieve this goal.

**New freezing technology retains fresh-like fruit quality when thawed.** ARS scientists in Albany, California, and colleagues at the University of California-Berkeley discovered that the isochoric method of freezing—first developed to preserve human organs for transplanting—can result in thawed sweet cherries that are indistinguishable from fresh cherries in terms of juice loss, texture, structure, ascorbic acid content, and antioxidant activity. This method uses 70 percent less energy compared with conventional freezing methods and promises to revolutionize the $54 billion U.S. frozen foods market.

**New, automated in-field apple sorting machine.** ARS scientists in East Lansing, Michigan, designed and constructed an automated in-field apple sorting system that separates low-quality from high-quality fruit at harvest, which increases harvesting efficiency and reduces food loss. This system can sort 11 or more apples per second with 100 percent sorting accuracy, superior grading repeatability, and no bruising damage. Schwallier's Country Basket, a commercial orchard, is testing the sorting system.

**New fruit storage clamshell container with superior freshness retention.** ARS scientists in Fort Pierce, Florida, designed a new clamshell container for fresh-fruit storage that maintains optimum humidity and prevents fruit weight loss in storage. The new container maintains firmness of sweet cherries and freshness of litchis, strawberries, blueberries, bayberries, apricots, loquats, and cherry tomatoes.

**New commercial control strategies to combat apple superficial scald.** Superficial scald is an apple peel browning disorder that occurs after postharvest chilling and contributes to fruit quality losses in markets where scald control compounds are restricted. ARS scientists in Wenatchee, Washington, demonstrated that chilling injury is preventable by postharvest hot water treatment or by exposing apples to low oxygen, high carbon dioxide storage atmospheres within 7 days after harvest. These nonchemical control measures reduce losses for apple producers, distributers, and retailers in markets where no consistent superficial scald mitigation strategy previously existed.

**Tough yet flavorful 'Keepsake' strawberry cultivar.** ARS researchers in Beltsville, Maryland, released and patented 'Keepsake', a mid-season strawberry producing fewer rotted or degraded fruits in the field or after refrigerated storage. The fruits are very sweet with outstanding flavor and are firm and tough enough for commercial handling. Nine U.S. and Canadian nurseries now have 'Keepsake' for propagation and licensing for sale. Nursery and grower demand for 'Keepsake' already exceeds supply.

FOR MORE INFORMATION: https://www.nal.usda.gov/main/

# EXPANDING PUBLIC ACCESS TO AGRICULTURAL INFORMATION

ARS maintains effective stewardship of agricultural data, literature, and other information resources through the National Agricultural Library (NAL), the world's largest collection of agricultural information. As the library of the USDA, NAL provides public access to scholarly literature and data funded by the department and digitized access to special collections. The following FY 2019 milestones demonstrate how NAL supports USDA's strategic goal of fact-based, data-driven decision-making.

**PubAg expanding quickly.** NAL makes available USDA-funded peer-reviewed literature through the PubAg platform (*https://pubag.nal.usda.gov/*). During FY 2019, PubAg reached 2.6 million citations to peer-reviewed agriculture-related scientific articles, an increase of more than 500,000 citations from FY 2018. NAL also increased the full-text corpus that is publicly accessible through PubAg by more than 130,000 full-text articles, for a total of more than 210,000 articles. This fulfills USDA and U.S. government mandates for open access to federally-funded research.

**NAL mass digitization continues.** To make the content of the world's largest agricultural library more accessible for scientific and other forms of research, the NAL is digitizing its physical collections not under copyright protection. In FY 2019, NAL digitized and created citation information for 13,110 items (930,432 pages), bringing the total number of digitized items to 160,985 (7,692,074 pages). Until all mass-digitized publications are migrated to NAL web services, public access is available at *https://archive.org/details/usdanationalagriculturallibrary*.

**i5K Workspace.** NAL hosts the i5K Workspace (*https://i5k.nal.usda.gov/*) for the i5K initiative (*http://i5k.github.io/*). The initiative aims to sequence and analyze the genomes of 5,000 arthropod species, and the Workspace is a website for curating, visualizing, and sharing these data. In FY 2019, the Workspace added 3 new organisms, 24 new data sets, and 98,435 new gene pages (or gene features). The number of publications citing the work of the i5K Workspace and thus now promoting it now totals 67 (up from 45 in 2018).

**Ag Data Commons and public access to digital scientific research data.** Ag Data Commons (https://data.nal.usda.gov) provides public access to USDA-funded digital scientific research data. In FY 2019, NAL carried out major upgrades to Ag Data Commons to meet customers' needs for data management and access. Additionally, NAL established USDA's first-ever policy on public access to digital scientific data.

**Life Cycle Assessment quantifies sustainability of beef.** Ag Data Commons also hosts the Life Cycle Assessment (LCA) collection (*https://data.nal.usda.gov/life-cycle-assessment*), a catalog and archive of data, tools, and resources that support LCA for agriculture and related areas of research. This collection hosts the newly completed full LCA of U.S. beef, which provides baseline information for comparing beef production systems and measuring the benefits of future improvements in sustainability. ARS researchers in University Park, Pennsylvania, in collaboration with scientists at the National Cattlemen's Beef Association (NCBA) and BASF Corporation, completed the assessment, which was third-party verified. ARS researchers and NCBA found beef cattle production emitted 3.3 percent of U.S. greenhouse gas emissions, produced 15 percent of reactive nitrogen losses, used 0.7 percent of fossil energy, and consumed 5.8 percent of its fresh water. When these figures are expressed per unit of meat produced, they compare very favorably with global averages. These data provide a baseline for comparison with future assessments and the evaluation of potential benefits of mitigation strategies.

**Additional copies of this Report on Science can be downloaded from** www.ars.usda.gov.

This publication is the Agricultural Research Service's 2019 annual report on science, composed of accomplishments and impacts for each goal in the ARS 2018-2020 Strategic Plan.



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