USDA

United States Department of Agriculture

Agricultural Research Service

2021 ANNUAL REPORT

ARS REPORT ON SCIENCE

CONTENTS

INTRODUCTION

- ARS at a Glance
- Specialized Infrastructure and Capabilities

ARS OVERVIEWS

- Animal Production and Protection Research
- Crop Production and Protection Research
- Natural Resources and Sustainable Agricultural Systems Research
- Nutrition, Food Safety, and Quality Research
- The ARS Office of International Research Engagement and Cooperation
- ARS Office of Technology Transfer
- The National Agricultural Library
- U.S. National Arboretum

TOP 2021 RESEARCH ACCOMPLISHMENTS

Part I – What ARS Does: Improving Crop, Livestock, and Aquaculture Production

- Developing New Crop Varieties with Enhanced Traits and Disease Resistance
- Advancing Sustainable Livestock Production
- Advancing Sustainable Aquaculture Production

Part II – Who ARS Serves: Supporting Consumers, Farmers, Communities, and Research Partners

- Advancing Human Nutrition Research
- Reducing Labor and Advancing Precision Agriculture through Automation
- Improving Rural Economies through New Uses of Agriculturally-based Materials
- Expanding Public Access to Agricultural Information

Part III – How ARS Does It: Prioritizing Animal, Human, Plant, and Environmental Health

- Protecting Animal Health through Disease Detection, Prevention, and Control
- Optimizing Agricultural Management to Mitigate Climate Change Impacts
- Safeguarding the Food Supply
- Protecting Human and Animal Health by Mitigating the Spread of Viruses
- Combating Antimicrobial Resistance
- Combating Citrus Greening Disease
- Protecting Pollinator Health
- Optimizing Agricultural Water Use and Management
- Monitoring and Mitigating the Spread of Plant Disease
- Controlling Insect Pests to Protect Plant, Animal, and Human Health
- Improving Pasture and Rangeland Management

INTRODUCTION

USDA'S AGRICULTURAL RESEARCH SERVICE (ARS) AT A GLANCE

The Agricultural Research Service (ARS) is the U.S. Department of Agriculture's chief scientific in-house research agency. Our job is finding solutions to agricultural problems that affect Americans every day from field to table.

MISSION

Our mission is to develop and deliver state-of-the-art, science-based methods that improve the post-harvest processing, preservation, quality, marketing and consumption of safe and nutritious foods. This effort extends to the development of value-added food and feed. A top priority is ensuring the productivity and end-user quality of specific crops, notably cucumber, peanut, sweetpotato, pepper and cabbage. Towards that end, we conduct research on the latest in fermentation procedures, microbiome analyses, product chemistry and safety, as well as nutritional and performance analyses. Throughout, we strive to ensure our research and outreach efforts are responsive to the high-priority needs of a diverse cadre of stakeholders—from farmers, food and allied industries, to regulatory agencies and consumers.

> **Through the ARS mission, we deliver scientific solutions to national and global agricultural challenges.**

Chavonda Jacobs-Young
ARS Administrator

VISION

To leverage robust, systems-based scientific research and technologies that enhance the production, processing, safety, nutrition, and availability of plant-based foods, reduce waste, promote human health and well-being in support of the United States agriculture

> **Through our scientific programs, ARS envisions global leadership in agricultural discoveries through scientific excellence.**

Steven Kappes
ARS Associate Administrator
of National Programs

CORE VALUES

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

> **Our core 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.**

Simon Liu
ARS Associate Administrator of Research Management and Operations

NATIONAL PROGRAM FOCUS AREAS:

- 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** ARS employees
- **90+** research locations
- **$1.5** billion budget

FY 2021 Outputs

3,967
peer-reviewed journal articles

74
patent applications filed

40
patents issued

51
licenses

46
release notices that yielded **1,024** varieties or germplasm lines

SPECIALIZED INFRASTRUCTURE AND CAPABILITIES

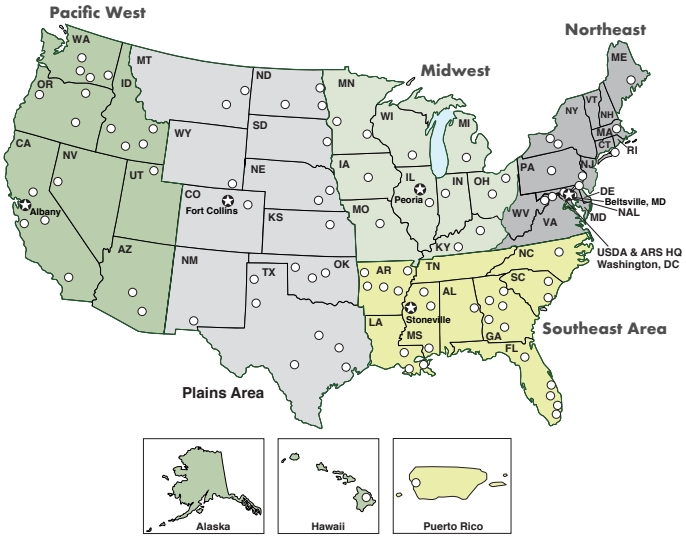
More than 90 research locations, featuring state-of-the-art facilities and resources such as:

- Four Overseas Biological Control Laboratories
- U.S. National Arboretum
- National Agricultural Library
- National Bio and Agro-Defense Facility

Scientific Collections and Genebanks, including:

- ARS National Plant Germplasm System
- ARS Culture Collection
- ARS National Rhizobium Germplasm Resource Collection
- National Animal Germplasm Program
- National Invertebrate Genetic Resources
- USDA Nematode Collection
- U.S. National Arboretum Herbarium
- U.S. National Fungus Collections

ARS Research Locations



Premier Networks of Scientific Expertise, including:

- Long-Term Agroecosystem Research (LTAR) network to develop national strategies for the sustainable intensification of agriculture
- USDA Climate Hubs, for providing region-specific, climate-informed assistance to agricultural and natural resource managers
- Greenhouse gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet), for promoting sustainability by reducing greenhouse gas emissions from soil
- Resilient Economic Agricultural Practices (REAP), for improving soil health and resiliency through improved management practices
- Partnerships for Data Innovation, for developing precision field monitoring systems and managing big data in agriculture
- Breeding Insight, for accelerating small breeding programs through the combination of modern breeding approaches, genomics, and informatics
- Federal LCA Commons, for publishing life cycle assessment models and developing federal standards in life cycle assessment modeling
- Ag100Pest, for sequencing the genomes of 100 significant agricultural pests, part of the Earth Biogenome Initiative

ARS NATIONAL PROGRAMS OVERVIEW

For more information, please visit https://go.usa.gov/xS92C

ARS ANIMAL PRODUCTION AND PROTECTION RESEARCH

The ARS Animal Production and Protection (APP) National Programs improve the livestock production efficiency and the health and well-being of livestock, poultry, and aquatic food animals to ensure a safe and wholesome food supply. These research programs provide the scientific information and tools to support U.S. food animal industries as they supply the nutritious animal products required by the nation, compete successfully in worldwide trade, and contribute toward global food security. APP programs also address a wide range of problems facing animal health, including zoonotic diseases caused by bacteria, viruses, parasites, and prions and arthropod pests and vectors. Our research produces solutions to protect the health and well-being of U.S. agriculture and the American public.

To achieve these goals, ARS conducts research that:

- Improves food animal production efficiency, industry sustainability, animal welfare, and product quality, while safeguarding animal genetic resources;
- Protects and ensures the safety of the U.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
- Mitigates arthropod vectors and the diseases they transmit to livestock, humans, and other animals, and reduces their economic impact.

Looking ahead, ARS prioritizes the development of precision agricultural management decision tools that will track and manage environmental stress, reproduction, disease, and behavior. ARS also works to improve using genomic and transcriptomic data to optimize gene expression in different tissues at different animal developmental stages and produce the best animal products for each production environment. APP promotes the responsible conduct of agricultural science at ARS, including the humane and conscientious use of live animals, through training opportunities by the biosafety and animal welfare staff and by developing effective policies and research monitoring programs.

ARS is co-leading efforts with the U.S. Department of Homeland Security to establish 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-3Ag and BSL-4) in the United States that will enable the safe investigation of especially dangerous and deadly pathogens, including emerging and high-consequence zoonotic diseases affecting livestock. NBAF will enhance current research programs and expertise in foot-and-mouth disease, African swine fever, classical swine fever, Japanese encephalitis, and Rift Valley fever. The new facility will also allow ARS to initiate new research and develop expertise in zoonotic disease agents, conduct real-time research in response to disease outbreak, and enhance our preparedness posture by conducting research gap analyses and prioritizing research to maximize the impact of our research programs. NBAF construction activities are nearly complete; facility commissioning is scheduled to take place in 2022, and the facility will be fully operational in 2024.

Jeff Silverstein
ARS Animal Production and Protection

For more information, please visit https://go.usa.gov/xS925

ARS CROP PRODUCTION AND PROTECTION RESEARCH

The ARS Crop Production and Protection (CPP) National Programs deliver science-based information, genetic resources, superior varieties, high-value crop traits, and technologies for increased crop productivity, economically and environmentally sustainable methods of crop and grassland production, and crop and natural area protection from diseases and pests. Research conducted under CPP programs supports the needs of producers, land managers, consumers, workers, the public, and the global community by increasing crop productivity and value; ensuring a ready supply of high quality, safe and affordable fiber, feed, ornamentals, industrial feedstocks, and nutritious food and beverages; improving the safety of working environments; advancing environmental protection; and meeting the needs 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 supply of high quality and safe food, fiber, feed, ornamental, and industrial crops for the United States;
- Improves and expands our knowledge of existing and emerging plant diseases and develops effective and sustainable disease management strategies that are safe for humans and the environment;
- Uses fundamental biological and ecological principles to develop innovative approaches for managing insect pest populations below economically damaging thresholds;
- Develops new control strategies for intractable weeds in cropping systems and invasive plants in natural areas that improve livelihoods and sustain biodiversity; and
- Develops crop production systems that focus on crop diversification options for producers and promote the health of beneficial insects that provide ecosystem services.

ARS is a steward for important national agricultural resources that protect U.S. agriculture. These resources include the National Plant Germplasm System (distributed across 20 locations), Overseas Biological Control Laboratories (four locations), the U.S. National Arboretum in Washington, D.C., and cutting-edge high-throughput phenotyping and sensing technologies housed at the U.S. Arid Land Agricultural Research Center. ARS also delivers important targeted programs, including the Areawide Pest Management Program, National Sclerotinia Initiative, National Plant Disease Recovery System, Pulse Crop Health Initiative, and the AgBioData consortium.

ARS is accelerating our understanding of crop and pest genomes by spearheading the following initiatives:

- Breeding Insight, which provides breeders with direct access and support to customized tools, informatics, and database technologies to adopt modern genomics strategies to their programs.
- 15k and Ag100Pest, which seeks to sequence the genomes of 5,000 insects and mites, including the top 100 agricultural pests in the United States.

Additionally, ARS fosters research synergies that cut across the continuum of scientific disciplines to achieve breakthrough innovations. CPP leads many such projects.

Deepak Bhatnagar
ARS Crop Production And Protection Research

For more information, please visit https://go.usa.gov/xS92E

ARS NATURAL RESOURCES AND SUSTAINABLE AGRICULTURAL SYSTEMS RESEARCH

The ARS Natural Resources and Sustainable Agricultural Systems (NRSAS) National Programs develop technologies and strategies that help farmers, ranchers, and other managers effectively steward the diverse agricultural mosaic that depends on national land, air, and water resources. These diverse landscapes include rangelands and managed pastures for grazing livestock and crop fields—from the most common commodity crops to the most unique and high-value specialty crops—cultivated in every corner of the country. These agricultural systems generate more than $200 billion in goods and services that are the basis of a strong rural economy; together, they produce the food, feed, fiber, renewable fuels, and ecosystem services that are critical to sustaining a growing U.S. and global population. ARS research aggressively seeks to provide the tools, techniques, technologies, and information to ensure the long-term viability, productivity, resilience, and sustainability of these production systems.

The NRSAS research programs investigate and develop tools and methods for:

- Effectively and safely managing watersheds and 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 increase their resilience 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. Growing out of the LTAR network, the Partnerships for Data Innovations (PDI) is transforming network data stewardship and has created a "Digital Research Workbench" as the foundation for facilitating data innovation, standardization, automation, and integration, which will accelerate agricultural research. PDI delivers field and researcher focused data management solutions that catalyze research collaborations, fulfill Agency and Departmental data priorities, inform Big Data analytics, and ensure compliance with federal data access policies. 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 Hubs confirmed that the Hubs' work and outputs are highly valued and highlighted their strengths in convening, leveraging funds, and expanding climate adaptation practices. ARS is also home for the Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), and the Resilient Economic Agricultural Practices (REAP) program.

Marlen Eve
ARS Natural Resources & Sustainable Agricultural Systems

For more information, please visit https://go.usa.gov/xS92y

ARS NUTRITION, FOOD SAFETY, AND QUALITY RESEARCH

The ARS Nutrition, Food Safety and Quality National Programs maintain a healthy and safe food supply while improving the economic viability and competitiveness of U.S. 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 human life cycle for all Americans;
- Protects food from microbiological pathogens, biological toxins, and chemical-based contaminants during production, processing, and preparation; and
- Improves postharvest agricultural product quality, develops new uses for plant and animal foods and fiber, and enhances the bioeconomy through bioprocessing technologies.

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 six internationally-recognized Human Nutrition Research Centers, as well as smaller research units in four other locations. The centers and locations have core capability for long-term, multidisciplinary, and translational research in high priority areas and premier scientists, state-of-the-science equipment, and facilities for human research across the life cycle. This program leverages unique national resources, including three centers that focus on specific portions of the life cycle. Other centers have programs that maintain the National Nutrient Database of food nutritional composition, track U.S food consumption patterns through What We Eat In America, determine the impact of agriculture on human nutrition, provide data to inform the development of dietary guidance and national nutrition policy and help reduce the burden of chronic disease.

The ARS Food Safety program plays a critical role in keeping the food safety supply safe and secure by developing tests and interventions to control or eliminate potentially harmful contaminants—both naturally occurring or deliberately introduced—in agricultural products. The program involves both national and international collaborations and delivers research results and advances to regulatory agencies, commodity organizations, industry, academia, and research and extension agencies and consumers.

The ARS Product Quality and New Uses program focuses on developing knowledge and enabling commercially viable technologies to measure, maintain, and enhance postharvest product quality; harvest and process cotton, wool, and leather; and create new value-added food and non-food products. This research also focuses on innovative bioprocessing using renewable non-food, low-value plant and animal resources that meets consumer demand for sustainable high-value consumer products and clean energy that increase producer profits.

Pam Starke-Reed
ARS Nutrition, Food Safety and Quality

For more information, please visit https://go.usa.gov/xS92p

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 domestic research alone. 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 to those who will benefit from them.

OIREC is the main contact for international activities in ARS. Working with the ARS Office of National Programs, OIREC regional international affairs specialists catalyze strategic international partnerships that can enhance the productivity, effectiveness, and impact of ARS National Programs, as well as 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 ARS' national programs for addressing critical needs of U.S. agriculture.
- Network with other U.S. government agencies and the international community to promote ARS interests.
- Manage the ARS Overseas Biological Control Laboratories, which identify and collect natural enemies of invasive species in the United States.

The four strategically-located ARS Overseas Biological Control Laboratories enable ARS to study and partner with countries that are the sites of origin for invasive species; these studies advance future U.S. mitigation efforts:

- The European Biological Control Laboratory (EBCL) is in Montpellier, France, and has a satellite laboratory in Thessaloniki, Greece. ARS owns and operates the EBCL.
- The Australian Biological Control Laboratory is in Brisbane, Australia, and is run through a cooperative agreement with Australia's federal research body, the Commonwealth Scientific and Industrial Research Organization.
- The Foundation for the Study of Invasive Species is in Hurlingham, Argentina, and is operated as a nonprofit research organization partnering with ARS.
- The Sino-American Biocontrol Laboratory is in Beijing, China, and is run through a cooperative agreement with the Chinese Academy of Agricultural Sciences.

Bryan Norrington
ARS Office of International Research Engagement and Cooperation

For more information, please visit https://go.usa.gov/xS927

ARS OFFICE OF TECHNOLOGY TRANSFER

The ARS Office of Technology Transfer (OTT) 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 non-commercial research purposes.

To facilitate technology transfer at ARS, OTT:

- 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.
- Leads and engages with the Agricultural Technology Innovation Partnership (ATIP) Foundation.
- 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.
- Promotes an entrepreneurial culture by piloting the National Science Foundation's Innovation Corps at ARS.
- Recognizes and incentivizes participation in technology transfer activities.
- Stays current on federal policies and best practices in technology transfer.
- Encourages the implementation of innovative methods for conducting technology transfer.

ARS has also been delegated authority by USDA to coordinate the technology transfer program for all USDA agencies. As part of this departmental coordination, ARS publishes an annual report on technology transfer that reports on the technology transfer of all USDA agencies, including ARS.

Brian Nakanishi
ARS Office of Technology Transfer

For more information, please visit https://go.usa.gov/xS92H

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 eight 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, USDA's online catalog and index to the agricultural literature;
- PubAg and Ag Data Commons, USDA's "one-stop-shop" for public access to USDA-funded scholarly literature and scientific research data;
- NAL Digital Collections, including digitized content from NAL's Special Collections; and
- DigiTop, the online resource for USDA staff that provides continuing 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 partners and internal and external stakeholders, 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 customer expectations and needs.
- Works efficiently and effectively, with integrity and customer focus.
- 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 Department's mission.

NAL is a leader in scientific data management and planning, benefiting researchers everywhere. Today's research studies in agriculture are data-intensive—and publishing that data fosters trust and drives innovation in agricultural research.

Paul Wester
National Agricultural Library

For more information, please visit https://go.usa.gov/xS92z

U.S. NATIONAL ARBORETUM

The U.S. National Arboretum (USNA) enhances the economic, environmental, and aesthetic value of ornamental and landscape plants through long-term multidisciplinary research, conservation of genetic resources, and interpretative gardens and exhibits. Established in 1927 by an act of Congress and administered by ARS, this premier scientific institution inspires discovery, understanding, conservation, and the love of plants. Through its programs and exhibits, USNA demonstrates the practical application of plant science and human dependence on plants.

The U.S. National Arboretum (USNA) enhances the economic, environmental, and aesthetic value of ornamental and landscape plants through long-term multidisciplinary research, conservation of genetic resources, and interpretative gardens and exhibits. Established in 1927 by an act of Congress and administered by ARS, this premier scientific institution inspires discovery, understanding, conservation, and the love of plants. Through its programs and exhibits, USNA demonstrates the practical application of plant science and human dependence on plants.

The USNA is ARS's flagship location for ornamental plants research, which includes:

- Wide-ranging developmental and applied research on trees, shrubs, turf, and floral plants.
- Collection, preservation, and distribution of ornamental crops as a National Plant Germplasm System genebank.
- Operating the official USDA herbarium, unique in its taxonomic focus on ornamental, economic, and agricultural crops and their wild relatives.
- Developing superior landscape plants through a program of genetic improvement, evaluation, and selection.
- Plant pathogen discovery and developing control technologies for those pathogens, particularly for viruses and bacteria threatening the floral and nursery crops industry.

Additionally, USNA boasts the National Bonsai & Penjing Museum, the most comprehensive collection of specimens and collections in the United States dedicated to the science and art of bonsai. The museum began with a gift from Japan to the United States in 1976. Both the museum and arboretum are routinely ranked as top destinations in Washington, D.C., where visiting public are exposed to the depth and breadth of ARS research through displays, gardens, and exhibits.

Richard Olsen
National Arboretum

TOP 2021 RESEARCH ACCOMPLISHMENTS

PART 1. WHAT ARS DOES: IMPROVING CROP, LIVESTOCK, AND AQUACULTURE PRODUCTION

DEVELOPING NEW CROP VARIETIES WITH ENHANCED TRAITS AND DISEASE RESISTANCE

ARS scientists are developing new crop varieties, including specialty crops (e.g., vegetables, fruits, and nuts), by exploiting the underutilized genetic diversity contained in ARS crop genebanks, In FY 2021 plant releases included two improved carrot lines, two Pinto dry bean varieties ('USDA Diamondback' and 'USDA Basin'), two pea varieties ('USDA Dint Winter' and 'USDA Mica Winter'), the 'Rainier Russet' potato variety, two peach cultivars ('May Joy' and 'Flavor Joy') and varieties of many other crops. The following accomplishments are examples of ARS advances in crop breeding for resistance to diseases and pests, tolerance to environmental stresses, superior yield, and trait enhancement in 2021.

New grass and wildrye cultivars improve rangeland use and restoration. On western rangelands, native grasses are planted for livestock grazing, rangeland revegetation, wildlife habitat, and soil conservation. For many of these grasses, seed shattering makes it difficult for suppliers to harvest seed that is needed for these uses. Furthermore, many ranchers are using less productive private lands for pasture as an alternative to grazing public lands. These marginal areas are often dry, salty, low in soil nutrients, and receive little irrigation, all of which makes plant establishment and growth difficult. ARS researchers in Logan, Utah, developed 'HighWest', a new meadow bromegrass with improved seedling establishment, protein and energy, and forage growth. HighWest total forage production was 23 percent greater than other cultivars and had up to 6 percent more protein and 22 percent more energy; regrowth also doubled after cutting. All these improvements make it an excellent grass for grazing on marginal lands. ARS researchers also developed 'L-74X', a new basin wildrye that had up to 167 percent more harvestable seed and 20 percent improved seed germination. This new basin wildrye is now being used as a parent by plant breeders to develop commercial varieties of basin wildrye. These developments are providing critical tools needed for rangeland revegetation, conservation, and cattle production.

> **ARS crop research makes small farming operations more competitive by developing new speciality crop varieties and germplasm for specific local growing conditions, establishing new methods to manage pests, and improving tolerance to extreme weather variations.**

'Yorizane', a new self-fertile almond cultivar. Eighty percent of the world's almonds are grown in California, and the majority of the 1.5 million acres are planted with cultivars that require bees to transfer pollen between different trees to produce nuts. Self-fertile varieties require fewer pollinators in the orchard because the pollen moves only a short distance within the flower or within the tree to produce nuts. The California almond industry wants new self-fertile cultivars to reduce the need for honeybees and pollinators. ARS researchers in Parlier, California, developed the new self-fertile 'Yorizane' cultivar, which yielded well in regional trials throughout the San Joaquin Valley for five commercial harvests. Yorizane nuts have been rated highly by the almond industry in marketing potential and kernel appearance and it has great potential for adoption by almond growers.

Modifying plant traits without modifying plant genes. Insect-vectored plant disease can be extremely difficult to control, especially in long-lived trees, because a single piercing-sucking insect can inject a dose of a disease pathogen. ARS researchers in Fort Pierce, Florida, in collaboration with ARS researchers

To download this two-pager, please visit https://go.usa.gov/xS9x6

in Ithaca, New York, and a small agribusiness in Florida, developed a novel Agrobacterium-based method of creating a host plant cell that can produce its own growth regulating molecules and can be grown as symbionts attached to crop plants. This method was first demonstrated in tomato and sunflower plants and results showed that symbionts engineered to produce Bacillus thuringiensis (Bt) toxins killed 100 percent of caterpillar larvae after 3 days of feeding on an artificial diet supplemented with engineered symbiont tissue. Insects with chewing mouthparts, such as caterpillars, were specifically chosen to prove that the symbiont produces a lethal amount of Bt toxin. The next steps of the study will be to test the engineered symbiont tissue on piercing-sucking insects, such as the Asian citrus psyllid, which is a vector of citrus greening disease. Implementing this pest-insect control strategy will enable a rapid response to emerging pest-insect threats and will more easily deliver therapeutic technologies to diverse germplasms. Researchers are also planning to test if engineered symbiont tissues can be used as a biofactory of harvestable biological insecticide molecules or therapeutics that could potentially create new cropping systems. Results of this study will show that symbiont technology has the potential to bring transformational advancements to plant disease management and the mass production of biomolecules.

Model predicts threat of zebra chip potato disease. In the U.S. Pacific Northwest, where most of the U.S. potato crop is grown, zebra chip has become a widespread and economically devastating potato disease. The zebra chip pathogen is a bacterium that is spread by the potato psyllid and proper pathogenic control can be accomplished only by controlling the insect vector. U.S. potato farmers have had difficulty controlling zebra chip because they lack the tools to estimate potato psyllids populations, which can fluctuate greatly from year to year. ARS scientists in Wapato, Washington, and Washington State University collaborators determined that the weed matrimony vine is an important host plant for potato psyllids in early spring. Matrimony vine was not found to be susceptible to the zebra chip pathogen, and is therefore not the source of infected psyllids, but ARS scientists found that psyllid numbers on matrimony vines in the spring can be used as an indicator of psyllid populations in potatoes in late August. This novel forecasting method for psyllid populations will allow growers to take action to protect their crops and associated revenues in years when psyllid outbreaks are expected.

Strough, Kirsten. A field of red beets grow on Rick and Robyn Purdum's farm. Fruitland, Idaho. 2012. USDA Photo.
https://flic.kr/p/2kLgkSS

ADVANCING SUSTAINABLE LIVESTOCK PRODUCTION

The ARS food animal production research program improves food animal production efficiency, sustainability, animal welfare, and product quality while safeguarding animal genetic resources. ARS scientists are using genomic technologies to enhance selection and develop livestock that have resistance to diseases and parasites and are better suited to different environments. Raising livestock is an effective way to use the resources of many rangeland areas that are not suitable for other purposes such as raising crops or other agricultural activities. The following accomplishments highlight ARS advances in animal production research in 2021

Rapid eye temperature measurement to evaluate animal health. Rapid temperature measurement using forehead thermometers has become normal practice for humans, but current practices in cattle rely on obtaining rectal temperatures, which is time-consuming. ARS scientists in Lubbock, Texas, and university collaborators studied infrared ocular thermography, measuring the temperature of the eye, to detect fever in cattle. Results indicate that infrared ocular thermography can detect fever in cattle in less than 30 seconds and that eye temperature is highly correlated with rectal temperature. Adopting this rapid method for detecting fever in cattle allows high-throughput measurement in production facilities that will improve cattle management and sickness identification practices, improve cattle well-being and productivity, and reduce production costs.

> **The ARS U.S. Sheep Experiment Station (USSES) in Dubois, Idaho, is studying sustainable sheep production that maintains ecosystem services in western rangeland regions.**

A swine-origin H3N2 influenza virus closely related to human H3N2v demonstrated transmission from swine to ferrets. The transmission of influenza A viruses (IAV) from swine to humans occurs sporadically and is often associated with U.S. agricultural fairs. IAVs from swine that are detected in humans are called "variant" to differentiate from human seasonal IAV. During the 2016-2017 influenza season, 61 H3N2 variant (H3N2v) cases were reported. ARS scientists in Ames, Iowa, compared the genomes of human H3N2v viruses and swine H3N2 viruses collected at the same 2017 state fair in Ohio, where ferrets were also directly infected with the H3N2 virus. In the study, pigs were infected with the virus and placed in an enclosure close to caged ferrets, which were chosen to test the spread of H3N2 because IAV transmission and infection in ferrets serves as model for human IAV transmission and infection. Results demonstrated that the swine H3N2 replicated in both pigs and ferrets exposed to the respiratory aerosols of infected pigs, showing potential transmission from pigs to susceptible ferrets. These results are the first to show a transmission model from swine to ferrets without modification to the virus and highlight the need to reduce swine IAV at animal exhibits. This study also demonstrates the importance of continued surveillance, research, and collaboration on swine and human IAV.

House flies can harbor SARS-CoV-2 but do not transmit infectious virus. The SARS-CoV-2 virus, responsible for the COVID-19 pandemic, is highly contagious and typically transmitted via respiration, but the possibility of transmission following contact with contaminated items cannot be dismissed. ARS scientists in Manhattan, Kansas, and Kansas State University collaborators explored if house flies could acquire and transmit the SARS-CoV-2 virus. Flies were exposed to SARS-CoV-2-spiked culture media or SARS-CoV-2-spiked milk substrates and then tested for the virus at either 4 or 24 hours after exposure. All flies exposed to inoculated media or milk carried viral RNA at 4 hours and 24 hours post-exposure,

To download this two-pager, please visit https://go.usa.gov/xS9xM

but infectious virus detection occurred only in the virus-spiked milk group. In a second experiment, flies exposed to SARS-CoV-2 for 24 hours were transferred to a clean container, and no infectious virus was detected. Results showed house flies can carry SARS-CoV-2 for up to 24 hours post-exposure, but do not transmit the virus due to quick clearing of the infectious virus in laboratory settings. While house flies likely do not play an important role in SARS-CoV-2 transmission, field-trapped house flies could potentially be used for virus surveillance.

ARS leads research to improve agricultural nutrient management and environmental quality. Nitrogen is an essential nutrient for crop production in modern agricultural systems. However, nitrogen losses to the atmosphere as nitrous oxide (N2O) and ammonia (NH3) can impair air quality and contribute to climate change. ARS researchers in Kimberly, Idaho, generated a comprehensive dataset of ammonia emissions from dairy facilities to identify the magnitude and origin of emissions and potential mitigation strategies. These data were used to improve farm emission estimates from the Dairy CropSys and Integrated Farm System models; are being included in a tool developed by the Global Research Alliance database, the DATAMAN; and are being provided to the U.S. EPA to improve ammonia emission estimation methodologies during manure storage. In related research, ARS scientists in Auburn, Alabama, used satellite-based modeling to assess how national changes in NH3 and N2O emissions over 14 years are linked to nitrogen fertilizer application, livestock manure production, and climate factors. Atmospheric NH3 concentrations were positively correlated with surface temperature in five U.S. regions, with the highest found in the Mid-South. Estimates also suggest global cropland N2O emissions increased by 180 percent during 1961-2014, with nitrogen fertilizer responsible for ~70 percent of total emissions during 2000-2014. This monitoring and modelling research is being provided to programmatic and policy agencies to help develop mitigation strategies and improve environmental outcomes related to nitrogen fertilizer practices.

To build soil health, cattle graze cover crops on land not currently in vegetable production at Square Peg Farm, which is a certified organic produce farm located near Forest Grove, Oregon. 2014. USDA Photo. https://flic.kr/p/2nfx52B

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. The following accomplishments in 2021 highlight ARS advances in trout yield, disease prevention, diets, and breeding.

Improved fillet yield and body weight in rainbow trout. The proportion of edible meat (fillet yield) on a carcass is of major economic importance and breeding animals with superior fillet yield can improve production efficiency and profitability. Animals must be slaughtered to measure fillet yield directly, so it cannot be measured in breeding animals. However, developing genetic gains for fillet yield is possible using information, including genome information, from siblings of fish that are potential breeders. ARS researchers in Leetown, West Virginia, compared the accuracy of genetic merit predictions for fillet yield between the family-based selective breeding—which used information about family relationships—and genomic selection, which used information about family relationships and genomic information. The genomic selection model increased the accuracy of genetic merit predictions for fillet yield by 50 percent, indicating that the use of genomic selection can enhance genetic improvement for the fillet yield trait and further enhance the efficiency and sustainability of rainbow trout aquaculture.

> **ARS scientists in Auburn, Alabama, are collaborating with faculty at Auburn University to determine the precise mechanisms governing acute die-offs, and the sublethal pathophysiological effects of harmful algal blooms and their toxins on the catfish or shrimp host.**

Sticky fish eggs thwarted by milk. Hybrid striped bass eggs become extremely sticky after they are fertilized. In a hatchery, this results in the eggs clumping together, which limits availability of oxygen and enables fungal infestations. Both problems can destroy an entire batch of eggs. Fish farmers typically use tannic acid treatments to prevent egg adhesion, but it is costly and, if left too long, will form a hard layer on the surface, which can prevent embryos from hatching. ARS researchers in Stuttgart, Arkansas, investigated 12 candidate compounds to prevent stickiness and found that 10 percent whole milk treatment was the most effective strategy. As a result, the largest commercial hybrid striped bass hatchery immediately began using milk for their 2020 production; in 2021, the hatchery exclusively used the milk to prevent clumping and successfully produced 80.9 million larvae using methods developed by ARS.

Algae oil in fish diets is a viable alternative to fish oil. Competition for the limited supplies of long-chain, omega 3 fatty acids (“fish oil”) used in the production of farmed fish feeds has created the need to identify alternative sources of long-chain, omega 3 lipids. Vegetable oils have proven to be insufficient in providing the nutritional requirements for normal growth and well-being of marine finfish and do not provide the heart healthy nutrients valued by U.S. seafood consumers. ARS-funded researchers in Fort Pierce, Florida, and their collaborators demonstrated that oils from algae can produce the same long chain omega 3 fatty acids found in fish oils. These findings provide an alternative lipid source that will increase the capacity for raising high-quality marine finfish aquaculture products and meeting the nutritional needs of U.S. seafood consumers.

To download this two-pager, please visit https://go.usa.gov/xS9xt

Breeding Nile tilapia for disease resistance does not affect harvest weight. Fish growth is economically important for farmers, so the relationship between growth and other traits that affect performance is paramount. ARS scientists in Auburn, Alabama, and industry stakeholders demonstrated that resistance to Streptococcus (S.) iniae and S. agalactiae is heritable and used these findings to developed improved lines of tilapia with increased resistance to these diseases. They examined data from eight generations of selective tilapia breeding, including data on survival following *S. iniae/S. agalactiae* infection, and did not find any significant associations between harvest weight and survival. These findings suggest that selectively breeding for disease resistance will not reduce tilapia harvest weight, and support using multi-trait selection as a potential strategy to balance growth and disease resistance.

Keres, Preston. Auburn University School of Fisheries Associate Professor Dr. William "Bill" Walton rises the floating cages filled with their oyster research at the Shellfish Lab in Dauphin Island, Alabama.2018. USDA Photo. https://flic.kr/p/MMudpF

TOP 2021 RESEARCH ACCOMPLISHMENTS

PART 2. WHO ARS SERVES: SUPPORTING CONSUMERS, FARMERS, COMMUNITIES, AND RESEARCH PARTNERS

ADVANCING HUMAN NUTRITION RESEARCH

The ARS Human Nutrition research program enhances the quality of the U.S. diet and improves health through research. Principal components of the Human Nutrition research program include linking agricultural practices and beneficial health outcomes; monitoring food composition and nutrient intake; ensuring the scientific basis for dietary guidance; prevention of obesity and obesity-related diseases; and life-stage nutrition and metabolism (understanding how nutrition promotes health from conception to old age). This research is conducted by 165 scientists who are either employed directly by ARS or by universities. The following accomplishments highlight ARS advances human nutrition research in 2021.

Lean beef in a Mediterranean diet pattern reduces heart disease risk. Eating red meat has a reputation for being bad for the heart, but when consumed as part of a healthy diet, it might reduce heart disease risk factors such as bad cholesterol. ARS researchers in Beltsville, Maryland, and Pennsylvania State University colleagues conducted a dietary intervention study to determine how much lean beef can be included in a Mediterranean diet pattern to promote heart health. Volunteers daily consumed either 0.5, 2.5, or 5.5 ounces of lean beef as part of a healthy Mediterranean diet pattern or 2.5 ounces as part of a typical American diet. The researchers determined that a Mediterranean diet pattern that included lean beef consumption at all three levels reduced bad cholesterol and other risk factors for heart disease. While the traditional Mediterranean diet is low in lean beef, this study demonstrates how people can incorporate lean beef into a healthy diet and benefit further from beef's other key nutrients.

> **The ARS program in human nutrition focuses on food-based strategies to ensure the nutritional health of all Americans. Research is primarily carried out at six Human Nutrition Research Centers that conduct carefully controlled human studies and support animal/biochemical studies.**

Adolescents with prediabetes or type 2 diabetes have impaired metabolic flexibility. Metabolic flexibility refers to the ability to utilize different nutrients (fats and sugars) and to transition between them while fasting and after a meal. Impaired metabolic flexibility can lead to metabolic disease, but it is not clear whether metabolic flexibility is impaired in obese youth. ARS-funded researchers in Houston, Texas, found that adolescents with prediabetes and type 2 diabetes have a defect in metabolic flexibility and are not able to change fuel use as easily as normal weight individuals or obese individuals who maintain normal sugar levels. The impairment results from severe insulin resistance that in turn impairs the appropriate use of available fuels. These results highlight the need for additional studies to investigate how changes in diet or physical activity could improve how the body utilizes these nutrients and help mitigate the risk of type 2 diabetes.

Carbohydrates and fat intake influence the risk of metabolic diseases. It is not clear how the cellular process methylation controls genes associated with the risk of metabolic diseases such as obesity, type 2 diabetes, high blood pressure, hypertension, and abnormal lipids. ARS-funded researchers in Boston, Massachusetts, enrolled 3,954 Hispanic, Black, and White volunteers in a study to assess if carbohydrate and fat intakes influenced methylation and the risk of metabolic diseases. For each group, and in a combination of the three groups, the analyses demonstrated strong associations of a specific methylation marker with metabolic characteristics such as body mass index, triglyceride, glucose, and hypertension. The results demonstrated carbohydrate intake induces a specific methylation site that reduces the risk of

To download this two-pager, please visit https://go.usa.gov/xS9xz

the metabolic diseases in the study, but that fat intake inhibits a specific methylation site and increases the risk of these metabolic diseases. These findings identify how balancing carbohydrate and fat intake can affect metabolic disease risks that currently affect millions of Americans.

Vitamin A (VA) supplementation improves immune function in Bangladeshi infants. Vitamin A (VA) protects against respiratory and intestinal infections, but the protective mechanism is not fully known. In animals, VA increases a protein that allows immune cells to migrate to the intestinal mucosal immune sites where they protect against pathogenic microorganisms. However, this has not been shown in humans. ARS researchers in Davis, California, and International Centre for Diarrhoeal Disease Research colleagues in Bangladesh conducted a trial of VA supplementation in 306 Bangladeshi newborns and found that VA increased expression of this protein by T regulatory (Treg) cells in early infancy. Treg cells play a central role in regulating immunity at mucosal surfaces. These results suggest that VA supplementation during infancy prompts an increased expression of this specific protein, which in turn reduces the risk of death from common childhood infections in populations at risk of VA deficiency.

Ausmus, Stephen. Registered dietitian and president-elect of the Maryland Dietetic Association Jessica Kiel (left) encourages shoppers to use the U.S. Department of Agriculture's (USDA) ChooseMyPlate.gov interactive tools, which use USDA Agricultural Research Service (ARS) national nutrient data to make better, healthier food choices on Dec. 28, 2011. USDA photo. https://flic.kr/p/dQok5p.

REDUCING LABOR AND ADVANCING PRECISION AGRICULTURE THROUGH AUTOMATION

ARS advances labor-saving tools and technologies to aid in crop and livestock breeding and production, improve preharvest and postharvest processing, and enable nondestructive quality assessment and grading of commodities. ARS researchers have developed precision irrigation techniques and instrumentation, and made advances in technology, automation, informatics, and remote sensing. These cross-cutting efforts—which advance agricultural science, help the industry overcome labor shortages, fine-tune management decisions, and conserve resources while meeting growing demand for food—are highlighted by the following accomplishments in 2021.

New precision management tool optimizes cotton producer decision-making. Quickly and accurately documenting cotton crop emergence allows a grower to identify problem areas in fields and replant if needed. The small size of newly emerged plants makes them difficult to identify with remote sensing, and the time required for extensive data processing to accurately detect them often prevents remediation based on the measurements. ARS researchers in Portageville and Columbia, Missouri, and University of Missouri collaborators used unmanned aerial vehicles to collect early-season images of cotton fields and then developed and refined methods to quickly process the images and provide emergence results. The method identified the number of plant seedlings in the field and recognized weeds and other extraneous material with an accuracy rate of more than 90 percent. The near real-time processing with the new method was much faster than traditional image processing methods and will enable cotton producers throughout the world to better manage their crops for more efficient production systems to ensure a stable supply of food (cottonseed oil), feed (cottonseed meal), and fiber.

> **ARS scientists are developing low-cost remote sensing and equipment control technologies that farmers, ranchers, and processors can use with smartphone apps to manage their daily operations while reducing labor costs and improving operating efficiencies, which enables small farms to benefit from precision agriculture technologies.**

Enhancing foodborne pathogen sampling at processing facilities. Establishments producing raw ground beef products develop sampling protocols that are used to determine if microorganism levels in products are below predetermined baseline levels and that control processes adequately protect against contamination. Sampling methods are critical since improper microbiological sampling can incorrectly indicate that processing methods are effective. ARS researchers in Clay Center, Nebraska, developed new continuous (CSD) and manual (MSD) meat sampling devices for raw beef trim, and developed and validated protocols now used in commercial processing that address common variations in sampling. Findings indicate that the various alternative applications of CSD and MSD-based trim sampling for pathogen detection are equivalent or better than previous methods and provide additional benefits in reduced labor costs, other costs, and improved worker safety.

New highly efficient apple harvesting robotic arm. Automated harvesting technology is urgently needed to address U.S. labor shortages and increasing labor costs facing the multi-billion-dollar U.S. tree fruit industry. Although research into robotic harvesting has been reported in recent years, two technical challenges—picking fruit from clusters and finding fruit obscured by leaves and branches—still need to be

To download this two-pager, please visit https://go.usa.gov/xS9ax

resolved. An ARS engineer in East Lansing, Michigan, and Michigan State University scientists developed a new robotic apple harvesting technology that couples an innovative concept of vacuum sucking and rotation with a simple and effective robot arm movement mechanism. When the new harvesting robotic arm was tested in 2020 during multiple commercial field trials, it effectively and skillfully picked fruit from clusters and from deep within the canopy where apples were obscured by leaves and branches. A patent application for this technology has been filed.

Advances in precision agriculture improve sustainability of wheat, corn, and canola cropping systems. ARS scientists are developing powerful mapping and imaging tools to fight weeds, improve planting outcomes, and fight diseases in crops. ARS researchers in Pendleton, Oregon, and Oregon State University researchers developed a way to map weeds in real time during harvest operations. The high resolution weed maps were used to help explain variation in crop yield within the field and enable direct spot spraying of weeds after harvest before they re-infest the next crop. ARS researchers in Columbia, Missouri, and University of Missouri researchers developed a method for using aerial drone images to monitor corn emergence within the first week after planting; this method can be automated to help farmers scout fields for sections that need replanting. ARS scientists in Pendleton, Oregon, developed a procedure for monitoring the timing of canola flowering from satellite or aircraft-based images that can be integrated with meteorological data to predict canola yield and disease risk. These newly developed remote sensing techniques are helping growers improve productivity and sustainability across a wide variety of national cropping systems.

Cheung, Lance. Alexander Frick, Jr. uses a smart device to review data and plans his customized seed application for the day. April 13, 2021. USDA Photo. https://flic.kr/p/2m4Ka33

IMPROVING RURAL ECONOMIES THROUGH NEW USES OF AGRICULTURALLY-BASED MATERIALS

ARS research enhances the economic viability and competitiveness of U.S. agriculture by improving the quality and marketability of harvested foods and agricultural feedstocks to meet consumer needs while developing environmentally friendly and efficient processing concepts. The development of new agriculturally based materials is beneficial to farmers, consumers, and retailers because they are environmentally friendly, improve utilization of crops, and enhance economic security for rural communities. The following accomplishments in 2021 are examples of how ARS researchers develop these products.

Environmentally friendly "green" plastics as packaging materials. Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) and polyhydroxyalkanoates (PHA) are considered promising "green" alternatives to fossil fuel-based synthetic polymers such as nylon, polyethylene, and polyester used to make plastics. PHBV and PHA are made by bacteria and are compatible with living tissues, and unlike fossil-fuel based plastics, they are biodegradable. PHAs have similar properties as plastics with good moisture/aroma transport properties, but they tend to be more brittle and stiffer. PHBV polymers are less stiff and tougher, making PHBV ideal for packaging materials. The properties of a PHBV blend depends on its composition, which can be analyzed by nuclear magnetic resonance (NMR). ARS scientists in Peoria, Illinois, developed an improved NMR method for determining PHBV structure that provides enhanced informatics on PHBV structural accuracy. This knowledge helps determine the structural relationships used for making better PHBV plastics, especially for packaging, orthopedic devices, and in controlled release of drugs.

> **ARS scientists used ARS-created estolides made from sunflower and soybean oils to develop a new type of engine oil additive that solves engine lubrication problems.**

A bacteria-based biopesticide controls pecan weevil and preserves natural enemies. The pecan weevil is a major pest of pecans and is typically controlled with chemical insecticides. However, these insecticides may be harmful to humans and the environment, kill beneficial natural enemies such as lady beetles, and boost numbers of pecan aphids, another group of major pecan pests. An environmentally safe biopesticide, "Grandevo", based on a naturally occurring bacterium that was discovered by ARS scientists in Beltsville, Maryland, was tested on pecans by ARS scientists in Byron, Georgia. It produced equal levels of pecan weevil control compared with commonly used chemical insecticides. Furthermore, the biopesticide contributed to pecan aphid control and did not harm beneficial natural enemies during field experiments. ARS scientists determined the bacteria-based biopesticides are a viable, eco-friendly tool for the control of pecan weevils in both organic and non-organic production systems.

Improved catalyst for biofuel production from vegetable oils. The transformation of vegetable oil into a material that can be directly used as a replacement for fossil-based oil is a difficult technical process. However, ARS scientists in Peoria, Illinois, developed a new catalyst made from recycled iridium chloride previously used in industrial and medical applications. Using this technique, a biofuel can be made from fatty acids naturally found in plants. This new biofuel produces a higher-value biofuel than fuels made using other technologies, meets standard specifications, and keeps fuel system seals pliable and elastic. This new vegetable-based, catalyst-derived biofuel is a sustainable replacement for fossil fuels when used alone or in combination with fossil fuels to produce high value blends. ARS has patented this technology.

To download this two-pager, please visit https://go.usa.gov/xS9ag

Green jet fuel from yeast now at commercial scale. U.S. airlines have committed to reducing carbon dioxide emissions by 50 percent in 2050, which has generated significant demand for renewable jet fuel that can be used to replace the 23 billion gallons of fossil fuel currently supplying the jet fuel market. ARS scientists in Peoria, Illinois, assembled a collection of yeasts that convert agriculture waste into bio-oil, which is then easily converted into biodiesel or renewable jet fuel. One of these yeasts (Rhorosporidium toruloides) was used in a pilot demonstration at a commercial development center to convert sugarcane bagasse into bio-oil. The yeast produced 18 grams of bio-oil/100 grams of agricultural waste, demonstrating that it is robust enough to produce bio-oil in a commercial, large-scale operation

Cheung, Lance. Agriculture Secretary Tom Vilsack greets researchers, members of Congress, and passengers of Alaska Airlines Flight 4, celebrating the first commercial flight powered in part by wood-to-jet fuel from Washington state to Reagan National Airport, Washington, D.C., on Monday, Nov. 14, 2016. USDA Photo. https://flic.kr/p/NKMcmG

EXPANDING PUBLIC ACCESS TO AGRICULTURAL INFORMATION

ARS facilitates the creation of agricultural knowledge through the effective stewardship of agricultural data, literature, and other information resources available at the National Agricultural Library (NAL), the world's largest collection of agricultural information. As the library of the USDA, NAL provides public access to USDA-funded scholarly literature and data and digitized access to special collections. The following milestones in 2021 demonstrate how NAL supports fact-based, data-driven decision-making.

Increasing USDA full-text publications and peer reviewed citations in PubAg. PubAg is NAL's search system for USDA-funded scholarly agricultural literature and is the source for researchers, scientists, and the public to find scientific, peer-reviewed, agriculture-related citations and publications. In FY 2021, PubAg reached 3,487,840 million citations for peer-reviewed, agriculture-related scientific articles, an increase of more than 437,063 citations from FY 2020. NAL also increased the full-text corpus publicly accessible through PubAg by nearly 10,000 full-text articles, for a total of 311,877 full-text articles.

> **"NAL supports public access to USDA-funded research data primarily via the Ag Data Commons cataloge and repository, but also via hosting of FoodData Central, i5K Workspace@NAL, and the LCA Commons."**

i5K Workspace. The i5K Workspace is a place for arthropod genome communities to curate, visualize, and share data about agricultural pests and other arthropods. In FY 2021 the total number of workspace users increased to 15,044, with 57,962 total annual page views. The i5k Workspace improved a functional annotation pipeline for arthropod genomes, added seven new genomes to its platform, and released five functional genome annotations to the National Center for Biotechnology Information (NCBI), with more slated for FY 2022. ARS i5k Workspace personnel also contributed to the Ag100Pest project in FY 2021 via upgrades that will support an initial assembly of 25 genomes.

LCA Commons. Life cycle assessment (LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. The LCA Commons is an open repository and publication workflow for government funded and produced LCA research products. Since 2018, the Federal LCA Commons at NAL has grown to include more than 12 agencies across government and includes participation from the Department of Commerce, Department of Defense, Department of Transportation, and the Council on Environmental Quality. The LCA Commons maintains access to more than 20 major LCA data collections, some of which have been included in tools that support policy making across the federal government. NAL leads the Federal LCA Community of Practice, an inter-agency group valued for its unbiased expertise and high-quality data that is supporting USDA priorities related to Climate Smart Agriculture.

Hosting and disseminating USDA nutrition data. FoodData Central is an integrated data system that provides expanded nutrient profile data and links to related agricultural and experimental research. NAL hosts the FoodData Central website, providing online access to data for more than 383,713 different foods with more than 18.5 million food component entries. Combined, the FoodData Central platform and the legacy Food Composition Database generated nearly 15 million pageviews during 2.1 million user sessions in FY 2021. Application developers from private industry and academia made nearly 36 million

To download this two-pager, please visit https://go.usa.gov/xS9CU

application programming interface (API) calls to FoodData Central, making the FoodData Central API among the most popular in government. NAL made major improvements in the API application code that increased the efficiency of the query system.

A satellite navigation system is mounted on the far right of this private spray plane's control panel. June 30, 2010. USDA Photo. https://flic.kr/p/8zybzv

TOP 2021 RESEARCH ACCOMPLISHMENTS

PART 3. HOW ARS DOES IT: PRIORITIZING ANIMAL, HUMAN, PLANT, AND ENVIRONMENTAL HEALTH

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. ARS researchers are developing diagnostics, vaccines, and other mitigation strategies for many diseases found in multiple livestock species to provide stakeholders with tools to reduce the need for antibiotics, facilitate antibiotic stewardship, and preserve animal welfare. ARS scientists developed vaccines against Streptococcus suis and avian coccidiosis that have been transferred to commercial partners for further development. The following accomplishments highlight ARS advances in animal health research in 2021.

Discovery of continuous cell line to detect African swine fever virus infectious field isolates. African swine fever virus (ASFV) field isolates only replicate in primary cultures of swine white blood cells (macrophages), which are time consuming to prepare and require a herd of healthy donor pigs. These factors make swine macrophage cultures inaccessible for most diagnostic laboratories trying to identify infections in suspect field samples. ARS scientists in Greenport, New York, discovered that a cell line of monkey origin, Ma-104, was highly susceptible to infection with field isolates of ASFV. Results showed Ma-104 cells can be readily infected by all ASFV isolates tested. Furthermore, ARS researchers discovered the detection sensitivity was just below that of primary swine macrophage cultures and above the sensitivity of conventional real-time PCR methods. This discovery is of paramount importance for ASFV diagnostics as it will enable diagnostic laboratories worldwide to perform detection of ASFV infectious particles using a readily available cell line that is easy to grow. A patent covering the use of Ma-104 cells for ASFV diagnostic was filed by the ARS Office of Technology Transfer.

> **"ARS scientists have identified a genetic change that can reduce boar taint in pork without the need for castration, which improves production efficency and pig welfare and creates opportunities for further scientific discovery of the underlying biology of reproduction in male and female pigs."**

Remotely operated nematode sprayers provide non-chemical control of cattle fever ticks. Cattle fever ticks (CFT) threaten U.S. animal agriculture because they transmit the microbes that cause bovine babesiosis, a disease that causes rapid death in cattle. In south Texas, wildlife such as white-tailed deer and nilgai antelope serve as alternative hosts for CFT, complicating efforts to eradicate the ticks. A novel technology to treat wildlife infested with cattle fever ticks with microscopic parasitic roundworms (nematodes) was successfully tested and shown to be effective. ARS scientists in Edinburg, Texas, worked closely with the Animal and Plant Health Inspection Service-Veterinary Services and ranchers in south Texas to conduct large-scale field tests of a nematode sprayer to eradicate CFT on free-ranging nilgai antelope. More than 100 sprayers were deployed to apply nematodes across more than 5,000 acres as the nilgai moved through fence crossings. Treated nilgai were found to be infested with significantly lower numbers of cattle fever ticks than non-treated nilgai.

Better dewormers for small ruminants. Anthelminthic drug resistance cripples attempts to deworm sheep and goats, which can lead to increased morbidity and mortality. Veterinarians and farmers urgently need new tools to protect animal health and ensure the productivity of small ruminant farms. ARS researchers in Beltsville, Maryland, worked with university collaborators to refine a new, safe,

To download this two-pager, please visit https://go.usa.gov/xS9Cy

and cost-effective method to produce a potent therapeutic paraprobiotic called Inactivated Bacterium with Cytosolic Crystals (IBACC). Whereas a probiotic contains live microbes, a paraprobiotic contains inactivated microbes to enhance health. When given to sheep, 3 doses reduced the number of eggs shed by 90 percent, the total number of worms by 72 percent, and the number of female worms by 96 percent. Biologists think worms will face difficulty evolving resistance to this therapy. Once commercialized, this approach has enormous potential to benefit livestock producers.

New Johne's vaccine for cattle. Johne's disease, a serious disease of dairy cattle, is caused by *Mycobacterium avium subsp paratuberculosis* (MAP). ARS researchers in Ames, Iowa, conducted trials in dairy calves to test a new sub-unit Johne's disease vaccine containing a cocktail of recombinant proteins. In two trials, the highest dosages of the vaccine significantly reduced MAP colonization of intestinal tissues and resulted in the greatest reduction in infection. The vaccine also reduced fecal shedding of the pathogen, which is important for stopping on-farm transmission. Data has been used to support the patent application for this vaccine. These results will be of interest to producers, regulatory personnel, and researchers interested in intervention strategies for preventing Johne's disease in domestic livestock.

Cheung, Lance (with permission of the Navajo Nation). Navajo Technical University (NTU) has been working with the U.S. Department of Agriculture (USDA) as they continue to improve their Veterinary Technology program. September 9, 2019. https://flic.kr/p/2hZ6U9T

OPTIMIZING AGRICULTURAL MANAGEMENT TO MITIGATE CLIMATE CHANGE IMPACTS

ARS climate change research builds the science-based foundations for mitigating greenhouse gas ARS climate change research focuses on adaptation and mitigation. Adaptation investigates how to make plant and animal ecosystems more resilient to predicted climate changes and weather extremes. Mitigation develops practices and technologies that reduce fossil fuel use and greenhouse gas (GHG) emissions, sequester carbon, and generate feedstocks or energy to offset fossil fuel use. ARS research provides critical measurement and model simulation data about GHG emissions from different land uses and activities for the U.S. National GHG Inventory and other international inventories. The following accomplishments in 2021 highlight ARS advances in developing new management approaches and decision support tools to reduce agriculture's carbon footprint and boost regional farmer incomes.

Steam-flaked corn and high-quality hay lower greenhouse gas emissions from cattle. Methane, nitrous oxide, and carbon dioxide are GHG that contribute to climate change. When added together, the global warming effects of these three gases make up the carbon footprint. ARS scientists in Bushland, Texas; Woodward, Oklahoma; El Reno, Oklahoma; and university and NGO partners studied how dietary ingredients affect the carbon footprint of cattle. GHG emissions were lower when cattle consumed a diet based on high quality hay. They found corn, a typical feedlot diet ingredient, is usually processed either by dry rolling or steam flaking before being fed. Feeding the cattle steam flaked corn reduced the carbon footprint by 9 to 13 percent. Steam flaked corn also reduced enteric methane emissions by 30 percent. These results show diet manipulation can be an effective method for reducing GHG emissions from cattle; high quality grass and steam flaked corn are two feed management practices immediately available to producers.

> **Through initiatives like Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), ARS is collecting GHG emissions data and developing production practices, cropping systems, animal waste management processes, and other cost-effective strategies to reduce emissions and preserve productivity.**

Climate change reduces frost exposure for high-value California orchard crops. Yearly frost damage can cause hundreds of millions of dollars in lost crop revenue to high-value perennials in California alone. ARS researchers in Davis, California, and collaborators with the USDA California Climate Hub used climate models to predict how the future shift of frost would affect a variety of perennials. They found that frost exposure is expected to decline by 63 percent by the mid-21st century. The results suggest that the majority of almond and orange acreage will see approximately 50–75 percent reduction in frost exposure by mid-century, with avocado acreage expected to experience more than 75 percent fewer frost hours. Irrigation is the most common means of mitigating damage, but is costly and energy intensive, and draws on limited water resources. The reduction in frost exposure means that water use and energy costs can also be reduced, and growers in the highest acreage counties may save more than 50,000 acre-feet of water and $4.2 million in electricity costs for water pumping per year, collectively—a significant benefit to the industry.

Climate change may exacerbate the threat of biological invasions by introduced bee species. Island ecosystems may be particularly sensitive to the combined effects of climate change and biological

To download this two-pager, please visit https://go.usa.gov/xS9Cd

invasions. In Hawaii, there are 21 non-native bees that have the capacity to spread pathogens and compete for resources with some 60 native bees to Hawaii. ARS researchers in Logan, Utah, modeled the predicted distributions for eight non-native bee species in Hawaii across the islands under current and future predicted climate conditions. Although the models predict expansion of the invasive bees into higher elevations under 2070 climate scenarios, areas below 500 meters in elevation were predicted to maintain their species richness. These models have the capacity to inform management decisions by federal and state stakeholders for non-native bees in Hawaii by assessing risk of invasion into new areas around the archipelago.

Winter rye cover crop reduces nitrogen loss to drainage under climate change. Hypoxia or dead zones in coastal oceans have been expanding since the 1960s and are expected to increase with climate change if nitrogen (N) reduction strategies are not implemented. Implementing a winter rye cover crop (CC) into agricultural systems is one of the more promising strategies to reduce N loads to subsurface drainage without reducing cash crop production, but its effectiveness in the Mississippi River Basin (MRB) under expected climate change is uncertain. ARS scientists in Ames, Iowa, and El Reno, Oklahoma, used the field-tested Root Zone Water Quality Model (RZWQM) to produce simulations that suggest implementing winter rye CC in a typical Upper Midwest cropping rotation effectively addresses current goals of reducing future N load in field drainage in a northern MRB agricultural system without affecting cash crop production. This research will help in designing effective management systems to reduce hypoxia in the Gulf of Mexico and reduce N export to the MRB.

Leach, Darin. Agriculture Secretary Tom Vilsack listens to U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) supervisory plant physiologist Dr. Jerry Hatfield explain the equipment to gather information on climate changes and impacts on corn and soybean plants in Iowa on Jun. 6, 2014. USDA photo. https://flic.kr/p/nWPMYF

SAFEGUARDING THE FOOD SUPPLY

A growing world population, increasing environmental challenges, changing consumer preferences, and the impact of small-scale farming on nutrition and human health have resulted in the need to study the food supply as an integrated system. 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 2021.

In-package pulsed light treatment for increasing produce safety. Post-processing contamination with pathogens such as Escherichia coli O157:H7 is a major contributing factor to foodborne illness outbreaks, and safe and effective methods are needed to minimize contamination. ARS researchers in Wyndmoor, Pennsylvania, developed an in-package high-intensity pulsed light treatment capable of penetrating plastic film and killing E. coli O157:H7 on the surface of Romaine lettuce inside sealed packages. The treatment also reduced native microbial populations by greater than 90 percent, irrespective of the thickness of the plastic wrapping. Pulsed light treatment is an alternative green, chemical-free, nonthermal, post-packaging intervention treatment for leafy greens and other fresh and fresh-cut fruits and vegetables.

Semicarbazide during poultry processing. To ensure food is safe from chemical contaminants, detection technologies should be accurate and reliable. Semicarbazide (SEM) is an indicator compound used by national and international organizations to infer the use of nitrofurazone, a banned antibiotic, in animal production. Recently, the detection of SEM by a significant importer of U.S. poultry resulted in an import ban for products from specific processing plants. The validity of using SEM as an indicator for nitrofurazone has been questioned in recent years. Strong evidence has emerged that sanitizers used in processing facilities to decontaminate meat may chemically create SEM from biological molecules in the complete absence of nitrofurazone use. ARS researchers in Athens, Georgia, conducted studies indicating that this unintentional production of SEM on poultry meat was creating false positives for the presence of nitrofurazone. An extensive survey of poultry processing plants indicated that the use of certain antiseptic chemicals, in combination with pH, can react with meat tissue to produce detectable levels of SEM. These data confirm that incidental production of the chemical can occur in processing facilities; therefore, SEM is not a reliable indicator of nitrofurazone, and alternative indicators of nitrofurazone use should be developed. This data has been transferred to food safety regulatory agencies, industry, and trade organizations to ensure and avoid inaccurate contamination reports, and to eliminate economic loss and potential trade issues.

> **Aflatoxins are carcinogenic fungal toxins produced by Aspergillus supp. that cause serious animal and human health issues. ARS researchers in Maricopa, Arizona utilized DNA-based markers to genotype nearly 29,000 isolates originating from 35 countries in North America, Central America, Africa, Europe, Asia, and Australia. Based upon these analyses, an online database called "AflaSat" was developed, and standardized genotype data for each isolate was uploaded and made accessible to international collaborators.**

To download this two-pager, please visit https://go.usa.gov/xS9CG

Deep learning approach for classifying contamination levels. Mercury (Hg) and arsenic (As) ions have been recognized as chemical threats to human health and can be present in foods in trace amounts. A critical issue recognized by the U.S. Food and Drug Administration and other organizations is the difficulty detecting low contamination levels in the parts per billion range. This remains challenging due to the small number of available data samples and significant intra-class variance. ARS researchers and colleagues at Purdue University's Center for Food Safety Engineering explored techniques for synthesizing realistic colorimetric images and proposed a Convolutional Neural Network (CNN) classifier. The system was trained and evaluated on a dataset of 126 images captured with a cell phone camera representing 5 contamination levels. The system accurately classified 88.1 percent of the contaminated images and classified contamination levels with a precision level of 91.9 percent. Using this system would allow regulators, processers, and consumers to use cell phone cameras to capture images that can estimate heavy metal contamination levels and advance the protection of the food supply.

Shelf life and season are drivers of Escherichia coli O157:H7 survival on cut lettuce. *Escherichia coli* O157:H7 infections from contaminated lettuce continue to impact public health and the U.S. lettuce industry, which is valued annually at nearly $2 billion. Outbreaks linked to products grown in California occur predominantly from fall-harvested lettuce, and the reason for this seasonality is unknown. ARS researchers in Albany, California, and partners at the U.S. Food and Drug Administration Center for Food Safety and Nutrition identified the fall season and lettuce cultivars with poor shelf life as the main drivers of *E. coli* O157:H7 survival and microbiome structure. These results open new fields for inquiry into the seasonal aspects of the physiology of fresh-cut lettuce and its microbiome that may prevent the seasonal occurrence of *E. coli* O157:H7 infections. Likewise, the identification of shelf life as an important lettuce trait in *E. coli* O157:H7 survival suggests that genetic breeding for improved lettuce shelf life could be an integral part of a successful strategy to enhance produce safety.

Cheung, Lance (with permission of Five Sandoval and Pueblo of Isleta.) Roy and Santana Townsend of San Felipe Pueblo, NM have checked in with the Five Sandoval Indian Pueblos, Inc. (Five Sandoval) food distribution center in Bernalillo, NM, on September 10, 2019. USDA Photo. https://flic.kr/p/2i1dVGS

PROTECTING HUMAN AND ANIMAL HEALTH BY MITIGATING THE SPREAD OF VIRUSES

ARS research informs and provides solutions to improve the U.S. biodefense posture, a cross-cutting issue for both agriculture and public health. The risk of disease introduction—whether natural, intentional, or accidental—is increasing due to climate change and the increased movement of animals, plants, arthropods, and people around the globe. These diseases are a threat to food security and to human, animal, and environmental health. The following accomplishments in 2021 highlight multidisciplinary efforts across ARS to prevent, mitigate, and respond to the spread of viruses.

Novel spatial insect repellent dispensing devices to protect military troops. ARS scientists in Gainesville, Florida, treated bootlaces with various formulations of spatial insect repellents and tested them under laboratory and semi-field conditions. The treated bootlaces provided effective repellency more than 3 meters (approximately 9 feet) in all directions against the yellow fever mosquito (Aedes aegypti) for more than 3 months. Additionally, novel tent entrance devices were designed and evaluated under semi-field conditions and provided significant spatial repellency against four mosquito species, including three genera that carry disease. The yellow fever mosquito spreads numerous human diseases (dengue fever, chikungunya, Zika fever, Mayaro, and yellow fever) and these repelling devices will help protect combat forces deployed to environments where these mosquitos thrive; they could also protect civilians, if they are marketed for the public.

> **ARS scientists developed a nonwoven cotton containing levels of hydrogen peroxide sufficient to kill coronavirus within minutes of contact. This ARS technology was transferred to H&M Medical to be manufactured into virus-killing masks once approval was obtained from the U.S. Food and Drug Administration.**

Discovery of 33 toxin-producing, plant pathogenic fungi. During the past three decades, epidemics of the fungal disease Fusarium head blight (FHB) have caused economically devastating damage to wheat and barley in the United States and elsewhere around the world. FHB significantly reduces seed quality and yields and contaminates grain with toxins that pose a serious global threat to agricultural biosecurity, food safety, and human health. ARS researchers in Peoria, Illinois, characterized the genetic diversity of a global collection of 171 Fusarium strains either known or predicted to produce toxins. The 171 strains comprised 74 different species, including 33 that are new to science, and the species were distributed among 6 species groups that corresponded to the type of toxins they produce. The researchers found that species within only two of the six groups could cause FHB of wheat and contaminate grain with toxins. These data further suggest that the type of toxin produced contributes to the ability of these plant pathogens to cause disease. These findings will be of interest to plant disease specialists and quarantine officials who are focused on minimizing the threat these toxigenic molds pose to U.S. and world agriculture. Moreover, knowledge gained from this research should assist plant breeders in developing cultivars with broad-based resistance to FHB.

Managing tomato brown rugose fruit virus. Tomato brown rugose fruit virus (ToBRFV), an emerging and economically important plant virus, has caused serious disease outbreaks on greenhouse tomatoes around the world in recent years. This seed-borne and mechanically transmitted virus poses a serious threat to the $2.5 billion tomato and pepper industries in the United States. Recently, ARS researchers

To download this two-pager, please visit https://go.usa.gov/xS9C6

in Charleston, South Carolina, reported an outbreak of ToBRFV on tomato for the first time in the United States. Based on this report, USDA-APHIS issued a federal order to inspect all imported tomatoes and peppers for ToBRFV infection to prevent potential devastation to the U.S. tomato industry. In addition, the researchers conducted molecular and biological characterizations of ToBRFV isolates in the United States and developed a highly sensitive real-time PCR detection system for the virus that can also be used for seed health testing. Additionally, several disinfectants that kill the virus and prevent the disease from spreading have been identified and recommended to growers. Furthermore, the researchers screened available tomato germplasm and identified new sources of resistance that are being used in breeding to develop plants with resistance to the virus. These research findings will provide fundamental knowledge and practical solutions to prevent and protect tomato and pepper crops in the United States and around the world from potential devastation by this emerging and economically important plant pathogen.

A new method to screen the gastrointestinal microbiome of livestock. The microbiome is the combined genetic material of all microorganisms—such as bacteria, fungi, protozoa, and viruses—that live in a particular environment. ARS scientists in Madison, Wisconsin, and Beltsville, Maryland, led research conducted by an interdisciplinary team of international researchers from four countries and two private United States companies to develop new methods for microbiome screening to identify the organisms present. Using the latest high accuracy, long-read DNA sequencing technologies, microbial strains could be resolved down to single nucleotide variants. More than 44 bacterial genomes were assembled into single, continuous chromosome genomes, which is the greatest number ever achieved in a single sequenced sample; more than 400 viral- and 250 plasmid-host associations were identified. These discoveries represent the highest resolution image of genomic DNA in a gastrointestinal sample, furthering the interpretation of microbiome sequencing discoveries and the future identification of 'high-value' organisms influencing animal efficiency and health.

Cheung, Lance. 2019 novel coronavirus disease — COVID-19 —vaccination injection into an arm on March 18, 2020, in San Antonio, TX. USDA Photo. https://flic.kr/p/2kNxNcT

COMBATING ANTIMICROBIAL RESISTANCE

ARS has a unique role in identifying antimicrobial resistance (AMR) associated with new and emerging animal, plant, environmental, and foodborne pathogens. Using multidisciplinary approaches, ARS scientists conduct research on factors that impact the development of AMR across the entire food production chain, including the environment. Studies include developing mitigation strategies and alternatives that reduce the need for antibiotics while protecting animals from disease. ARS has contributed significant new information about AMR associated with multidrug-resistant human and animal pathogens; the ecology of AMR in agricultural and natural systems; the susceptibility of foodborne pathogens to biocides such as preservatives and disinfectants; and antibiotics critical to human medicine. The following 2021 accomplishments highlight ARS advances in optimizing the use of and reducing the need for antibiotics in agriculture.

Defining baseline antibiotic resistance levels in agricultural systems. There is broad consensus that agricultural antibiotic resistance in environmental bacteria needs to be reduced, but it is unclear what an appropriate target level for reduction should be or how to measure progress. ARS scientists in Lincoln, Nebraska, addressed both questions by measuring antibiotic resistance in microorganisms in soils from natural settings and organic farming operations. The data were shared with the USDA Office of Chief Scientist, Presidential Advisory Council on Combating Antimicrobial Resistance, National Academies of Science and Engineering, The Wellcome Trust, and U.S. Centers for Disease Control and Prevention, and helped support U.S. policy positions for international trade negotiations around antibiotic resistance in U.S. agricultural products. The scientists also developed molecular surveillance tools and quality control measures that are now broadly used to track antibiotic resistance in the environment and from farm-to-fork assessments.

> **ARS currently has more than 18 projects across the country among its various national programs in which interdisciplinary research ia being conducted to identify and control new and emerging antimicrobial resistance in human and food animal pathogens, at food processing facilities, on farms, and in the environment.**

A new tool to identify resistance genes in pathogens. Antimicrobial resistant (AMR) bacteria cause 2.8 million infections and more than 35,000 deaths each year in the United States. A multi-agency team that included the National Center for Biological Information, U.S. Food and Drug Administration, USDA-Food Safety Inspection Service, and ARS researchers in Athens, Georgia, developed the Bacterial Antimicrobial Resistance Reference Gene Database and the AMRFinderPlus gene detection tool. The database includes 7,737 antibiotic, acid, biocide, metal, and stress resistance genes that can be detected by AMRFinderPlus in whole genome sequences of any bacteria. Users can restrict their searches to antibiotic resistance genes or can include stress response and virulence genes in the search. This tool increases the number and type of gene that can be targeted to better understand AMR in important human pathogens, thereby improving food safety and public health.

Germ-fighting, durable, nano-enhanced cotton. Current methods to make fabrics with germ-fighting properties rely on surface coatings, but these surface coatings typically have poor durability and lose their functionality after only a few uses. ARS scientists in New Orleans, Louisiana, developed a new technology to produce permanent antimicrobial cotton products by synthesizing inexpensive copper oxide

To download this two-pager, please visit https://go.usa.gov/xS9Ce

nanoparticles, which are powerful antimicrobial agents, within the cotton fiber. This process does not require the use of harsh chemicals. It is the first known development of a nano-enhanced cotton having long-lasting antimicrobial performance (50 laundering cycles) that is easily transferrable to large-scale manufacturing. It is anticipated that these active fabrics will have a market value reaching $1.1 billion by 2026.

Characterization of metal tolerance in a pork outbreak-associated Salmonella strain. High levels of copper and zinc are frequently included in young pig diets as alternatives to antimicrobials to reduce pathogens and increase animal growth. However, the continuous use of copper or zinc may promote metal tolerance in bacterial pathogens. ARS researchers in Ames, Iowa, found that a Salmonella strain associated with a 2015 U.S. human outbreak linked to pork had increased genetic tolerance to copper, arsenic, and antimony. Furthermore, ARS researchers found that metal tolerance in this *Salmonella* strain can be transferred to other bacterial isolates and increase their metal tolerance; therefore, using elevated levels of zinc and copper in nursery swine diets may prompt the evolution of pathogen strains with more metal resistance and enable their colonization in pigs over the long term. This research provides information to veterinarians, swine producers, and microbiologists that certain *Salmonella* strains in U.S. pig populations have increased tolerance to copper used in animal production. The presence of metal tolerance genes in bacterial populations may limit the effectiveness of metals used to control disease.

Greb, Peggy. Cows enjoy eating orange peel and pulp, but these citrus byproducts are more than just tasty and nutritious, they also have an antimicrobial effect in the cow's gut. 2002. USDA Photo. https://flic.kr/p/dQoutH

COMBATING CITRUS GREENING DISEASE

ARS combats citrus greening disease through disease detection, prevention, and mitigation research. In 2021, the California Department of Food and Agriculture (CDFA) confirmed 2,510 trees in 5 counties were infected, including the county where the ARS Citrus Germplasm Collection is located. This is an increase in infected trees reported from the past 2 years. The Citrus Research and Field Trial (CRAFT) program is in its third year supporting citrus replant efforts across all citrus-growing regions of Florida. Nearly 5,000 acres of new citrus planting are part of CRAFT research projects. The following ARS advancements in 2021 highlight ongoing citrus greening response efforts.

Biotechnology improves early detection of citrus greening bacteria. Early detection and rapid response are the keys to mitigating citrus greening. Pennsylvania State University and ARS researchers in Fort Pierce, Florida, have used cutting-edge CRISPR/Cas technology to develop a diagnostic test that could enable early diagnosis of citrus greening, or huanglongbing (HLB). The new assay can detect the presence of the disease's causal agent—the bacterium *Candidatus* Liberibacter asiaticus (CLas)—at a sensitivity level 100 to 1,000 times greater than the commonly used qPCR diagnostic test. The new assay called DETECTR, or DNA endonuclease-targeted CRISPR trans reporter, is compatible with current technology and holds promise for providing a rapid and economical test for citrus greening in the field.

> **ARS scientists in Fort Pierce, Florida and Ithaca, New York, have advanced research on a $15 million NIFA grant to demonstrate and patent a novel method for delivering biological molecules to citrus trees using engineered citrus cells that grow a cluster of cells called a symbiont. Inital field trials are underway and tree health improvements have been observed.**

A parasitoid used to control pests transmits citrus greening. Parasitoids are frequently used in biological control and integrated pest management strategies all over the world. ARS researchers in Fort Pierce, Florida, demonstrated for the first time a risk posed by these control agents. Deployment of parasitoids has been promoted as a means of suppressing Asian citrus psyllid (ACP), a pest that transmits citrus greening disease , or HLB, in citrus orchards. However, while controlling ACP, the parasitoid *Tamarixia radiata* can inadvertently vector the HLB pathogen CLas. This diminishes *Tamarixia radiata's* biological control efficiency, particularly in orchards where CLas-infected and uninfected asymptomatic citrus trees coexist. This finding presents a new and significant caution to the strategy of implementing biological control using parasitic wasps.

Two for one: new technology detects two citrus pathogens in one test. Citrus greening is managed in California by intensive surveys and immediate eradication. Detecting citrus greening is complicated by the presence of citrus stubborn disease, which is caused by a different pathogen than the citrus greening pathogen. However, trees infected with either pathogen exhibit symptoms that are similar, resulting in misidentification and complicating citrus greening control and eradication efforts. ARS researchers in Parlier, California, developed two different PCR tests that can rapidly differentiate between the two pathogens populations. These methods provide clear quantitation of pathogens, which is critical when there are only low concentrations of target DNA and is critically important in regulatory programs involving mandatory eradication.

To download this two-pager, please visit https://go.usa.gov/xS9Cz

There are more insect pests in citrus orchards in China than previously known. Citrus is an important commercial crop throughout the world and citrus pests severely limit production and economic returns. Scientists in the ARS-associated laboratory in Beijing, China, conducted surveys of citrus pests in China, which is one of the centers of origin of citrus. Collected insects from citrus orchards in China underwent DNA analysis and were grouped as either pests or beneficials. Results showed that the number of pests is much higher than has been documented in literature. The data generated in this study provide a valuable resource for research in a broad range of areas, such as citrus pest management and monitoring programs.

Bartels, David. Huanglongbing, also known as citrus greening, causes color inversion on fruit in Texas. USDA Photo. January 20, 2012. https://flic.kr/p/2kfnjSK

PROTECTING POLLINATOR HEALTH

ARS promotes sustainable crop production by protecting crops and pollinators from pests that threaten their health and consequently reduce crop yields. Modern cropping systems may play a significant role in reduced populations of pollinators and other beneficial insects. ARS researchers across the country are evaluating the ecology, distribution, conservation, and effectiveness of insect predators, pollinators, and other beneficial insects. Researchers are quantifying the impact of agricultural management practices on insect populations and their activities and quantifying the services that beneficial insects provide to crop productivity, including pollination. The following accomplishments in 2021 highlight several ARS advances in pollinator health and pest management research.

Flowers as hubs for the microbial symbionts of bees. Native bees are important for cranberry pollination and the role of floral substrates as the 'hub' of microbial transmission among native bee fauna has been a focus of investigation by researchers. The survival of native bees depends on microbial symbionts within the pollen provision. Microbes are critical to the development of bee larvae, but the various mechanisms and key factors for this relationship have not been explored. ARS scientists in Madison, Wisconsin, showed that flowers serve as the pick-up and drop-off sites for beneficial bacteria and yeasts. Microbial communities pre-digest the pollen grains within the larva's pollen provision. These symbiont microbes function much like those within the rumen of a cow, providing access to amino acids and lipids that would otherwise be unavailable to young developing bees. ARS scientists showed that these microbial communities are not specific to certain bee species, but rather are shared widely throughout bee species. The mechanisms of transmission are mediated by flowers in the landscape and ensure that critical microbial groups are harbored long enough to be broadly distributed among pollinator populations. This work is critically important for agriculture because pollinators are essential to fruit set and development.

> **The new ARS Pollinator Health unit in Stoneville, Mississippi, will focus on improving honeybee and native bee health and enhancing natural habitat and minimizing risk to stressors, including pesticides and pests, in a way that is beneficial to both beekeepers and farmers.**

New methods to protect managed solitary bees from parasites. Solitary bees, including alfalfa leafcutting and bumble bees, are important pollinators. Alfalfa leafcutting bees are crucial to pollination for seed production, whereas bumble bees are used to pollinate greenhouse crops such as tomato. Alfalfa leafcutting bees need to be incubated prior to adult emergence, but parasitic wasps can destroy the entire population, and, bumble bee species are plagued by parasitic cuckoo bumble bees, which steal nest resources. ARS scientists in Logan, Utah, found that adding a dichlorvos insecticide strip at 3 days into incubation of alfalfa leafcutting bees killed several species of parasitic wasps. This treatment was much earlier than previously recommended and did not harm alfalfa leafcutting bees. For bumble bees, a fabricated excluder was designed to prevent cuckoo bumble bee invasion and was 100 percent effective at reducing bumble bee colony loss. Using these tools can help ensure effective delivery of alfalfa leafcutting bee and bumble bee pollination services.

Natural compounds combat against major viral diseases in honeybees. There are currently no registered treatments or medicines that are effective against honeybee viruses and other microbes. Natural

To download this two-pager, please visit https://go.usa.gov/xS9Cu

products that range from extracts of secondary compounds in plants and other living organisms to organic molecules provide a rich source of candidates for bee disease treatment. ARS scientists in Beltsville, Maryland, developed efficient and inexpensive screening techniques for testing new natural medicines for bees. Researchers discovered and patented several natural product compounds that are effective hive-based treatments against major bee viruses. These efforts expand the available options for beekeepers to control diseases, and help ensure better colony health, pollination services, and the production of honey and other hive products.

Nutrients in seasonal pollens support the annual cycle of honeybee colonies. Colony losses from malnutrition could be reduced by providing pollen sources that meet the annual nutritional needs of honeybees. ARS researchers in Tucson, Arizona, identified the nutrients in spring and fall pollen and bee responses to them. Pollens were collected in Arizona and Iowa where seasonal cycles of colony growth are similar in spring and summer but differ in the fall and winter. In Iowa, brood rearing is followed by cold temperatures, leading to months of confinement in the hive. Spring pollens from Arizona and Iowa had higher levels of nutrients that support brood rearing, and bees consuming spring pollens developed larger brood food glands for feeding the queen and rearing larvae. Fall pollen from Iowa had higher levels of fatty acids and certain amino acids needed to support colonies during confinement. These findings are important for developing pollinator seed mixtures that provide pollen with required nutrients throughout the period when colonies are active, and in the formulation of pollen substitute diets that need to be specific for the season when they are being fed to colonies.

Keres, Preston. A Swallowtail butterfly visits Goldpetal Farms in Chaptico, Md., July 17, 2021. USDA Photo. https://flic.kr/p/2mc1ouQ

OPTIMIZING AGRICULTURAL WATER USE AND MANAGEMENT

Public awareness of water shortages is increasing as the pressures of growing populations increase the demand for water. Rural areas are experiencing mounting pressure to provide more water for expanding urban areas at the expense of water supplies needed to support rural and agricultural communities. The ARS Watershed and Water Availability research program develops solutions that improve water management for efficient agricultural production. The following accomplishments in 2021 highlight ARS advancements in irrigation technology and decision support systems for addressing the challenges associated with agricultural water use.

A novel, water-conserving microgreen growing system. Feeding the increasing world's population with shrinking arable land and water resources requires novel alternatives to soil-based cultivation systems and creative solutions to minimize water usage.
ARS scientists in Beltsville, Maryland, developed a biodegradable, hydrogel-based "artificial soil" that minimizes water use and labor. By improving water retention/delivery and root zone aeration, this new technology supports a full 14-day growth cycle for microgreens, which equals conventional production yields without the daily watering requirements. This current technology supports facilitating live plant shipping and user-friendly vegetable growth kits for health-conscious consumers and novice urban farmers. Early and enthusiastic feedback and adoption from urban farmers indicates potential widespread adoption by the urban farming industry. In addition, NASA scientists are investigating using this technology for producing food during space travel.

> **ARS scientists are using infrared thermometers to measure crop canopy temperatures for irrigation scheduling. Four locations are testing a commercial system based on the technology to provide decision support for variable-rate center pivot irrigation, further reducing the water required for optimal yields.**

New satellite algorithm provides improved evapotranspiration measurements for crop water use and irrigation management. Recent droughts in the western United States have put tremendous strain on water resources, and there is increased pressure on the agricultural community to improve irrigation efficiency. However, established satellite evapotranspiration (ET) algorithms, particularly thermal algorithms that work well in the western United States, have limited utility for managing irrigation in specialty vegetable crops. ARS researchers in Riverside, California, and Maricopa, Arizona, evaluated a new thermal satellite ET algorithm based on the ECOsystem Spaceborne Thermal Radiometer Experiment (ECOSTRESS) on the International Space Station that flies over the Earth's surface once every four days and found that ECOSTRESS works very well for measuring crop water use in the western United States. This discovery provides another tool that could be adapted to help farmers improve irrigation scheduling.

Sctillometery for assessing temperature and vapor flux over vineyards. A laser-based method called sctillometery has been developed by ARS researchers in Corvallis, Oregon, for assessing temperature and moisture changes over large heterogeneous vineyards. These techniques allow for long term measurement of fine scale changes in vineyards without interfering with vineyard operations. This approach will aid the development of improved predictive models for pest and pathogen spread and disease development. Additionally, this approach will lead to improved assessment of water use and the development of predictive models for plant growth that will aid vineyard managers' decision making.

To download this two-pager, please visit https://go.usa.gov/xS9rc

A new and rugged ground-based method estimates crop water use. Farmers in the drought-stricken western United States require better tools to improve precision irrigation management. Reliable ground-based sensors can complement efforts to quantify crop water use and measure crop stress remotely with satellites and drones. ARS researchers in Davis, California, along with University of California-Davis collaborators, found a way to utilize rugged infrared temperature sensors to measure crop water use and stress down to the single plant level. This new method determines crop water use by measuring changes in crop temperatures every second. The effectiveness of this new method was shown in vineyards and tree crop orchards by comparing measurements against gold standard methods. This breakthrough enables the use of these durable, readily available sensors to improve precision irrigation management and environmental stewardship.

Cheung, Lance. Kitayama Brothers, Inc. (KBI) hydroponic greenhouses with micro irrigation have been in use for years in their 40 acres of green houses on Thursday, August 27, 2015, in Watsonville, CA. https://flic.kr/p/BwvBDn

MONITORING AND MITIGATING THE SPREAD OF PLANT DISEASE

ARS is committed to controlling plant diseases to protect our food security and ensure an adequate supply of non-food crops for feed, fiber, energy, and horticultural uses. Plant diseases have significant impacts on yields and quality, resulting in billions of dollars in economic losses and management inputs each year to crops, landscapes, and forests in the United States. Crop losses due to plant pathogens that did not originate in the United States are estimated to cost $21 billion per year. The National Plant Disease Recovery System (NPDRS) provides the flexibility for rapid response to new and emerging diseases and immediate threats identified in other countries, often before they reach the United States. Effective control of plant diseases requires an understanding of the biology of disease-causing agents. The following accomplishments in 2021 highlight ARS successes in identifying and halting the spread of plant diseases.

Establishment of rice plants as an important tool for functional genomic studies to understand and manage plant disease resistance in bread wheat. The genetic complexity of the common bread wheat, which contains three different genomes, has been extremely challenging to researchers to conclusively pinpoint the role of numerous insect/pest-responsive genes that are potentially involved in disease resistance. ARS researchers in West Lafayette, Indiana, demonstrated that this problem can be overcome by analyzing less complex model genomes, such as rice. Since rice resembles bread wheat in its responses to Hessian fly infestation at the physical and molecular level, the scientists found that rice plants are suitable for functional gene studies that can help elucidate how wheat defends against Hessian fly and other destructive insect pests. This strategy can be employed by other plant researchers to characterize genes, study other plant-pest/pathogen interactions, and develop effective mitigation strategies that complement native resistance.

> **The National Predictive Modeling Tool Initiative (NPMTI) is a multi-organizational group that includes commodity stakeholders, ARS, other federal agencies, and land-grant universities working to develop a tool for monitoring and predicting disease outbreak in field crops. In 2021, four ARS locations and 21 universities continued collaboration to develop models for diseases on corn, cotton, and wheat diseases.**

New viruses transmitted by whiteflies threaten cucurbit crops in California's Central Valley. In the U.S. Southwestern low desert, two yellowing viruses are known to impact summer and fall cucurbit production. These two viruses had not been previously known to infect plants in the Central Valley of California, where more than half of U.S. cantaloupe production occurs. During the fall of 2020, ARS scientists in Salinas, California, identified both viruses from melon plants in Fresno County, California, using a virus detection system developed by the ARS laboratory. The viruses have the potential to cause severe losses, and it is important for the cucurbit industry that continued monitoring occur to determine prevalence and to develop strategies to reduce the impact of the virus.

Screening for sunflower resistance to Sclerotinia basal stalk rot. Field trials to evaluate sunflower resistance to Sclerotinia basal stalk rot are time consuming and offer limited resolution for identifying resistance. ARS scientists in Fargo, North Dakota, and colleagues at North Dakota State University and Iowa State University developed and validated a new greenhouse method using sclerotinia-infected millet seed to infect single sunflower plants to evaluate basal stalk rot resistance. The new method is

To download this two-pager, please visit https://go.usa.gov/xS9rY

time- and space-efficient and allows for disease evaluations in a single year, compared to multi-year, multi-location studies using inoculated field trials. Results from the new method were strongly correlated with field observations. This new method will assist sunflower breeders and pathologists in their evaluation of sunflower genetic populations to improve the rapid identification of genomic regions associated with resistance to basal stalk rot.

Training dogs to detect early infection of plants by pathogens. Early detection and rapid response are key to the mitigation of all plant diseases. Representative samples for testing can be difficult to collect, especially early in the growing season or epidemic when pathogens are at their fewest. This same caveat applies at the individual plant scale when a pathogen is incompletely distributed in its plant host, particularly with large and/or perennial host plants. Both these sampling scenarios can lead to false negative test results. ARS researchers in Fort Pierce, Florida, and industry cooperators demonstrated that canine detection of plant pathogens is a novel approach that is rapid, sensitive, and reliable for bacterial and viral plant pathogen detection. Since canines holistically and non-destructively assay the entire plant, sampling error can be avoided at both agroecosystem and individual plant scales while maintaining testing accuracy. Real-time canine detection generates rapid results that can be translated into immediate corrective actions by growers.

Citrus Canker causes lesions on the leaves, stems, and fruit of plants including citrus and other plants in the citrus family. January 28, 2004. USDA Photo. https://flic.kr/p/2kfo5Pt

CONTROLLING INSECT PESTS TO PROTECT PLANT, ANIMAL, AND HUMAN HEALTH

ARS collaborates across the human, animal, and environmental health communities to achieve sustained health outcomes for plants, animals, and people. Research at ARS informs and provides solutions to improve the U.S. biodefense posture and encompasses animal health; medical, veterinary, and urban entomology; plant health; and natural resources and sustainable agricultural systems. The rapid evolution of insecticide resistance in insect pest populations can make chemical controls unsustainable, so alternative and effective management strategies for these insect pests are needed. The following accomplishments in 2021 illustrate ARS efforts to eliminate insect vectors of disease, those that feed on crops, and nullify their impacts.

Nanoparticle formulations enhance biopesticide efficacy. Environmentally friendly biopesticides such as entomopathogenic (insect-killing) fungi can control various economically important insect pests such as pecan weevils. The efficacy of these biopesticides, however, can be limited due to their sensitivity to ultraviolet radiation, so it is critical to develop new formulations that protect the biopesticide organisms from environmental stress. ARS researchers in Byron, Georgia, and Israeli partners discovered that nanoparticle-based formulations protect biopesticides from ultraviolet radiation and thereby increase pest control efficacy. This technology could potentially lead to improved sustainability in pest management practices.

> **ARS is global leader in developing knowledge and sustainable management strategies for controlling whiteflies and whitefly-transmitted viruses in crops. ARS research teams, in collaboration with federal, state, and other stakeholders, use a wide suite of management approaches because whiteflies can easily adapt to plants and environments and develop resistance to numerous pesticides.**

Methyl bromide alternatives to control invasive and quarantine horticultural insect pests. Methyl bromide (MB) is a broad-spectrum fumigant used largely in several countries for combating soil-borne pests and others in postharvest, pre-shipment, and quarantine treatments. Despite its biological effectiveness, the fumigant has been identified as a major ozone depleting substance, and its use needs to be phased out in countries where it is still being used. ARS researchers in Parlier, California, conducted studies to optimize, develop, and register MB alternatives to support regulatory compliance and enhance global food security. The researchers developed a novel postharvest phosphine fumigation to control the devastating spotted wing drosophila in fresh citrus exports from California to New Zealand that are valued at $12 million annually. In addition, a novel postharvest sulfuryl fluoride fumigation was developed to control other economically important insect pests, including navel orangeworm, almond moth, and Mediterranean flour moth, in California almond exports to India, which are valued at $2 billion annually. The research directly resulted in market retention or expansion and served as the basis for technical interaction between industry, USDA Foreign Agricultural Service, USDA Animal and Plant Health Inspection Service, U.S. Environmental Protection Agency, and respective counterparts in foreign governments.

The value of biological control in the Asia-Pacific region. Biological control of insect pests has immense economic value in many agricultural systems throughout the world. Still, this value is

To download this two-pager, please visit https://go.usa.gov/xS9r2

underappreciated by many involved in spurring the innovation and adoption of biological control research and technology. An ARS researcher in Maricopa, Arizona, and partners in China, Australia, and the United Kingdom estimated that classical introductory biological control against 43 insect pests in food, feed, and fiber crops in the Asia-Pacific region has an economic impact from $17.1 to $22.7 billion USD annually. In addition, biological control was shown to promote rural growth and prosperity even in marginal, non-rice environments. This research provides lessons for future efforts to mitigate invasive species, restore ecological resilience, and sustainably increase the output of global food systems.

Discovery of safer pesticides. For the past 20 years, botanic pesticides have received acclaim and recognition as attractive alternatives to synthetic pesticides for pest management due to their reduced threat to human and environmental health. In 2018, ARS scientists in Beltsville, Maryland, showed that methyl benzoate, a volatile organic compound (VOC) from fermented apple juice, exhibited significant insecticidal activity against invasive spotted wing drosophila. The scientists showed that some methyl benzoate analogs can kill or repel many insects and non-insect pests in various stages of development, including mosquitoes, bed bugs, fire ants, ticks, flies, moths, and nematodes, through contact or fumigation. These methyl benzoate analogs will provide growers with an environmentally friendly alternative to synthetic pesticides for managing insects and non-insect pests and have great potential to be used as safe pesticides for human protection.

Ausmus, Stephen. This female mosquito (Aedes aegypti) has filled up on human blood on May 23, 2012. USDA Photo. https://flic.kr/p/dPqraQ

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 on smart agriculture is being conducted to enhance the resilience of agricultural systems that support resource conservation and enhance productivity. To support rural prosperity, food security, and healthy agroecosystems, ARS research helps producers improve management decisions and ultimately achieve healthy and productive pastures and rangelands, as illustrated by the following research accomplishments in 2021.

Impacts of fire on mesquite persistence. Mesquite encroachment into arid lands worldwide has negatively impacted livelihoods and ecosystems. In Texas, more than $50 million has been spent in 10 years to control mesquite. ARS researchers in Sidney, Montana, and university collaborators assessed mesquite persistence across a range of fire intensities. High-intensity fire caused mortality in 29 percent of mesquite, but did not alter soil chemistry or microbes, and did not permanently harm dominant grass species. High intensity fires are a low-cost option as part of an overall management program for reducing mesquite abundance in rangelands.

> **ARS research is in the process of exploring the use of global positioning to locate cattle in pastures and rangelands and provide information to improve forage utilization.**

Improved pasture mixes and annual forages increase dairy cow productivity. Milk production from cows grazing pasture is the fastest growing segment of organic agriculture. One challenge of organic production is that grazing dairy cows produce up to 32 percent less milk than non-grazing cows, mostly because they eat up to 30 percent less forage. ARS researchers in Logan, Utah, and Utah State University collaborators determined how much young dairy cattle eat and grow when grazing four different grasses alone or in mixtures with the legume birdsfoot trefoil. They found the mixtures of grass and birdsfoot trefoil increased the amount dairy heifers ate by 34 percent, improved growth by 25 percent, and increased heifer value around $166. In related research, ARS scientists in University Park, Pennsylvania, and University of New Hampshire collaborators evaluated five winter annual forages for providing high-quality, lower-cost pasture in early spring to meet grazing needs that traditional pasture forages cannot. Barley showed the most potential and fewest tradeoffs for supplementing spring pastures to maximize harvest yield and livestock nutrient value. These grazing tools are now being used by dairy farmers to increase cow forage intake and milk production.

Finding cause of acute liver toxicity in cattle helps "save the ranch." A herd of cattle in Colorado were poisoned after eating weed-contaminated alfalfa hay produced in Wyoming, resulting in the death of 165 cattle and other production losses. ARS scientists in Logan, Utah, worked with the U.S. Food and Drug Administration and Colorado State University over 5 years to identify toxic compounds in the hay and traced the poisoning back to the toxic weed *Salvia reflexa* in the contaminated hay. *Salvia reflexa*, commonly known as lanceleaf sage, is an annual native U.S. weed that is found in pastures and prairies and can be toxic to cattle, sheep, and goats. Identifying the cause of the poisoning allowed the cattle owners to file an insurance claim to recover their losses. This is the first report of *Salvia* causing liver injury, and the research was used to retrospectively identify the cause of poisoning in other cases. This information is now available to veterinary practitioners and diagnostic laboratories to aid in solving future cases where Salvia poisoning may be involved.

To download this two-pager, please visit https://go.usa.gov/xS9rj

New stocking rate guide shows 72 percent more grazing capacity for semiarid rangelands. ARS developed a stocking rate guide in the 1960s for use in semiarid rangelands worldwide. The guide relates grazing animal weight gain and beef production to how much forage remains at the end of the grazing season. ARS scientists in Cheyenne, Wyoming, and Fort Collins, Colorado, and collaborators at the University of Wyoming analyzed contemporary data (2000-2018) from the same long-term study initially used for the 1960s stocking rate guide. They determined that sustainable stocking rates for western Great Plains semiarid rangelands increased by 72 percent over the past 50 years, likely due to combined effects of recovery from the 1930s Dust Bowl, more carbon dioxide in the atmosphere, and better livestock genetics. The scientists revised the guide and made it available on the web as a Colorado State University extension fact sheet. The guide is being used by more than 60 ranchers and on approximately 200,000 acres of the U.S. Forest Service Pawnee National Grassland for adaptive stocking adjustments to increase profitability, production efficiency, and resilience of the semiarid shortgrass steppe rangeland.

LOOKING AHEAD

As the U.S. Department of Agriculture's chief scientific in-house research agency, ARS focuses on solutions to agricultural problems affecting America. Each dollar invested in agricultural research results in $17 of economic impact. Going forward, ARS will continue to conduct important research with bold action, collaborative leadership, active dialogue, and a deep commitment to serving all Americans. These efforts will enable us to work together and maximize impact to achieve extraordinary results for years to come.

Keres, Preston. Dominique Herman leads a flock of Corriedale Merino cross and Ike-de-France Merino cross to pasture for morning grazing on her farm in Warwick, New York. May 16, 2022. USDA Photo. https://flic.kr/p/2nmgCeq

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

This publication is the Agricultural Research Service's 2021 annual report on science.

U.S. Department of Agriculture, Agricultural Research Service. 2022. Agricultural Research Service 2021 Report on Science. Washington, D.C.