Salmonella Grand Challenge 1 Year Progress Report

Table of Contents

Approved Grand Challenge proposal

Project Title: Integrated Food Safety Systems to Reduce Foodborne Salmonellosis

Project Leader: Tommy L. Wheeler, PhD
National Program Leader Facilitator: Kim Cook, PhD

Executive Summary

Salmonella causes over one million illnesses and nearly 400 deaths each year and is the second leading cause of foodborne illness in the United States (USDA-ERS, 2021). Despite millions of dollars spent annually and a decrease in *Salmonella* prevalence on meat and poultry products, *Salmonella* illness rates have not decreased in the last twenty years (Figure 1). Attempts to reduce salmonellosis have been hindered by siloing of research projects and lack of integrated approaches for effective, interdisciplinary, and cross-scale management solutions. The goal of this Grand Challenge Synergy (GCS) proposal is to improve ongoing research on *Salmonella* by combining, standardizing, and coordinating research efforts across a diverse GCS team to optimize utilization of data from genomics, ecology, climate, economics, and intervention studies. This integrated approach represents a novel, comprehensive approach to enhance data use and machine learning analytics to uncover, predict and facilitate the reduction of *Salmonella* entering the supply chain from the farm. Alignment of this diverse team to the Grand Challenge goals will bring unique perspectives and synergies to bear on the most recalcitrant *Salmonella* challenges across the food animal system. We will provide stakeholders actionable data, standardized methods, and implementable intervention tools to reduce *Salmonella* associated with food animals and meat and poultry products, thus helping them implement affordable, effective, data-driven strategies to address their *Salmonella* food safety goals.

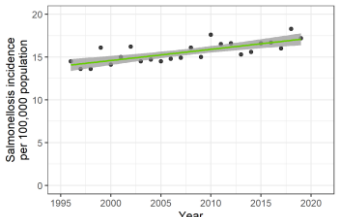

Figure 1. Salmonellosis incidence per 100,000 population. Source: FoodNet

Section I: Synergistic Goal

What brings this team together?

Prior to conceptualization of this project, GCS team leaders convened more than 15 meetings with industry stakeholders (Appendix IV). Attendees across multiple points within the food supply chain identified a suite of priority needs. Key findings of focus group discussions included a need to optimize use of available data, to expand detection capabilities to include bacterial numbers and pathogenicity, and to identify economical and effective management strategies to reduce *Salmonella*. In 2020, the Food Safety and Inspection Service (FSIS) launched a new Roadmap to Reducing *Salmonella* (FSIS, 2020). As part of that effort, in August 2022, FSIS proposed their intent to declare *Salmonella* at ≥1cfu/g an adulterant in breaded and stuffed raw chicken products. If implemented, it will be the first regulation of *Salmonella* as an adulterant, increasing the urgency of this project. The framework proposed herein empowers a group of ARS scientists already working with the meat and poultry industries to leverage ongoing project efforts, extensive industry

feedback, and outside collaborations to address the priorities of stakeholders to meet the Healthy People objective of reducing salmonellosis incidence by 25% by 2030 (HHS, 2020).

How does this goal relate to the independent project plan goals?

The GCS team integrates USDA/ARS expertise from 18 scientists working across eight fields of expertise in six national programs (Appendix I) to break down silos and integrate physical, chemical, geospatial, and microbiological data to achieve value-add goals. Coordination of efforts will result in improved project plan efficiency enabling goals to be met more rapidly. Combining disciplines will lead to innovative ideas allowing the projects to exceed their original goals and enhancing the options for controlling *Salmonella*. Standardized protocols will provide data that can be pooled for big data analyses to identify intervention points, validate new interventions, gain a greater understanding of *Salmonella* control points, and develop a fit-for-purpose decision support tool for industry use that will reduce *Salmonella* entering the supply chain and, ultimately, the burden of foodborne illness. Scientists at different locations will then conduct coordinated experiments using these standardized protocols to compile large datasets for advanced, machine learning-based analytics.

What is the potential impact of achieving this common goal?

At the highest level, successful accomplishment of this project will improve public health by reducing salmonellosis from meat and poultry products, reducing pressure on stakeholders and helping meet the Healthy People *Salmonella* illness goals in 2030(HP2030). In 2021, FDA released their Blueprint to a New Era of Smarter Food Safety, highlighting the need for novel, integrated, data-driven approaches as proposed by this GCS team. Incorporating economic analyses will identify approaches that are both effective and feasible for implementation. Collaborative efforts will result in stronger stakeholder interactions and enhance grant funding opportunities. Finally, the work presented herein will create a useful framework which can be translated to other food systems to enhance control over foodborne pathogens.

How does this proposal benefit from an integrated, multiple-disciplinary approach?

This GCS project applies machine learning data analytics to integrated, standardized data from multi-regional, multi-species studies designed to identify effective interventions and to produce decision support tools requested by stakeholders (Fig. 2). Without the GCS project, much of the data would be generated without standardization and without integration of metadata needed for robust data analytics. There are significant Genetics × Management × Environment (G×E×M) interactions impacting *Salmonella* risks. An integrated, multi-disciplinary, and this data-driven approach addresses these intricacies to find situation-specific solutions and provide unique insight to inform new approaches to manage *Salmonella*. Economists from the USDA, Economic Research Service (ERS) will provide insight and publications on economic factors that affect technology adoption and aid in assessing the cost-effectiveness of research products. These economic analyses were requested by stakeholders and will provide information needed to determine the feasibility of implementation. Finally, the integration of a communication plan, including the National Agricultural Library (NAL), will facilitate outreach and demonstration projects to translate outcomes to implementation.

Section II: Approach

The National Program Leader and Project Leader recruited a steering committee of five ARS scientists with diverse expertise in *Salmonella* research and a history of working closely with industry stakeholders to lead development of the project objectives. The steering committee engaged ARS National Program Leaders (Appendix II) and stakeholders (Appendix IV) over a year-long period to obtain feedback on critical research needs. Additional ARS collaborators were recruited to build out the objectives, and finally, an industry stakeholder advisory board (Appendix III) was established for ongoing feedback and direction. Team leads have been selected for each objective.

Project Management: The Meat Safety and Quality Research Unit at the U.S. Meat Animal Research Center in Clay Center, NE will serve as the central hub for this project and will be responsible for coordinating all project-wide meetings and hosting a centralized, relational database for data consolidation and analyses. A SciNet postdoc assigned to the GCS Project Leader will assist with overall project management, data management, and data analyses. After the GCS project is approved, an in-person meeting will be planned to discuss project goals, priorities, timelines, and communication and data management plans including all logistics of standardizing, collecting, organizing, storing, sharing, and analyzing

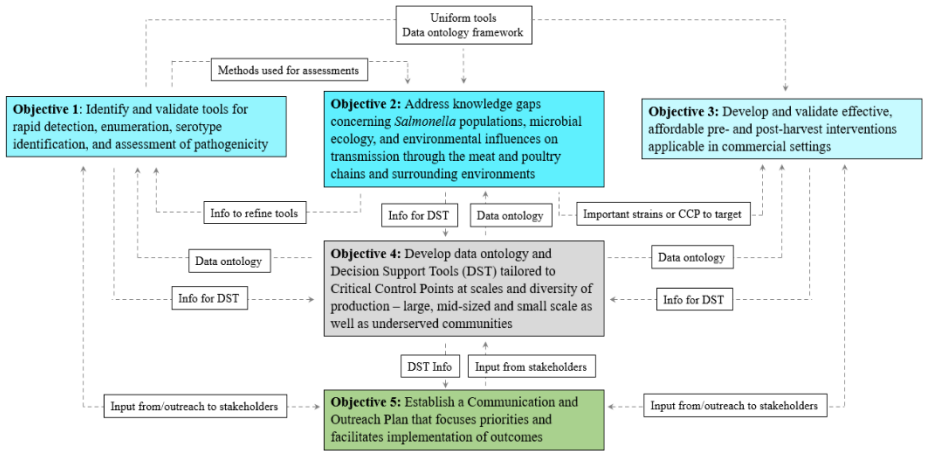

Figure 2. Overview of Salmonella GCS

the data with milestones for individual objectives. Team meetings will be conducted virtually prior to the initiation of each phase of the research with quarterly virtual progress update meetings of the entire project team. Grand Challenge team meetings will consist of presentations and facilitated discussions of next steps to advance individual objectives and maintain the integrated approach. The Industry Advisory Board (Appendix III) will collaborate to review all *Salmonella* Grand Challenge experiments and products to ensure the needs and concerns of large, small, and underserved stakeholders are addressed.

OBJECTIVE 1. Establish 'Gold Standard' methods, approaches, and integrated protocols

To reach the Healthy People 2030 goal, FDA and FSIS are calling for systematic evaluation of approaches to quantify, detect, and reduce *Salmonella* entering the supply chain (FSIS, 2022). FSIS plans to implement quantitation for the first time in 2022. There are more than 2500 different serotypes of *Salmonella*, but a relatively small group of those cause most of the illnesses (Jones et al., 2008). To achieve the greatest impact, the GCS team will evaluate and optimize 3 to 5 existing and novel approaches to detect and quantify the most highly pathogenic *Salmonella* based on risk and relevance for each commodity. The team will conduct an inter-laboratory comparative analysis of identified methods. Before studies begin the entire GCS team will come together to develop standardized protocols, data management, and ontologies for field-scale studies (Objectives 2 and 3) that standardize physical, chemical, and biological methods for detection and data integration. Approaches will be optimized for each commodity (swine, turkey, broiler, beef) based on existing preharvest biosafety and biosecurity sampling procedures (BIFSCo, 2022; NPIP, 2022; NTF, 2020; NPB, 2018) and further enhanced for farm-specific scale of production, geography, climate, and corporate factors based on data analytics (Objective 4). In addition to increasing collaboration, statistical power, and research impact through the adoption of standardized methods, the protocols will be made publicly available on Protocols.io.

OBJECTIVE 2. Identify drivers, reservoirs, and sentinels of highly pathogenic *Salmonella* in pre-harvest

To incorporate the full range of factors affecting *Salmonella* presence and prevalence in pre-harvest production, the GCS team of ecologists, climatologists and geospatial scientists, soil scientists, microbiologists, and geneticists will work collaboratively to evaluate G×E×M factors including both macro-environments (e.g., soil nutrient and metal content, weather and climate and the stress they pose on animals, and corporate factors) and micro-environments (*Salmonella* population dynamics, pathogenicity, and microbiome interactions) for their roles in *Salmonella* persistence, transmission, and virulence. Protocols, data management and ontologies will be standardized (Objective 1) and data will be fed into advanced data analytic tools (Objective 4) to determine key drivers, reservoirs, and critical control points for interventions (Objective 3). The GCS team will validate new findings against real data from collaborating stakeholder facilities with predictive modeling approaches. Consultation with the GCS team, industry advisory board, ERS colleagues and stakeholders (Objective 5) will be used to inform next steps. Pilot projects will be developed to demonstrate value and receive feedback from stakeholders.

OBJECTIVE 3. Design novel, synergistic and/or multi-hurdle approaches to mitigate highly pathogenic *Salmonella*

Reduction of *Salmonella* load during food animal production and processing is contingent upon implementation of effective pre-harvest mitigations in each commodity, which could include optimally managing biosecurity tools on the farm and/or administering interventions to food animals or their production environment. Ecological and transmission dynamic paradigms elucidated under Objective 2 will inform the development and application of interventions in Objective 3. Building on industry experience and recommended best practices, the GCS team will work with ARS, the industry advisory board, and university collaborators to develop and test comprehensive, commodity-specific approaches and proof-of-concept projects for stakeholder feedback and evaluation. Novel, standardized detection methodologies (Objective 1) with state-of-the-art data analytics (Objective 4) will identify approaches that not only reduce the load of highly pathogenic *Salmonella* serovars entering the processing chain, but that are also economically and logistically viable and readily transferrable for stakeholder use. Innovative post-harvest interventions will be evaluated in a multi-hurdle approach to assess synergistic value. Partnership of team expertise on animal science, molecular biology, economics, and data visualization, with that of social scientists and food system modelers will help tailor applied approaches for on-farm food safety and feed into demonstration projects to illustrate their value (Objective 5).

OBJECTIVE 4. Harness machine learning and large standardized datasets to build decision support tools for stakeholders

We will utilize machine learning technology to build a decision support tool which leverages the standardized database of inputs (Objective 1) collected during the pre- and post-harvest process (Objective 2) to predict optimal intervention strategies and where to employ them (Objective 3). Suggested intervention strategies, accompanied by a cost-effectiveness analysis done in partnership with ERS, will be displayed in an easy-to-interpret, interactive dashboard format intended for subsequent individualized implementation by industry, facilitated by communications and outreach with the help of the Partnerships for Data Innovations (Objective 5). Including an economic analysis will increase industry trust and use as economic viability is highly important to stakeholders. Importantly, the decision tool will be specific for each type of commodity and stage in the harvest process and will account for heterogeneity within different producer processes and scales (Figure 3). Industry stakeholders will be involved in each step of the development process to ensure the tool meets practical needs.

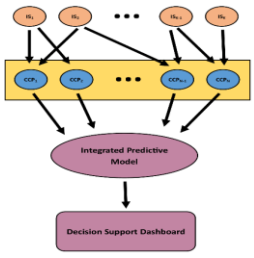

Figure 3. Decision Support Tool Concept. CCP 1:n represent critical control points identified in Objective 2. IS 1:k represent intervention strategies identified in Objective 3.

OBJECTIVE 5. Implement Communication and Outreach Activities

Science communication is a vital part of this GCS. During focus group discussions, stakeholders voiced concern that there is a lack of effective communication of the applied, functional solutions for industry. This objective includes all members of the GCS team but will be led by representatives from the National Agricultural Library, Food Safety Research Information Office (FSRIO), the Office of National Programs (ONP), and the GCS Project Lead. This team will guide production of content

that is readily accessible to stakeholders and is relevant across diverse scales of production, type of commodity, and U.S. geographical regions. We will formulate a communications plan that translates *Salmonella* Grand Challenge outcomes to implementation. A key part of outreach will include development of demonstration projects. These projects will include webinars, pilot locations, and proof of concept research projects in collaboration with team members and stakeholders to demonstrate the value of implementing *Salmonella* research outcomes. The GCS team will help FSRIO develop science content (bibliography, research highlights, sharable content (videos), and the availability of open access tools). In addition to science content, the team will ensure 508 compliance accessibility, a One USDA platform that is aligned with all USDA enterprise-wide government systems. Included is outreach to target audiences and communication of approaches to help producers at all scales and diversity of production including underserved communities with implementation of GCS outcomes.

Data Management Plan

Data will be recorded in laboratory notebooks, Word documents, Excel spreadsheets (.xls, .csv, .doc) or lab equipment systems. Digital image files will be TIFF. When possible, data will be collected electronically. Non-digital data will be scanned to PDF files or digitized as TIFF before conversion to text-format files for data analysis. Sequence data with metadata will be stored on SciNet or local servers with dedicated backup systems and will be uploaded to public databases such as NCBI (https://submit.ncbi.nlm.nih.gov/). A relational database at USMARC will store all data generated under this project with the data input from all members of the GCS team. Data standards and ontologies will be developed and enforced across all GCS projects to allow ease of pooling of data and increase statistical power of analyses. All stakeholder source data will be anonymized for analyses based on methods suggested by the Industry Advisory Board. Validated protocols will be made available on Protocols.io (https://www.protocols.io/), a secure, open-source, online platform for developing and sharing reproducible methods. Information pamphlets describing data use will be developed and "town-halls" will be held where producers can directly speak with data scientists to understand and comment on how their data are being used. This information will be developed and communicated as part of Objective 5. In addition to science content, the team will ensure 508 compliance accessibility. We will monitor activity from team members through student outreach database and measurable timelines. The stakeholder advisors will contribute to the format of outputs. Long-term data archiving will be through Ag Data Commons with proper project tracking identification.

Anticipated products

1. Gold standard protocols for rapid enumeration and categorization of highly pathogenic *Salmonella*.

2. Cutting-edge data management platforms and ontologies, advanced data standards, metadata collection, and data collection procedures for integrated, pre-harvest research.
3. Pilot studies to validate findings for application in real-world systems.
4. Data-driven, data-informed, and economically viable *Salmonella* intervention strategies and systems-based approaches verified for each commodity (broiler, turkey, swine, beef).
5. Economic cost-effectiveness models for industry buy-in and to ensure economically viable management suggestions for all commodities and levels of the pre-harvest industry.
6. Decision support tools for stakeholders that are easy-to-interpret and ready for company-specific individualization and implementation as next steps.
7. FSRIO publicly available science content including outreach to target audiences and communication of approaches to help a diverse set of producers.
8. Demonstration projects including webinars, pilot locations, and projects in collaboration with stakeholders to demonstrate the value of implementing *Salmonella* research outcomes.
9. Communications outreach tools and metrics (publications highlighting research, sharable content (videos), and the availability of open access tools) and outreach to the public and target audiences about the Grand Challenge and its products.

Section III: Next steps

As part of the synergies, this team will leverage relationships and projects to submit proposals for grant funding. The team plans to engage in agreements with companies developing food safety models for salmonella control and with industry producer/stakeholders to build individual decision tool dashboards for specific companies within commodity and tailored to their individual needs. We have diagnostic corporate interest and stakeholder buy in for this approach. The GCS Industry Advisory Board will facilitate beta testing for stakeholder use and will support continuing communications through outreach and demonstrations. This project will serve as a model for new integrated ARS food safety projects, enabling them to build off existing tools, data, and project management approaches developed as part of this project.

References

Beef Industry Food Safety Consortium. BIFSCo, 2022. https://www.bifsco.org/resources

FoodNet Fast, 2020. https://wwwn.cdc.gov/foodnetfast/

Food Safety Inspection Service. FSIS, 2020. Roadmap to Reducing Salmonella: Driving change through science-based policy. https://www.fsis.usda.gov/sites/default/files/media_file/2020-12/FSISRoadmaptoReducingSalmonella.pdf

Food Safety Inspection Service. FSIS, 2022. https://www.fsis.usda.gov/science-data

Health and Human Services. HHS, 2020. HealthyPeople2030. https://health.gov/healthypeople/objectives-and-data/browse-objectives/foodborne-illness/reduce-infections-caused-salmonella-fs-04

Jones, T. F., L. A. Ingram, P. R. Cieslak, D. J. Vugia, M. Tobin-D'Angelo, S. Hurd, C. Medus, A. Cronquist, and F. J. Angulo. 2008. Salmonellosis outcomes differ substantially by serotype. *Journal of Infectious Disease*. 198:109114. https://doi.org/10.1086/588823

National Pork Board. NPB, 2018. http://porkcdn.s3.amazonaws.com/sites/all/files/documents/PorkStore/04939.pdf

National Poultry Improvement Plan. NPIP, 2022. http://www.poultryimprovement.org/default.cfm?CFID=57242&CFTOKEN=da832b0121540c8d-E58843C6-E868-53AC-5A7F9E4CA1F70092

National Turkey Federation. NTF. *Salmonella* Risk Mitigation Practices, 2020. http://www.eatturkey.org/wp-content/uploads/2020/10/*Salmonella*-Interventions_September2020.pdf

USDA-ERS, 2021. http://ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx

Appendices

Appendix I. Personnel, Locations, Project Plans by Objective

Team	Members (leads in bold)	Location	Project number, title, NP
Steering Committee	**Tommy Wheeler, *Research Leader*** Shawn Bearson, *Microbiology* John Brooks, *Microbiology* Allen Byrd, *Microbiology* John Schmidt, *Microbiologist* Tatum Katz, *ARS SCINet Postdoc* **Kim Cook, *National Programs***	Clay Center, NE Ames, IA Mississippi State, MS College Station, TX Clay Center, NE Clay Center, NE Beltsville, MD	NP108, 42000-020-00D NP108, 32000-227-00D NP216, 21660-001-00D NP108, 32000-037-00D NP108, 42000-021-00D NP108, 42000-021-00D NP108
OBJECTIVE 1. Establish 'Gold Standard' methods, approaches, and integrated protocols	**Dayna Harhay,** *Microbiology* **Jonathan Frye,** *Microbiology* Shawn Bearson, *Microbiology*	Clay Center, NE Athens, GA Ames, IA	NP108, 42000-020-00D NP108, 32000-079-00D NP108, 32000-227-00D
OBJECTIVE 2. Identify drivers, reservoirs, and sentinels of highly pathogenic Salmonella in pre-harvest	**Allen Byrd,** *Microbiology* **John Brooks,** *Microbiology* **John Schmidt,** *Microbiology* Ade Oladeinde, *Microbiology* Mike Rothrock, *Microbiology* Christian Peters, *Research Leader* Dennis Todey, *Regional Climate Hub* Ardeshir Adeli, *Soil Science* Joseph Purswell, *Animal Science*	College Station, TX Mississippi State, MS Clay Center, NE Athens, GA Athens, GA Burlington, VT Ames, IA Mississippi State, MS Mississippi State, MS	NP108, 32000-037-00D NP216, 21660-001-00D NP108, 42000-021-00D NP108, 32000-012-00D NP108, 32000-012-00D NP107, 44530-001-00D NP212, 12610-001-00D NP216, 21660-001-00D NP101, 32630-008-00D
OBJECTIVE 3. Design novel, synergistic and/or multi-hurdle approaches to mitigate highly pathogenic *Salmonella*	**Shawn Bearson,** *Microbiology* **Ade Oladeinde,** *Microbiology* Allen Byrd, *Microbiology* Brad Bearson, *Microbiology* John Schmidt, *Microbiology* LaPorchia Collins, *Economics* Christopher Davis, *Economics*	Ames, IA Athens, GA College Station, TX Ames, IA Clay Center, NE ERS ERS	NP108, 32000-227-00D NP108, 32000-012-00D NP108, 32000-037-00D NP101, 31000-006-00D NP108, 42000-021-00D
OBJECTIVE 4. Build targeted cutting-edge data analytic and decision support tools	**Tatum Katz, *ARS SCINet Postdoc*** **Brittney Keel, *Mathematics*** Phillip Owens, PDI Christian Peters, *Research Leader* Ade Oladeinde, *Microbiology* John Schmidt, *Microbiology* LaPorchia Collins, *Economics* Christopher Davis, *Economics*	Clay Center, NE Clay Center, NE Boonville, AR Burlington, VT Athens, GA Clay Center, NE ERS ERS	NP108, 42000-021-00D NP101, 31000-099-00D NP215, 21310-011-00D NP107, 44530-001-00D NP108, 32000-012-00D NP108, 42000-021-00D

OBJECTIVE 5. Implement Communication and Outreach Activities	**Kim Cook, National Programs** **Dawana James-Holly, FSRIO** Tommy Wheeler, *Research Leader* Stephanie Ritchie, *Library Services* Patrice Armstrong, *FSRIO* Stephanie Gaddam, *AMR Coordinator*	ONP NAL Clay Center, NE NAL NAL ONP	NP108, 42000-020-00D

Appendix II. National Program Leaders

National Programs	
Kim Cook (GCS Lead)	Food Safety (NP108)
James Lindsay	Food Safety (NP108)
Steve Moeller	Food Animal Production (NP101)
Sarah Beebout	Sustainable Agricultural Systems Research (NP216)
Roxann Motroni	Animal Health (NP103)
John Finley	Human Nutrition (NP107)

Appendix III. Industry Advisory Board

	Chicken	**Turkey**	**Beef**	**Pork**
Member	Shanice Krombeen	Tom Smith	Ben Holland	Aaron Asmus
Position	Sr. Quality Assurance Manager	Vice President of Quality Management	Director of Research and Operations Analysis	Director of Lab Services and Refrigerated Foods Product Development
Organization	Pilgrim's Pride Corp.	Jennie-O Turkey Store	Cactus Feeders	Hormel Foods Corp.

Appendix IV. Industry Stakeholders Contributing to GCS Design

Stakeholder	**Position**	**Organization**
Aaron Asmus	Director of Lab Services and Refrigerated Foods Product Development	Hormel Foods Corp.
Mandy Carr-Johnson	Sr. Executive Director of Scientific Affairs	National Cattlemen's Beef Association
Marty Ewing	Quality Assurance Manager	Sanderson Farms
Suzanne Finstad	Vice President of Food Safety & Quality Assurance	Tyson Foods
Lindy Froebel	Director of Scientific & Regulatory Affairs	National Turkey Federation
Shanice Krombeen	Sr. Quality Assurance Manager	Pilgrim's Pride Corp.
Michelle Kromm	Vice President of Animal Health	Jennie-O Turkey Store

Ashley Lembke	Vice President of Food Safety & Quality Assurance	American Foods Group
Dan Malin	Sr. Director of Quality Assurance	Tyson Fresh Meats
Barbara Masters	Vice President of Regulatory Policy, Food, and Ag.	Tyson Foods
KatieRose McCullough	Director of Science and Public Health	North American Meat Institute
Patrick Mies	Director of Regulatory Affairs	National Beef
Robert O'Connor	Sr. Vice President of Technical Services	Foster Farms
Ashley Peterson	Sr. Vice President of Scientific and Regulatory Aff.	National Chicken Council
Angie Siemens	Vice President of Food Safety, Quality & Regulatory	Cargill Incorporated
Bruce Stewart-Brown	Sr. Vice President of Technical Services	Perdue Farms
Paul Sundberg	Executive Director	Swine Health Information Center
Kendra Waldbusser	Global Head of Food Safety and Quality Assurance	Pilgrim's Pride Corp.
Jennifer Williams	Vice President of Food Safety & Quality Assurance	Tyson Foods

List of associated National Programs

- NP101 Food Animal Production
- NP107 Human Nutrition
- NP108 Food Safety
- NP212 Soil and Air
- NP215 Grass, Forage, and Rangeland Agroecosystems
- NP216 Sustainable Agricultural Systems Research

Core team member names

All names for our core team as of 01/2024.

Name	Title	Email Address	Location	Position
Tommy Wheeler	Research Leader	tommy.wheeler@usda.gov	Clay Center, NE	Steering Committee Lead, Obj5
Shawn Bearson	SY	shawn.bearson@usda.gov	Ames, IA	Steering Committee, Obj3 Lead, Obj1
John Brooks	SY	john.brooks@usda.gov	Mississippi State, MS	Steering Committee, Obj2 Lead
Allen Byrd	SY	allen.byrd2@usda.gov	College Station, TX	Steering Committee, Obj2 Lead, Obj3
John W. Schmidt	SY	john.w.schmidt@usda.gov	Clay Center, NE	Steering Committee, Obj2 Lead, Obj3, Obj4
Tatum Katz	Postdoc	tatum.katz@usda.gov	Clay Center, NE	Steering Committee, Obj4 Lead
Kim Cook	NPL	kim.cook@usda.gov	Beltsville, MD	Steering Committee Lead, Obj5 Lead
Dayna Harhay	SY	dayna.harhay@usda.gov	Clay Center, NE	Obj1 Lead
Jonathan Frye	SY	jonathan.frye@usda.gov	Athens, GA	Obj1 Lead
Ade Oladeinde	SY	ade.oladeinde@usda.gov	Athens, GA	Obj3 Lead, Obj2, Obj4
Mike Rothrock	SY	michael.rothrock@usda.gov	Athens, GA	Obj2
Christian Peters	Research Leader	christian.peters2@usda.gov	Burlington, VT	Obj4
Dennis Todey	SY	dennis.todey@usda.gov	Ames, IA	Obj2
Ardeshir Adeli	SY	ardeshir.adeli@usda.gov	Mississippi State, MS	Obj2
Joseph Purswell	SY	joseph.purswell@usda.gov	Mississippi State, MS	Obj2
Brad Bearson	SY	brad.bearson@usda.gov	Ames, IA	Obj3
LaPorchia Collins	ERS	laporchia.collins@usda.gov		Obj3, Obj4
Christopher Davis	ERS	christopher.davis2@usda.gov		Obj3, Obj4
Brittney Keel	SY	brittney.keel@usda.gov	Clay Center, NE	Obj4 Lead

Phillip Owens	Research Leader	phillip.owens@usda.gov	Boonville, AR	Obj4
Dawanna James-Holly	NAL	dawanna.james-holly@usda.gov		Obj5 Lead
Stephanie Ritchie	NAL	stephanie.ritchie@usda.gov		Obj5
Zerena Murillo	Intern	zerena202@gmail.com		Obj5
Nirav Shah	Office of Comms	nirav.shah@usda.gov		Obj5
Xiang Li	SY	xiang.li@usda.gov	Athens, GA	Obj3
Weifan Wu	Postdoc	weifan.wu@usda.gov	Clay Center, NE	Obj2, Obj3
Stephanie Gaddam	AMR Coordinator	stephanie.gaddam@usda.gov	Beltsville, MD	Obj5

Executive Summary

Salmonella causes over one million illnesses and nearly 400 deaths each year and is the second leading cause of foodborne illness in the United States (USDA-ERS, 2021). Despite millions of dollars spent annually and a decrease in *Salmonella* prevalence on meat and poultry products, *Salmonella* illness rates have not decreased in the last twenty years. Attempts to reduce salmonellosis have been hindered by siloing of research projects and lack of integrated approaches for effective, interdisciplinary, and cross-scale management solutions. The goal of this Grand Challenge is to improve ongoing research on *Salmonella* by combining, standardizing, and coordinating research efforts across a diverse GCS team to optimize utilization of data from genomics, ecology, climate, economics, and intervention studies. This integrated approach represents a novel, comprehensive approach to enhance data use and machine learning analytics to uncover, predict and facilitate the reduction of *Salmonella* entering the supply chain from the farm. Alignment of this diverse team to the Grand Challenge goals will bring unique perspectives and synergies to bear on the most recalcitrant *Salmonella* challenges across the food animal system. We will provide stakeholders actionable data, standardized methods, and implementable intervention tools to reduce *Salmonella* associated with food animals and meat and poultry products, thus helping them implement affordable, effective, data-driven strategies to address their *Salmonella* food safety goals.

List of Grand Challenge project objectives

1. Tools. There is an ongoing shift to target the most dangerous *Salmonella* instead of all *Salmonella*, and rapid quantification remains an open challenge.
    a. Goals:
        i. Develop a common data ontology and gold standard methods.
        ii. Optimize existing and novel detection and quantitation methods.
2. Drivers. *Salmonella* ecology in meat and poultry pre-harvest production is poorly understood. Genetics x environment x management interactions need to be explored.
    a. Goals:
        i. Identify drivers, reservoirs, and critical control points for interventions.
        ii. Validate experimental findings with on-site studies at collaborating stakeholder facilities.
3. Interventions. Stakeholders noted a lack of applied pre-harvest interventions for mitigating *Salmonella*.
    a. Goals:
        i. Support biological and ecological interventions with economic analyses to ensure viability.
        ii. Work closely with industry advisory boards to develop strategies tailored to commodities.
4. Decision Support. Stakeholders noted a lack of use of available data, and high-level ecological and management interactions will require advanced modeling techniques to be understood.
    a. Goals:
        i. Provide statistical, mathematical, and data analytic support to the rest of the team.
        ii. Develop a web-based decision support tool for use by stakeholders.
5. Communications. Research cannot turn into functional, applied solutions in a vacuum.
    a. Goals:
        i. Produce content that is readily available to stakeholders.
        ii. Ensure content is relevant across diverse scales of production, commodities, and regions.

Current challenges and needs

Current challenges for our Grand Challenge primarily include data needs. Many experiments which were planned prior to the start of our Grand Challenge and which are now occurring do not have the necessary sample size to support our planned data analytics. Increasing our ability to process and collect samples from various points of the farm-to-fork pipeline will dramatically increase our research output. To this end, we have hired a postdoc and master's student to assist with laboratory assays. Additionally, for the large-scale geospatial processes we want to model, such as how extreme weather events and wildlife affect on-farm prevalence of *Salmonella*, we currently lack both data and the required expertise. We plan to address these challenges through the hiring of additional postdocs as well as working closely with University collaborators who have these types of data and expertise.

Current action items

Objective 1

- Interlab comparison of assays
- Assess utility of base set of measurements
- Establish interoperable database on SCINet

Objective 2

- Initiate and continue experiments to identify critical control points
- Collaborate with APHIS to collect preliminary data on *Salmonella* in wildlife that may potentially enter the pre-harvest sphere

Objective 3

- Initiate and continue experiments evaluating and validating *Salmonella* intervention strategies
- Develop economic analyses for each intervention found to be biologically effective

Objective 4

- Initiate and continue demonstration projects using preexisting data
- Develop a computational postdoctoral community of practice to support data analysis needs of the GC

Objective 5

- Continue to develop and update communications plan
- Develop a GC website
- Plan a GC workshop with stakeholders to present research findings and plan next phase of GC

Summary of primary research accomplishments

Within the first year of our Grand Challenge, we have met our objective goals as well as produced several research accomplishments. Most importantly, our team has produced five peer-reviewed publications spanning the topics of poultry vaccine efficacy, new molecular detection tools for virulent *Salmonella*, and epidemiological analyses to identify target *Salmonella*. Under Objective 4, we have completed analyses on a previously-collected 3-year study and have identified new research targets for future studies. Under Objective 2, we have continued to collect samples to build a dataset describing *Salmonella* presence in key wildlife species and have begun a collaboration with APHIS to collect additional samples ad data. Additionally, we secured funding through SCINet to hire two new computational postdocs to assist with modeling and analysis of data as well as with the decision dashboard. To support these incoming postdocs we have also initiated a postdoctoral Community of Practice working group to enhance collaboration across projects and datasets.

Team and stakeholder engagement activities

Objective meetings

- Objective 1 Meetings
  - November 9th 2022
  - December 9th 2022
  - February 10th 2023
  - March 10th 2023
  - May 12th 2023
- Objective 2 Meetings
  - November 18th 2022
  - December 1st 2022
  - February 2nd 2023
  - May 4th 2023
  - March 2nd 2023
- Objective 3 Meetings
  - November 10th 2022
  - December 5th 2022
  - February 2nd 2023
  - May 4th 2023
  - March 2nd 2023
- Objectives 1, 2, and 3 Meetings
  - June 1st 2023
  - August 3rd 2023
  - September 7th 2023
  - November 2nd 2023
  - December 6th 2023
  - February 1st 2024
- Objective 4 Meetings
  - October 26th 2022
  - November 18th 2022
  - December 5th 2022
  - February 10th 2023
  - March 7th 2023
  - May 2nd 2023
  - May 23rd 2023
  - June 14th 2023
  - August 1st 2023
  - September 6th 2023
  - November 7th 2023
  - December 5th 2023
  - February 9th 2024

- Objective 5 Meetings
    - November 14th 2022
    - December 5th 2022
    - February 6th 2023
    - March 6th 2023
    - June 8th 2023
    - August 7th 2023
    - September 18th 2023
    - October 31st 2023
    - December 4th 2023
    - February 5th 2024

Quarterly meetings with all ARS GC members

- January 13th 2023
- April 7th 2023
- July 14th 2023 (included the Industry Advisory Board)
- October 202th 2023 (included the Industry Advisory Board)
- January 19th 2024 (included the Industry Advisory Board)

Other meetings

- Industry Advisory Board Update
    - January 12th 2023
- Meeting with Adam Rivers to discuss data sources and new research group
    - April 26th 2023
    - Attendees: Objective 4 and Adam Rivers
- Risk Analysis meeting with the University of Minnesota
    - April 27th 2023
    - Attendees: all GC scientists and university collaborators Tim Johnson and Randall Singer from the Department of Veterinary and Medical Sciences at the University of Minnesota
- *Salmonella* and machine learning meeting with Georgia Tech
    - July 6th 2023
        - Attendees: Tommy Wheeler, Dayna Harhay, John Schmidt, Tatum Katz, and university collaborators Jie Xu and Stephanie Richter from the Georgia Tech Research Institute
    - October 19th 2023
        - Attendees: Tommy Wheeler, Dayna Harhay, Mick Bosilevac, Arthur Terrance, Tatum Katz, John Scmidt, and university collaborators Jue Xu, Stephanie Richter, and Doug Britton from the Georgia Tech Research Institute
- Sampling wildlife for *Salmonella* collaboration with APHIS meetings
    - October 13th 2023

        - Attendees: Kim Cook, John Schmidt, John Brooks, and APHIS collaborators Alan Franklin and Scott Goetz
    - November 1st 2023
        - Attendees: Kim Cook, John Schmidt, John Brooks, Tatum Katz, Tommy Wheeler, and APHIS collaborators Alan Fanklin, David Marks, and Travis Guerrant
    - February 5th 2024
        - Attendees: Kim Cook, Tatum Katz, John Schmidt, John Brooks, Michael Rothrock, and APHIS collaborators Alan Franklin, Scott Goetz, and David Marks
- Discussion about research goals for the GC with Pilgrim's Pride
    - November 13th 2023
    - Attendees: Tatum Katz and Industry Advisory Board member Shanice Krombeen of Pilgrim's Pride
- Salmonella Grand Challenge Postdoctoral Community of Practice meetings
    - February 14th 2024
        - Attendees: Tatum Katz, Weifan Wu, postdoc GC collaborators Paul Villanueva, David Bradshaw, Walid Al Hakeem, Yewande Ajao, Nathaniel Ellis, and PhD student Minho Kim from the University of Illinois

Research accomplishments

- Publications
    - Katz TS, Harhay DM, Schmidt JW and Wheeler TL (2024) Identifying a list of *Salmonella* serotypes of concern to target for reducing risk of salmonellosis. *Front. Microbiol.* 15:1307563. doi: 10.3389/fmicb.2024.1307563
    - Bearson SMD, Monson MS, Bearson BL, Whelan SJ, Byrd JA II, Burciaga S (2024) Commercial vaccine provides cross-protection by reducing colonization of *Salmonella enterica* serovars Infantis and Hadar in turkeys. *Vaccine*, 42(2), 727-731. https://doi.org/10.1016/j.vaccine.2023.12.054
    - Elizabeth A McMillan, Lari M Hiott, Joao A Carrico, Miguel P Machado, Hannes Pouseele, Charlene R Jackson, Jonathan G Frye, Polymerase chain reaction for the *in vitro* detection of the pESI plasmid associated with the globally circulating *Salmonella* Infantis outbreak strain, *Letters in Applied Microbiology*, Volume 76, Issue 8, August 2023, ovad088, https://doi.org/10.1093/lambio/ovad088
    - Burciaga S, Trachsel JM, Sockett D, Aulik N, Monson MS, Anderson CL and Bearson SMD (2023) Genomic and phenotypic comparison of two variants of multidrug-resistant *Salmonella enterica* serovar Heidelberg isolated during the 2015–2017 multi-state outbreak in cattle. *Front. Microbiol*. 14:1282832. doi: 10.3389/fmicb.2023.1282832
    - Cho S, Hiott LM, Read QD, Damashek J, Westrich J, Edwards M, Seim RF, Glinski DA, Bateman McDonald JM, Ottesen EA, Lipp EK, Henderson WM, Jackson CR, Frye JG. Distribution of Antibiotic Resistance in a Mixed-Use Watershed and the Impact of Wastewater Treatment Plants on Antibiotic Resistance in Surface Water. Antibiotics (Basel). 2023 Nov 2;12(11):1586. doi: 10.3390/antibiotics12111586. PMID: 37998788; PMCID: PMC10668835.
- Data sets
    - In order to bring together all the diverse data from projects throughout the Grand Challenge, we are developing a standard data template for use by all collaborators. This data template will help us collect key core measurements used to link all studies together, as well as additional data for secondary analyses, in a standardized framework that allows ease of querying and modeling. This template is being developed with input from all Grand Challenge scientists and is currently being tested on a variety of different datasets to make sure it works for our diverse projects.
    - Wildlife reservoirs of *Salmonella* and AMR
        - PIs: Dr. John P. Brooks and collaborators at Mississippi State
        - Current research efforts identifying 'non-obvious' contributors to the environmental antimicrobial resistome are lacking. Foodborne pathogens such as *Salmonella* are often reduced to minimal levels at processing plants, but 'cryptic' environmental sources and selection

pressures for these pathogens and AMR are still unknown. With our current study, we are investigating the carriage rate and spatial movement of 'cryptic' wildlife such as wild turkeys carrying *Salmonella* and antimicrobial resistant fecal indicator bacteria, such as *Escherichia coli* and *Enterococcus*. This works continues to build on our ongoing research investigating environmental sources of AMR and bacterial pathogens, thus supporting a key aspect of One Health. In our current study, we have completed 3 of the first 4 seasons of 2023's sampling efforts and now aim to utilize the collected data to model the spatial distribution to inform next year's environmental sampling of suspected hotspots. Through the first three seasons, overall *Salmonella* carriage has been low, below 10% of all samples collected.

- Presentations
    - Li, X. Comparison of metagenomic sequencing methods using *Salmonella* Heidelberg infected broilers. Poster Presentation. *International Poultry Scientific Forum*, January 29-30, 2024, Atlanta, Georgia