2024 EXECUTIVE SUMMARY

CENTER FOR LOW-MOISTURE FOOD SAFETY

COLLABORATORS

Michigan State University

Purdue University

The Ohio State University

University of California-Davis

Washington State University

University of Arkansas

North Carolina State University

Illinois Institute of Technology

U.S. Food and Drug Administration (FDA)

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USDA National Institute of Food and Agriculture
U.S. DEPARTMENT OF AGRICULTURE

LEAD COLLABORATORS

Center for Low-Moisture Food Safety

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Teresa Bergholz, Ph.D. – Theme 2

Sanghyup Jeong, Ph.D. – Theme 2

Felicia Wu, Ph.D. – Themes 1 and 4

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Juming Tang, Ph.D. – Theme 2

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PURDUE UNIVERSITY

Yaohua (Betty) Feng, Ph.D. – Themes 1 and 3

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Nathan Anderson, Ph.D. – Themes 2 and 3

Elizabeth Grasso-Kelley, Ph.D. – Themes 2 and 3

PROJECT HIGHLIGHTS

Center for Low-Moisture Food Safety

NOTE FROM THE DIRECTOR

Bradley Marks (Michigan State University)

This very brief Executive Summary is designed to give a high-level overview of the key areas of progress and planning in each of our four overall Themes at the end of the fourth year of our six-year project. A bibliography at the end lists the project outputs for the year (and links to cumulative lists of outputs); the reader is encouraged to explore topics of interest more deeply, and to reach out to any member of the project team (or to me, to help broker connections) with any questions, suggestions, or feedback. As a reminder, our ***overall goal*** is to accelerate the adoption of a sustainable food safety culture in commodity-based low-moisture food systems via an integrated, transdisciplinary, systems-based approach, with interconnected and parallel research, extension, and education activities, and our ***long-term objective*** is to reduce foodborne illnesses and product recalls linked to low-moisture foods to improve the protection of public health and the economic health of large and small entities within the industry. I look forward to any questions or feedback you might have. – Brad

2024 HIGHLIGHTS

Our fourth year was a year of transition as we have increased our focus on cross-theme synergies and our desired, ultimate "headline outcomes." Given our prior foundational research, we now are focusing on increasingly complex, increasingly impactful outputs that seek to improve low-moisture food safety. These outputs include numerous conference events improving perspectives/practices for low-moisture food processes, and studies that are tailored to improve the integration of our research into industry practices. Studies include those examining consumer behavior, improving process validations (through models, surrogates, and through direct involvement in improving guidance documents), and a systematic assessment of remaining food safety research and extension needs for the U.S. low-moisture food industry. As we head into the final two years of this project, we now are focused on activities that will serve as capstones ("headline outcomes") for this project, activities that will support the U.S. low-moisture food industry by delivering on the very needs identified by our research. *Examples* include: (1) A deep analysis of how industry culture impacts the transition of low-moisture food sectors from commodity to food safety paradigms, (2) Integrated approaches for monitoring, modeling, and validating pathogen control steps in fruit drying systems (and appropriate targets), (3) Deployment of extension and education resources tailored to low-moisture food systems, and (4) Integration of economic analyses and food safety risk models into a decision-support tool for evaluating investments in food safety technologies. We are moving the needle, but there is important work still in front of us!

BY THE NUMBERS

Impact can be measured in many ways, and our team has always kept the "long game" in the viewfinder as we pursue our specific short-term objectives. In terms of traditional, immediate measures of scholarly output, our project team has continued to be incredibly productive, relative to publications, presentations, and student completion. Lists of these outputs for 2023-2024 are included at the back of this report, along with links to the actual articles (when available as open access) and to a cumulative repository of project outputs on our webpage. A few key metrics are as follows:

- *Publications.* Our team published 15 journal articles this past year and a cumulative total of 56 publications to date. Notably, our team is publishing in journals with an average impact factor of 5.8, which is almost double the median impact factor in this category (3.1). Additionally, our work has already been cited 497 times (corresponding to a project h-index of 12), in just the fourth year of the project.
- *Students*. 6 graduate students on this project completed their theses/dissertations this past year (17 over the course of the project to date), and 16 current graduate students continue to work on the various Themes of the project.
- *Conference Presence.* Our team presented 20 posters and 5 technical presentations related to this project at the International Association for Food Protection (IAFP) 2024 Annual Meeting. We also organized/led one symposium (on surrogates), one roundtable (on *Cronobacter*), and one very successful, two-day workshop.

THEME 1: HUMAN FACTORS

Center for Low-Moisture Food Safety

SUMMARY

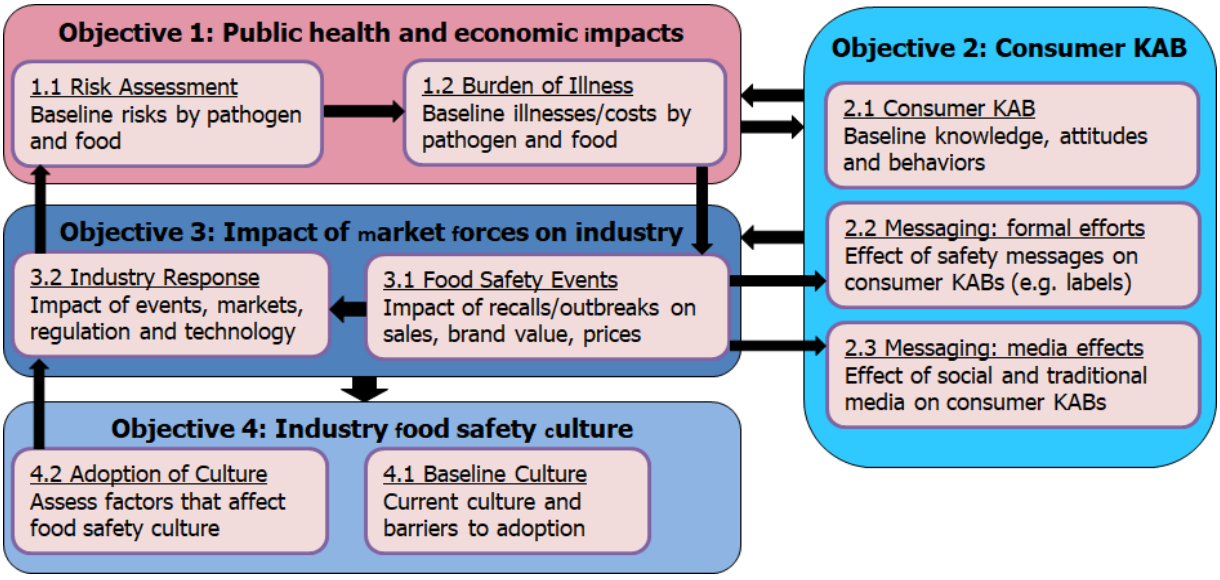
- Quantify public health and economic impacts of illnesses linked to low-moisture foods.
- Evaluate consumers' knowledge attitudes, and behaviors related to low-moisture food safety, and develop and test intervention/extension/outreach programs and strategies.
- Conduct economic analyses examining the influence of market forces, regulatory changes and novel technologies on industry stakeholders' food safety behaviors.
- Assess barriers to adopting a food safety culture in the low-moisture food industry, especially for small companies.

2024 HIGHLIGHTS

Theme 1 reached a significant milestone with the publication of a study entitled "food safety research and extension needs for the U.S. low-moisture food industry." In this study, major barriers to food safety culture and education were identified using data collected from two surveys of various low-moisture food safety experts. Guidance for future works from academia, the food industry, and regulatory agencies to improve the adoption of adequate food safety culture was provided. Theme 1's efforts to evaluate food safety culture and/or burden of foodborne illness for specific food commodities continued throughout the past year, which include almonds and dried fruit. Work has also begun on assessing industry response and resilience to food safety events.

FUTURE GOALS

The next year will involve working closely with industry stakeholders (e.g., The Almond Board of California) to understand how successful food safety cultures evolve and are implemented. Research will also include evaluating actions taken by companies in response to food safety events (investment in food safety controls, investment in food safety culture, resilience). Finally, members of Theme 1 will continue their contribution to important food safety databases tracking foodborne illness events and cost estimates.



THEME 2: PATHOGEN BEHAVIOR AND CONTROL

Center for Low-Moisture Food Safety

SUMMARY

- Characterize and model pathogen persistence, propagation, transfer, survival, and inactivation through the entire low-moisture food system, from harvest-to-consumer.
- Develop improved design standards and novel technologies for hygienic design and sanitation of low-moisture food handling and processing equipment.
- Develop engineering tools and extension resources supporting to support small companies in implementing measurement systems for critical process factors.

2024 HIGHLIGHTS

Theme 2 has completed various tasks that contribute to each of the objectives established for this Theme. For Obj. 5, we have examined the impact of several post-harvest activities on the survival of pathogens. For almonds and wheat berries, we identified optimal experimental methodologies for generating robust and reproducible inoculated batches. For wheat berries, this enabled us to examine the impact of different tempering procedures (i.e., solutions containing industry-relevant antimicrobial agents). For almonds, the research on refined methodologies contributed directly to industry validation guidelines. Over the past year we examined the impact of wax applications on *Listeria* stability on apples and different hurdle technologies (steam and peroxyacetic acid) on *Listeria* stability on food contact surfaces relevant to apple processing environments. Multiple Theme 2 institutions coordinated research efforts to characterize *Salmonella* inactivation kinetics in apple drying processes, resulting in a comprehensive evaluation of various factors relevant to fruit drying processes.

Significant milestones for Obj. 6 (cleaning/sanitation standards) and Obj. 7 (engineering tools for measuring critical factors) were reached. Standard methodological practices for evaluating the efficacy of cleaning/sanitation technologies were established. As a result, we were able to establish the difference between “visibly” and “quantifiably” clean surfaces and the factors (treatment parameters, humidity, attachment forces) that contributed to attainment of either state. Publications are being drafted examining the impact of vacuum, infrared, and UV treatments in dry cleaning/sanitation systems. Our evaluation of relative humidity sensors at elevated temperatures has been completed and we are in the process of drafting industry guidance.

FUTURE GOALS

Over the next year, we plan on targeting research that would most effectively advance the industry-readiness of our overall grant. For almonds, as the most comprehensively researched food our project focused on, we will be working directly with the Almond Board of California to address gaps for the development of updated validation guidelines. This work will also enable us to extend our expertise to improve resources supporting all tree nut processes. For apples and wheat, our research is shifting to generating information that directly supports the validation of preventive controls. This includes identifying suitable surrogates for wheat tempering and apple drying, developing the resources necessary for implementing these findings in industry processes. This also includes pooling the massive amount of thermal inactivation data that has been collected to work on development and pilot-scale validation of a *Salmonella* inactivation predictive model. In wheat products, we will be investigating desiccation tolerance amongst a genetically diverse set of *Salmonella* strains to help identify strains of most concern.

With the standardized methodologies established by our Theme 2 cleaning/sanitation researchers, we plan on expanding our investigation of different pathogen control strategies. We are coordinating with other cleaning/sanitation researchers (e.g., Dr. Abigail Snyder from Cornell) industry leaders (e.g., SAG and 3A), as well as performing a comprehensive literature review on existing cleaning/sanitation practices, in order to maximize the impact of this research component in the final stretch of the project.

THEME 3: EXTENSION AND EDUCATION

Center for Low-Moisture Food Safety

SUMMARY

- Develop and evaluate multi-level extension/outreach programs and resources spanning the cultural, technical, scientific, regulatory, and economic domains for industry personnel.
- Develop, implement, and assess formal educational courses in low-moisture food safety systems at the associate-degree (workforce) and graduate (scientific/technical) levels, and involve young professionals in project workshops to expand knowledge and networks.
- Develop and test decision-support tools to enhance industry adoption of optimal food safety interventions at multiple points in the low-moisture food system.

2024 HIGHLIGHTS

Theme 3 team members were active this past year, engaging stakeholders at various conferences and at events led by our members of our team. Most notably, at this year's International Association for Food Protection (IAFP) annual meeting, our team led a pre-conference workshop on validating low-moisture food preventive controls (25 attendees that were predominantly industry members), organized/presented a symposium on surrogates for the validation of preventive controls, and organized/moderated a roundtable discussion on *Cronobacter* spp. Our team continued our extension and engagement activities with the consumer food safety education summer school and IFSH Low Moisture Food Safety Task Force meeting. Dr. Harris has been working closely with the Almond Board of California to update their guidelines documents for improved validation practices.

FUTURE GOALS

Our team will continue our annual reoccurring activities (Low Moisture Task Force meeting, consumer food safety education summer school, annual stakeholder meeting). Dr. Feng is organizing an IAFP symposium on accessing and improving food safety culture in the food industry. Our team will continue our work with the Almond Board of California to revise guideline documents (e.g., blanching and roasting process validations). Lastly, web-based formal education resources for workforce and two-year post-secondary programs will be finalized and tested.

THEME 4: INTEGRATED RISK AND SUSTAINABILITY ANALYSES

Center for Low-Moisture Food Safety

SUMMARY

- Conduct risk analyses that uniquely integrate and link quantitative measures for probability of illnesses, communication efficacy, and management impacts for low-moisture food systems.
- Conduct sustainability analyses of current and alternative/novel food safety interventions at multiple points in the low-moisture food system.

2024 HIGHLIGHTS

Sustainability analyses for all three representative commodities (almonds, dried apples, and wheat flour) were completed and are being drafted into manuscripts with the expected publication in the late fall 2024 or early spring 2025. This work will be instrumental in contextualizing the impact of various food safety intervention strategies still being evaluated by our team beyond the relative utility for reducing foodborne pathogen risk.

FUTURE GOALS

With the recent completion of sustainability analyses for each of the three representative commodities (almonds, dried apples, and wheat flour), our Theme 4 members plan on working across other Themes to inform their work and continuing to integrate new information, refining different aspects of the sustainability analyses. Work with Theme 1 will improve how industry behaviors are integrated into overall systems sustainability and risk models. Results being generated by Theme 2 will improve the integration of different preventive controls or sanitation/cleaning technologies into life-cycle analyses and risk models. Overall, integration of sustainability and food safety risk models will be one of the significant, unique contributions of these collaborative efforts. Lastly, all the above results will inform final development and field testing of a decision-support tool for justifying economic investments in food safety technologies, with the goal of supporting food safety professionals in making the case for economic investments in food safety technologies, justified by quantifying the economic value of reducing the risk of recalls and outbreaks.

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A cumulative list of all CLMFS peer-reviewed journal articles can be viewed at lowmoisture.msu.edu/project-outputs

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3. Ian Klug. 2023. M.S., Michigan State University. Elucidating critical factors for practical dry-cleaning applications on low-moisture food contact surfaces

4. Jessica Bain. 2024. Ph.D., University of Arkansas. Integrating Sustainability and Food Safety through Quantitative Microbial Risk Assessment and Life Cycle Assessment of Low-Moisture Foods.

5. Kasey Nelson. 2024. M.S., Michigan State University. Evaluating the efficacy of radiative dry sanitation techniques on *Salmonella*-inoculated stainless steel surfaces post visible cleaning.

6. Zachary Berglund. 2023. M.S., Purdue. Exploratory data analysis of consumer food safety behaviors.

Presentations

View the full collection of USDA SAS CLMFS conference posters, technical presentations, webinars, seminars, symposiums, and round tables at lowmoisture.msu.edu/project-outputs