**NE19173: Improving Sustainable Poultry Production through Collaborative Research and Outreach**

**Duration**: 10/01/2024 to 09/30/2029

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**Statement of Issues and Justification**

As the demand for sustainable and efficient poultry production continues to grow worldwide, the role of advanced research and innovation in the industry becomes increasingly significant. The United States Poultry and Egg Association, recognized as the worlds’ largest and most dynamic organization in the poultry industry, has acknowledged the imperative of integrating engineering and technology to optimize energy and resource efficiencies across layers, broilers, and turkeys. As a non-profit entity, it aligns its strategic goals with the evolving needs of the poultry industry, emphasizing advancements in poultry science and technology, and the assurance of safety in processed poultry and poultry products. The organization's ongoing and past research initiatives closely align with these objectives, fostering collaboration in critical areas such as nutrition, environmental control, air quality, housing systems, lighting, automation, robotics, food safety, security, health, and bird welfare.

Furthermore, the United Egg Producers (UEP), representing the laying hen industry, recognizes the necessity for enhanced technology to improve management practices and the well-being of laying hens in alternative housing systems, particularly cage-free aviaries. Additionally, industry entities like the Egg Industry Center actively support collaborative research and outreach endeavors aimed at addressing challenges faced by the poultry and egg industry.

In response to the rising global population, there is an escalating demand for sustainably, efficiently, and safely produced protein, particularly in poultry. The adoption of Precision Livestock Farming (PLF) techniques in poultry production and processing systems; is identified as a strategic measure to meet this growing demand. Evolving consumer and retail preferences have led to diverse production and feeding systems, each presenting unique challenges and knowledge requirements. The collaborative research proposed here aims to further expand PLF concepts, incorporating automated continuous monitoring of animals to enable real-time recording and assessment of their health and welfare. This inclusive approach encompasses automation, robotics, equipment efficiency, facility design, as well as energy and resource allocation. Additionally, enhancements in antimicrobial intervention technologies and processing methods are, envisioned to reduce the risk of foodborne pathogens in poultry and poultry products.

Optimizing poultry production systems for energy/resource efficiency, minimizing carbon footprint, and ensuring sustainability across the production chain (breeder, hatchery, producer, processor, and consumer) is paramount. Collaborative research serves as the foundation that connects different components of the system and their intricate relationships. The failure to renew this project would jeopardize the poultry industry's standing in the global marketplace, hindering its ability to deliver safe and nutritious poultry products to consumers worldwide.

The multi-state poultry research team, composed of diverse experts including environmental physiologists, behaviorists, animal welfare scientists, nutritionists, engineers, extension scientists, microbiologists, and economists, operates with access to commercial-type, pilot-scale, and laboratory-scale facilities. Their collective expertise and collaborative efforts have yielded documented success in the past. Moreover, the team includes several leading industry experts actively engaged in the collaborative process, providing invaluable insights and establishing crucial links between researchers and commercial operations, birds, and equipment. This dynamic collaboration enhances the relevance and feasibility of research endeavors, ensuring their practical applicability in the field.

**Objectives:**

Collaborators at the experimental stations in AL, AR, CA,CT, DE, GA, USDA-ARS (GA), HI, IL, IA, IN, KY, MD, MI, MN, MS, NE, NC, PA, SC, TN, TX, and VA will work on research related to the following objectives:

1. **Advancing Sustainable Poultry Systems through Precision Management:**
2. ***Pre-harvest:*** This section will cover environmental control and management, housing, litter management, ventilation, lighting, pre-harvest food safety, nutrition, feed processing, behavior, and welfare.
3. ***Post-harvest:***

Post-harvest considerations will encompass food safety, processing methods, waste-water- management, offal, and rendering.

1. ***Environmental footprint:*** This section willexplore avenues related to carbon footprint, nutrient utilization, production systems, and life cycle analysis.

**2**. **Fostering Innovative Production Practices through Research and Extension:**

* 1. ***Pre-harvest:*** This section will cover incubation and hatchery, reproductive physiology, nutrient excretion reduction, precision nutrition, alternative feed ingredients, NAE/ABF practices, alternative feeding strategies, gut health, gut microbiome, poultry health and disease management, alternative sustainable production systems, production systems under regulatory exemption, economic analysis, and bird welfare. Various research initiatives are underway.
	2. ***Post-harvest:*** This section will cover cutting-edge processing methodologies, production systems under regulatory exemption, and the quality of meat and eggs.

***c. Outreach and training:*** This section will cover various aspects of outreach and training that several of the universities will and are pursuing.

***d. Poultry economics:*** This section will cover the aspect of how poultry economics plays a role in conducting the studies to answer some of the questions outlined in the objectives.

We have state of the art commercial poultry production facilities, which will allow us, to conduct research (AL, IA, IN, IL, MN, MS, NC, PA, and VA). Facilities with fully functioning processing plants for converting birds to food (GA and AL) are available for use. The specialized equipment located at these stations can enhance collaborative research efforts and could bring synergistic outcomes. Therefore, the collaborative use of these facilities by participating universities and USDA stations will maximize research productivity.

Due to the complexity of the poultry industry needs, research objectives addressed by this multi-state project could not, be accomplished at any single station/university. Each of the researchers has expertise and facilities to address some component(s) of poultry production efficiency, well-being, nutrition, environmental concerns, facility management, and/or technical monitoring of poultry environments and poultry processing. To best, comprehensively address the challenges facing the poultry industry identified in this project, a collaborative effort is necessary and will eliminate duplication of effort and conserve resources.

Data generated from these collaborative research efforts will enhance the resiliency of the poultry industry through real-time monitoring of facilities, leading to improved poultry welfare, performance, food safety and security throughout poultry production.

The successful completion of the objectives outlined in this proposal will lead to:

1. Incorporation of advanced science, engineering and technology into poultry production facilities to enhance system efficiency, and improve production efficiency and poultry well-being.

2. Identification of relationships between environmental, nutritional, and disease factors that affect poultry well-being, food safety, and economics.

3. Establishment and adoption of current and future poultry husbandry practices and development of a trained scientific workforce to address a changing industry landscape.

4. Development of new antimicrobial intervention technologies or processing methods to control foodborne pathogens in poultry and poultry products.

**Related, Current and Previous Work**

A CRIS search on poultry environment or production systems did not identify any active multi-state projects, other than the existing NE1942 state projects, other than the existing NE1942.

**Contributions NE1942 investigators.**

NE1942 was, founded in 1978 to facilitate research in the area of poultry production recognizing collaboration and communication amongst the research institutions would advance poultry management strategies. NE1942 has grown from 11 universities in 1999 to 18 universities and 2 USDA-ARS units for the 2019 renewal. The multistate group has expanded to 22 universities and 1 USDA-ARS unit, for this 2024 rewrite. An annual, meeting is, held each year to discuss research results and plans collaborative projects for the coming year. The NE1942 philosophy is to help implement sustainable practices in poultry production for the industry from a multi-state collaborative approach. Recognizing that more advances can be, made as a collaborative group rather than working as a single investigator-initiated grant. The complexities of animal-environment interactions overlaid with animal welfare and consumer demands require a multi-discipline, collaborative approach to identifying ways to best achieve the producer and societal goals.

**Examples of sustained endeavors by NE1942 participants include:**

1. History of publication in the scientific literature. Over the last 4 project years of this 5-year project, this regional poultry research group has published 284 peer-reviewed journal articles, 380 abstracts, 45 popular-press articles, 35 peer-reviewed extension reports, and 80 proceedings at national and international meetings.
2. Success with joint proposals demonstrates the capacity of NE1442 to coordinate ideas, resources, and execute multi-state research projects.
3. The multistate research group has secured over $20 million in grants to conduct research with the NE1442 project during the last project cycle (5-year) period.

Collaborative research previously conducted and currently being, worked on by these research stations is, listed, below.

Collaborative research between stations in CA and TN is underway to develop and validate systems tracking hens' resource utilization in cage-free housing systems. Noteworthy multistate collaborators include Dr. Richard Blatchford from UC Davis and Dr. Yang Zhao from the University of Tennessee.

Collaborative research between the GA and NC stations involve the study of hen-housing interactions on welfare parameters. UGA and NC researchers are also collaborating to understand the gut-brain-behavior axis in chickens. Multistate members include Dr. Prafulla Regmi from UGA, Dr. Kenneth Anderson, and Dr. Allison Pullin from NC.

Researchers at the University of Minnesota (UM) will persistently investigate sustainable food safety solutions applicable to poultry production systems. Collaborations with industry and other university partners will inform multiple research projects. Ongoing efforts include investigating targeted microbial interference strategies against pathogens relevant to the turkey industry, with a focus on producing gut friendly and environmentally friendly solutions, to strengthen a sustainable poultry food supply.

The CA station collaborates on the investigation of woody breast causes a measurement method in broilers. The CA and TN stations are jointly exploring housing and genetic factors contributing to keel bone fractures in laying hens, with collaboration from multistate members Dr. Richard Blatchford (UC Davis) and Dr. Yang Zhao (U. Tennessee).

**Current Work: Literature Review**

According to the United Nations, the global population will reach 9.8 billion in 2050; this rapid growth necessitates a dramatic increase in the world’s food supply, requiring 60 to 110% more agricultural products produced. However, the yield projected based on the current increasing rates are insufficient to meet the 2050 demand. Therefore, farmers worldwide will have to boost agricultural production, either by increasing the amount of agricultural land/facilities or by enhancing productivity with existing resources. The objectives of this multistate project aim to help in achieving this growth in agricultural production.

**OBJECTIVE 1**

**1. Advancing Sustainable Poultry Systems through Precision Management.**

***1a. Pre-harvest:***

***Engineering and Technology.*** Poultry producers will inevitably rely on advanced tools and technologies to handle challenges in the process of production expansion. Compared to other industrial sectors, agriculture has been a sector tardy in applying high-tech engineering systems. In the early '80s, scientists promoted the concept of 'precision agriculture,' which aims to optimize agricultural returns on inputs and preserve resources by observing, measuring and responding to inter and intra-field variabilities with advanced technologies. Since then, precision agriculture has been exhibiting significant impacts to sustainable agricultural production. While most efforts in precision agriculture have been, dedicated to crop production, its application and research on livestock and poultry are scarce. Real-time monitoring of metrics (i.e., ventilation, air quality, lighting, acoustics, microbial, and others) within the production system needs to be at both a flock and individual bird basis; this allows for welfare elements and distinctions to be, balanced for the flock and individuals, which is a critical component of precision agriculture.

***Technology, Monitoring Systems, and Environmental Control Management.*** Currently, poultry producers have a limited ability to identify and address problems within in a production system rapidly. This is because more real-time monitoring systems have been, directed at larger animals, such as swine or dairy. The discrepancy in innovation efforts directed at poultry likely reflects monitoring difficulties caused by the small size of the birds, and related to tracking similarly looking individuals within very large flocks (up to 100,000 plus per poultry house). While there has been some development of sensor technology to track hen movement, the existing methods are not without problems. Many rely on video to track patterns of the flock (therefore, do not provide information at the individual level) or electronic technologies that are incompatible with poultry housing systems (e.g., other birds and objects within the environment interfere with signals). The development of hen-mounted acoustic sensors and acoustic monitoring systems offers a novel approach with the potential for mitigating these problems. For instance, sensors can be placed under the feathers, reducing damage from pecking, and allow continuous recording of hen location compared to sensors that require readers in fixed locations. These devices can be, quite small, easily automated, and, do not need external readers, compared to devices used now.

***Poultry Welfare and Housing Environment.*** A need for objective determination of poultry welfare is of utmost importance as guidelines transition from resource-based allocations to outcome-based inspections of the birds in their housing environment (Hester, 2005). Many factors in the housing environment have been, shown to effect poultry welfare (Kang et al., 2023; Jacobs et al., 2023). Currently, outcome-based welfare assessments of poultry (Abdelfattah et al., 2020; Johnsonon et al., 2019), are performed by subjective evaluation of trained individuals. This can still lead to different interpretations of the numerous indicators of welfare, such as, overall plumage score, cleanliness, keel deformation, comb pecking, footpad dermatitis, claw length, skin lesions, beak trimming, and toe damage. Furthermore, the scoring of these indicators is discrete without any discretion for intermediate scores. Advances in technology have led to machine vision systems capable of advanced pattern recognition needed to identify and classify different indicators of bird welfare accurately. The use of technology to aid in welfare assessments could substantially decrease observer-observer differences, and allow, for a rapid and widespread application of welfare assessments to advance the industry at the rate needed to match demand. This is especially relevant in the layer industry, where legislation in states (California) has mandated for certain alternative housing standards. Due to consumer demand and this legislation, producers have had to change to these alternative hen-housing systems, without knowing the impact on bird health and welfare.

***Environmental Control Management.*** As novel technologies, new housing, and system designs emerge, there is a need for evaluation and optimization of these systems to establish best management practices for producers. Bist et al. (2023) published a review of the effects of ammonia emissions, impacts, and mitigation strategies for poultry. Particular interest is, focused on perches, lighting, system layout, and ventilation (including equipment, thermal and air quality) depending on poultry production system (Zheng et al., 2020; Liang et al., 2022). Considerable research has been, conducted on ventilation requirements of broiler houses as well (Li et al., 2023b). The provision of perches in hen housing systems could still lead to many detrimental effects (e.g., keel bone deformities, foot disorders, and bone fractures) that would negatively, impact production and welfare of the birds (Ali et al., 2019). Considerable efforts are still needed towards optimizing perch design (e.g., shape, size, texture, material, and temperature), spatial arrangement (e.g., height, angle, and relative position), and management (e.g., timing of bird’s introduction to perches). Furthermore, lighting is of critical importance and a crucial environmental factor that affects behavior, development, production performance, health, and well-being of poultry (Lewis and Morris, 2000; Parvin et al., 2014). The effects of blue and red light can influence egg production in laying hens (Poudel et al., 2022). Recently, LED lights have become more readily available and affordable to poultry producers; these lights, are promoted as being more energy-efficient, readily dimmable, and long lasting. However, the existing lighting guidelines/recommendations were mainly, established based on the traditional incandescent or CFL lights and may not accurately reflect the operational characteristics and impact of the LED lights on birds.

***Aviary and Floor Rearing Systems.*** Although layer aviary systems have existed in the US for the last decade, the ventilation and environmental control requirements are vastly different from the conventional housing (Hayes, 2012; Zhao et al., 2015). This situation is in part due to the lower stocking density and access to litter on the floor. Mainly during the winter, ventilation for indoor air quality at the lower stocking density requires supplemental heat, which must be, properly distributed throughout the house. Further challenges in aviary systems include design ventilation rates, indoor air quality, heat, and moisture production of the birds and the surroundings, fuel usage, and the birds’ preference for winter temperature-ammonia combinations (Zhao et al., 2013). Another concern with these housing systems is that a portion of manure from the birds is, held in the house on the floor as litter. Litter on the floor impacts indoor air quality and can lead to elevated ammonia and dust concentrations (Shepherd et al., 2015).

There have been, resent research published, that has been, directed at the effects of aviary design on laying hen behavior and pullet rearing (Yang et al., 2023). Some research has looked at providing ramps in a cage-free aviary to provide for better movement of birds (Stratmann et al., 2022a; 2022b), while more recent research has used machine learning to track floor eggs produced by cage-free hens and monitor and record their pecking behavior (Subedi et al., 2023a; 2023b). Ali et al. (2020) researched the effects of aviaries on the general health of laying hens, and Yang et al. (2022) developed a model for detecting cage-free hens on the litter floor. These studies have indicated that there is still much to learn about, how to, properly manage cage-free aviaries for the optimum health and welfare of laying hens.

***Nutrition, Alternative Ingredients and Feedstuffs.*** The use of alternative feed ingredients in poultry diets has many implications. Many of these ingredients and feedstuffs, impact, broiler and laying hen welfare, health, growth, and performance. Feeding ingredients such as cassava root tips (Yadav et al., 2019), high-oleic peanuts (Toomer et al., 2019), orange corn (Abraham et al., 2021), insects (Koutsos et al., 2021), and bigheaded carp meal (Upadhyaya et al., 2022) have sown to have an enhanced effect on broiler growth and performance. In addition, numerous studies have focused on feeding varying levels of microbial phytase to broilers in hopes of determining the optimum levels of phytase to include in the diet (Babatunde et al., 2020; Broch et al., 2021; Gulizia et al., 2023). Other studies have concentrated on feeding varying levels of organic minerals (Macalintal et al., 2020), total sulfur amino acids (Adhikari et al., 2022), and zinc methionine and manganese methionine (Pacheco et al., 2021), and dietary antibiotic alternatives (Wang et al., 2019). Considerable work has also been, reported on the effect of varying particle size of diets for starting broilers (Brown et al., 2023). Finally, research conducted within our group has tested the impact of pellet quality on broiler performance (Ovi et al., 2020a; 2020b; Lynch et al., 2023; Poholsky et al., 2023).

***Feed Processing and Feed Manufacturing.***Feed and feed manufacture represent the largest production cost (60-70%) for a commercial integrator. All commercial broilers, and most turkeys, are fed diets that, are pelleted due, to improvements in body weight gain, feed efficiency, and feed intake, with these benefits being more pronounced as feed form improves (Sellers et al., 2017). Therefore, research relating to feed manufacture and feed quality has the potential to have a dramatic impact on commercial integrator production costs and ultimately reduce the cost for the consumers. During the pelleting process, mash feed is, subjected to conditions of high moisture, pressure, and temperature; thus, adding additional costs and variables to the feeding process.  In addition, it has been, shown that steam conditioning can have an impact on the quality of processed feed (Boltz et al., 2019; Homan et al., 2019). Commercial poultry feed mills (in general) utilize the same equipment to accomplish the pelleting process. However, due to variations in equipment manufacturers, the age of the mill, ingredients in the diet, feed throughput demands, ambient temperature, and others, the quality of the feed produced at a given mill and at a given time may vary (Buchanan et al., 2010). Feed quality, also referred to as durability or pellet quality, is, defined as how durable a pellet responds to intense handling and transportation from the time the feed is, manufactured to the point of consumption. This is important to consider because finished feed at the feed mill will have to be loaded onto a truck, transported to a farm, augured into a feed bin, and finally augured throughout the feed system at a house before reaching the point of consumption. The delivery process adds severe stress on the feed and pellets often dramatically deteriorate before being consumed, placing more importance on creating high-quality feed at the feed mill.

The starter growth phase represents a critical stage in a broiler’s lifecycle. During this time, gastrointestinal tract formation is rapid and extremely critical for improvements in digestion to maximize performance (Lilburn and Loeffler, 2015). While ample research on feed quality improvement on broiler performance exists, research pertaining to feed quality presented in the early growth phases is lacking. Determining the optimal starter feed particle size may optimize starter performance, and impact, the overall performance of the bird (Lemons et al., 2019).

***Role of Space on Behavior.*** The role of 3-D space available for broilers on a litter floor pen is difficult to determine; however, recently Li et al. (2023a) provided evidence as to how to track broilers use of floor pen space. Chai et al. (2022a) developed an automated approach for monitoring poultry distribution on floors. In addition, Li et al. (2022) used technology to design, and develop, a broiler mortality removal robot. For laying hens, aviaries, offer laying hens more space per bird in comparison to conventional (Cooper and Albentosa, 2003). However, merely providing more space does not ensure hens will be able to perform essential behaviors. Therefore, it is important to understand factors that may interfere with hens’ abilities to use resources and perform key behaviors, which would reduce potential welfare benefits of transitioning hens to cage-free housing.

In a production setting, hen housing guidelines and codes of practice frequently include recommendations on the amount of space or resource allocation per hen with the intent of allowing expression of behavioral needs such as standing, lying, perching, wing flapping, and dust bathing. If hens cannot perform these behaviors, possible results are frustration, injury, or deprivation. For example, hens will work to gain perch access, particularly at night (Olsson and Keeling, 2000), and if sufficient perch space is provided for each hen, hens may spend 100% of their night perching (Olsson and Keeling, 2000). Dust bathing, is also well documented as having a positive benefit for hens. This “high priority behavior” (EFSA, 2015) is a maintenance behavior that can improve feather condition and dislodge skin parasites (Weeks and Nicol, 2006).

However, relatively little research has directly examined the amount of space required for laying hens to perform these key behaviors (Mench and Blatchford, 2014; Spindler et al., 2016) or postures, such as standing and lying, in which hens spend much of their day (Channing et al., 2001). Recently, we developed a unique approach to determine the physical space required by hens to perform key behaviors in commercial style aviaries and reported differences in space requirements between four different strains to perform certain behaviors (Riddle et al., 2018). We found that popular commercial hen strains such as Hy-Line W36, Bovan Brown, Hy-Line Brown, and DeKalb White required more physical space to perform key behaviors such as standing, lying, dust bathing, wing flapping and perching than proposed by housing guidelines and codes of practice or reported by previous research (Mench and Blatchford, 2014; Spindler et al., 2016).

However, there is more to a hen being able to perform a behavior than just the amount of space physically taken up by her body during the behavior. For example, we must also consider how many hens will engage in a given behavior simultaneously, a phenomenon called flock synchrony (Mench and Blatchford, 2014) as well as how much space a hen will place between herself and others in her group when performing a behavior (Collins et al., 2011). Aviary systems are, designed to promote behaviors shown by hens, and to provide more space per enclosure and per hen than conventional cages. However, to understand if the amount and type of space provided by aviaries allow hens to meet behavioral needs, space needs, to be, considered in the context of the presence of other birds. To understand how laying hens may use 3-D space, Rentsch et al. (2023) has provided some insight into a hen’s use of space in an aviary.

***Broiler Enrichment.*** *A*n area of animal welfare with poultry even less explored is broiler enrichment. Although several animal welfare certification programs have encouraged the scattering of feeding as a form of broiler enrichment, there is little evidence to support that broilers would benefit from this practice. The idea that the scattering of whole grains or other food items can be used, as a form of environmental enrichment is grounded in the assumption that foraging behavior is important for broilers and will be readily expressed if the scattered substrate is provided. However, what constitutes a normal behavior (i.e., a behavior that is important to the animal) can be altered by selective breeding and environmental conditions. It has been, suggested that along with selection for fast growth the broiler behavioral repertoire has shifted towards the performance of behaviors that allow the birds to conserve their energy. For example, previous research has shown that broiler chickens are less willing to work for food when a freely available food source is available as compared to laying hens or red jungle fowl, their wild counterparts (Linqvist et al., 2006). Additionally, provision of foraging or pecking materials as an enrichment in the presence of freely available food has not been associated with benefits, such as increased locomotion or improvements in leg condition (Pichova et al., 2016). Together, the results of these previous studies put into question whether scatter feeding has the potential to be an effective form of broiler enrichment. If scattering of feed is, to be, recommended, as a form of environmental enrichment for broilers, its implications for broiler welfare must first be, examined.

***Heat Stress.***Climate change-associated hot weather is an increasing threat to the animal production industries (Hajat et al., 2010). When ambient temperature increases toward the critical upper thermal limits in animals, heat gain exceeds heat loss, resulting in hyperthermia. As one of the critical reasons causing pathophysiological damage, hyperthermia leads to oxidative stress, i.e., disturbance in the pro-oxidant/antioxidant balance in favor of producing reactive oxygen species (ROS; Droge, 2002). Increased ROS contributes to cytotoxicity, causing cell death, tissue injury and organ damage resulting in increased morbidity and mortality (Solymosi et al., 2010). Estimated heat stress (HS) related losses for livestock was estimated at $2.4 billion in the U.S. (St-Pierre et al., 2003).

Heat stress (HS) is of great concern for poultry operations, as chickens, have been continuously selected for fast growth with much heavier harvest weight (broilers) or increased egg production (layers), which may increase susceptibility to HS by shifting energy from maintenance in response to stressors to productivity (Berong and Washburn, 1998). When the temperature exceeds the comfort level of a bird, behavioral and physiological changes occur, that are accompanied by changing physiological homeostasis (Jiang et al., 2019; Greene et al., 2022) and oxidative balance (Lin et al., 2006). These changes reduce feed intake and nutrient metabolism and immune response (Mohammed et al., 2019) while increasing morbidity and mortality. Thus, it is critical to increasing their heat tolerance. Gut microbiota reacts to various internal and external stimuli, influencing brain function in regulating the host’s health via the gut-brain axis (Yarandi et al., 2016). Some probiotics have demonstrated beneficial effects on alleviating oxidative stress and related tissue damage in rodents (Lei et al., 2015). These data suggest that supplementing probiotics may provide a new strategy to inhibit HS-associated damage to health and welfare in poultry.

***1b. Post-harvest:***

***Food Safety.*** During the post-harvest phase of poultry production, food quality and safety is very important. Since the poultry industry is all about producing a safe affordable product, it is extremely important that a high level of food security be, maintained. Previous research conducted by our group has published numerous studies examining ways to reduce the *Salmonella* and Campylobacter contamination of poultry meat products as an example (Nair et al., 2019; Kumar et al., 2020; Bourassa et al., 2021; Shijinaraj et al., 2021; Grace Dewi et al., 2021). These studies have shown some of the various ways in which poultry meat products can be, kept safe. In addition, some studies have, investigated several egg-processing techniques, to enhance, egg safety (Cassar et al., 2021; Beining et al., 2020; Chai et al., 2022b). Further research conducted by our group will provide more answers to discovering potential methods to keep poultry meat safe for human consumption.

**OBJECTIVE 2**

**2. Fostering Innovative Production Practices through Research and Extension.**

***2a. Pre-harvest and Post-harvest:***

Understanding the way in which chickens and turkeys partition their nutrient intake in different production systems is mostly unknown. Therefore, research is, needed on the breadth of poultry feeding programs by examining feed form, dietary ingredients, feed additives, and individual nutrients and how these influence not only the bird performance but also other elements of the production system such as well-being, environment, health, and food safety. This research will create replicated data to investigate the relationship between physical activity and production uses of nutrients in the current egg and meat-type bird genotypes and bird performance and health. Identification of bird strain and feed form effects on bird performance and nutrient utilization will be determined. Further research conducted by our group on the effects of the poultry house environment will help determine optimum raising environments. Future research conducted by our group during the post-harvest phase of poultry production will help ensure the production of safe and affordable poultry meat and eggs.

**Objectives**

1. Advancing Sustainable Poultry Systems through Precision Management.

Comments: This will include collaborative research, which covers environmental control and management, housing, litter management, ventilation, lighting, pre-harvest food safety, nutrition, feed processing, behavior, and welfare during the pre-harvest stage of production. Post-harvest considerations will encompass food safety, processing methods, waste-water-management, offal, and rendering. Another consideration in this section will explore avenues related to carbon footprint, nutrient utilization, production systems, and life cycle analysis.

2. Fostering Innovative Production Practices through Research and Extension.

Comments: This collaborative research will cover incubation and hatchery, reproductive physiology, nutrient excretion reduction, precision nutrition, alternative feed ingredients, NAE/ABF practices, alternative feeding strategies, gut health, gut microbiome, poultry health and disease management, alternative sustainable production systems, production systems under regulatory exemption, economic analysis, and bird welfare, during the pre-harvest stage of production. Cutting-edge processing methodologies, production systems under regulatory exemption, and the quality of meat and eggs, will be, examined in the post-harvest phase. Outreach and training will be a part that several of the universities will pursue. Poultry economics plays a role in conducting the studies to answer some of the questions outlined in the objectives.

**Methods**

**Objective 1**

 **1. Advancing Sustainable Poultry Systems through Precision Management.**

***1a. Pre-harvest:*** This section will, cover, environmental control and management, housing, litter management, ventilation, lighting, pre-harvest food safety, nutrition, feed processing, behavior, and welfare.

Collaborative research between stations in CA and TN is underway to develop and validate systems tracking hens' resource utilization in cage-free housing systems. Noteworthy multistate collaborators include Dr. Richard Blatchford from UC Davis and Dr. Yang Zhao from the University of Tennessee.

Research efforts in CT will be, dedicated to devising alternatives to antibiotic growth promoters, aiming to support optimal broiler/layer performance while effectively controlling the transmission of pathogens like *Salmonella* in poultry and their environment.

Mississippi State University (MSU) is set to conduct research identifying best management practices for poultry producers. The focus will be on readily employable practices that can reduce the incidence of *Salmonella*, *Campylobacter*, and other pathogens across commercial poultry operations, spanning farms, hatcheries, feed mills, and transportation.

Auburn will be conducting evaluations on the gut microbiome and transcriptome, exploring their relationship to the reduction of foodborne pathogens such as *Salmonella* and *Campylobacter* in live poultry. This will involve the use of feed and water additives like probiotics and organic acids.

Researchers at Auburn will also engage in assessing artificial intelligence (AI) and deep learning techniques. These techniques aim to identify and map poultry facilities to support responses to animal health outbreaks. Additionally, video analysis techniques will be, used to evaluate lighting programs and thermal management strategies on bird welfare and behavior.

In IA, research will be concentrated on examining the impacts of feed alternatives, technologies, ventilation, and the thermal environment on turkey and laying hen performance, intestinal health, and behavior.

NC researchers will be actively developing and validating innovative interventions applicable in the poultry environment. This will include the assessment of feed additives and water treatment to reduce the prevalence, population, and virulent serotypes of *Salmonella* and *Campylobacter* in poultry. Dr. Lin Walker from NC will be conducting this work.

Collaborative research between GA and NC stations will involve the study of hen-housing interactions on welfare parameters. UGA and NC researchers are also collaborating to understand the gut-brain-behavior axis in chickens. Multistate members include Dr. Prafulla Regmi from UGA and Dr. Kenneth Anderson, and Dr. Allison Pullin from NC.

Researchers at, the University of Arkansas (UA) are evaluating environmental management, genetic selection, and welfare strategies for broiler chickens. A common focus among researchers will be the exploration of multidisciplinary strategies to mitigate heat stress, involving Drs.’ Liang, Orlowski, and Weimer.

In HI, ongoing research includes the evaluation of novel feedstuffs and feed additives. This will aim to develop sustainable feeding programs and nutrition strategies to modulate gut health and manage stressors, including those induced by climate change in broilers. Strategies to enhance reproductive efficiency in layers and broiler breeders will also be, developed.

University of Kentucky (UK) researchers continue to generate valuable data on feed ingredient evaluations. Their focus is on increasing the efficiency of energy and nutrient utilization while concurrently reducing nutrient excretion into the environment. The team is particularly interested in evaluating field contamination of grains, especially mycotoxin-contaminated corn, and its impact on performance, nutrient utilization, and gut health. Selected feed additives are also being, assessed for their effectiveness in ameliorating the effects of mycotoxin contamination and cyclic heat stress on performance, nutrient and energy digestibility, and utilization in broiler and laying hens, as well as egg quality.

Researchers at Purdue University are persisting in efforts to improve housing, welfare, and production in pullets/layers, turkeys, and ducks. Their multidisciplinary approach combines behavior, environmental factors, egg quality, general physiology, nutrition, and neuroendocrine disciplines. Ongoing investigations include understanding the physiological stress response, evaluating the epigenetic impacts of heat stress, and determining if feed additives can ameliorate these effects. The team is also exploring environmental enrichment, evaluating visual perception in poultry, and developing a holistic view of layer chicken behavior, performance, physiology, and neuroendocrine status.

Research at Michigan State University (MSU) will focus on computer vision strategies to mitigate problematic behaviors in laying hens occurring in the litter area. This will involve automating detection of problematic behaviors and developing targeted intervention strategies to disrupt the behavior without causing unintended consequences to hen welfare, such as increased fear, injury, or reduction in positive behavior.

Researchers at the University of Minnesota (UM) will persistently investigate sustainable food safety solutions applicable to poultry production systems. Collaborations with industry and other university partners will inform multiple research projects. Ongoing efforts include investigating targeted microbial interference strategies against pathogens relevant to the turkey industry, with a focus on producing gut-friendly and environmentally friendly solutions to strengthen a sustainable poultry food supply.

***1b. Post-harvest:*** Post-harvest considerations will encompass food safety, processing methods, waste-water-management, offal, and rendering.

CT's research focus will center on the development of natural antimicrobials, including probiotics. The objective is to control *Salmonella* in meat and eggs without compromising their quality and shelf life.

Auburn's investigation will extend to evaluating the microbiome of poultry products and its correlation with the presence of foodborne pathogens like *Salmonella* and *Campylobacter*. Alternative interventions, such as high-intensity light and the use of bacteriophages will be, assessed for potential implementation in commercial facilities.

NC's research initiatives aim to develop and validate innovative technologies, including high-intensity pulsed light, to mitigate the food safety risks associated with poultry and egg products. Additionally, predictive models will be, devised to estimate the growth and survival of foodborne pathogens in these products, with LW from NC leading these efforts.

Researchers at the University of Minnesota are exploring plant-based solutions to enhance the post-harvest safety of turkey products. Collaborations with industry partners and other universities will be, established to facilitate multiple projects addressing this aspect.

***1c. Environmental Footprint:*** This section will explore avenues related to carbon footprint, nutrient utilization, production systems, and life cycle analysis.

The University of Minnesota researchers are actively engaged in seeking environmentally sustainable solutions. Their focus will be on developing industry-friendly approaches that effectively address challenges faced by poultry producers and turkey growers while simultaneously minimizing the environmental impact of these solutions. Emphasis will be on collaborative and translational research incorporating science, engineering, and technology to enhance system efficiency and sustainability through infrastructure development of block-chain production.

**Objective 2**

**2. Fostering Innovative Production Practices through Research and Extension.**

***2a. Pre-harvest:*** This section will cover incubation and hatchery, reproductive physiology, nutrient excretion reduction, precision nutrition, alternative feed ingredients, NAE/ABF practices, alternative feeding strategies, gut health, gut microbiome, poultry health and disease management, alternative sustainable production systems, production systems under regulatory exemption, economic analysis, and bird welfare. Various research initiatives are underway.

The CA station collaborates on the investigation of woody breast causes a measurement method in broilers, with CY from UC Davis. The CA and TN stations are jointly exploring housing and genetic factors contributing to keel bone fractures in laying hens, with collaboration from multistate members Dr. Richard Blatchford (UC Davis) and Dr. Yang Zhao (U. Tennessee).

In CT, the focus will be on devising alternative strategies supporting growth, health, and performance in layer and broilers throughout the production pipeline, spanning incubation, hatching, grow-out, and laying periods. This will include studying the chicken microbiome's acquisition, temporal evolution, and impact on intestine development, immune health, and function.

Mississippi State University will be addressing ways to enhance hatchability of fertile eggs and increase the production of fertile eggs in broiler breeder hens. The multifaceted approach will involve examining changes in the hens' diet, storage conditions, temperatures, and incubation methods. Additionally, culturomics will be, employed to explore and harness the benefits of poultry microbiota, identifying beneficial microbial species and their functions for improved gut health and growth performance. Investigations will also cover new feed additives, precision nutrition, and bone health assessments in laying hens, with economic analyses conducted in both layers and broilers.

UGA's Chen Lab will be evaluating the impact of diet formulation on the economics and sustainability of broiler production, while UGA's Regmi Lab will be delving into the genetic basis of hen activity in aviary houses.

Clemson University will concentrate on evaluating the effectiveness of alternative feedstuffs in preventing coccidiosis and necrotic enteritis in broilers, along with studying changes in the transcriptome and intestinal microbiome.

The Purdue Team is actively engaged in translational research addressing production challenges in ducks, turkeys, broilers, and layers. Their projects will cover environmental enrichment, parasite control, prevention of keel bone issues, and understanding behavioral aspects in ducks. Stakeholder engagement will include extension activities, industry meetings, and educational outreach.

Michigan State's research continues to explore non-cage aviary design and management's impact on laying hen behavior and welfare, with a specific focus on floor laying rates and related aspects.

Virginia Tech will be investigating dietary energy in response to challenges posed by renewable fuels' standards, exploring alternative energy sources and strategies to enhance energy utilization in broiler chickens and laying hens.

The University of Minnesota researchers will be testing strategies to identify and implement alternative protein sources, targeted probiotics, and immune-enhancement strategies in the breeder, hatchery, and production segments, collaborating with partner universities and industry stakeholders.

***2b. Post-harvest:*** This section will cover cutting-edge processing methodologies, production systems under regulatory exemption, and the quality of meat and eggs.

Mississippi State University is, dedicated, to conducting assessments, of eggshell quality, offering producers insights into the structural integrity of their eggs and shedding light on the condition of the hens. The research will include strategies to enhance eggshell quality, primarily through dietary manipulations aimed at producing eggs with improved quality, ultimately reducing the likelihood of cracked or contaminated eggs reaching consumers.

***2c. Outreach and Training:*** This section will cover various aspects of outreach and training that several of the universities will and are pursuing.

The Purdue Team has successfully mentored a total, of five graduate students who have subsequently pursued advanced academic degrees, entered veterinary school, or embarked on careers within the poultry industry. In addition, team members have actively involved a combined total, of 25 undergraduate students in their research initiatives. The team will continue its efforts in training the next generation of researchers. Serving as co-advisors for the Purdue Poultry Club, team members will continue to play an integral role in facilitating presentations at various meetings and exhibits during campus-wide events such as Spring Fest, the Boiler Barnyard, and the Annual Alumni Fish Fry. Furthermore, Poultry Club undergraduates will actively participate in notable events, including the PEAK conference and internship program, with plans to engage in IPSF/IPPE in 2024. The Purdue Team takes pride in teaching several poultry-related courses, such as "Cracking the Poultry Industry" and upper-level courses in Welfare and Poultry Management. The latter includes a Course-Based Undergraduate Research Experience (CURE), providing teams of undergraduates with opportunities to investigate real-life challenges in poultry management. The team will continue its commitment to diversity and inclusion as team members continue to recruit, educate, and train underrepresented individuals for the poultry industry, contributing to a more diverse workforce.

The Purdue team will actively engage with stakeholders through extension activities, including monthly article publications and biannual symposia through outlets like the Poultry Extension Collaborative. Participation in industry meetings, such as PEAK, will ensure the effective dissemination of valuable information. Moreover, the Purdue team will extend its impact to the public through outreach and educational initiatives at events such as the Indiana State Fair, collaborations with community partners like The Farm at Prophetstown, and workshops for 4-H youth. Purdue Extension Specialists maintain a strong presence, engaging with poultry companies in Indiana and nationally, addressing key industry concerns, and providing essential training programs for poultry workers.

The University of Connecticut will focus on various challenges associated with ensuring food safety in poultry production that are underscored by the prevalent presence of bacterial pathogens like *Salmonella* and *Campylobacter,* in both layer hens and broilers. Studies will emphasize the potential health risks to consumers, if these pathogens, are not, effectively managed throughout the poultry production chain. To address these concerns, a comprehensive series of poultry extension activities will be, carried out in CT. These initiatives, developed in collaboration with the CT agricultural agencies, farm bureau and other local poultry groups, will encompass multifaceted training programs. Workshops and seminars will not only disseminate the latest research findings but also focus on industry best practices related to biosecurity measures, sanitation protocols, and effective management strategies. Additionally, specific extension activities will target poultry health, emphasizing disease prevention, vaccination protocols, and application of alternatives to antibiotics in poultry production. These extension activities, led by the UConn extension group, aim to empower poultry producers with practical tools for risk mitigation and the improvement of overall poultry health. By fostering a culture of continuous improvement, these initiatives aspire to enhance the safety, sustainability, and productivity of poultry production in CT. Through collaborative efforts and evidence-based practices, the extension activities seek to contribute to the resilience of the poultry industry in the face of evolving

climate changes.

***2d. Poultry Economics:*** This section will cover the aspect of how poultry economics plays a role in conducting the studies to answer some of the questions outlined in the objectives.

North Carolina State University will be conducting many studies on the economic analysis for the poultry industry. (i) Analysis of Industry Organization, Structure, and Competitiveness: Monitor industry trends and conduct research to assess the impacts of industry concentration, market power, mergers, and acquisitions on consumer welfare and cost synergies. (ii) Evaluating Economics of Poultry Contracts and Integrator-Grower Relations: Investigate the relative performance-based settlement schemes, such as tournaments, in broiler production contracts. Explore potential alternatives with fewer incentives and analyze their effects on firm-level profitability and growers' income. (iii) Economic Assessment of Animal Welfare: Perform cost-benefit and/or enterprise budgeting analyses for innovative animal welfare production technologies or regulatory proposals. This analysis will be, conducted at the individual project level or within the context of partial market equilibrium settings.

Mississippi State University will also cover economic analyses in both broilers and in layers with respect to new feed additives, precision nutrition, and bone health assessments. Moreover, UGA's Chen Lab will be evaluating the impact of diet formulation on the economics and sustainability of broiler production.

**Measurement of Progress and Results**

**Outputs**

* Enhanced collaborative research and development of research proposals for submission to federal agencies
* Successful extramural funding from industry and government programs that target specific collaborative research goals outlined in the project
* Support and training for undergraduate, graduate and post-doctoral students
* Data published in peer-reviewed high impact journals and presented at major scientific venues including association conferences such as Poultry Science, Worlds Poultry Science, International Poultry Scientific Forum, Institute of Food Technologists, International Association for Food Protection, and American Society of Agricultural and Biological Engineers
* Results are translated and available for various stakeholders including government agencies, poultry associations, poultry, and food industry and consumers. Different formats used include various media (print, web-based, webinar and other media specific to the target audience
* Optimize poultry house environments, monitoring and management will improve producer economic situations
* Performance and well-being data generated from alternative housing and pasture-raised studies will improve decision-making in a rapidly changing industry
* Data generated from nutrition trials utilized by producers for feed formulations, feed milling and feed suppliers
* Producers will have access to data related to poultry well-being to supplement decisions related to management practices
* Economic analyses of poultry production systems will improve industry profitability and consumer demand for poultry products
* Industry adoption of recommendations generated from research findings

**Outcomes or Projected Impacts**

* Improved productivity in broiler, turkey and layer chickens (feed conversion, weight gain, dozens of eggs produced)
* Improved disease management and food safety as a result of feed supplements or management practices
* Adoption of new engineering strategies and technology for reducing energy consumption and improve poultry house environments and food safety
* Improved poultry well-being through advanced monitoring systems and precision livestock farming
* Management recommendations on alternative housing systems for laying hens and other poultry that will assist producers in making sound business decisions on which systems are most suitable to their operations; and identify best practices to be adopted to allow these systems to function to full potential
* Strategized feeding programs with the use of alternative feed additives or feed ingredients or under constrained ingredient use while maintaining or improving broiler, turkey, and/or hen performance, well-being, and environment parameters

**Milestones**

**(2025):**

* Studies conducted at the stations in CA and TN will validate various systems used to track hens’ resource utilization in a cage-free housing environment
* Research studies in CT will be, dedicated to finding alternatives to antibiotic growth promoters to support broiler/layer performance and control transmission of *Salmonella* in poultry and their environment
* Artificial intelligence (AI) and deep learning techniques will be conducted at Auburn to identify and map poultry facilities to support responses to animal health outbreaks
* Research studies in IA will examine the impacts of feed alternatives, ventilation, and the thermal environment on turkey and laying hen performance
* Studies conducted in AR will evaluate environmental management, genetic selection, and welfare strategies for broilers
* Feed ingredient evaluation studies will be conducted at KY that focuses of increasing the efficiency and nutrient utilization of poultry while reducing nutrient excretion in the environment
* Translational research conducted by Purdue (IN) will address production challenges in ducks, turkeys, broilers, and layers. Environmental enrichment, parasite control, prevention of keel issues and behavioral aspects in ducks will be the focus
* Experiment conducted at MS will address various ways to enhance hatchability of fertile eggs and increase the production of fertile eggs in broiler breeder hens

**(2026):**

* The incidence of *Salmonella*, Campylobacter and other pathogens will be assessed at commercial poultry operations, including various farms, hatcheries, feed mills, and transportation (MS)
* Auburn will be conducting gut microbiome and transcriptome relationships to reduce foodborne pathogens such as *Salmonella* and Campylobacter
* NC researchers will develop innovative interventions applicable to the poultry environment. Feed additives and water treatment will be the focus
* Experiments will be conducted by the CA and TN stations to investigate woody breast causes, and evaluate contributing factors leading to keep bone fractures in laying hens kept in cage-free environments

**2027):**

* NC will continue developing technologies, including high-intensity pulsed light to mitigate food safety risks associated with poultry and egg products
* CT will continue to develop natural antimicrobials, including probiotics to control *Salmonella* contamination in poultry meat and eggs
* MN will explore plant-based solutions to enhance post-harvest safety of turkey products
* Alternative feedstuffs will be the concentration of the station at Clemson (SC) and their effect on preventing coccidiosis and necrotic enteritis in broilers

**(2028):**

* The MN station will be testing strategies to identify alternative protein sources, targeted probiotics, and immune-enhancement strategies in breeder, hatchery, and production segments
* VA will investigate dietary energy responses to challenges posed by renewable fuels’ standards which will enhance the energy utilization in broilers and layers
* MI will continue to explore non-cage aviary design and management’s impact on laying hen behavior and welfare. Solutions to floor laying rates and related aspects will be analyzed
* Outreach and training of students, at all university experiment stations will be the focus throughout the project period. In IN (Purdue), graduate and undergraduate students will be trained to understand the various aspects of the poultry industry
* CT will summarize various challenges associated with ensuring food safety in poultry production systems

**(2029):**

* Numerous studies at NC will be summarized which center on assessing the economic condition of the poultry industry. The analysis of industry organization, structure, and competitiveness will be included
* MS will also summarize the economic condition of the broiler and layer industries with respect to the effect of new feed additives, precision nutrition, and bone health of poultry

**Outreach Plan**

Study findings will be disseminated promptly to the academic communities, industry stakeholders, and the general public through press releases, web publications, extension reports, presentations at professional conferences and industry educational workshop, such as the Annual Industry Issues Forum organized by the Egg Industry Center ([www.eggindustrycenter.org](http://www.eggindustrycenter.org)). The results will also be disseminated via extension publications (e.g., Animal Industry Report produced at ISU, NCLP and MT Reports at http://poultry.ces.ncsu.edu/layer-performance/), graduate student theses and dissertations, and peer-reviewed journal articles. While some of the outreach will be passive (user identifies information through web searching or other means), other outreach will be active (planned "events"). The "events" will be, planned by the Extension specialists participating in the project including, seminars, field days, and workshops at which results of the research technologies will be discussed/disseminated to poultry producers. On-farm demonstrations, will be conducted when feasible to allow farmers to see firsthand the results of the research in conjunction with traditional producer education programs. Members of the group will identify relevant information to share with interested clientele groups within their states or regions. Engagement of the poultry industry stakeholders (UEP, National Chicken Council, National Turkey Federation, USPEA, and others) will allow for input on the relevance of research being conducted and provide feedback on strategic ways to actively share information as well as provide ideas on future research topics. We believe a partnership between industry, government, and academia must exist to improve poultry production systems and well-being.

**Organization/Governance**

The Technical Committee is responsible for the planning and supervision of the Multi-State Research Project. The membership of this committee shall consist of an Administrative Advisor, a technical representative of each participating agency or experiment station, and representative of the USDA Cooperative States Research Service. Each participating agency or experiment station is entitled to one vote. The Technical Committee shall be responsible for review and acceptance of contributing projects, preparation of reviews, modification of the regional project proposal, and preparation of an annual report. Each technical committee member will prepare annual written reports and distributed at the annual meeting. Annual reports will be, compiled and distributed to Technical Committee members, and Agricultural Experiment Station Directors. The Technical Committee will meet yearly and conduct an election for the office of Junior Executive. The position should alternate between Poultry Scientists and Agricultural Engineers. The person elected to serve as Junior Executive will rotate through the remaining offices of Senior Executive and Secretary and will serve as Chair in the fourth year. All voting members of the Technical Committee are eligible for office. The Chair prepares the meeting agenda and presides at meetings. The Chair is responsible for the preparation of the annual report. The Secretary records minutes and assists the Chair. The Senior and Junior executives help with policy decisions and nominations. The Technical Committee functions as a unit with sub-committees formed as necessary, which is, preparing nominations for elections.

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