**NETEMP\_2442: Improving Sustainable Poultry Production through Collaborative Research and Outreach**

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

**Administrative Advisor(s):**

[Kumar Venkitanarayanan](https://www.nimss.org/users/66141)

**NIFA Reps:**

[Angelica Van Goor](https://www.nimss.org/users/1000002976)

Steve Smith

**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 various causes of woody breast and its measurement methods 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.

***Engineering and Technology/Aviary and Floor Rearing Systems:***

Collaborative research between stations in CA and TN is underway to develop and validate systems tracking hens' resource utilization in cage-free aviary housing systems, including their use of perches an movement within the system. Noteworthy multistate collaborators include Dr. Richard Blatchford and Maja Makagon from UC Davis and Dr. Yang Zhao from the University of Tennessee.

Researchers at Auburn will engage in assessing artificial intelligence (AI) and deep learning techniques to identify and map broiler and broiler breeder facilities to support responses to animal health outbreaks. Geo-tagged remote sensing, imagery will, be acquired from the USDA National Aerial Imagery Program (NAIP) for the years 2021 – 2023. The ability of two deep-learning-based paradigms to, correctly identify broiler and broiler breeder facilities from aerial imagery will be explored and compared by computing average precision, mean average precision, sensitivity, specificity, and intersection over union metrics. In other experiments, video analysis techniques will be used to evaluate lighting programs (natural light versus traditional) and thermal management strategies on bird performance (body weight, body weight gain, FCR, mortality), welfare (footpad scores, gait scores) and behavior (response to observe test, novel object test).

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.

***Nutrition, Alternative Ingredients and Feedstuffs/ Environmental Control Management/ Food Safety:***

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 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. Management practices, to be, explored are improvements in biosecurity measures, such as novel pest and insect control measures that would reduce these vectors and in turn reduce these pathogens across all poultry operations. In addition, developing best management practices in, regard to litter and water lines in the poultry house are also, being, explored for improvements that can reduce these pathogens.

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.

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.

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.

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. We are investigating probiotics (for e.g., Propionibacterium and Ligilactobacillus), phytobiotics (essential oils and their ingredients) and vaccination strategies against the colonization and dissemination of foodborne pathogens, including Salmonella, relevant in turkey production. Parameters, including the populations of pathogens in dependent tissues and organs, will be assessed using microbiological approaches.

***Poultry Welfare and Housing Environment/ Role of Space on Behavior/Heat Stress:***

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. Experiments will evaluate the effects genetic selection for high and low water efficiency, temperature, relative humidity, lighting, and commercial sprinklers on broiler performance, stress physiology, behavior, and welfare.

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 benefits of environmental enrichment on production values and welfare variables, such as body condition, behavior, glucocorticoids and organ morphometrics. We are also evaluating visual perception in poultry to determine how different lighting environments impact birds’ ability to visualize resources, and to develop a holistic view of layer chicken behavior, performance, physiology (glucocorticoid and immune factors), and neuroendocrine status (stress and reproductive neurohormones) to determine the best housing design form the birds’ perspective.

***Feed Processing and Feed Manufacturing:***

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. Response variables to be measure include performance, nutrient and energy digestibility and utilization, intestinal morphology, blood gas (heat stress study only), organ (liver, spleen, etc) relative weight, cecal microbial composition, changes in intestinal and serum cytokines levels, skeletal integrity, gene expression of intestinal tight junction genes, liver heat shock proteins, etc.

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

***Food safety:***

CT's research focus will center on the development of natural antimicrobials, nano emulsions, phytochemicals, 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 (for e.g., lemongrass and Pimenta essential oils) 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. We are collaborating with the leading turkey processors for fine-tuning the use of essential oils in turkey products. Parameters, including their pathogen reduction potential, color parameters, pH, antioxidant status, and spoilage organisms will be determined.

***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 (based on the preharvest and postharvest 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 various causes of woody breast and its measurement methods 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 Drs. Richard Blatchford and Maja Makagon (UC Davis) and Dr. Yang Zhao (U. Tennessee). The project will focus on provision of resources (e.g. ramp, perch type) that facilitate the hens’ movements within multi-tier aviaries.

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. Research includes both short term and long laying hen and pullet feeding study that will include- alternative feed ingredients evaluation, formulating into low crude protein and additive enzymes like protease and combination of enzymes, gut health additives such as pre-pro and symbiotics. The concept of precision feeding will be, applied where hens will be, only fed feed formulated into their dietary intake level where all the nutrients, are matched and met according to the age and status of them. In addition, bone health and welfare will be a component of these studies as there is a regular exchange and trade-off with calcium and egg production that affects the egg and bone system in laying hens. The necessity to evaluate the low oil residue of soybean meal and compare that with the similar and lower protein level ingredients such as DDGS has been the primary focus of the lab for the next 2 years. In all the research, the egg and egg economics will be a part of the nutrition studies in layers.

The University of Arkansas team will evaluate the economic, environmental, and bird performance and welfare implications of sprinkler systems in commercial houses. Research projects will also include experiments to determine the effects of environmental and genetic impacts on broiler performance, behavior, and welfare. Research results will be, presented at stakeholder engagement activities, including university workshops and symposia.

UGA's Chen Lab will be evaluating the impact of diet formulation on the economics and carbon footprints of broiler production. The focus will be on the role of synthetic amino acids, the metabolic energy level of diets on body composition, and their impacts on carbon footprints. Additionally, other factors such as parasite challenges, mycotoxins, and heat stress will be, integrated into different research models and study their contributions to the economic 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 focus 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 effect of sorghum on the intestinal tract will be evaluated for male commercial broilers from 1 to 42 days of age. A 2 x 2 factorial design will be used with 2 challenge treatments (unchallenged or challenged with E. maxima + Clostridium perfringens), and 2 dietary treatments (corn-based diet as the standard or sorghum-based diet). Performance parameters will be evaluated weekly and intestinal lesion scores will be, evaluated 21 days of age. Digesta and jejunal mucosa will be, collected for microbiome and transcriptomic analysis, respectively.

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 impacts on laying hen behavior and welfare, with a specific focus on floor laying rates and spatially intense behaviors in the litter area such as wing flapping, dust bathing, and play behavior.

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 (e.g., insects, algae, plant proteins), targeted probiotics, and immune-enhancement strategies (vaccination, probiotics) 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.

CT will research use of novel antibacterial nano emulsions and ultra-fine bubble technology to reduce foodborne pathogen contamination on poultry carcass, chicken skin, breast, thigh and other cuts. The application of this would be, further tested in processing environments.

***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.

The University of Arkansas team actively collaborates and interacts with a diverse range of stakeholders. The team organizes and hosts quarterly Tyson Short Course workshops with Tyson employees and their customers on topics spanning the U.S. poultry industry, hatchery management, broiler and breeder production and management, animal wellbeing, biosecurity, nutrition and feed milling, processing and meat quality, food safety, and industry challenges. The course includes tours of hatchery, breeder, broiler, as well as hands-on necropsy and processing activities. The Center for Food Animal Wellbeing hosts an annual symposium and engages with poultry industry organizations. Symposium speakers include scientists, veterinarians, and industry leaders that share their insights into research findings, best practices, responsibilities in their respective roles, and legal perspectives on relevant challenges and advancements in agricultural animal wellbeing. The Center also works with poultry industry stakeholders, including the Center for Food Integrity, Professional Animal Auditor Certification Organization, and American Humane Association on scientific committees to review and improve poultry wellbeing standards.

Extension specialists from the University of Arkansas, University of California Davis, and Purdue University are members of the Poultry Extension Collaborative (PEC), a cohesive group of poultry welfare experts focusing on developing and disseminating science-based information to guide poultry welfare decisions in practice. The PEC’s mission encompasses creating and disseminating educational and outreach materials, including the monthly Poultry Press, offers scientific expertise to poultry industry stakeholders, and hosts online symposia on topics spanning poultry welfare assurance and research from international perspectives. The PEC disseminates this information online through their website, YouTube channel, and Facebook page.

***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.

**Literature Cited**

Abdelfattah, E., G. Vezzoli, and M.M. Makagon. 2020*.*On-farm welfare assessment of commercial Pekin duck: A comparison of methods. Poult. Sci*.*99:689-697.

Abraham, M. E., S. L. Weimer, K. Scoles, J. I. Vargas, T. A. Johnson, C. Robison, L. Hoverman, E. Rocheford, T. Rocheford, D. Ortiz, and D. M. Karcher. 2021. Orange corn diets associated with lower severity of footpad dermatitis in broilers. Poult. Sci. 100:101054.DOI: 10.1016/j.psj.2021.101054.

Adhikari, P., F. L. Castro, G. Liu, and W. K. Kim. 2022. Effects of total sulfur amino acids on growth performance, immunity, and meat yield in broilers fed diets with and without antibiotics. Front. Vet. Sci. 9:903901.

Ali A. B. A., D. L M. Campbell, J. M. Siegford. 2020. A risk assessment of health, production, and resource occupancy for 4 laying hen strains across the lay cycle in a commercial-style aviary system. Poult. Sci. DOI: 10.1016/j.psj.2020.05.057.

Ali A.B. A., M.J. Toscano, and J. M. Siegford. 2019. Later exposure to perches and nests reduces individual hens’ occupancy of vertical space in an aviary and increases force of falls at night. Poult. Sci. 98:6251-6262. DOI: 10.3382/ps/pez506.

Babatunde, O. O., J. A. Jendza, P. Ader, P. Xue, S. A. Adedokun, and O. Adeola. 2020. Response of broiler chickens in the starter and finisher phases to three sources of microbial phytase. Poult. Sci. <https://doi.org/10.1016/j.psj.2020.05.008>.

Beining Ouyang, B., A. Demirci, and P. H. Patterson. 2020. Inactivation of escherichia coli K12 in liquid egg white by a flow-through pulsed UV light treatment system. J. Food Protect. 83:418-425.

Berong, S. L., and K. W. Washburn. 1998. Effects of genetic variation on total plasma protein, body weight gains, and body temperature responses to heat stress. Poult. Sci. 77:379-85.

Bist, R.B., S. Subedi, L. Chai, and X. Yang. 2023. Ammonia emissions, impacts, and mitigation strategies for poultry production: A Critical Review. J. Environ. Manage. 328:116919.

Boltz, J. W., C. Boney, J. Shen, J. Jaczynski, and J. S. Moritz. 2019. The effect of standard pelleting and more thermally aggressive pelleting utilizing a hygieniser of feed manufacture and reduction of *Enterococcus faecium*, a *Salmonella*surrogate. J. Appl. Poult. Res. 28:1226-1233.

Bourassa, D. V., R. J. Buhr, C. E. Harris, and L. N. Bartenfeld Josselson. 2021. Assessment of stabilized hydrogen peroxide for use in reducing *Campylobacter* levels and prevalence on broiler chicken wings. J. Food Prot. 84:449-455.

Broch, J., V. D. L. Savaris, L. Wachholz, E. H. Cirilo, G. L. S. Tesser, W. J. Pacheco, C. Eyng, G. M. Pesti, and R. V. Nunes. 2021. Influence of phytate and phytase on performance, bone, and blood parameters of broilers at 42 days old. S. Afr. J. Anim. Sci. 51:160-171.

Brown, A. T., M. J. Alvarenga, M. E. Lemons, C. D. McDaniel, J. S. Moritz, and K. G. S. Wamsley. 2023. Determining the average particle size consumed (APSC) between two genetic strains (GS) receiving starter diets varying in feed form (FF) and feed quality (FQ). J. Appl. Poult. Res. 100336.

Buchanan, N. P., K. G. S. Lilly, C. K. Gehring, and J. S. Moritz. 2010. The effects of altering diet formulation and manufacturing technique on pellet quality. J. Appl. Poult. Res. 19:112-120.

[Cassar J. R.,](https://www.sciencedirect.com/science/article/pii/S0032579120309743#!) [L. M. Bright,](https://www.sciencedirect.com/science/article/pii/S0032579120309743#!) [P. H. Patterson,](https://www.sciencedirect.com/science/article/pii/S0032579120309743#!) [E. W. Mills, and A. Demirci](https://www.sciencedirect.com/science/article/pii/S0032579120309743#!). 2021. The efficacy of pulsed ultraviolet light processing for table and hatching eggs. Poult. Sci. 100(3) March 2021, 100923. <https://doi.org/10.1016/j.psj.2020.12.021>

Chai, L., S. Aggrey, A. Oladeinde, C. Ritz, and T. Applegate 2022a. An Automated Approach to Monitoring Poultry Floor Distribution. *UGA Extension Bulletin*.

Chai, L., Y. Zhao, H. Xin, and B. Richardson 2022b. Heat treatment for disinfecting egg transport tools. Appl. Eng. Agric. 38;:343-350.

Channing, C. B. Hughes, and A. Walker. 2001. Spatial distribution and behaviour of laying hens housed in an alternative system. Appl. Anim. Behav. Sci. 72:335-345.

Collins, L. M., L. Asher, D. U. Pfeiffer, W. J. Browne, and C. J. Nicol. 2011. Clustering and synchrony in laying hens: The effect of environmental resources on social dynamics. Appl. Anim. Behav. Sci. 129:43-53.

Cooper, J. J., and M. J. Albentosa. 2003. Behavioural priorities of laying hens. Avian Poult. Biol. Rev. 14:127-149.

Droge, W. 2002. Free radicals in the physiological control of cell function. Physiol. Rev. 82:47-95.

EFSA, E. A. 2015. Scientific Opinion on welfare aspects of the use of perches for laying hens. EFSA J. 197:1-23.

Grace Dewi, Shijinaraj Manjankattil, Claire Peichel, Shiliang Jia, Zata Vickers, Timothy Johnson, Carol Cardona, Sally Noll, Anup Kollanoor Johny. 2021. Effect of plant-derived antimicrobials against multidrug-resistant *Salmonella* Heidelberg in ground Turkey. Poult. Sci. 101:101581. <https://www.sciencedirect.com/science/article/pii/S0032579121006027>

Greene, E. S., E. Adeogun, S. K. Orlowski, K. Nayani, and S. Dridi. 2022. Effects of heat stress on cyto (chemo) kine and inflammasome gene expression and mechanical properties in isolate red and white blood cells from 4 commercial broiler lines and their ancestor jungle fowl. Poult. Sci. 101:101827. <https://doi.org/10.1016/j.psj.2022.101827>

Gulizia, J. P., S. M. Bonilla, J. I. Vargas, S. J. Sasia, S. Llamas-Moya, T. Doung, and W. J. Pacheco. 2023. The effects of phytase and multicarbohydrase complex containing ahpha-galactosidase on performance, processing yield, and nutrient digestibility in the broiler chicken. J. Appl. Anim. Res. 1:308-322.

Hajat, S., M. O'Connor, and T. Kosatsky. 2010. Health effects of hot weather:  From awareness of risk factors to effective health protection. Lancet. 375:856-863.

Hayes, Morgan Davis. 2012. "Environmental and energy assessment of an aviary laying-hen housing system in the Midwestern United States". Graduate Theses and Dissertations. 12601. https://lib.dr.iastate.edu/etd/12601.

Hester, P. Y. 2005. Impact of science and management on the welfare of egg laying strains of hens. Poult. Sci. 84:687-696.

Homan, V. B., J. W. Boney, and J. S. Moritz. 2019. The effects of steam conditioning temperatures on commercial phytases and subsequent broiler performance and tibia mineralization. Appl. Anim. Sci. 35:298-303.

Jacobs, L., R. A. Blatchford, I. C. de Jong, M. A. Erasmus, M. Levengood, R. C. Newberry, P. Regmi, A. B. Riber, and S. L. Weimer. 2023. Enhancing their quality of life: environmental enrichment for poultry. Poult. Sci. 102:102233. DOI: 10.1016/j.psj.2022.102233.

Jiang, S., A. A. Mohammed, J. A. Jacobs, T. A. Cramer, and H. W. Cheng 2019. Effect of synbiotics on thyroid hormones, intestinal histomorphology, and heat shock protein 70 expression in broiler chickens reared under cyclic heat stress. Poult. Sci. 99:142-150.

Johnsonon, A. K., J. D. Colpoys, A. Garcia, C. Jass, S. T. Millman, M. D. Pairis-Garcia, C. J. Rademacher, S. Weimer, and S. Azarpajouh. 2019. A proactive blueprint to demonstrate on-farm animal welfare. CAB Reviews. 14:1-8. DOI: [10.1079/PAVSNNR201914037.](https://www.cabi.org/cabreviews/review/20193352461)

Kang, S. W., K. D. Christnesen, M. T. Kidd Jr., S. K. Orlowski, and J. Clark. 2023. Effects of a variable light intensity program on the welfare and performance of commercial broiler chicken. Front. Physiol. 14. https://doi.org/10.3389/fphys.2023.1059055

Koutsos, E. A., P. H. Patterson, K. Livingston, and T. Freel: Book Chapter: 2021. The Role of Insects for Poultry Feed: Present and Future Perspective. *In* Mass Production of Beneficial Organisms: Invertebrates and Entomopathogens, 2nd Edition, Dr. Morales-Ramos, Editor. Elsevier, Cambridge, MA.

Kumar, S., M. Singh, D. E. Cosby, N. A. Cox, and H. Thippareddi. 2020. Efficacy of peroxy acetic acid in reducing *Salmonella* and *Campylobacter* spp. populations on chicken breast fillets. Poult. Sci. 99:2655-2661.

Lei, K., Y. L. Li, Y. Wang, J. Wen, H. Z. Wu, D. Y. Yu, and W. F. Li. 2015. Effect of dietary supplementation of Bacillus subtilis B10 on biochemical and molecular parameters in the serum and liver of high-fat diet-induced obese mice. J. Zhejiang Univ. Sci. B. 16:487-95.

Lemons, M., C. D. McDaniel, J. Moritz, and K. G. S. Wamsley. 2019. Increasing average feed particle size during the starter period maximizes Ross × Ross 708 male broiler performance. J. Appl. Poul. Res. 28:420-434.

Lewis, P. D., and Morris, T. R. 2000. Poultry and coloured light. World’s Poult. Sci. J. 56:189-207.

Liang, Y., M. Janorschke, and C. E. Hayes. 2022. Low-cost solar collectors to pre-heat ventilation air in broiler houses. *Energies* 2022, 15, 1468. https://doi.org/10.3390/en15041468

Li, G., G. D. Chesser, J. L. Purswell, C. Magee, R. S. Gates, and Y. Xiong. 2022. Design and development of a broiler mortality removal robot. Appl. Engin. Agric. 38: 853-863.

Li, G., Gates, R. S., Meyer, M. M., and E. A. Bobeck. 2023a. Tracking and characterizing spatiotemporal and three-dimensional locomotive behaviors of individual broilers in the three point gait-scoring system. Animals. 13(4):717.

Li, G., Gates, R. S., Xiong, Y., Ramirez, B. C., and R. T. Burns. 2023b. Evaluating draft EPA emissions models for broiler operations. J. Appl. Poult. Res. doi: 10.1016/j.japr.2023.100365

Lilburn, M. S., and S. Loeffler. 2015. Early intestinal growth and development in poultry. Poult. Sci. 94:1569-1576.

Lin H., E. Decuypere, and J. Buyse. 2006. Acute heat stress induces oxidative stress in broiler chickens. Comp. Biochem. Physiol. A Mol. Integr. Physiol. 144:11-17.

Lindqvist C. E., P. Zimmerman, and P. Jensen. 2006. A note on contrafreeloading in broilers compared to layer chicks. Appl. Anim. Behav. Sci. 101:161-166.

Lynch, E., K. Bowen, V. Ayers, T. Boltz, K. G. S. Wamsley, J. W. Boney, and J. S. Moritz. 2023. Hygenic pelleting can decrease Hubbard x Ross 708 parent ileal amino acid digestibility, broiler performance, and increase digestible amino acid requirement. J. Appl. Poult. Res. 32:100355. DOI: https://doi.org/10.1016/j.japr.2023.100355

Macalintal, L. M., A. J. Pescatore, T. Ao, M. J. Ford, and K. A. Dawson. 2020. Organic minerals restore the acid-base and electrolyte balance in broiler chicks with nutritionally induced metabolic acidosis. J. Appl. Anim. Nutr. 8:41-48.

Mench, J. A., and R. A. Blatchford. 2014. Determination of space use by laying hens using kinematic analysis. Poult. Sci. 93:794-798.

Mohammed, A. A., S. Jiang, J. A. Jacobs, and H. W. Cheng. 2019. Effect of a synbiotic supplement on cecal microbial ecology, antioxidant status, and immune response of broiler chickens reared under heat stress. Poult. Sci. 98:4408-4415.

Nair, V. T., and A. Kollanoor Johny. 2019. *Salmonella*in poultry meat production. *In*Food Safety in Poultry Meat Production, Steven Ricke, Siddhartha Thakur, and Kumar Venkitanarayanan, Editors. Springer. Pp. 1-24.

Olsson, I. A. S., and L. J. Keeling. 2000. Night-time roosting in laying hens and the effect of thwarting access to perches. Appl. Anim. Behav. Sci. 68:243-256.

Ovi, F. K. C. Bortoluzzi, T. J. Applegate, C. R. Starkey, K. S. Macklin, A. Morey, W. J. Pacheco. 2020a. Effects of pre-pelleting whole corn inclusion on broiler performance, intestinal microbiota, and carcass characteristics. J. Appl. Poult. Res. <https://doi.org/10.1016/j.japr.2020.100114>

Ovi, F. K., R. Hauck, J. Grueber, F. Mussini, and W. J. Pacheco. 2020b. Effects of pre-pelleting whole corn inclusion on feed particle size, pellet quality, growth performance, carcass yield, and digestive organ development and intestinal microbiome of broilers between 14 to 42 day of age. J. Appl. Poult. Res. <https://doi.org/10.1016/j.japr.2020.10.012>

Pacheco, W. J., D. B. Patiño, J. I. Vargas, J. P. Gulizia, K. S. Macklin, and T. J. Biggs. 2021. Effect of partial replacement of inorganic zinc and manganese with zinc methionine and manganese methionine on live performance and breast myopathies of broilers. J. Appl. Poult. Res. 30: <https://doi.org/10.1016/j.japr.2021.100204>

Parvin, R., M. M. Mushtaq, M. J. Kim, and H. C. Choi. 2014. Light emitting diode (LED) as a source of monochromatic light: a novel lighting approach for behaviour, physiology and welfare of poultry. World’s Poult. Sci. J. 70:543-556.

Pichova, K, J. Nordgreen, C. Leterrier, L. Kostal, and R. O. Moe. 2016. The effects of food-related environmental complexity on litter directed behaviour, fear and exploration of novel stimuli in young broiler chickens. Appl. Anim. Behav. Sci. 174:83-89.

Poholsky, C. M., L. S. Erb, A. M. Lyons, P. Rohlf, and J. Boney. 2023. Improving pellet quality enhances Nicholas Select turkey performance in targeted phases of production. J. Appl. Poult. Res. 32:100340. https://doi.org/10.1016/j.japr.2023.100340

Poudel, I., M. M. Beck, A. S. Kiess, and P. Adhikari. 2022. The effect of blue and red LED light on the growth, egg production, egg quality, behavior, and hormone concentration of Hy-Line W-36 laying hens. J. Appl. Poult. Res. 31:100248. <https://doi.org/10.1016/j.japr.2022.100248>

Rentsch, A. K, E. Ross, A. Harlander, L. Niel, J. Siegford, T. M. Widowski. 2023. The development of laying hen locomotion in 3D space is affected by early environmental complexity and genetic strain. Scientific Reports. 13:10084. doi: 10.1038/s41598-023-35956-1.

Riddle, E. R., A. B. Ali, D. L. Campbell, and J. M. Siegford. 2018. Space use by 4 strains of laying hens to perch, wing flap, dust bathe, stand and lie down. PloS ONE 13: e0190532.

Sellers, R. B., P. B. Tillman, J. S. Moritz, and K. G. S. Wamsley. 2017. The effects of strain and incremental improvements in feed form on d 28 to 42 male broiler performance.  J. Appl. Poult. Res. 26:192-199.

Shepherd, T. A., Y. Zhao, H. Li, J. P. Stinn, M. D. Hayes, and H. Xin. 2015. Environmental assessment of three laying-hen housing systems. Part II:  Ammonia, greenhouse gas, and particulate matter emissions. Poult. Sci. 94:534-543.

Solymosi, N., C. Torma, A. Kern, A, Maroti-Agots, Z. Barcza, L. Konyves, O. Berke and J. Reiczigel. 2010. Changing climate in Hungary and trends in the annual number of heat stress days. Int. J. Biomet. 54:423-431.

Spindler, B., M. Giersberg, A. Briese, N. Kemper, and J. Hartung. 2016. Spatial requirements of poultry assessed by using a colour-contrast method (KobaPlan). Br. Poult. Sci. 57:23-33.

St-Pierre, N. R., B. Cobanov, and G. Schnitkey. 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci. 86:E52-E77.

Stratmann, A., D. Guggisberg, C. Benavides-Reyes, J. Siegford, and M. J. Toscano. 2022a. Providing ramps in rearing aviaries affects laying pullet distribution, behavior and bone properties. J. Appl. Poult. Res. 31:100283. doi:10.1016/j.japr.2022.100283.

Stratmann A, J. Siegford, M. Toscano. 2022b. Laying hen chicks make earlier use of elevated areas and perform more intertier transitions when provided with ramps in the rearing aviary. Proc. 55th Congr. Intl. Soc. Appl. Ethol. 55:92.

Shijinaraj Manjankattil Divek V. T. Nair, Claire Peichel, Sally Noll, Timothy J. Johnson, Ryan B. Cox, Annie M. Donoghue, Anup Kollanoor Johny. 2021. Effect of caprylic acid alone or in combination with peracetic acid against multidrug-resistant *Salmonella* Heidelberg on chicken drumsticks in a soft scalding temperature-time setup. Poult. Sci*.* 100:101421. <https://doi.org/10.1016/j.psj.2021.101421>

Subedi, S., R. B. Bist, X. Yang, and L. Chai. 2023a. Tracking floor eggs with machine vision in cage-free hen houses. Poult. Sci. 102637.

Subedi, S., R. B. Bist, X. Yang, and L. Chai. 2023b. Tracking pecking behaviors and damages of cage-free laying hens with machine vision technologies. Comput. and Elect. Agric. 204: 107545.

Toomer, O. T., A. M. Hulse-Kemp, L. L. Dean, D. L. Boykin, R. Malheiros, and K. E. Anderson. 2019. Feeding high-oleic peanuts to layer hens enhances egg yolk color and oleic fatty acid content in shell eggs. Poult. Sci. 98:1732-1748. <https://doi.org/10.3382/ps/pey531>

Upadhyaya, I., K. Arsi, A. Fanatico, B. Wagle, S. Shrestha, A. Upadhyay, C. N. Coon, C. Owens-Hanning, B. Mallman, J. Caldas-Cueva, J. Trushenski, M. N. Riaz, M. B. Farnell, D. J. Donoghue, A. M. Donoghue. 2022. Impact of feeding bigheaded carp fish meal on meat quality and sensory attributes in organic meat chickens. J. Appl. Poult Res. <https://doi.org/10.1016/j.japr.2021.100224>.

Wang, X., E. D. Peebles, K. G. S. Wamsley, A. S. Kiess, and W. Zhai. 2019. Effects of coccidial vaccination and dietary antibiotic alternatives on the growth performance, internal organ development, and intestinal morphology of Eimeria-challenged male broilers. Poult. Sci. 98:2054-2065. <https://doi.org/10.3382/ps/pey552>.

Weeks, C., and C. Nicol. 2006. Behavioural needs, priorities and preferences of laying hens. Worlds Poult. Sci. J. 62:296-307.

Yadav, B., R. Mishra, and R. Jha. 2019. Cassava (*Manihot esculenta*) root chips inclusion in the diets of broiler chickens: effects on growth performance, ileal histomorphology, and cecal volatile fatty acid production. Poult. Sci. 98:4008-4015.

Yang, X., R. Bist, S. Subedi, Z. Wu, T. Liu, and L. Chai. 2023. An automatic classifier for monitoring applied behaviors of cage–free laying hens with deep learning. Eng. Appl. Artif. Intell. 123:106377.

Yang, X., L. Chai, R. B. Bist, S. Subedi, and Z. Wu. 2022. A deep learning model for detecting cage-free hens on the litter floor. *Animals* 12:1983.

Yarandi, S. S., D. A. Peterson, G. J. Treisman, T. H. Moran, and P. J. Pasricha. 2016. Modulatory effects of gut microbiota on the central nervous system:  How gut could play a role in neuropsychiatric health and diseases. J. Neurogastroenterol. Motil. 22:201-212.

Zhao, Y. T. A. Shepherd, J. Swanson, J. A. Mench, D. M. Karcher, and H. Xin. 2015. Comparative evaluation of three laying-hen housing systems:  Description of the production systems and management practices. Poult. Sci. 943:475-484.

Zhao, Y., H. Xin, T. A. Shepherd, M. D. Hayes, J. P. Stinn, and H. Li. 2013. Thermal environment, ammonia concentrations, and ammonia emissions of aviary houses with white laying hens. Transactions of the ASABE. 56:1145-1156.

Zheng, W., Y. Xiong, R. S. Gates, Y. Wang, and K. W. Koelkebeck. 2020. Air temperature, carbon dioxide and ammonia assessment inside a commercial cage layer barn with manure-drying tunnels. Poult. Sci. 99:3885-3896. DOI:  10.1016/j.psj.2020.05.009.

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