ABSTRACT

Title of Thesis:	CIRCULATION FANS AND BROILER WELFARE IN COMMERCIAL BROILER HOUSES
	Zoie McMillian, Master of Science, 2022
Thesis Directed By:	Advisor, Dr. Shawna Weimer, Department of Animal and Avian Sciences

Footpad dermatitis (FPD) is a welfare concern in broiler houses today that is often caused by inadequate management of living conditions. The objective of this study was to evaluate the effect of high-capacity circulation fans on house litter moisture, temperature, relative humidity, noise volume, and broiler body weight, FPD prevalence and severity, hock burn prevalence, feather cleanliness, and behavior from 2 organic commercial flocks. For both flocks, two houses had 16 high-capacity circulation fans (Houses 1 and 2) and two did not (Houses 3 and 4). Welfare assessments took place when the birds were 3 and 6 weeks of age. With both flocks combined, a greater prevalence of FPD ($P=0.001$) and hock burn ($P=0.0002$) was observed for birds in the houses without fans than in the houses with fans at week 6. Flock 1 birds in the houses without fans had greater FPD lesion areas ($P=0.0001$) and FPD severity scores ($P=0.0004$) than birds in houses with fans. In Flock 2, there were more small birds in the houses without fans at week 6 ($P\leq0.03$). The results of this study indicate that high-capacity circulation fans in commercial broiler houses could positively impact FPD and hock burn prevalence, FPD severity, and flock uniformity.

CIRCULATION FANS AND BROILER WELFARE IN COMMERCIAL BROILER HOUSES

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2022

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Acknowledgements

First, I would like to thank my parents for their unconditional love and support throughout my entire academic journey. Mom, thank you for seeing me through every challenge with faith, patience, and reassurance. Dad, thank you for always being an unwavering source of encouragement in my life. I love you both so much.

I would like to thank my advisor, Dr. Shawna Weimer for seeing me through graduate school for the past two years and believing in my capabilities every step of the way. Under her instruction, I have learned more than I ever imagined, and I am so grateful for all of the great animal welfare conversations that we were able to have together.

I would also like to thank my advisory committee members Dr. Jonathan Moyle, Dr. Rachel Dennis, Dr. Nathaniel Tablante, and Dr. Tom Porter for their time, support, and expert advice throughout every part of this project.

Thank you to the other graduate students that I've had the pleasure to work with in my lab, Ashlyn and Anna, for constantly providing me with encouragement and advice that has been instrumental to my graduate student experience. I would also like to thank the undergraduates that I've worked with in this lab for assisting with my research; you are all amazing people, and I am so thankful for the opportunity to get to know you.

Lastly, I would like to thank all of my friends and family members for believing in me, supporting me, and always giving me reasons to smile. I am so blessed to have such an unwavering support system. It truly means the world to me.

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CHAPTER 1: Review of Literature

1.1 Introduction to the Literature Review

Domestic animals, such as broiler chickens, can adapt to a variety of environmental conditions. The broiler chickens used in the United States today have been genetically selected to thrive under modern management conditions (NCC, 2020). More than 9 billion broilers, weighing 56.6 billion pounds, were produced in the United States in 2018 alone (NCC, 2019). Generally accepted humane treatment of broilers consists of farm management practices that promote good health and production, minimize bird stress, and help prevent disease in flocks (NCC, 2020).

Animal welfare is an animal's physical, mental, and emotional state regarding its attempts to cope with its environment, often measured on a continuum from good to poor (Broom, 1996; AZA, 2021). An animal's welfare can be affected by many things, including management practices, environmental conditions, and health status. Footpad dermatitis, lameness, and disease are common problems in broiler houses today; these issues are often believed to be caused by lack of exercise, inadequate living conditions, poor litter quality, and inadequate biosecurity on farm (Bessei, 2006; Bull et al., 2008; Van Limbergen et al., 2018). Footpad dermatitis is a broiler welfare concern because when severe, it can lead to a deteriorated state of health and intense pain for the animal (Berg, 1998). To protect chickens on farms that are raised for human consumption, it is essential that their welfare is both evaluated and prioritized. Animal welfare is assured by assessment programs that are enforced by retailers.

This literature review will cover past and current research on how management practices and environmental conditions, with a focus on ventilation in commercial

houses, can affect the welfare of broilers as well as effective methods of evaluating broiler welfare.

1.1.1 Terminologies used in this thesis.

- **Animal Rights**: The idea that non-human animals should be free to live as they wish, without being used, exploited, or otherwise interfered with by humans (The Humane League, 2020).
- **Animal Welfare**: "An animal's state in regard to its attempts to cope with its environment" (Broom, 1996). "An animal's collective physical, mental, and emotional states over a period of time, and is measured on a continuum from good to poor (AZA, 2021).
- **Certification Program**: An assessment of how animals are managed in terms of the welfare guidelines and standards set using an organization's audit tool; conducted by a second or third party. (Weimer et al., 2018).
- **Certified Organic**: Specific requirements that must be verified by a USDA (United States Department of Agriculture)-accredited certifying agent before products from a farm can be labeled USDA organic. Some requirements are listed below:
    - "All organic livestock and poultry are required to have access to the outdoors year-round. Animals may only be temporarily confined due to documented environmental or health considerations" (USDA Agriculture Marketing Service). However, temporary confinement indoors is acceptable depending on the animal's stage of life, such as during the brooding period for broiler chicks (USDA Agriculture Marketing Service).

    - "Animals for slaughter must be raised under organic management from the last third of gestation, or no later than the second day of life for poultry" (USDA Agriculture Marketing Service).
    - "Producers must feed livestock agricultural feed products that are 100 percent organic, but they may also provide allowed vitamin and mineral supplements" (USDA Agriculture Marketing Service).
- **Foot-pad dermatitis**: A type of contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998).
- **Poultry Litter**: A mixture of bedding product, poultry feces, and feathers that is kept under individuals in commercial broiler houses (Poultry Hub Australia).
- **Second Party:** A person or group affiliated with a company that is affected by the outcomes of company actions (Weimer et al., 2018).
- **Stakeholder**: A person or organization with an investment or interest, or concern in something, especially in business (Weimer et al., 2018).
- **Third Party:** A person or organization that is independent of the consumer-supplier relationship and is free of any conflict of interest (Weimer et al., 2018).

1.1.2 Animal Welfare

Animal welfare assessments are imperative to ensuring animal productivity and physical health (Grandin, 2010). There are multiple types of organizations with welfare assessment programs in place to expand and safeguard current welfare standards because welfare is such an important part of agricultural industries. The World Organization for Animal Health (OIE, 2021) is "the intergovernmental organization responsible for improving animal health worldwide" (OIE, 2021). The OIE, consisting of 128 member

countries, provides species-specific animal welfare standards for the slaughter, transport, and killing of broilers (OIE, 2021). In addition to international animal welfare standards, each country has its own broiler-specific standards, laws, and regulations for animal welfare (Grandin, 2010; Crown, 2019).

Other groups that create animal welfare standards are customers, scientific societies, and producer groups (Grandin, 2010). Because these regulations are typically an organization's internal standards, they can often be quite strict compared to the legislated standards outlined by a nation's government or the OIE (Grandin, 2010). Generally, legislated standards stakeholders, and welfare assurance programs all play an important role in establishing and safeguarding the welfare standards upheld by large operations.

History

To understand animal welfare in our society today, the history of animal welfare and related policies should be discussed. As public concern for animal welfare began to rise in the 1950's, the federal Humane Methods of Slaughter Act was passed (49 U.S.C. 80502; passed in 1958) (USDA National Agricultural Library). The purpose of the act was to require meat companies to practice rapid, effective stunning of livestock before killing them for meat (Animal Welfare Institute). Originally passed in 1958, it was then passed again as the Humane Slaughter Act of 1978, this time enforced by the USDA Food Safety and Inspection Service (USDA National Agricultural Library). Under this version of the act, USDA inspectors have the authority to stop a U.S company from slaughtering livestock if their practices are not in accordance with the law (Animal

Welfare Institute). While the Act enforces “the proper treatment and humane handling of all food animals slaughtered in USDA inspection plants”, it does not apply to poultry. Thus, there are currently no federal laws in place to safeguard humane slaughtering and handling regulations for broilers at processing plants.

A similar law that was passed during this time was the Animal Welfare Act (AWA) of 1966. This law is the only federal legislation concerning research and exhibition animals (USDA National Agricultural Library). Transportation, sale, and handling practices of certain animals in the U.S must be in accordance with the AWA (USDA Animal and Plant Health Inspection Service). The AWA is considered the minimum acceptable standard for any guidelines that describe specifications for animal care and use, however, farm animals used for food and fiber, such as poultry, are not covered under this act (USDA Animal and Plant Health Inspection Service).

One of the specific livestock transportation requirements that is enforced by the USDA is the Twenty-Eight Hour Law, initially passed in 1873 and then reenacted in 1906 and 1994 (9 CFR 313; passed in 1873; amended in 2005) (USDA National Agricultural Library). The law requires that any livestock transported in the United States for more than 28 consecutive hours must be provided a 5-hour break from transportation to receive nourishment and rest (USDA National Agricultural Library).

Moving on to the ethics of animal welfare, another important aspect of animal welfare history is the Five Domains model. The main purpose of the Five Domains model, which was derived from the Five Freedoms formulated by the United Kingdom’s Farm Animal Welfare Council in 1979, was to aid in facilitating proper welfare assessments for animals (Mellor & Reid, 1994; Mellor et al., 2020). The Five Freedoms

consist of freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury, and disease (Mellor et al., 2020). The Five Domains Model is a collection of information focused on animal welfare scientific thinking and the affective state of animals (Mellor & Reid, 1994). The domains consist of standards for nutrition, physical environment, health, behavioral interactions, and mental state (Mellor et al., 2020). The model does not necessarily determine what specific animals need or how they function, but it can be used to access the living conditions for broilers in a reliable manner that can be systematically compared across multiple different domains (Mellor et al., 2020). The updated 2020 Five Domains model is similar to previous versions but has updated language and new considerations about the effect of human behavior on animal welfare (Mellor et al., 2020). The current version provides guidelines about evaluating the impact, both positive and negative, of human behavior on animal welfare (Mellor et al., 2020).

Food companies have also been known to make marketing plans to inform the public of their commitment to uphold animal welfare standards. While the call to improve animal welfare conditions within agricultural corporations and restaurant chains is somewhat recent, McDonald's and Burger King have been trailblazers in the changes that they have implemented globally. Both McDonald's and Burger King created Animal Welfare Committees and published their own welfare guidelines in 2000 and 2001, respectively (Johnson, 2008). More recently in 2017, McDonald's committed to only purchasing poultry meat and products from producers who rear them with certain welfare considerations (McDonald's). For example, McDonalds was the first organization to implement controlled atmospheric stunning (CAS) (Johnson, 2008). This is a method

approved by the USDA to improve conditions for workers while also providing more humane environments for the animals. According to the McDonald's, they not only require third party auditing for their supply chain partners, but they also claim to provide enrichments for the broilers that their partners provide (McDonald's). McDonald's states that all of this is done to promote natural broiler behavior and implement their global broiler key indicators of welfare and standards. McDonald's is part of a large group of retailers that have publicly committed to upholding animal welfare standards in an attempt to help customers feel more comfortable about their impact on animal treatment in agricultural corporations.

Animal Rights

Public opinion about animal rights has changed over the years and there are many opposing thoughts about what constitutes ethical animal treatment. Dr. Tom Regan was an influential moral philosopher who held specific views and produced detailed academic works about animal treatment and animal rights (Fenwick, 2017). Regan worked at North Carolina State University for over 34 years, as a faculty member, professor, and eventually as the head of the Department of Philosophy and Religion. In his works, Regan provides a deep criticism of the foundation of animal treatment. Regan suggests that "all who have inherent value have it equally, whether they be human animals or not" (Regan, 1986). When abiding by Regan's ideals, the goal is to treat animals as if they have rights, not because we value them as much as humans, but because they are beings with intrinsic value and humans should not be viewing them as things at our disposal in

the first place (Regan, 1986). Regan believed that is our duty to treat animals well and by observing this duty, we become worthy of happiness (Kant et al., 1996).

Many animal rights activists today use Regan's beliefs as a standard for their campaigns to change the animal production industry and increase animal rights. For example, People for the Ethical Treatment of Animals (PETA) is an international animal rights organization that consists of over 6 million members and supporters. The organization uses education, litigation, research, animal rescue, and cruelty investigations to uphold their mission of stopping animal cruelty and inhumane treatment (PETA). This organization has special ties to Maryland; it was founded in 1981 after PETA founder Indrid Newkirk worked to shut down the Institute for Behavioral Research in Silver Spring, Maryland due to inhumane treatment of monkeys in their research lab (PETA). PETA supports the idea that animals should not be eaten, worn, experimented on, or used for entertainment (PETA). A common criticism of animal rights activist groups is that they don't use their funds or influence to encourage policy changes that might improve animal welfare, but instead emphasize disrupting animal meat industries altogether. While many animal rights advocates wholeheartedly believe that PETA' s standards are the best way to stop animal cruelty, others who support animal agriculture, such as the Animal Agriculture Alliance, believe that animal rights advocates aim to mislead consumers about how livestock and poultry are actually raised (Animal Agriculture Alliance). Organizations that support animal agriculture often emphasize animal welfare, but their views are less extreme than those of many animal rights advocates.

Varying public opinions about animal rights has impacted the animal and alternative protein markets in numerous ways. The public discussion about meat

consumption has shifted from being entirely focused on the ethics of killing animals for food. Now, the public is also starting to consider sustainability and the effect animal agriculture has on our environment and heath (Andrei, 2021). Impossible Foods, founded in 2011, is an organization that provides consumers with meat substitutes made entirely from plants. They state that since animal agriculture may take up half of the internationally recognized climate budget by 2030, it is important to begin relying on other sources for our protein needs (Harwatt, 2018; Moses, 2019). Today, meatless protein alternatives are gaining traction because flavor, to taste more like actual meat, has improved over the years. Even fast-food restaurants and non-vegetarian consumers are starting to try the impossible burger and other meatless alternatives, such as Beyond Meat (Andrei, 2021). As of 2020, Starbucks, KFC, and Chipotle have all started offering plant-based meat options in their restaurant chains (Starbucks Corporation, 2020; KFC Corporation, 2022; Chipotle Mexican Grill, 2022). Global meat consumption is rising, but the consumer interest in meat alternatives is starting to shift in wealthier countries with stable economies, particularly European countries (Andrei, 2021).

Environmental sustainability and agricultural practices go hand in hand, but industrial activities such as the burning of fossil fuels and deforestation have a significant impact on climate change as well (NASA, 2020). Scientific education about both animal welfare and the environmental impact of meat production are imperative to creating legislation that provides the best outcome for animals and humans alike.

Stakeholders and Animal Welfare Assurance

As farmers work to meet more recent animal welfare audit requirements, it is ideal for certified animal welfare auditors to be from independent, third-party training programs such as Professional Animal Auditor Certification Organization (PAACO) and Farm Animal Care Training and Auditing (FACTA). These organizations are useful to producers because animal welfare auditors offer a "seal of approval" for the animal welfare audit instruments that they evaluate (Weimer et al., 2018). To keep the audits consistent and standardized, it is also required that each organization gets its own audit process audited by the USDA (Weimer et al., 2018; USDA Agriculture Marketing Service). When it comes to local regulations, some states also have animal confinement regulations in place. According to The National Agriculture Law Center, 19 states have regulations/statutes on farm animal confinement (Rumley, 2021) regulating the amount of space each animal should have. The confinement species included in these state regulations are swine, bovine, ovine, caprine, and laying hens; these animals can be confined in stalls, creates, or cages (Rumley, 2021). Because broilers are not kept in cages, they are not included in these state regulations.

The low production and resource costs of broiler chickens make them an ideal choice for producers compared with other livestock industries, such as beef cattle production (Eshel et al., 2014; Shepon et al., 2016). The affordability of chicken meat, and the trend of many consumers substituting red meat for healthier options, makes it a common protein source for many buyers as well (Wang et al. 2010; Phibbs et al., 2021). However, balancing profitability, sustainability, and the implementation of welfare standards are all necessary aspects of a thriving broiler meat industry. There are currently no federal laws in place to regulate the raising of poultry (Weimer et al., 2018), so it is

imperative that commercial broiler companies take the initiative to monitor the welfare of their animals. In The United States, the system of regulating poultry welfare is essentially dependent on food retailers. These retailers typically control how and when producers must have animal welfare audits conducted because they require producers to be certified if those producers intend to sell their products to the retailers (Weimer et al., 2018). It is common for animal welfare standards to be changed over time to better protect the chickens that we rely on for nourishment, but they must be backed by science to persuade policy makers and organizations with producer incentives to support those changes. Consumers deserve access to affordable protein and producers deserve the opportunity to maintain profitable broiler operations while also prioritizing broiler health and welfare.

Stakeholders are people or organizations with an investment, interest, or concern in something, especially in business (Weimer et al., 2018). In animal welfare, these are groups or individuals who are compensated based on the success of the production of meat or byproducts from certain farm animal species. The stakeholders of the poultry industry are producers, processors, customers, consumers, and veterinarians working with poultry organizations. Retailers of poultry products are important stakeholders in this industry because they can require their producers to have their animal husbandry practices inspected to gain certain animal welfare certifications.

Consumer perception is a big influencer of a company's success, especially when animal welfare is becoming increasingly considered by today's public. Producers looking for welfare certification programs for their poultry business can get them from both nonprofit organizations and other organizations designed specifically for animal welfare audits (Weimer et al., 2018). Participating in these programs is not required by any

federal regulations, but there are many potential benefits to be gained by participating. Labels that ensure proper welfare on broiler farms are likely to make consumers feel better about purchasing those products. According to the National Chicken Council (NCC), broiler producers and processors who endorse NCC welfare standards must adhere to specific guidelines (NCC, 2020). The NCC Animal Welfare Guidelines and Audit Checklist consists of specifications regarding personnel training, nutrition and feeding, management practices, comfort and shelter, health care and monitoring, and catching and transportation, amongst many other. The NCC states that producers must manage litter, ventilation, feed formulations, and drinking systems in order to prevent footpad issues like footpad dermatitis. The NCC also states that footpad health must be assessed and scored at processing plants by auditors, according to their provided scoring system (NCC, 2020).

National livestock and poultry producer organizations that provide animal welfare guidelines for assessments and audits include:

- American Sheep Industry Association (ASI)
- National Cattlemen's Beef Association (NCBA)
- National Chicken Council (NCC)
- National Pork Board (NPB)
- National Milk Producers Federation (NMPF)
- United Egg Producers (UEP)
- National Turkey Federation (NTF)

The animal assessment criteria used by these groups is based on scientific research and updated regularly (Weimer et al., 2018). The goal is to improve practices for

animal housing, husbandry, transport, and slaughter, specifically in the areas where welfare may be lower than ideal.

Animal-based Measures

On-farm broiler welfare assessments consist of housing and environment (resource-based) measures and animal-based measures. Animal-based measures of welfare include using health features, body conditions, and behaviors of individual animals as indicators of their own welfare status (Butterworth et al., 2009). Welfare assessment strategies, such as animal-based measures, should be established and evaluated in terms of their efficacy on-farm. Furthermore, welfare indicators need to be useful and practical for producers to adopt them as assessment methods (Marchewka et al., 2013).

Behavioral indicators of welfare can be divided into positive and negative categories. Some positive behavioral indicators of broiler welfare are play and species-specific behaviors (Broom, 1991; Held & Špinka, 2011). Some negative behavioral indicators of broiler welfare are panting (heat stress), huddling, and avoidance distance testing (Butterworth et al., 2009). Animal-based measures of broiler welfare can also consist of some of the following physical factors: lameness, hock burn, feather cleanliness, breast blisters, and footpad dermatitis (Butterworth et al., 2009). More specifically, lameness, hock burn, and footpad dermatitis fall under the "absence of injury" category in the 2009 Welfare Quality® Assessment Protocol for Poultry.

Within the Welfare Quality® Assessment for broilers, lameness (gait score) is evaluated based on a 6-point scale (0-5), where 0 indicates a bird with a normal gait that

is dexterous and agile, 1 indicates a bird with a slight gait abnormality that is difficult to define, 2 indicates a bird with a definite and identifiable gait abnormality, 3 indicates a bird with an obvious gait abnormality that affects the bird's ability to move, 4 indicates a bird with a severe gait abnormality that only takes a few steps, and 5 indicates a bird that is incapable of walking (Butterworth et al., 2009).

Hock burn, like footpad dermatitis, is a type of contact dermatitis. Hock burn is found on the skin of the caudal (back) hock joint of broilers (Butterworth et al., 2009). Its prevalence is evaluated on a 5-point scale (0-4), where 0 represents no evidence of hock burn, 1 represents minimal evidence of hock burn, 2 represents minimal evidence of hock burn, 3 represents evidence of hock burn, and 4 represents evidence of hock burn. Footpad dermatitis is evaluated on the same 5-point scale (0-4) as hock burn, where 0 represents no evidence of footpad dermatitis, 1 represents minimal evidence of footpad dermatitis, 2 represents minimal evidence of footpad dermatitis, 3 represents evidence of footpad dermatitis, and 4 represents evidence of footpad dermatitis. Feather cleanliness is evaluated on a 4-point scale (0-3), where 0 represents no evidence of dirty feathers, 1 represents minimal evidence of dirty feathers, 2 represents minimal evidence of dirty feathers, and 3 represents evidence of dirty feathers (Butterworth et al., 2009). When auditors and producers assess broilers for hock burn, footpad dermatitis, and feather cleanliness on-farm, a 3-point scale is typically used to simplify scoring. When using a 3-point scale to evaluate these physical factors, 0 scores represent no evidence, 1 scores represent minimal evidence, and 2 scores represent severe evidence.

Fear tests are also included as valid behavioral indicators of animal welfare in the Welfare Quality® protocols and the assessment criteria for the Avoidance Distance Test,

a fear test used to evaluate human-animal relationships, involves an assessor squatting for 10 seconds and then counting the total number of broilers within one meter of the assessor (Butterworth et al., 2009). To assess thermal comfort, the percentage of birds panting and huddling is recorded and evaluated. Panting prevalence is determined by counting the number of birds in a group of 100 that are panting, while huddling prevalence is determined by an estimation of the proportion of birds huddling in an entire flock (Butterworth et al., 2009). Animal based measures are essential to broiler welfare assessments on-farm; when evaluated along with resource-based measures, assessors can gain a holistic perception of broiler well-being.

1.1.3 Management

Resource-based Measures

Broiler management typically encompasses management practices that contribute to broiler health, welfare, and sustainability of broiler operations. Controlling broiler house ventilation, managing litter moisture, and providing adequate space allotment are important aspects of broiler management (Martland, 1985; Ekstrand et al., 1998). Consideration for house ventilation and litter moisture enables producers to keep mortality as low as possible and grow healthy broilers with high body weights to maximize profit (Martland, 1985; Ekstrand et al., 1998). Litter, the bedding material on which broilers spend their time, used in broiler houses should be kept relatively dry. Wet litter can cause footpad dermatitis in flocks as it can hold chemical irritants, feces, and moisture that lead to infection on ventral footpads and hocks (Ekstrand et al., 1998). Additionally, the air in broiler houses should stay well ventilated to keep litter moisture low and prevent heat stress during warm months (NCC, 2020). Ventilation, litter

moisture, and other aspects of broiler welfare are discussed further in upcoming sections of this literature review.

1.2 Review of Literature

1.2.1 Broiler Welfare Concerns

As the public becomes more concerned about welfare in animal production systems, ethical production practices have been of increasing importance to consumers and the poultry market (Alonso et al., 2020). Producers must consider and account for the ethical concerns of the public when it comes to keeping demand high and making an adequate profit. By staying informed with changing public perceptions about on-farm animal welfare, farmers can improve their sustainability, social accountability, and credibility (Alonso et al., 2020).

Broiler issues such as footpad dermatitis, lameness, and mortality are often believed to be caused by lack of exercise, inadequate living conditions, and poor litter quality (Bessei, 2006). Types of contact dermatitis can include hock burn, breast blisters, and footpad lesions seen in broiler flocks (Hartung, 1994). Because contact dermatitis has been shown to cause pain, it is one of the most obvious welfare issues in broilers (Bessei, 2006).

High stocking density, which is the amount of space provided to birds, can impact broiler production, performance, and welfare (Manning et al., 2007; Estevez, 2007). Previous studies indicate that there is a decline in bird body weight when stocking density was lower than $0.066 m^2$ per bird (Estevez et al., 1997). There is evidence that increasing broiler stocking density can lead to slower growth, increases in gait scores (poorer walking ability), and more collisions amongst conspecifics (Dawkins et. al, 2004). Outdoor stocking density is an important element of broiler welfare, especially since

many assurance programs require specific outdoor space allotments for various certification labels, like “free-range” and “organic” (Phillips & Heins, 2021).

Footpad Dermatitis in Broilers

Footpad dermatitis in broilers is typically characterized as lesions on the skin of the foot pads and on the hocks. It can also represent itself as severe lesions, often seen as painful ulcers that increase the likelihood of infection from harmful bacteria also found in litter (Bassler et al., 2013). Moisture from waterline nipples and bird excrement, along with ammonia and other corrosive substances often found in the litter of broiler houses, can lead to this type of contact dermatitis (Nairn & Watson, 1972; Schmidt & Luders, 1976). It should also be noted that diet (e.g., biotin), bird weight, skin structure, and litter type may contribute to the likelihood of a broiler contracting foot-pad dermatitis (Mayne, 2005).

Footpad dermatitis reduces bird welfare because when severe, it can lead to a deteriorated state of health and intense pain for the animal (Berg, 1998). Footpad dermatitis can also cause lameness or unstable gaits in broilers, but it is difficult to identify lameness caused by this specific dermatitis as it often presents as immobility as opposed to obvious limping (Hester, 1994; Berg, 1998).

Footpad dermatitis prevalence also poses a threat to the poultry meat industry; it can have a negative impact on financial profit for producers when a lack of weight gain and product results from the disease becoming more widespread (Ekstrand et al., 1998). Not only do broilers with severe cases show slower weight gain (presumably due to their pain), but increased footpad dermatitis prevalence can also lead to increases in other

types of dermatitis, like breast blisters and hock burn (Martland, 1985; Berg, 1998). Even if reducing flock size could help reduce these cases in commercial houses, it would likely significantly reduce the profitability of the flocks as well (Cravener et al., 1992). Thus, footpad dermatitis not only affects animal quality of life on an individual and flock level, but it also harms the poultry meat industry by reducing its profitability and sustainability.

Litter Moisture and Footpad Dermatitis

Footpad dermatitis is a form of dermatitis from contact with the litter used in broiler houses. Maintaining low litter moisture is important, especially because U.S. broiler producers typically re-use their litter with several flocks, and de-cake, windrow, and top-dress in-between flocks to reduce moisture, ammonia levels, and microbial load (Mou, 2020). Upholding this standard helps producers to avoid an unideal environment for chemical irritants, feces, and humid air to sit for long periods of time and spread across flocks of broilers (Ekstrand et al., 1998).

Ideally, litter moisture should be kept below 20%-25% in broiler houses (Küçüktopcu & Cemek, 2022). Planned prevention is the best way to lower the effects of footpad dermatitis in a flock. It is recommended that litter moisture is regularly checked and kept low (Furo, 2019). Another possible wet litter prevention method could be implementing the use of more efficient water line mechanisms that are less likely to leak, drip, or break after regular broiler use. Checking for holes and leaks could also aid in preventing additional water buildup from rain in commercial houses (Furo, 2019). Foot pad lesions are typically more common in heavier broilers that may already suffer from lameness, but there are still steps that can be taken to mitigate the severity of lesions once

they are noticed. In fact, transitioning broilers to dry litter is suggested to assist in lesion healing (Martland, 1985). While litter moisture is a significant contributor to footpad dermatitis prevalence, proper dietary intake and care provided to the birds could also have a positive effect on footpad dermatitis cases (Ekstrand et al., 1998). For example, increasing biotin in commercial rations has been shown to help reduce the number of footpad dermatitis cases on-farm (Mayne, 2005).

In the Processing Operations section of the NCC Animal Welfare Guidelines and Audit Checklist, it is stated the footpad assessment carried out by broiler processors must involve evaluation of a random sample of 100 birds for footpad health, scoring paws as either passing or failing. In order for producers to abide by NCC guidelines, 90% of the randomly selected paws must receive a passing score (have no lesions, ulcerations, or scabs that cover more than half of the footpad) (NCC, 2020). Footpads are the third most valuable part of the chicken when it comes to consumer demand (Shepherd & Fairchild, 2010), so it is in the best interest of the grower and integrator to focus on minimizing wet litter and, as a result, increasing their yield of quality footpads to sell.

Measuring Affective State

Past animal welfare efforts have, for the most part, been focused on minimizing negative experiences for animals, as opposed to increasing positive ones (Yeates & Main, 2008). Now, researchers have become more aware that positive experiences and good affective state are essential to animal welfare (Yeates & Main, 2008; Laurijs et al., 2021). When compared to research on indicators of negative welfare, the positive aspects of animal welfare are far less studied (Lawrence et al., 2019). Determining the affective

state of broilers can be challenging because there are not many direct measures of affective state. While physical health is an efficient indicator of welfare status, there is not always a linear relationship between affective state and physical health. Currently, there are not many indicators of positive affective state available for researchers or producers to use, especially indicators that are considered fast, non-invasive, and reliable (Laurijs et al., 2021). Animal vocalizations are considered to be particularly assuring indicators of affective state (Manteuffel et al., 2004), but real-time technologies to quantify vocalizations on broiler farms cease to exist. Due to the scarcity of validated and effective positive welfare indicators, there is great need for the development of these types of indicators that can be used on farm animals and on-farm assessment protocols (Laurijs et al., 2021).

Indicators of animal welfare can be considered “lead” and “lag”. Lag indicators are signs of compromised welfare status that have already occurred in the bird and thus, only give us information about how to change future production cycles to improve welfare (Manning et. al, 2007). Common broiler lag indicators are mortality, contact dermatitis prevalence, and poor leg health (Manning et. al, 2007). These poor welfare indicators help us evaluate affective state of the broilers because research indicates that these features are often associated with pain and stress. Lead indicators, on the other hand, are signs that provide welfare information before negative outcomes can occur (Manning et. al, 2007). Indicators such as feed and water consumption, air and litter quality, and daily weight gain are lead indicators that enable flock managers to take preventative or corrective action to improve the quality of life for the animals (Manning et. al, 2007). While lag indicators can provide us with a clearer idea of welfare status,

focusing on lead indicators is often more beneficial for the welfare of individuals within a specific flock and requires a more attentive eye.

1.2.2 Environmental Management

Environmental Stewardship in Maryland

Environmental stewardship is an important part of environmental management on large commercial broiler farms. The state of Maryland enforces an approval system for farmers that helps protect local waterways and the Chesapeake Bay agriculture (Maryland Department of Agriculture, 2020). The system consists of permits, registrations, certifications, licenses, and other approvals to ensure that producers that use nutrients and pesticides also abide by regulations outlined by the Maryland Department of Agriculture, Environment and Natural Resources (Maryland Department of Agriculture, 2020).

When it comes to large poultry operations, producers in Maryland must have a Concentrated Animal Feeding Operation (CAFO) Permit (Maryland Department of Agriculture, 2020). This permit is required for any large animal feeding operation (of 37,500 chickens or more per flock) that have the potential to discharge pollutants from manure or poultry litter to Maryland waters (Maryland Department of Agriculture, 2020). This permit is reviewed every five years for the designated Concentrated Animal Feeding Operations and producers must pay an annual permit fee of $120-$1200, depending on the size of their operation (Maryland Department of the Environment). To obtain a CAFO permit, producers must also submit a comprehensive nutrient management plan that is in accordance with the USDA Natural Resources Conservation Service (NRCS) standards.

Strategies to control bacteria, nitrogen, phosphorus, and sediment runoff are important parts of this nutrition management plan, as these substances have the potential to harm the local environment (Maryland Department of the Environment). This permit requirement is a standard that CAFOs must adhere by, setting aside time and money to do their part to protect the environment as responsible feeding operation proprietors. At the end of the day, environmental regulations aid in increasing the sustainability of the broiler industry by protecting Maryland waters.

Environmental Management to Control Welfare Issues

Environmental factors in broiler houses are also important elements of broiler welfare. Houses with high litter moisture and air ammonia levels are often correlated with dirty footpads, hocks burn, and increased stress (fecal corticosterone) (Dawkins et. al, 2004). Keeping within recommended humidity and temperature ranges, 50-70% humidity and approximately 90°F at placement and 70°F after 4 weeks of age, in broiler houses is ideal because it can reduce mortality and the risk of disease (Marshall, 2017; Aviagen, 2018). Whether done manually or more effectively with computer controller systems, maintaining house climate is important because it enables producers to keep chickens within their thermal neutral zone, which changes daily, but is within 60-75°F for older poultry, allowing them to live and grow as comfortably as possible (Marshall, 2017; Noll, 2018). As we learn about the true impact of house climate on broiler welfare, there is increased incentive to monitor environmental management practices and follow standards that outline recommended temperature, humidity, litter moisture, and ammonia levels for broilers.

Ventilation in Broiler Houses

There are many potential benefits to applying ventilation to broiler houses. Even in the 1990's researchers knew that installing tunnel ventilation fans in new broiler houses would help keep temperatures from rising too high in the summer and prevent heat stress in their birds (Lacy & Czarick, 1992). Having a proper ventilation system will greatly impact animal welfare and production on broiler farms. Broiler houses can hold tens of thousands of birds, so proper ventilation can help ensure sufficient air exchange throughout the houses, control litter moisture, keep temperatures regulated, and maintain suitable carbon dioxide and oxygen levels (Riley, 2018). Even when ventilation systems are used on-farm, it is important that there is regular, manual or automatic, monitoring of the air quality, such as humidity, oxygen and ammonia levels, and temperature changes in the houses (Riley, 2018). Broiler behavior is affected by their environment, and uneven bird distribution, panting from heat stress, and increased respiratory issue prevalence in broiler houses are good indicators of ventilation system issues (Riley, 2018).

Fan Types

The type of fans installed in broiler houses is important because they can have an effect on house static pressure, the efficiency of air circulation, air flow ratio, and future maintenance obligations (Tabler & Wells, 2019). Cheaper fans can lead to decreases in efficiency over time and wasted energy. Poor fan choice and an inadequate number of fans can impact bird health because poor air quality increases risk of bird stress and thus disease outbreaks as well, especially respiratory disease (Tabler & Wells, 2019). Even

when suitable fans are used in a broiler house, it is important for producers to periodically measure static pressure, wind speed, and rpms (revolutions per minute) of fans to ensure that they are still working properly over time (Tabler & Wells, 2019).

The types of fans installed in broiler houses also vary in their ability to maintain proper litter moisture. In 2001, Eriksson de Rezende et al. reported a higher and unvarying flow of air over the litter surface in broiler houses that had tunnel ventilation compared to houses that only had wind and propeller fans. Increased and continuous air flow (of 150-200 feet per minute) could also help producers control foodborne pathogens, such as *Salmonella,* prevalence in litter, which can also be affected by litter moisture (Eriksson de Rezende et al., 2001). Traditional low volume circulation fans are typically used in the U.S. broiler industry to save energy, reduce temperature stratification, and to keep air movement at floor level relatively low to prevent chilling young birds (Mou, 2020; Aviagen, 2018). Although fans that produce low air movement at floor level (< 30 ft/min) are purposefully used to protect chicks during their first 14 days of life, previous research indicate that such low levels of air movement are less effective at drying litter than high volume circulation fans that produce air movement of about 155 ft/min at floor level (Weaver & Meijerhof, 1991; Eriksson de Rezende et al., 2001; Aviagen, 2018).

A recent field study conducted by Mou et al. (2020) found that when high air movement was applied to houses with high relative humidity of 50%-60%, litter was 25% drier and had more uniform conditions than houses without the higher air movement. Additionally, the incidence of birds with footpad lesions was 45% lower in the houses with high air movement (Mou et al., 2020). In contrast, low-volume circulation fans are not generally known to keep litter dry but are rather often used by producers to save

energy and aid in temperature destratification (Czarick & Fairchild, 2012). As producers aim to grow larger birds, higher air exchange rates are becoming more popular; air speed goals of 800 feet per minute are common in new broiler houses today (Tabler & Wells, 2019).

Regarding the emphasis on protecting chicks during the first week of growth (brooding), it is unlikely that high-volume circulation fans would lead to chicks being chilled if temperatures are closely monitored. Producers keep broiler houses ventilated to regulate temperature, remove carbon dioxide and ammonia with negative pressure, and to control moisture, dust, and odors (Czarick & Fairchild, 2012). As outside air mixes with the inside air during ventilation, cooler air is prevented from settling close to the litter surface and chilling the chicks (Czarick & Fairchild, 2012). It is important that inlet openings are small enough and that air speed is high enough to keep cool air from dropping to litter level in the house. Circulation fans are designed to break up temperature stratification and make temperatures more even, they are already working to prevent cold pockets from forming in the house (Czarick & Fairchild, 2012). Thus, the benefit of controlling litter moisture and preventing diseases associated with wet litter by using high volume circulation fans may outweigh the risk associated with increased air movement over chicks. Although much research has not been conducted on the topic, there is potential for high volume circulation fans to be used on farm to maintain dry litter and aid in safeguarding footpad health in broilers (Mou, 2020).

1.2.3 Behavioral Indicators of Welfare

An animal experiences stress when a physiological or behavioral response is stimulated in the body due to a change in that animal's environment (Harvey et al., 1984). Stressors can be a combination of physical or mental factors that can negatively impact the animal, both in the moment or over time (Harvey et al., 1984). Common causes of stressors in poultry consist of certain management practices and poor environmental conditions (Otu-Nyarko, 2010). Intensive production is a known source of stress in broilers, along with stocking density, environmental deterioration, and thermal stress (Sassi et al., 2016). Some stressors are more manageable than others are. Overcrowding and starvation are examples of stressors that are avoidable, while stress associated with vaccinations and transportation may be unavoidable (Mohan, 2005). When proper welfare is not provided to poultry, they are likely to experience physical stressors from things like injury, poor litter conditions, or inadequate temperatures. These physical stressors may ultimately lead to mental stressors like fear and pain (Elrom, 2000).

Chicken welfare is typically evaluated on-farm, with assessments and auditing protocols in place to allow producers to assess gait score, footpad dermatitis, feather cleanliness, and plumage condition (Abeyesinghe et al., 2021). These health outcomes are evaluated in broilers to ensure that the common health issues they face are found and mitigated as soon as possible. There is also a push to raise better and healthier chicken breeds, so candidate breeds are sometimes tested for various features (Abeyesinghe et al., 2021). Broiler behavior has also been shown to be associated with the health outcomes that are often assessed, and certain behaviors are associated with positive welfare (Abeyesinghe et al., 2021). Determining behavioral profiles in chickens and having

systems in place to notice changes in their behavior could enable early detection of pathology as well as methods to compare the level of discomfort caused by various health issues (Abeyesinghe et al., 2021). Using behavior to evaluate welfare, although time-intensive, is both non-invasive and generally less disruptive than typical welfare assessments that involve handling of the birds (Abeyesinghe et al., 2021).

Observing the presence or absence of species-specific behavior is an essential part of evaluating animal well-being. Husbandry practices are considered sufficient when animals can perform normal behaviors without obstruction or suffering, adapt to their environment safely, and can satisfy their own needs within their environment (Broom, 1991; Bergmann et al., 2017).

Behavioral changes allow the chicken to meet internal demands as well as demands of the flock while adapting to husbandry practices (Mauldin, 1991). Broilers spend a lot of time engaging in social behavior. Social organization aids in reducing fighting and other non-adaptive energy expenditures, as well as providing a foundation for establishing pecking order and relationship hierarchies (Mauldin, 1991). The ability of flock mates to recognize each other, however, becomes challenging under commercial poultry farm conditions where group sizes are large (Mauldin, 1991).

Behavioral observation is also an ideal way to gain insight into the value of enrichments on commercial broiler farms because behavior is closely related to an animal's environment. Environmental enrichments are modifications that act to enhance the level of physical stimulation provided in a captive environment (Würbel et al., 1998). Enrichments can be quite beneficial for broilers because they have been shown to stimulate species-specific behaviors and increase welfare even while cost-effectively

meeting consumer needs (Bergmann et al., 2017). Previous research has shown that the addition of enrichments in a commercial house is associated with reduced avoidance behavior in broilers (Baxter et al., 2019). This study's results also indicate that displacing broilers with an observer walk-through led to increased play behaviors (frolicking and sparring) during the five minutes after the birds were displaced (Baxter et al., 2019). Play is typically considered to be opportunity-based behavior that is not often seen when animals must endure a poor environment (Held & Špinka, 2011). While it is unknown if play behavior is a suitable measure of positive affective state in poultry, there is reason to believe that the presence of play behaviors in broilers indicates more positive welfare status. Alternatively, fear indicators, such as avoidance behavior, are closely linked to negative affective state; fear responses are often accompanied by potential injury risk, which also has negative implications for chickens (Reed et al., 1993). Thus, a decrease in fearful behavior is another potential indicator of positive welfare in broilers that are given more complex and enriching living conditions (Baxter et al., 2019).

When using behavioral assessments to evaluate illness in animals, it is important to note that behavioral indicators are often based on accumulated experience of their handlers, making assessments subjective and prone to reliability issues (Weary et al., 2009). More recent animal illness research tends to have a focus on objective quantitative measures such as feeding behavior and intake (Weary et al., 2009). Due to the pain caused by physical injuries and disease, such as footpad dermatitis in poultry, animals often experience a loss in normal functioning, which is reflected in their behavior (Weary et al., 2009). When behaviors such as lameness or irregular gate are observed in a flock of broilers, pain can be more precisely identified by using analgesics in feed and

monitoring behavior (Danbury et al., 2000). In a 2000 study by Danbury et al., lame broilers significantly chose to eat more analgesic drugged feed than healthy birds; increased lameness and drugged feed consumption were positively correlated (Danbury et al., 2000). This research is an example of how behavior could be indicative of not only health status, but pain severity as well.

Novel Technologies and Methodologies used On-farm

Observing boiler behavior from video recordings has become more commonplace in recent years, especially when researchers want to gain insight into broiler behavior in commercial settings. By mounting digital cameras in commercial broiler houses, researchers can observe broiler behavior in detail, over longer periods of time, while causing minimal disturbance to birds (Bergmann et al., 2017; Abeyesinghe et al., 2021; etc., many others).

Recent technological advancements have also enabled the use of new methods of evaluating health and welfare of broilers on-farm. Lameness in broilers, which can be caused by a range of injuries and health issues, leads to locomotion difficulties, pain, and chest soiling/dirty feathers (Weeks et al., 2000; Aydin, 2017). In a 2017 study by Aydin and colleagues, an early detection system for lameness was developed and tested on broilers with five different gait scores. An image analysis algorithm was used to detect different visual variables such as speed, step frequency, step length, and lateral body position (Aydin, 2017.) The results of this study indicated that all of the features used for the early detection system were useful in detecting lameness in broilers that had a gate score of 3 or above (Aydin, 2017). Broiler behavior quantification with advanced

technology has the potential to help producers observe health and welfare issues/changes more accurately and on a larger scale, however, more research is needed to identify practical, cost-effective, reliable technologies for use on-farm.

Transect Method of Welfare Assessment

On-farm welfare assessments are often based on individual evaluations that involve handling birds to get accurate indicators of their health status. More recently, the transect method of observation was developed by Marchewka et al. (2013) to use as a practical on-farm welfare assessment tool that is less time consuming and disruptive, yet more feasible than individual sampling methods. It was based on routine walk-throughs that farmers typically implement to evaluate general flock health and the transect methodology seen in wildlife studies (Marchewka et al., 2013). In this method, the transect walk approach is conducted by having an observer walk in randomly set paths, down the length of a broiler house, covering the entire house area. During each transect walk, the observer recorded all occurrences of observed birds that fell within the categories: immobile, dirty, sick, agonizing, and dead (Marchewka et al., 2013). These specific categories were chosen because they were established as validated welfare indicators by the ESFA (Marchewka et al., 2013; European Food Safety Authority); European Food Safety Authority, 2012). Researchers found that the transect method welfare results indicated higher welfare status compared to individual sampling results, so there was a clear discrepancy between the two methods (Marchewka et al., 2013). The discrepancies, however, may have been due to the smaller sample size used for individual sampling, which is difficult to increase with limited personnel and time (Marchewka et

al., 2013). These results further emphasize the feasibility of the transect method in terms of the ideal time, staff, and handling requirements associated with it.

The transect method has also been used in other studies. In 2015, commercial turkey welfare was evaluated with the transect method and the transect results were compared with traditional individual sampling methods of assessing welfare (Marchewka et al., 2015). Researchers recorded the number of observed birds that were immobile, lame, aggressive, wounded, showing mounting behaviors, small, featherless, dirty, sick, terminal, or dead; they then conducted individual assessments within 48 hours, selecting random birds and focusing on the same observation parameters (Marchewka et al., 2015). The results of this study indicated that there was no difference between welfare data collected with the two methods, besides the immobile and dead results. Researchers suggested that the reason for the lack of correlation of the number of immobile birds is that individual sampling is not suitable for differentiating between immobile and dead birds (Marchewka et al., 2015). It is also possible that dead birds were harder to observe during the individual welfare assessments. The data from this study suggests that the transect method could be a feasible and effective way to assess the welfare of meat poultry, as well as large toms (Marchewka et al., 2015). Hrženjak et al., implemented the method in 2021 to evaluate welfare in commercial turkey flocks. Although they did not compare the transect method to individual sampling, their results indicated that assessing welfare using the transect walk approach could provide important information on animal health and welfare and could help farmers improve welfare in commercial turkey flocks (Hrženjak et al., 2021). The transect method has also been used in previous research to evaluate the welfare of laying hens and Pekin ducks (Abdelfattah et al., 2020; Vasdal et

al., 2022). While the transect method of observation may not produce data that is identical to individual assessments, it can be used to evaluate many of the same characteristics and the ability to assess larger portions of a flock could lead to more accurate findings.

A potential limitation of the transect method is that it may cause observers to overlook walking deficiencies, as they may be harder to notice when observing many birds simultaneously (Marchewka et al., 2013). On the other hand, a limitation of individual scoring methods is that less mobile birds are more likely to get caught and assessed as a representation of the entire flock, potentially leading to biased results. If the transect method is used to evaluate welfare from several flocks, producers could predict arising welfare concerns and implement defensive strategies (Marchewka et al., 2015). The transect method is a tool that can be practically implemented in both internal and external welfare evaluations, especially since consumers have recently been demanding increased animal welfare standards (Barbut, 2010; Marchewka et al., 2015). Furthermore, the transect method could potentially detect the consequences of welfare impairment on slaughter outcomes, making it a useful tool for finding and mitigating welfare issues as early as 3 weeks of age (BenSassi, et al., 2019).

1.3 Summary, Objective, and Hypothesis

The objective of this literature review was to outline potential causes of footpad dermatitis in broilers, measures to assess broiler welfare, and the relationships between broiler welfare, ventilation, and moisture in commercial broiler houses.

Based on previous literature, we hypothesized that broiler welfare can be increased if moisture in commercial broiler houses is more accurately controlled with the addition of circulation fans. We hypothesized that footpad dermatitis and hock burn prevalence could be reduced as a result of the increased air movement, with general improved feather conditions in the broilers raised in houses with increased ventilation.

The objective of this study was to evaluate circulation fan use in relation to litter moisture, house temperature and relative humidity, house noise volume, body weight, footpad dermatitis prevalence and severity, hock burn prevalence, feather cleanliness, and behavior as an indication of welfare status in the broilers. The circulation fans were installed in two of four houses within an organic rearing system. The farm used for this study was located in eastern Maryland on a contract with a local broiler integrator.

We expected that the broilers raised in houses with the circulation fans would have higher welfare than broilers in houses without circulation fans. By increasing air circulation in broiler houses, the aim was to provide the birds with an environment that maximizes their welfare and enables them to reach their full genetic potential.

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CHAPTER 2: Evaluating the Effect of Circulation Fans on Broiler Welfare

2.1 Abstract

An animal's welfare can be affected by management practices, environmental conditions, and health status. Footpad dermatitis (FPD) is a welfare concern for broilers today that is often caused by poor litter quality in commercial houses. The objective of this study was to evaluate the effect of high-capacity circulation fans on house litter moisture, temperature, relative humidity, and noise volume, and broiler body weight, FPD prevalence and severity, hock burn prevalence, feather cleanliness, and behavior from 2 commercial flocks. This study was conducted in 4 commercial organic broiler houses in eastern Maryland. For both flocks, two 60 x 600 ft. houses had 16 high-capacity circulation fans (Houses 1 and 2) and two did not (Houses 3 and 4). Welfare assessments and behavior recording took place when the birds were 3 and 6 weeks of age, house temperature and relative humidity was recorded, and litter samples were collected at week 0, 3, and 6. With both flocks combined, a greater prevalence of FPD ($P=0.001$) and hock burn ($P=0.0002$) was observed for birds in the houses without fans than in the houses with fans at week 6. Flock 1 birds in the houses without fans had greater FPD lesion areas ($P=0.0001$) and FPD severity scores ($P=0.0004$) than birds in houses with fans at week 6. In Flock 2, there were more small birds in the houses without fans at week 6 ($P\leq0.03$). In Flock 1, the houses with fans had less litter moisture than houses without fans at week 0 ($P=0.02$) and week 6 ($P=0.04$) in Flock 1, and at week 0 in Flock 2 ($P=0.0001$). Mobility, play, and active behaviors decreased as birds aged from 3 to 6 weeks ($P<0.0001$). When comparing flocks, there was significantly higher FPD prevalence in Flock 1 at both week 3 ($P=0.02$) and week 6 ($P=0.03$), but this was only the case in the houses with fans. The results of this study indicate that high-capacity

circulation fans in commercial broiler houses could positively impact footpad dermatitis prevalence, footpad dermatitis severity, and hock burn prevalence. The transect method of welfare observation showed that circulation fans could help improve flock uniformity as well. This information can assist producers in maintaining profitable broiler operations while also prioritizing broiler health and welfare.

Keywords: broilers, welfare, footpad dermatitis, circulation fans

2.1 Introduction

Chicken meat is a popular protein source for people in many parts of the world. The low production and resource costs of broiler chickens make them an ideal choice for producers; there are relatively low production and resource costs associated with broiler farms when compared with other livestock industries, such as beef cattle production (Eshel et al., 2014; Shepon et al., 2016). The affordability of chicken meat, and the trend of many consumers substituting red meat for healthier options, makes it a common protein source for many buyers as well (Wang et al. 2010; Phibbs et al., 2021).

More than 9 billion broilers, weighing a total of 56.6 billion pounds, were produced in the United States in 2018 alone (NCC, 2019). The high demand for chicken meat in the U.S. contributes to the great number of broilers that are raised here commercially. The broiler chickens used in the U.S. today have been genetically selected to thrive under modern management conditions (NCC, 2020). Generally accepted humane treatment of these broilers consists of farm management practices that promote good health and production, minimize bird stress, and counteract disease in flocks (NCC, 2020).

Animal welfare is an animal's physical, mental, and emotional state regarding its attempts to cope with its environment, often measured on a continuum from good to poor (Broom, 1996; AZA, 2021). An animal's welfare can be affected by many factors, including management practices, environmental conditions, and health status. Footpad dermatitis, lameness, and high mortality are common problems in broiler houses today. Footpad dermatitis in broilers is typically characterized as lesions on the skin of the foot pads and on the hocks. It can also represent itself as severe lesions, often seen as painful

ulcers that increase the likelihood of infection from harmful bacteria also found in litter (Bassler, 2013). Footpad dermatitis is a broiler welfare concern because when severe, it can lead to a deteriorated state of health and intense pain for the animal (Berg, 1998). As the public becomes more concerned about welfare in animal production systems, ethical production practices have been of increasing importance to consumers and the poultry market (Alonso et al., 2020).

Given that large flocks of chickens are raised in commercial houses, moisture management can be difficult. Poultry litter is a mixture of bedding product, poultry feces, and feathers that is kept under the individual broilers in commercial houses (Poultry Hub Australia). Broilers must sit, stand, and walk on their litter throughout the duration of their lives, and that litter contains moist manure from every bird in the flock. Because there is so much moisture in commercial broiler houses, ventilation is essential to commercial management. Having a proper ventilation system can greatly impact welfare and production on broiler farms by ensuring sufficient air exchange throughout the houses, controlling litter moisture, keeping temperatures regulated, and maintaining suitable carbon dioxide and oxygen levels (Riley, 2018).

The objective of this study was to evaluate circulation fan use in relation to litter moisture, house temperature and relative humidity, house noise volume, body weight, footpad dermatitis prevalence and severity, hock burn prevalence, feather cleanliness, and behavior as an indication of welfare status in broilers from 2 commercial flocks. The circulation fans were installed in two of four houses within an organic rearing system. The farm used for this study was located in eastern Maryland on a contract with a local broiler integrator.

We hypothesized that the broilers raised in houses with the circulation fans would have higher welfare than broilers in houses without circulation fans. By increasing air circulation in broiler houses, the aim was to provide the birds with an environment that maximizes their welfare and enables them to reach their full genetic potential.

2.3 Materials and Methods

Animals and Housing

This field study was conducted on 2 flocks in 4 commercial organic broiler houses on a farm in eastern Maryland (**Figure 2.1**) in 2021. Flock 1 took place during the months of February, March, and April 2021. Flock 2 took place during the months of September, October, and November 2021. All animal procedures were approved by the University of Maryland Institutional Animal Care and Use Committee (protocol FR-JUL-20-37).

About 36,000 birds were initially placed in each house for both flocks. For Flock 1, the birds were placed 2 days earlier in House 1, making them 2 days older than the birds in the other 3 houses. Chicks were placed in House 1 on 2/23/2021 and on 2/25/2021 in Houses 2, 3, and 4. For Flock 2, the birds in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. The chicks in Houses 1 and 2 were placed on 9/17/2021 and the chicks in Houses 3 and 4 were placed on 9/20/2021.

The experimental treatment used for this study consisted of high-capacity circulation fans (CX24, Munters Corporation, Krista, Sweden) that were installed in House 1 and House 2 (**Fans**). Each treatment house contained 16 fans, hung from the ceiling (**Figure 2.2**). The fans have a 24” fan diameter and are designed to help with

airflow and circulation; they have a propeller design that maximizes airflow and centerline velocity to de-stratify large volumes of air and keep temperatures even throughout the houses during cold weather. The fans are corrosion-resistant and engineered to reduce sound levels, have a thrust level of 6.08 pounds per foot, efficiency retail of 18.5 pounds of force/kilowatts, and airflow of 5,440 thrust cubic feet per minute. In the houses with Fans, the controller was set to run the experimental circulation fans every 200/300 seconds during the first 7 days of the study. After day 7, the circulation fans were running constantly up until the time the birds were processed. Houses 3 and 4 did not have the high-capacity circulation fans installed and served as control replicates (**No Fans**).

Apart from the circulation fans installed in Houses 1 and 2, each house had the same set up. The houses were about 600 feet long, 61 feet wide, about 10 feet in height (**Figure 2.3**). For data collection, each house was divided into 4 equal quadrants divided from the eastern wall to the southern wall (**Figure 2.4**). The cool cells were located in Quadrant 4 and tunnel fans were located on the western wall of Quadrant 1. Brooding took place in Quadrants 1 and 2 from placement until the chicks were 10 days of age, when the migration fences were moved, and birds were allowed to access Quadrants 3 and 4 within the house (**Figure 2.4**). There were about 30 windows spaced evenly throughout the northern and southern walls of each house. Each half of the houses had 3 feedlines and 6 waterlines, for a total of 6 feedlines and 12 waterlines per house. Additionally, each house had environmental enrichments in the form of plastic migration fence pieces (repurposed as enrichments), wooden ramps, wooden boxes, and wooden boxes with hay bales.

Data Collection

The experimental procedures and timeline for Flock 1 are summarized in **Table 2.1** and **Table 2.2** for Flock 2. Prior to chick placement, 2 data loggers were set to record ambient temperature (°F) and relative humidity (%) every 15 minutes throughout each house. Litter samples were taken from all quadrants of each house at week 0, 3, and 6 to determine litter moisture content (%). Individual bird welfare assessments were performed in each quadrant at 3 and 6 weeks. During each individual bird welfare assessment, birds were weighed and scored for footpad dermatitis, hock burn, and feather cleanliness. Ambient volume (dB) was recorded at every welfare assessment location in all 4 houses. The transect sampling method was also performed in all 4 houses at the time of the week 6 welfare assessment for Flock 1, and at week 3 and week 6 for Flock 2. Behaviors were analyzed for week 3 and week 6.

Environmental Measures

Temperature and Relative Humidity

Two data loggers (HOBO UX100-003, Onset Inc., Cape Cod, MA) were mounted in each house near the day-of-hatch (day 0) to record temperature and relative humidity. Each logger collected data from day 0 to the end of the growout period for Flock 1, and from day 3 to the end of the growout period for Flock 2 (The data loggers were launched on day 3 in House 1 and 2 for Flock 2 because the placement date was moved to an earlier date with very short notice).

One logger was placed on the northern wall of each house, in the middle of quadrant 2, and the other was placed on the middle feedline at the very center of quadrant 3 (**Figure 2.4**). Ambient temperature (°F) and relative humidity (%) was recorded once every 15 minutes. At the end of the study, at the time of the week 6 welfare assessments for both flocks, the data loggers were removed, and temperature and relative humidity data were uploaded to a computer. Daily and monthly average outdoor temperatures (°F) and humidity (%) were taken from Weather Underground and Time and Date (TWC Product and Technology; Time and Date). Outdoor daily weather means were collected from the closest available weather station to Queen Anne, Maryland, which was in Baltimore, Maryland (TWC Product and Technology).

Litter Moisture

Composite litter samples were collected from 8 locations within each of the 4 quadrants within each house at weeks 0, 3, and 6. Litter samples were weighed, then dried in an oven at 120°F for 24 hours. Three replicates for each sample were used to account for as much variation as possible. After weighing the dry samples, the percent litter moisture was calculated using the following equation:

$$\% \text{ Litter moisture} = 100 - ((\text{Dry litter weight}/\text{Wet litter weight}) \times 100)$$

After the percent litter moisture of each sample replicate was calculated, an average of the three replicate samples was calculated to determine the average litter moisture of each quadrant, within each broiler house.

Noise Volume

Noise volume (dB) was measured with a handheld decibel meter (Digital Sound Level Meter, EXTECH Instruments, Nashua, New Hampshire).

Welfare Measures

Body weight (g) and welfare assessment score data was collected at week 3 and 6 in both Flock 1 and Flock 2**.** Body weight was collected from a hanging scale (BAT1, VEIT Electronics, Moravany, Czech Republic). Body weight data from Flock 2 was not used due to a scale calibration issue that caused the weights to be inaccurate.

During the individual bird welfare assessments, footpad scores, hock burn scores, and feather cleanliness scores were recorded by observers on-farm. During individual bird welfare assessments, images of the footpads of each bird were captured with two digital cameras (Panasonic Lumix DC-TS7, Panasonic, Kadoma, Osaka, Japan). Footpad dermatitis scores were taken for each paw and hock according to the 2009 Welfare Quality® Assessment protocol for poultry (**Figures 2.5-2.7**) and the average of each bird was used for analysis. For Flock 1 welfare assessments in each house, 80 birds within 2 locations of each quadrant (N=10 birds/location) were caught, weighed, and scored for footpad dermatitis, hock burn, and feather cleanliness (**Figure 2.8**). For Flock 2 welfare assessments in each house, 80 birds from 1 location in each quadrant (N=20 birds/location) were caught, weighed, and scored for footpad dermatitis, hock burn, and feather cleanliness (**Figure 2.8**).

Transect Sampling Method

The transect sampling method of flock welfare observation was done at the same time as other week 6 welfare assessments for Flock 1, and at week 3 and week 6 for Flock 2, according to the methods described in BenSassi et al., 2019. To implement this live observation sampling method to assess broiler welfare on a commercial scale, one observer walked down the 4 isles of each house, following the red arrows shown in **Figure 2.10**. During observation periods, they recorded the following bird characteristics: lame, immobile, sick, terminally ill, dead, head wounds, back wounds, tail wounds, small, dirty, and featherless (**Table 2.3**). The number of birds observed per transect walk was counted and repeated in each house. The same observer performed all transect sampling method observations in both flocks.

Footpad Dermatitis Lesion Severity Analysis

During welfare assessments, images of the footpads of each bird were captured with two digital cameras. Lesion severity analysis was performed on Flock 1 birds only. During welfare assessments, digital images were taken of each bird's feet (**Figure 2.8b**). Then, the lesion surface area (%) of birds with a score of 1 or 2 were measured in ImageJ (National Institute of Health, Bethesda, Maryland) (**Figure 2.9**). Birds with a FPD score of 0 were excluded from the data because a lesion needed to be present for the software to identify and determine the lesion area. Due to the color threshold methodology used to identify darker lesion areas, we were unable to use ImageJ to confirm zero scores.

The surface area of each footpad was calculated by isolating the footpad portion of each image with a drawing tool and blocking the background out of the image to isolate the footpads. The lesion area of each foot was analyzed by calculating the number of pixels that were darker than the color of the foot using a selected hue, saturation, and brightness in the color threshold tool. The lesion color threshold was calibrated for each image, due to the variation in image brightness and quality. The ImageJ software color threshold tool was used to determine which pixel colors were part of the lesion (**Figure 2.9**). The lesion area percentage of each footpad was calculated as a lesion area percentage; lesion area was divided by footpad area. The individual footpads were averaged for each bird for data analysis.

Video Recording

GoPro (Hero 7 Black Camera, GoPro, San Mateo, California) cameras were mounted at week 3 and 6 of the study to record bird behavior. These durable popular action cameras are waterproof, with 12MP video resolution. The Re-fuel Battery (9HR Action Extended Battery for GoPro Hero 7 cameras, Digipower Solutions, Avenel, New Jersey) enabled us to extend the GoPro battery life to about 6 hours.

Four GoPro cameras were mounted in each house, with one placed in each quadrant. In each house, a GoPro camera was placed on the northern wall facing the 1st quadrant, on the northern hopper facing the 2nd quadrant, on the eastern hopper facing the 3rd quadrant, and on the southern wall facing the 4th quadrant (**Figure 2.11**) Each GoPro camera recorded 5-6 hours of video on the day before the welfare assessments took place. The GoPro cameras were all set to record at the same time (within minutes of each other),

around 11:00AM EST in each house. Before recording, the settings on each GoPro camera were set to record at 1080p high-definition resolution, 30 frames per second, and on superview (the widest view to capture as many birds as possible). The cameras were removed from each house the following day at both week 3 and 6 of the study.

Behavior (Flock 1)

Four GoPro Hero 7 (GoPro cameras were mounted in each house (16 total cameras), with one placed in each quadrant. In each house, a GoPro camera was placed on the northern wall facing the 1st quadrant, on the easternmost hopper facing the 2nd quadrant, on the westernmost hopper facing the 3rd quadrant, and on the southern wall facing the 4th quadrant. Each GoPro camera recorded 5-6 hours of video on the day before the welfare assessments took place. The GoPro cameras were all set to record at the same time in each flock (within minutes of each other), around 11:00AM EST in each house. The percentage (%) of birds observed exhibiting a specific behavior was recorded from video recorded from 4 cameras per house. The cameras captured a portion of each quadrant in all houses used for this study (**Figure 2.11**). Five hours from each camera was analyzed for behaviors.

The scan sampling method of observation was performed for videos from each camera (16 total) at 10-minute intervals over the 5-hour recording period. For each of the 4 cameras per house, 17 scans were performed for a total of 68 scans per house per age. All cameras within each house were combined for analysis. The first 5 minutes of each camera's video were not used for observation to account for the potential effect of the

researcher mounting the cameras in the houses and to allow for the birds to readjust after the disturbance.

Researchers coding behavior first counted the total number of birds within a standardized portion of the screen to record total bird count per scan (**Figure 2.12**). The entire frame of each video could not be analyzed because birds that were too far away from the camera were too small for behaviors to be observed, so an observation area was established. The observation areas of the screen were standardized according to camera location (wall vs. hopper) so that the area observed in videos from cameras mounted in the same location in each house were comparable. The observation areas consisted of about 25% of the screen. Cameras mounted on the hoppers were positioned with the hopper in the center of the observation area. Cameras mounted on the walls were positioned in the leftmost bottom corner of the screen. Two researchers then counted the number of birds performing each behavior described in the ethogram (**Table 2.4**). A t-test was run to confirm interobserver agreement between the two researchers' results (at least 95% in every behavior category). The total bird count was divided by each behavior count to determine the percentage of birds performing each behavior at the time of each scan.

Statistical Analysis

The study was a matched pairs design, with a house as the experimental unit and 2 house replicates per treatment per flock (Fans = House 1 and House 2, No Fans = House 3 and House 4). Data was analyzed in JMP Pro v14 (SAS Institute, Inc., Cary, NC) with the main effect of fan treatment. Flock 1 and 2 were combined for analysis, with the

experimental unit being treatment (Fans vs. No Fans) (N = 8 houses, 4 house treatment replicates). Two-way ANOVA tests with the fixed effects of treatment, flock, the interaction of treatment and flock, and with house as a random effect were used to analyze the effect of treatment in both flocks on litter moisture, noise volume, weekly temperatures, weekly relative humidity, and transect data. Welfare score data (footpad dermatitis and hock burn) from week 6 was analyzed with chi-square tests for the fixed effect of treatment.

Flock 1 and 2 were also analyzed separately, with the experimental unit being house (N = 4 houses, 2 house treatment replicates per flock). Body weight and transect data were analyzed with separate 1-way ANOVA tests for the fixed effects of house, by week. Behavior, litter moisture, noise volume, and FPD lesion area data were analyzed with separate 1-way ANOVA tests for the fixed effects of house and treatment, by week. A Shapiro-Wilk test showed that lesion area (%) data was not normally distributed ($W=0.82$, $P< 0.0001$), so data were log transformed, resulting in more normally distributed data ($W=0.98$, $P=0.004$) that were used for analysis. Welfare score data (footpad dermatitis, feather cleanliness, and hock burn) was analyzed with chi-square test for the fixed effects of house and quadrant within house.

For treatment comparisons between flocks, the house replicate data was combined (N = 2 treatment groups, 2 houses per treatment group, per flock) for hock burn, footpad dermatitis, litter moisture, and noise volume data by week. Noise volume data were analyzed with separate 1-way ANOVA tests for the fixed effects of flock by week. Behavior and litter moisture data were analyzed with separate 1-way ANOVA tests for the fixed effects of flock and week. Welfare score data (footpad dermatitis and hock

burn) within each week were analyzed with chi-square tests for the fixed effects of flock. LSmeans for daily and weekly temperature and relative humidity results were compared. Data were considered significant at a $P \leq 0.05$ and a tendency at $P \leq 0.10$.

2.4 Results and Discussion

Flock 1 Details

Flock 1 data were collected during the months of February through April 2021. The Flock 1 environmental data included temperature (°F), relative humidity (%), litter moisture (%), and noise volume (dB) and animal welfare data included body weight (g), transect method counts of individual animal welfare indicators (lame, head wounds, back wounds, tail wounds, sick, small, immobile, terminally ill, dead, dirty, featherless), footpad dermatitis, hock burn, and feather cleanliness prevalence (%), footpad dermatitis lesion area (%) (measured in digital images), and behavior (%, scans from video recorded in 4 locations/house). Average outside temperature was 34 °F in February, 47°F in March, and 54°F in April 2021 (Time and Date).

Flock 2 Details

Flock 2 data were collected during the months of September through November 2021. The Flock 2 environmental data included temperature (°F), relative humidity (%), litter moisture (%), and noise volume (dB) and animal welfare data included body weight (g), transect method counts of individual animal welfare indicators (lame, head wounds, back wounds, tail wounds, sick, small, immobile, terminally ill, dead, dirty, featherless), and footpad dermatitis, hock burn, and feather cleanliness prevalence (%). Body weight results are not shown due to scale calibration issues at the time of the Flock 2 welfare

assessments, rendering body weight results inaccurate. Average outside temperature was 69°F in September, 61°F in October, and 43°F in November 2021 (Time and Date).

Environmental Results

Temperature and Relative Humidity

Flock 1 temperature and relative humidity were measured every 15 minutes from two locations (center feedline in quadrant 3 and northern wall in quadrant 2) in all 4 houses from the day the chicks were placed until they were 6 weeks of age, which was day 43 in House 1 and day 41 in Houses 2, 3, and 4.

Flock 2 temperature and relative humidity were also measured every 15 minutes from two locations (center feedline in quadrant 3 and northern wall in quadrant 2) in all 4 houses from the first farm visit, which was day 3 in Houses 1 and 2 and day 0 in Houses 3 and 4, until they were 6 weeks of age, which was day 42.

Due to bird ages differing in both flocks, the calendar date and bird age do not match in all 4 houses for either flock. The results for daily temperature and relative humidity are presented in **Figures 2.13-2.24** in two ways 1) by matching the data to the calendar date and 2) by matching the data to the same bird age in each house.

Temperature

With results from both flocks combined, there was no consistent weekly difference in temperatures in the houses with and without fans (**Table 2.5**). However, there was a tendency for the houses without fans to be slightly hotter than the houses with

fans; this was true at week 1, 2, 5, and 6. At week 3, the houses without fans were significantly hotter than the houses with fans (P=0.0214).

Flock 1 Temperature

During brooding (day 1 – 10), average daily temperatures had a similar trend (a maximum difference of 3.53°F by date and 2.74°F by age) in all 4 houses (**Figure 2.13**). Noticeably, during the last 7 days of brooding, temperatures from Houses 1 and 4 had similar daily fluctuations, while temperatures from Houses 2 and 3 had similar daily fluctuations (**Figure 2.13a**). At week 0, House 2 was significantly hotter than the other 3 houses; at week 1, Houses 2 and 3 were significantly hotter than Houses 1 and 4 (**Table 2.6**). When comparing a house with fans (House 2) with the houses without fans that contained birds of the exact same age (Houses 3 and 4), the significantly higher temperatures in House 2 at weeks 0 and 1 indicate that the circulation fans likely did not put the chicks at risk of being chilled during the brooding period, as mean temperatures were warmer in the fan houses. Average daily temperatures after brooding (day 11-41) were numerically greater in Houses 3 and 4, when compared with Houses 1 and 2, by 0.76°F by date and 0.52°F by age (**Figure 2.14**).

At weeks 2 and 3, House 3 had the highest average temperature (P<0.0001) compared with the other houses (**Table 2.6)**. At weeks 4 and 5, Houses 3 and 4 had greater average temperature (P<0.0001) compared with the other houses (**Table 2.6)**. At week 6, House 4 had the highest average temperature (P<0.0001) compared with the other houses (**Table 2.6)**.

While all houses were set to follow the same temperature curve, the birds in House 1 were older and consequently, the House 1 controller settings were 3 days ahead of the other houses. It should also be noted that House 1 controller settings were different from Houses 2-4; it was likely set to a slightly lower temperature than the other 3 houses on any given day because the birds were older and required less heating. The difference in controller settings could have been part of the reason House 1 had significantly lower temperatures than the other 3 houses from week 0 to week 5 (**Table 2.6**). Additionally, the fans in House 1 could have also helped to control temperatures because proper ventilation in broiler houses aids in temperature regulation (Riley, 2018).

While the houses without fans tended to be slightly hotter than the houses with fans throughout the course of Flock 1, there was no consistent significant daily or weekly difference in the control and treatment house temperature for the entire duration of the flock. Still, the houses without fans were significantly hotter at multiple times after brooding, indicating that circulation fans could lead to cooler broiler houses and ultimately aid in keeping houses from overheating during the warmer months (Lacy & Czarick, 1992).

Flock 2 Temperature

During brooding, average daily temperatures varied over time and there was no consistent trend in temperatures (**Figure 2.16**). Average daily temperatures after brooding (day 11-41) were numerically greater in Houses 3 and 4, the control houses, by 1.67°F by date and 0.57°F by age (**Figure 2.17**). The houses with and without fans had similar temperatures from day 1-41, with the maximum difference between the two groups being

0.57°F by date and 0.38°F by age (**Figure 2.18**). Numerically, the houses without fans had higher temperatures than the houses without fans periodically from day 11-41, but overall daily temperatures results were similar throughout the growout period for Flock 2.

Based on weekly averages, temperatures in the control houses were higher than temperatures in the houses with fans. At weeks 1, 3, 5 and 6, House 4 had the highest average temperature ($P<0.0001$) compared with the other houses (**Table 2.7)**. At weeks 0, 2, and 4, Houses 3 and 4 had the highest average temperature ($P<0.0001$) compared with the other houses (**Table 2.7**). The 2 houses with fans had very similar daily and weekly temperature results; the same can be said for the 2 houses without fans. Because the birds from each treatment group were placed on different days, it is likely that outdoor temperatures associated with each date seemed to have a big impact on temperature trends within the houses.

While the houses without fans tended to be slightly hotter than the houses with fans throughout the course of Flock 2, there was no consistent significant daily or weekly difference in the control and treatment house temperature for the entire duration of the Flock. These results were reflected in Flock 1 as well. Similarly, the fact that the houses without fans were significantly hotter during various periods indicates that circulation fans could lead to cooler broiler houses and ultimately aid in keeping houses cooler during the warmer months (Lacy & Czarick, 1992).

Relative Humidity

With results from both flocks combined, there was no consistent weekly difference in relative humidity in the houses with and without fans (**Table 2.8**). However,

at week 3, the houses with fans were significantly more humid than the houses without fans (P=0.0129).

Flock 1 Relative Humidity

Relative Humidity is the moisture content (water vapor) of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere (moisture-holding capacity) at a given temperature and pressure without condensation (Callahan et al., 2019). Apart from House 1, which housed 2-day older birds than the other 3 houses, humidity levels had similar trends during brooding (day 1 – 10), with a maximum difference of 7.56% by date and 15.08% by age (**Figure 2.19**). Houses 3 and 4, the control houses, had the most similar humidity results during brooding, with a maximum difference of 2.36% by date and 1.58% by age (**Figure 2.19**). House 1 average daily humidity levels after brooding (day 11-41) were greater than the other houses by 1.00%-8.38% by date and 0.36%-7.76% by age (**Figure 2.20**). In general, average humidity levels were similar in all 4 houses from day 1-41, with a maximum difference of 7.31% by date and 22.16% by age (**Figure 2.21**).

At weeks 0, 4, and 5, Houses 1 and 4 had the highest average humidity (P<0.0001) compared with the other houses (**Table 2.9**). At weeks 1, 2 and 3, House 1 had the highest average humidity levels (P<0.0001) compared with the other houses (**Table 2.9**). Since relative humidity in broiler houses has been shown to increase quickly when minimum ventilation rates are not properly adjusted, it is possible that daily adjustments to minimum ventilation rates could have played a role in the increased humidity levels observed in Houses 1 and 4 (Menzies et al., 1998; Mou, 2020).

While House 1 and House 4 were slightly more humid than the other houses throughout most weeks in Flock 1, there was no consistent significant daily or weekly difference in the control and treatment house relative humidity levels for the entire duration of the flock. Throughout Flock 1, there was more variation in relative humidity results over time when compared with temperature results. Houses 1 and 2 had more similar temperature results while Houses 1 and 4 had more similar humidity results, although there was not a consistent similarity across all days or weeks. House 1 and House 4 were both located on the ends of group of broiler houses; the southern side of House 1 was fully exposed to wind, while the northern side of House 4 was fully exposed to wind (**Figure 2.1**). The middle houses, Houses 2 and 3, were somewhat blocked from wind on both sides by other houses. The difference in relative humidity levels seen in the middle and outside houses on the farm could have been affected by the variable wind exposure of the outside houses. Fans are less efficient when wind comes in the house and blows against them, and wind variation can affect house ventilation and humidity. Future studies could measure wind speed and direction to determine the precise impact of wind variation on house relative humidity Also, previous studies indicate that indoor relative humidity tends to increase during warmer months and decrease during colder months (Nguyen et al., 2014). The relationship between temperature and relative humidity are typically inversely proportional, and that was true of the Flock 1 temperature and relative humidity results from the measures collected in terms of daily fluctuations (Nguyen et al., 2014). The high-capacity circulation fans might have had a greater impact on temperature than humidity and the combination of the fans and variable wind exposure may have caused House 1 to be the coolest and most humid house while Flock 1 birds were present.

Flock 2 Relative Humidity

There were similar shifts in relative humidity levels in the houses with and without fans during the time that the chicks were brooding (day 3-10), with the maximum difference between houses with fans being 1.77% by date and age and the maximum difference between houses without fans being 4.02% by date and 5.64% by age (**Figure 2.22**). Brooding relative humidity was greater in the houses with fans by 5.66% by date and 5.31% by age when compared to the houses without fans (**Figure 2.22**).
House 2 was more humid, on average, than the other houses by at least 1.1% after brooding (**Figure 2.23**). Also, Houses 1 and 2 were more humid, on average, than Houses 3 and 4 (the control houses) by 2.7% throughout Flock 2 grow out (**Figure 2.24**). Based on weekly averages, humidity levels in the houses with fans were greater than humidity levels in the houses without fans. At weeks 2, 3, 4, and 5, House 2 had the highest average humidity ($P<0.0001$) compared with the other houses (**Table 2.10**). At weeks 0, 1, and 6, Houses 1 and 2 had the highest average humidity levels ($P<0.0001$) compared with the other houses (**Table 2.10**). While House 1 and 2, the houses with fans, seemed to be slightly more humid than the houses without fans throughout most weeks in Flock 2, there was no consistent significant daily or weekly difference in the control and treatment house humidity levels for the entire duration of the flock.

Flock Comparison

In Flock 1, House 1 and House 4 were slightly more humid than the other houses throughout most weeks. This result was not reflected in Flock 2, and that could have been

a result of seasonal weather changes. In the colder months, outdoor air tends to have higher relative humidity than in warmer months; perhaps the effect of variable wind exposure on relative humidity in Houses 1 and 4 was less significant when the weather was warmer for most of Flock 2, compared to the effect of colder outdoor temperatures during Flock 1. Flock 2 also had higher house relative humidity levels when compared with Flock 1. Previous studies indicate that relative humidity is easier to manage in cooler weather when houses are being heated due to minimum ventilation settings (Mou, 2020). Also, outdoor absolute humidity is typically lower in colder months. Perhaps because the weather was warmer during Flock 2, it was more challenging for the house controller settings to keep relative humidity levels as low as they were during Flock 1.

When analyzing temperature and relative humidity averages by both date and age, the results analyzed by date had more similar trends over time; the peaks and drops in temperature and humidity tended to occur on the same date rather than when birds were the same age. Even though temperature and humidity levels were regulated by controllers and closely monitored in the broiler houses, the similarity in daily measurements by date could be a result of daily fluctuations in outdoor temperature and weather. This effect was especially considerable on the data collected in Flock 2 of our study because birds from each treatment group were placed on different days. Thus, when monitoring changes in broiler house temperature and humidity, outdoor weather should be considered an uncontrollable variable that can impact results.

Litter Moisture

Composite litter samples were collected from 8 locations within each of the 4 quadrants within each house at weeks 0, 3, and 6. With results from both flocks combined, there was no difference in litter moisture content (%) in the houses with and without fans at week 0, 3, or 6 (**Table 2.11**). Overall litter moisture results were inconsistent and repeated trials, with litter samples taken at more than 3 time periods during the life of the flock, are needed to determine the true impact of the circulation fans on litter moisture.

Flock 1 Litter Moisture

Houses 2 and 4 had the greatest increase in litter moisture from week 3 to week 6 (**Figure 2.25b and Figure 2.25d**). These two houses were from different treatment groups, but houses with fans had greater litter moisture (15%) than houses without fans (11%) at week 3 ($P<0.0001$) while houses with fans had lower litter moisture (22%) than houses without fans (25%) at week 6 ($P=0.0378$) (**Table 2.12**). As expected, average litter moisture increased from week 0 to week 6; it increased by about 4.5% (**Table 2.13**). This increase was likely due to moisture from bird excrement and water being deposited into the litter while the birds grew in the broiler house (Ekstrand et al., 1998).

Surprisingly, average week 3 litter moisture was numerically lower than week 0 litter moisture (**Table 2.13**). At week 3, litter moisture content was significantly greater in the houses with circulation fans, but that may not have been a result of the circulation fans. To mitigate flooding that took place in some of the houses, it was confirmed that the grower top dressed each house shortly before week 3 litter samples were collected. Also,

litter moisture content was consistently the lowest at week 3 compared with weeks 0 and 6 in all the houses. Inherent to field studies, there are some uncontrollable variables that likely affected litter moisture content.

At week 3, House 1 had the greatest litter moisture content (19%) compared to the other 3 houses (13%-14%) (P<0.0001) (**Table 2.14**). At week 6, House 4 had the greatest litter moisture content (28%) compared to the other houses (21%-25%) (P<0.0001) (**Table 2.14**). Average litter moisture content was still greater in the houses without fans than in the houses with fans at weeks 0 and 6 (**Table 2.12**). A previous study indicated that litter from broiler houses with circulation fans is dryer, on average, than litter from houses without circulation fans (Mou, 2020). Thus, the circulation fans may have aided in keeping litter slightly dryer, despite the change in results observed at week 3 due to the addition of fresh litter.

The top dressing done prior to the week 3 collection date likely caused litter samples to be significantly dryer than expected. Also, although researchers were trained to collect litter samples in a standardized manner, there were 5 researchers that collected litter samples and the same person did not always collect litter samples at each week.

Flock 2 Litter Moisture

Litter samples were collected at weeks 0, 3, and 6 from multiple locations in each quadrant of each house. Houses 1 and 2 had the most similar trends in litter moisture over time (**Figure 26a-b**). At week 0, Houses 3 and 4 had the highest litter moisture content (15.00% and 15.22%) compared to Houses 1 and 2 (P=0.0022) (**Table 2.15**). At week 3, House 3 had the highest litter moisture content (16.96%) compared to the other 3 houses

(P=0.1336) (**Table 2.15**). At week 6, Houses 1 and 2 had the highest litter moisture content (24.38% and 24.25%) compared to Houses 3 and 4 (P<0.0001) (**Table 2.15**).

At week 6, average litter moisture was greater in the houses with fans than the houses without fans (24.32% vs. 19.53%) (**Table 2.16**). As expected, average litter moisture increased from week 0 to week 6; it increased by about 7.8% (**Table 2.17**). Surprisingly, there was a greater increase in litter moisture from week 3 to week 6 in the houses with fans compared with houses without fans. Also, although researchers were trained to collect litter samples in a standardized manner, there were 5 researchers that collected litter samples and the same student did not always collect litter samples at each week. Perhaps the extremely rainy weather on the collection date for Houses 1 and 2 could have also contributed to litter moisture in those week 6 samples. Overall, the litter moisture results from both flocks were inconsistent. Trends in the results, however, indicate that the circulation fans could have positively impacted moisture. Repeated trials, with litter samples taken at more than 3 time periods during the life of the flock, are needed to determine the true impact of the circulation fans on litter moisture.

Flock Comparison

There was no difference in average flock litter moisture from all collection dates in the houses with and without fans (**Table 2.18).** Flock 1 litter had significantly more moisture than Flock 2 in both houses with and without fans at week 0 (P< 0.0001) and in the houses without fans at week 6 (P< 0.0001) (**Table 2.18**). Flock 2 litter had significantly more moisture than Flock 1 in the houses without fans at week 3 (P< 0.0001) (**Table 2.18).** During colder months, outdoor air tends to have higher relative

humidity levels than during warmer months; the warmer weather and decrease in outdoor relative humidity during Flock 2 could have contributed to the lower mean litter moisture observed at week 0 (in all houses) and week 6 (in control houses).

Noise Volume

With results from both flocks and weeks combined, the houses with fans were louder than the houses without fans (61dB vs. 58 dB) (P=0.0018) (**Table 2.19**). These results indicate that high-capacity circulation fans could significantly increase house volume, although they are not as loud as the tunnel fans. When considering the potential litter moisture maintenance benefits, noise pollution caused because of the circulation fans is likely not a significant threat to boiler welfare.

Flock 1 Noise Volume

Noise volume (dB) measurements were recorded at each welfare assessment location, within house. Environmental data indicated that the noise volume (dB) in in the houses with fans was louder on average, by about 6.6 dB, than the volume in the houses without fans at the time of the week 3 assessment (P<0.0001) (**Figure 2.27a**). There was no difference in noise volume in the houses with or without fans at week 6 (**Figure 2.27b**). The tunnel fans were turned on at the time of the week 6 visit due to the outdoor temperatures increasing with the season change. These results indicate that high-capacity circulation fans could significantly increase house volume, but they are not as loud as the tunnel fans. While noise levels could potentially influence broiler welfare, fans used in broiler houses are essential to prioritizing bird health because poor air quality increases

risk of bird stress and disease outbreaks (Tabler & Wells, 2019). When also considering the potential litter moisture maintenance benefits, noise pollution caused because of the circulation fans is likely not a significant threat to boiler welfare.

Flock 2 Noise Volume

Environmental data indicated that the noise volume (dB) in the houses with circulation fans was louder on average, by about 5.1dB, than the volume in the houses without circulation fans at the time of the week 3 assessment (P=0.0001) (**Figure 2.28a**). At week 6, however, there was no significant difference in volume between the treatment and control houses (**Figure 2.28b**). It should be noted that the circulation fans were off at the time of week 3 volume measurement in all House 1 and 2 quadrants besides quadrant 4 in House 2, and tunnel fans were on in all houses. At week 6, all circulation fans in Houses 1 and 2 were running at the time of volume measurement besides quadrant 2 of House 2, and the tunnel fans were on in all houses. For Flock 2, circulation fans were typically running when the tunnel fans were not running, but that was not always the case.

Flock Comparison

Similar to Flock 1, Flock 2 noise results indicate that high-capacity circulation fans could significantly increase house noise volume, but they are not as loud as the tunnel fans. There was no significant difference in average volume from Flock 1 or 2 in houses with or without fans, across both weeks combined (**Table 2.20**). There was no significant difference in average volume from Flock 1 or 2 houses with or without fans at

week 3 (**Table 2.20**), but Flock 2 had significantly greater volume levels in houses without fans at week 6 (P=0.0073) (**Table 2.20**). Noise volume was likely significantly louder in Flock 2 houses with no fans, a time when both circulation and tunnel fans were running, because of the proximity of the research to the tunnel fans at the time of noise volume measurement. Noise volume was taken at half as many locations in Flock 2 due to the change in welfare assessment location (**Figure 2.4**). It is also possible that the tunnel fans in Flock 2 were set to run at a higher speed because outdoor temperatures were warmer than they were in Flock 1, causing tunnel fans to create more noise.

Welfare Results

For Flock 1, the transect method was performed at week 6 only. Body weight was measured at both weeks 3 and 6. Footpad dermatitis (FPD), hock burn (HB), and feather cleanliness results are reported on a binomial scale where birds scored as having any evidence of FPD, HB, or dirty feathers are in red, and no evidence are in blue in **Figures 2.38-2.39, Figures 2.47,** and **Figures 2.49-2.50.**

For Flock 2, the transect method was performed at both week 3 and week 6. Footpad dermatitis (FPD), hock burn (HB), and feather cleanliness results are reported on a binomial scale where birds scored as having any evidence of FPD, HB, or dirty feathers are in red, and no evidence are in blue in **Figures 2.42-2.43, Figure 2.48, and Figure 2.51**.

For combined flock results, footpad dermatitis (FPD) and hock burn (HB) are reported on a binomial scale where birds scored as having any evidence of FPD or HB are in red, and no evidence are in blue in **Figures 2.37 and 2.46.**

Flock 1 Body Weight

The birds in House 1 were significantly heavier than the birds in the other 3 houses at both week 3 (**Figure 2.29**) and week 6 (**Figure 2.31**) (P<.0001). Body weight of birds in Houses 2, 3, and 4 was similar at both week 3 and week 6 (**Figures 2.29 and 2.31**) and body weight was 673g at week 3 and 2,556g at week 6 across houses. There was no difference in body weight across houses or quadrants within each house (**Figures 2.30 and 2.32**).

According to as-hatched Ross performance objectives, broilers should weigh 837g at Day 19, 985g at Day 21, 2,821g at Day 41, and 2,918g at day 42 (Aviagen, 2019). When birds were weighed at week 3, they were between 19-21 days in age. At week 6, birds were between 41-42 days in age. In general, Flock 1 birds were slightly lighter than performance objectives indicated. When birds were caught on farm for welfare assessments, it is likely that our collected samples consisted of birds that were slower, less agile, and potentially less healthy than their flock mates. Methods used to catch and weigh subpopulations can have errors because catching birds for welfare assessments involves corralling them; the fastest birds, which are usually the healthiest birds, are more likely to escape being corralled (Koolhaas et al., 1999; Marchewka et al., 2013). Since the birds caught may not have been the strongest members of their flock, perhaps they were less likely to reach maximum performance expectations such as body weight or daily body weight gain.

Transect Method

Although it was not statistically significant, when transect results from both flocks were combined, more small birds were observed per transect walk in the houses without fans than in the houses with fans (11.6 vs. 5.9) (**Figure 2.33**). The reason this difference was not significant was because the 2-way ANOVA included flock and treatment as the main effects and house as a random effect. Flock accounted for most of the variation in the model, diluting the treatment effect. Flock 2 week 6 results, however, indicate that there were significantly more small birds in the houses without fans and thus, there could be some benefit of the fans that contributes to improving flock uniformity.

Flock 1 Transect Method

There were no differences in the number of birds categorized as sick, terminally ill, and dirty and there were no wounded birds. There was a low frequency of bird counts in most characteristic categories per walk (**Table 2.21**). Significant house differences were observed in the number of lame, small, immobile, dead, and featherless birds counted (**Table 2.21**).

House 4 had the greatest number of observed small birds per transect walk at week 6 (9.50), compared to the other 3 houses (2.75-4.25) ($P \leq 0.04$) (**Figure 2.34, Table 2.21**). House 4 also had more immobile birds than the other 3 houses per transect walk (5.75 vs. 1.75-4.00) (**Table 2.21**). House 1, however, had more lame and dead birds ($P=0.0384$), while House 2 had more featherless birds ($P=0.0065$) than the other houses (**Table 2.21)**.

Small birds were identified as approximately half the average size of flock mates and the difference in small birds in each treatment group was more significant than the other characteristic differences in the houses. Similarly, a previous study found the most frequently observed welfare indicators were birds of small size (Hrženjak et al., 2021). Apart from House 1 birds, which were 2 days older and heavier than the birds from the other houses, the average weight of the birds across houses was not statistically different (**Figure 2.31**). The house body weight data supports the significance of the greater number of small birds observed in House 4 during the transect method of observation. There were more small birds in House 4 than the other houses, but that result was not reflected in House 3, the other treatment house. Perhaps there were more small birds in House 4 because at week 6, House 4 had the greatest litter moisture content (28%) compared to the other houses (21%-25%) ($P<0.0001$) (**Table 2.14**). Additionally, House 4 had the highest average temperature compared with the other houses at week 6 (**Table 2.6)**. Because litter moisture is often correlated with increased stress and smaller body weights (Martland, 1985; Ekstrand et al., 1998; Dawkins et. al, 2004), the higher levels of heat and litter moisture in House 4 might have affected the prevalence of runts.

Flock 2 Transect Method

At both week 3 and week 6, significant house differences were only observed in the number of small birds counted (**Figures 2.35** and **2.36).** There were wounded birds at either week. There were no differences in the number of birds categorized as sick, immobile, terminally ill, dead, dirty, or featherless at week 6, but it should be noted that there was a low frequency of bird counts in most characteristic categories per walk

(**Table 2.22**). In this study, birds with stunted growth that were approximately half average size of flock mates were considered small (**Table 2.3**).

At week 3, House 3 had the highest number of observed small birds per transect walk compared to the other 3 houses (**Figure 2.35**). Significantly more small birds were observed in House 3 at week 3 than in House 2 (18.75 vs. 10.25) (P=0.0457) (**Figure 2.35**). More small birds were observed at week 3 than at week 6, which was likely a result of farm management culling birds that were severely underweight before they could reach market age (**Figures 2.35 and 2.36**). At week 6, the houses without fans had the highest average number of observed small birds per transect walk compared to the houses with fans (16.9 vs. 8.25) (**Figure 2.36**). Significantly more small birds were observed per transect walk in Houses 3 and 4 than Houses 1 and 2 (P≤0.0288) (**Table 2.22**). These results indicated that there could be some benefit of the fans that contributes to improving flock uniformity because there were more small birds in one of the houses without fans at week 3 and in both houses without fans at week 6.

Flock Comparison

When comparing Flock 2 transect method results with Flock 1 at week 6, more small birds were observed during each transect walk in Flock 2. In Flock 2, researchers noticed that runts did not seem to be culled and removed prior to when week 6 transect method and welfare assessments were conducted. Although it was clear that necessary culling was done on the same day in all 4 houses, the farm culling schedule was an uncontrollable variable, inherent to field studies, that could have impacted the number of small birds observed in each flock. There was also a more consistent relationship between

the number of small birds observed and the circulation fan treatment in Flock 2, likely due to the greater sample size of small birds in Flock 2.

Footpad Dermatitis

With results from both flocks combined, more footpad dermatitis (P=0.0011) was observed in the houses without fans than in the houses with fans at week 6 (**Table 2.23 and Figure 2.37**). Because footpad dermatitis is an indicator of poor welfare, these results support our hypothesis that birds in the houses with circulation fans would have higher welfare than birds in the houses without circulation fans.

Flock 1 Footpad Dermatitis

There was no statistically significant difference between footpad dermatitis prevalence across houses at week 3 (**Figure 2.38)** or week 6 (**Figure 2.39)** and prevalence was about 9% at week 3 and about 74% at week 6 across all houses. When analyzed by treatment, houses with fans had numerically lower footpad dermatitis prevalence at week 6 (71.88% vs. 76.25%) compared with houses without fans, although it was not significantly different. Combined Flock 1 results by treatment indicate that out of the birds with footpad dermatitis (FPD score of 1 or 2), the birds in the houses without the circulation fans (Houses 3 and 4) had greater (P=0.0004) FPD severity scores (**Figures 2.40** and **2.41**).

Footpad dermatitis prevalence increased with bird age; it was greater at week 6 compared to week 3 (**Table 2.24).** Ideally, there should be no footpad dermatitis observed in commercial house broilers; however, the increase observed is not surprising (Mou,

2020). Footpad dermatitis prevalence likely increased as broilers aged and spent more time sitting in litter, especially because litter moisture increased significantly from week 3 to week 6 (**Table 2.13**).

Flock 2 Footpad Dermatitis

There was no difference in FPD prevalence across houses or houses within quadrant at week 3 (**Figure 2.42).** At week 6, there was significantly more footpad dermatitis in House 3 compared to House 1 ($P<0.0001$) (**Figure 2.43).** At week 6, there was significantly more footpad dermatitis in the houses without fans than the houses with fans ($P=0.0002$) (**Table 2.25**). As expected, average footpad dermatitis prevalence increased with bird age; it was higher at week 6 compared to week 3 (70% vs. 10%) (**Table 2.25**). The results, similar to previous studies, indicate that high-capacity circulation fans could aid in reducing footpad dermatitis prevalence when broilers are closer to market age/weight (Mou, 2020).

Flock Comparison

In the houses without fans, there was no significant difference between Flock 1 and 2 footpad dermatitis prevalence at week 3 or 6. In the houses with fans, there was significantly higher footpad dermatitis prevalence in Flock 1 at both week 3 ($P=0.0246$) and week 6 ($P=0.033$) (**Table 2.26**). The difference in Flock 1 and Flock 2 footpad dermatitis prevalence could also indicate that seasonality might have an impact on poultry welfare factors, particularly when combined with increased air movement from circulation fans.

Footpad Dermatitis Lesion Severity (Flock 1 Only)

Flock 1 birds in the houses without the circulation fans had greater FPD lesion areas than birds in houses with fans (P=0.0001) (6.8% vs. 4.2%) (**Figure 2.44**). This finding confirms the severity score results indicating that Flock 1 birds in the houses without the circulation fans had greater FPD severity scores (P=0.0004) (**Figure 2.40**).

Birds in House 1 had smaller (P≤0.009) FPD lesion areas than birds in the other houses (3.1% vs. 5.5-7.2%) (**Figure 2.45**). Birds in the houses without fans also had greater lesion area variation than birds in the houses with fans and both houses had 3 birds with large lesion areas (between 20% and 30%) (**Figure 2.45**). Welfare outcomes can be affected by many uncontrollable variables in the house such as environmental conditions (Dawkins et al., 2004). These limitations are often associated with field studies and may help explain why birds from House 1 had smaller lesion areas than birds from the other houses. These data suggest that the addition of circulation fans in commercial broiler houses could aid in decreasing footpad dermatitis severity and increase general broiler welfare. Although our litter moisture results did not indicate a clear trend in litter moisture being lower in the houses with fans, that is likely the reason why footpad dermatitis severity was affected by treatment (Mou, 2020). It should also be noted that litter samples were only collected at 2 time periods in Flock 1 and welfare assessments, such as footpad evaluations, can be more robust indicators of welfare over long periods of time because they can be used to ensure animal productivity and health (Grandin, 2010).

Hock Burn

With results from both flocks combined, more hock burn (P=0.0002) was observed in the houses without fans than in the houses with fans at week 6 (**Table 2.23 and Figure 2.46**). Because hock burn, which is an indicator of poor welfare, was less prevalent in the houses with fans, these results support our hypothesis that birds in the houses with circulation fans would have higher welfare than birds in the houses without circulation fans.

Flock 1 Hock Burn

There was no observation of hock burn across houses at week 3; prevalence was low/non-existent (data not shown). At week 6, there was no statistically significant difference in hock burn prevalence across quadrants within house, but there was a significantly higher prevalence of hock burn in House 1 than House 3 (**Figure 2.47**). When analyzed by treatment, houses with fans had numerically greater hock burn prevalence (8.75%) than houses without fans (4.38%), although it was not significantly different. This difference in hock burn prevalence in the houses with and without fans does not indicate that circulation fans helped reduce hock burn in broilers. Perhaps circulation fans are more likely to impact footpad dermatitis than hock burn prevalence, or this result could also be due to observer variation.

Hock burn prevalence was 0% at week 3 and about 7% at week 6 across all houses (**Table 2.24**). It is not surprising that hock burn prevalence increased over time as broilers aged and spent more time sitting in litter, especially because litter moisture increased from week 3 to week 6 (**Table 2.13**).

Flock 2 Hock Burn

There was no hock burn across houses at week 3; prevalence was non-existent. At week 6, there was significantly more hock burn in House 4 compared to Houses 1 and 2 ($P<0.0001$) (**Figure 2.48**). At week 6, there was significantly more hock burn in the houses without fans when compared to the houses with fans ($P<0.0001$) (**Table 2.25**).

Flock Comparison

In the houses with and without fans at week 3, there was no significant difference between Flock 1 and 2 hock burn prevalence. In the houses with and without fans at week 6, there was significantly higher hock burn prevalence in Flock 2 than in Flock 1 ($P=< 0.0001$). At week 6, significantly more hock burn was observed in both treatment and control houses during Flock 2 ($P=0.0001$) (**Table 2.26**). The large difference in Flock 1 and 2 hock burn prevalence may be due to differences in house lighting at different times of year, as well as the method in which the observers were coding. There were windows along the northern and southern walls of each broiler houses and light distribution in each quadrant varied based on season and time of day. During times of low lighting, it was more difficult to observe slight cases of hock burn on the birds, which could have affected prevalence results. The difference in Flock 1 and winter Flock 2 footpad dermatitis and hock burn prevalence could also indicate that seasonality might have an impact on poultry welfare factors, particularly when combined with increased air movement from circulation fans.

Feather Cleanliness

With both flocks combined, there was no effect of the fan treatment on broiler feather cleanliness. In Flock 1, there was no statistically significant difference between feather cleanliness across houses or quadrants within house at week 3 (**Figure 2.49)** or week 6 (**Figure 2.50).** In Flock 2, there was no difference in feather cleanliness across houses or quadrants within house at week 3; prevalence of dirty feathers was non-existent. There was no statistically significant difference between feather cleanliness across houses or quadrants within house at week 6 (**Figure 2.51).** As expected, feather cleanliness decreased with bird age in both flocks; there were more dirty feathers at week 6 compared to week 3 ($P<0.00001$) (**Figures 2.49-2.51**). It is not surprising that feather cleanliness decreased over time as broilers aged and spent more time sitting in litter and exposing their feathers to feces and dirt.

Behavior (Flock 1 Only)

Videos were recorded around 11:00AM at weeks 3 and 6 in each house and 5 hours from each camera was analyzed for behaviors. The percentage of birds observed exhibiting a behavior (walking, running, flapping, dust bathing, preening, sparring, food-running, frolicking, and drinking) was recorded from video from 4 cameras per house. The cameras captured a portion of each quadrant in all houses used for this study (**Figure 2.11**). Due to low frequencies of observed behaviors, they were grouped into categories for analysis. The categories were: mobility (walking, running, and flapping), comfort (dust bathing, and preening), play (sparring, food-running, and frolicking), and total (all behaviors besides drinking).

Play behaviors were observed and analyzed for this study because play is typically considered to be opportunity-based behavior that is not often seen when animals endure poor environments (Held & Špinka, 2011). Mobility and comfort behaviors were analyzed because the presence or absence of species-specific behavior is an essential part of evaluating animal well-being. Broilers with ideal living conditions should be able to perform normal behaviors and satisfy their own needs (Broom, 1991; Bergmann et al., 2017). Drinking behavior was analyzed because literature suggests that water consumption is a lead indicator of broiler welfare (Manning et al., 2007).

Flock 1 birds in the houses without fans displayed more play behaviors (sparring, food-running, and frolicking) at week 3 (0.21% of observed birds per treatment group) (P=0.0402) (**Table 2.27**). There was no significant difference in mobility, comfort, play, or total active behaviors at week 6 and frequency of observed behaviors was low (**Table 2.27**). Perhaps the fans were more likely to cause discomfort and agitation in younger week 3 birds, causing them to perform play behaviors less than birds in the control houses. Additionally, previous research indicates that birds become less fearful as they age (Bailie and O'Connell, 2015). There was no difference in behavior of older birds that were 6 weeks of age, either because play motivation is lower as they reached market weight, or because birds in the houses with fans have become acclimated to the additional air flow and behaved more similarly to their control flock mates. Because active behaviors decrease with broiler age (Baxter et al., 2019), older broilers may feel less motivated to move, regardless of house temperature, because it requires more energy. Running and frolicking were the only individual behaviors with significant differences in treatment group from either week; a greater percentage of birds in the houses without

fans were observed running (P=0.0348) and frolicking (P= 0.0425) at week 3, compared to the houses with fans (**Table 2.28**). Also, birds in houses without fans performed more total active behaviors than birds in houses with fans at week 3 (9.15% vs. 8.04% of observed birds per treatment group) (P=0.595) (**Table 2.27**). Fans and de-stratified air might cause young birds to be less inclined to play or move around, but for producers, the benefit of dry litter and reduced footpad dermatitis prevalence is worth the potential decrease in play and mobility behaviors.

Birds numerically performed more drinking behavior in the houses without fans at both week 3 and 6, although it was not a significant difference (8.93% vs. 8.17% of observed birds per treatment group, 8.41% vs. 7.97% of observed birds per treatment group) (**Table 2.27**). The houses without fans were slightly hotter than the houses with fans at multiple weeks in Flock 1, so perhaps the warmer birds were more inclined to drink water.

It should be noted that frequency of all behaviors was low and repeated trials might provide more insight into the effect of circulation fans on broiler mobility, comfort, and play behaviors.

Effect of Age on Behavior

As expected, active behaviors decreased as the birds aged. At week 3, birds performed more walking (P<0.0001), running (P<0.0001), flapping (P= 0.0072), sparring (P<0.0010), and frolicking (P=0.0001) behaviors than at week 6 (**Table 2.29**). At week 3, birds performed more mobility, play, and active behaviors than they did at week 6 (P<0.0001) (**Table 2.30**). Previous research indicates that overall activity decreases as

broilers age (Baxter et al., 2019). Faster growing broiler strains have been shown to be more inactive, spend more time sitting and feeding, and spend less time standing and walking than slower growing strains of the same age, with differences mostly occurring when birds are younger (Dawson et al., 2021). It is possible that older broilers then spend more time on maintenance behaviors like preening because it is a natural behavior that require less energy than walking or playing. That could explain why active and play behaviors decreased with age, but comfort (preening and dustbathing) did not. Previous research also indicates that broilers are more likely to perform play behaviors when they have large amounts of space to do so; there was more free space in the broiler houses at week 3 (Baxter et al., 2019). Also, the high amounts of daily gain typically seen in broilers, in combination with their low levels of activity, could make it more difficult for them to perform active behaviors as they age.

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Table 2.1. Flock 1 timeline for equipment set-up, welfare assessments, noise volume recording, and litter sample collection in 4 commercial broiler houses.

Date	Week	Age (Day)	House	Tasks
2/22/21	0	-1, -3	1	• HOBO data loggers set up
2/24/21	0	1, -1	2,3,4	• HOBO data loggers set up (Houses 2-4) • Litter samples collected (all houses)
3/15/21	3	20, 18	1,2,3,4	• GoPro set-up • Litter samples collected
3/16/21	3	21, 19	1,2,3,4	• Individual welfare assessments • Noise volume recorded • GoPro collected
4/6/21	6	42, 40	1,2,3,4	• GoPro set-up • Litter samples collected • Noise volume recorded
4/7/21	6	43, 41	1,2,3,4	• Individual welfare assessments • Transect method • Equipment removed

Table 2.2. Flock 2 timeline for equipment set-up, welfare assessments, noise volume recording, and litter sample collection in 4 commercial broiler houses.

Date	Week	Age (Day)	House	Tasks
9/20/21	0	0	3,4	• HOBO data loggers set up • Litter samples collected
9/20/21	0	3	1, 2	• HOBO data loggers set up • Litter samples collected
10/7/21	3	20	1, 2	• Litter samples collected • GoPro set-up
10/8/21	3	21	1, 2	• Welfare score assessments • Transect method • Noise volume recorded
10/10/21	3	20	3, 4	• Litter samples collected • GoPro set-up • Transect method • Noise volume recorded
10/11/21	3	21	3, 4	• Welfare score assessments
10/28/21	6	41	1, 2	• Litter samples collected • GoPro set-up • Transect method • Noise volume recorded
10/29/21	6	42	1, 2	• Welfare score assessments • Equipment removed
10/31/21	6	41	3, 4	• Litter samples collected • GoPro set-up • Transect method • Noise volume recorded
11/1/21	6	42	3, 4	• Welfare score assessments • Equipment removed

Table 2.3. Transect method ethogram of characteristics observed in 4 commercial broiler houses.

Indicator[1]	Description	Category
Lame	Walks with obviously uneven strides or unsteady steps. May exhibit outward or inward twisting of one or both legs leading to severe limping. Lameness is clearly advanced rather than in early stages.	Walking difficulties
Immobile	Does not move away when approached or moves by propping on wings or crawling. If gently nudged, moves with difficulty, no more than three steps before sitting down again.	
Sick	Signs of impaired health, including small and/or pale comb, red, watery or closed eyes, retracted neck and disarranged/raised feathers. Usually found in a resting position. Includes wry neck.	Illness
Terminally ill	Lying with head resting on ground or lying on back, with signs of being close to death (e.g., labored breathing, half-closed eyes). Excludes panting related to heat stress.	
Dead	No signs of life.	
Head wounds	Skin scratches on head or neck indicated by the presence of fresh or dried blood/scabs visible from 1–2 m away.	Skin wounds
Back wounds	Skin scratches on back (between neck and tail) and/or wings indicated by the presence of fresh or dried blood/scabs visible from 1–2 m away.	
Tail wounds	Skin scratches around tail and hips indicated by the presence of fresh or dried blood/scabs visible from 1–2 m away.	
Small	Stunted growth. Approximately half the average size of flock mates. May have yellow downy feathers, especially on head.	Small
Dirty	Extensive dark staining of body sides, wings, chest, back, and/or tail feathers due to prolonged contact with wet litter. Excludes light soiling or discoloration of feathers caused by dust, peat or excrement.	
Featherless	Lacking feathers on majority of back and wings. Excludes molting.	

[1] Adapted from BenSassi et al., 2019.

Table 2.4. Flock 1 ethogram of behaviors coded in 4 commercial broiler houses.

Behaviors[1]	Description
Mobility Behaviors	
Walking	Relatively low speed displacement of bird on the ground in which the propulsive force is derived from the action of the legs. Bird takes 2 or more consecutive steps, with the first step occurring before or during the time of the scan.
Running	Higher speed displacement of bird on the ground in which the propulsive force is derived from the action of the legs. Bird takes 2 or more consecutive running steps, with the first step occurring before or during the time of the scan. If the bird is flapping, then behavior should be counted under frolicking instead.
Flapping	Bird is standing in an upright position or walking slowly and extends its wings repeatedly. Birds may flap to balance themselves while walking or hopping; if a bird does this, code as flapping.
Comfort Behaviors	
Dust bathing	Bird is lying on the ground and attempting to toss dirt onto its body by ruffling and shaking its feathers. Bird can also be kicking up litter immediately before beginning dustbathing.
Preening	Bird is using its beak to peck, stroke, or comb plumage.
Play Behaviors	
Sparring	A bird simulates fighting behavior with no obvious aggression or injurious contact. The following behaviors may begin a bout and occur during a bout: jumps with light kicking that make little or no contact with the receiver; stand-offs (threats) in which birds will face up to one another briefly, stepping close to one another and raising their necks to stand practically beak-to-beak (with or without a difference in head height); raising feathers around the neck, usually during a stand-off; stand-off with wing-flapping; stand-off with light pecks at the neck, head or beak of the receiving bird. These differ from aggressive actions in that they are not forceful, prolonged and they do not elicit strong avoidance from the receiver. It would be difficult to estimate a pecking order based on these behaviors. The bird that these behaviors are directed at may or may not respond, in some cases, birds attempt a stand-off with a seated bird and are ignored. Birds usually end the short behavior by sitting down or engaging in another activity.
Food-running	A bird follows and chases (runs at least two paces after another bird to begin the bout) a bird that has picked up or obtained a large object that projects from their beak. This bird has run from conspecifics but may make rapid and counter-intuitive direction changes towards conspecifics. There are conspicuous peeping noises that typically accompany this behavior. The bout ends when the chasing bird loses interest and begins another behavior, for example, sits down or begins feeding
Frolicking	Spontaneous and rapid running and/or jumping and wing-flapping with no obvious intention, often with rapid direction changes. Running without wing-flapping is not classified as frolicking. A frolicking bout ends when the bird sits down or resumes another activity. Birds displaying frolicking directly leading to sparring are categorized as sparring, to avoid misinterpretation of their movements.
Maintenance Behaviors	
Drinking	Bird is standing and positioned under the drinker, neck is extended with beak facing in the direction of the nipple. Bird may not be physically drinking at the time of the scan, but the bird is looking at the nipple, trying to reach it. Multiple birds may be attempting to drink out of the same nipple. Birds simply sitting under the waterline or nipple should not be coded as drinking. If a bird performs any of these drinking behaviors while walking, it should be coded as walking.

[1]Adapted from Ventura et al., 2012 and Baxter et al., 2019

Figure 2.1. Areal image of the farm and the 4 commercial broiler houses used for both flocks of this study.

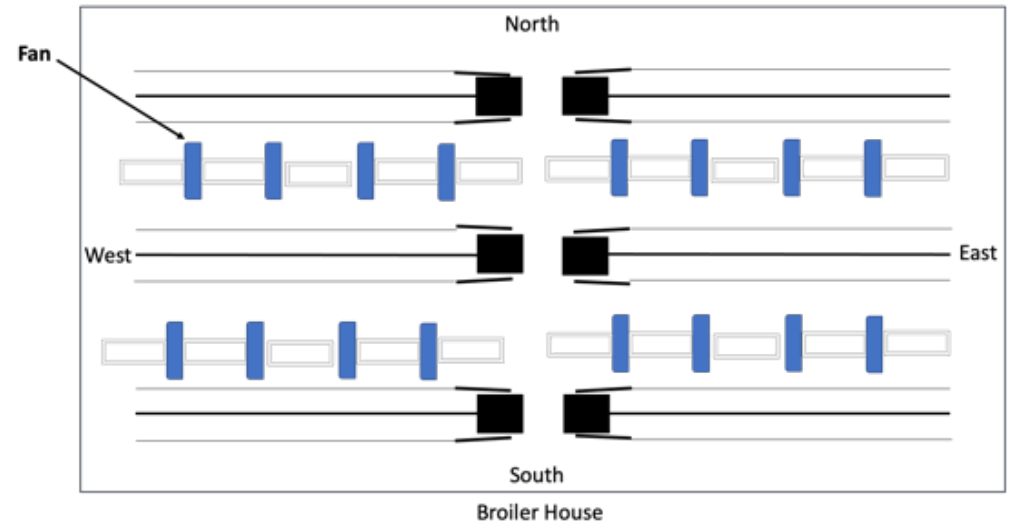


*Figure not drawn to scale

Figure 2.2. Set-up for commercial broiler houses with fan treatment (House 1 and 2). Apart from the high-capacity circulation fans (shown in blue) installed in Houses 1 and 2, all 4 commercial broiler houses had the same set-up.

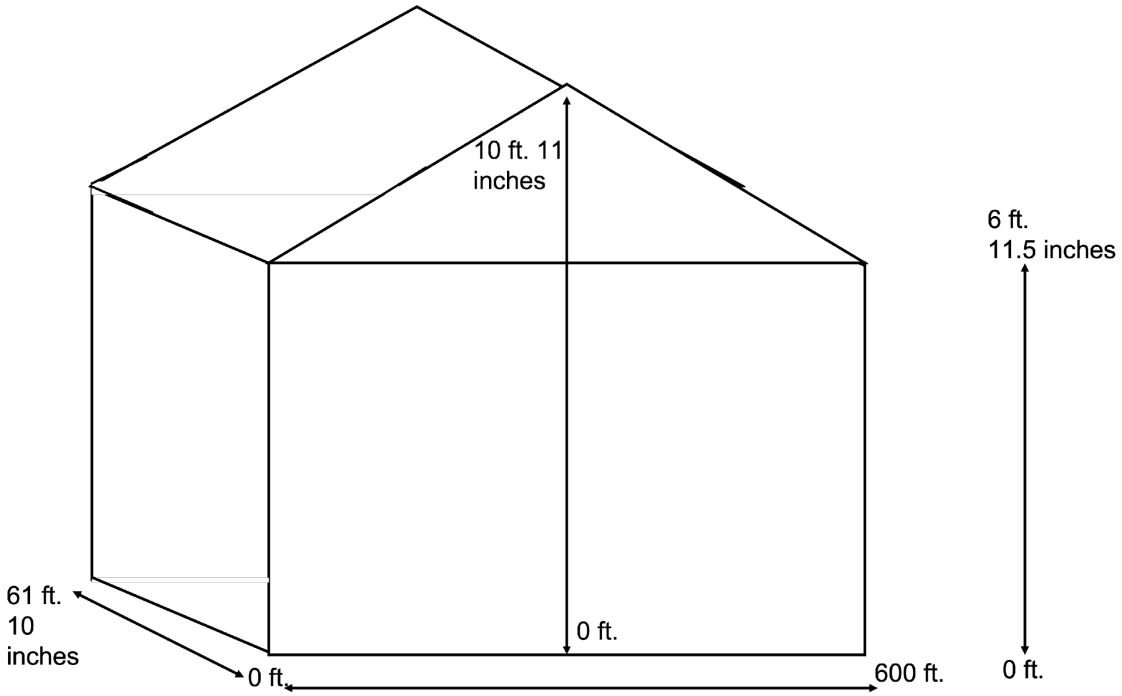


Figure 2.3. Dimensions of 4 commercial broiler houses. Each broiler house was 600 feet in length, 61 feet, 10 inches in width, 10 ft, 11 inches in height at the center of the house, and 6 feet, 11.5 inches at the in height along the house walls. All 4 houses used in this study were of the same size, dimensions, and basic set-up.

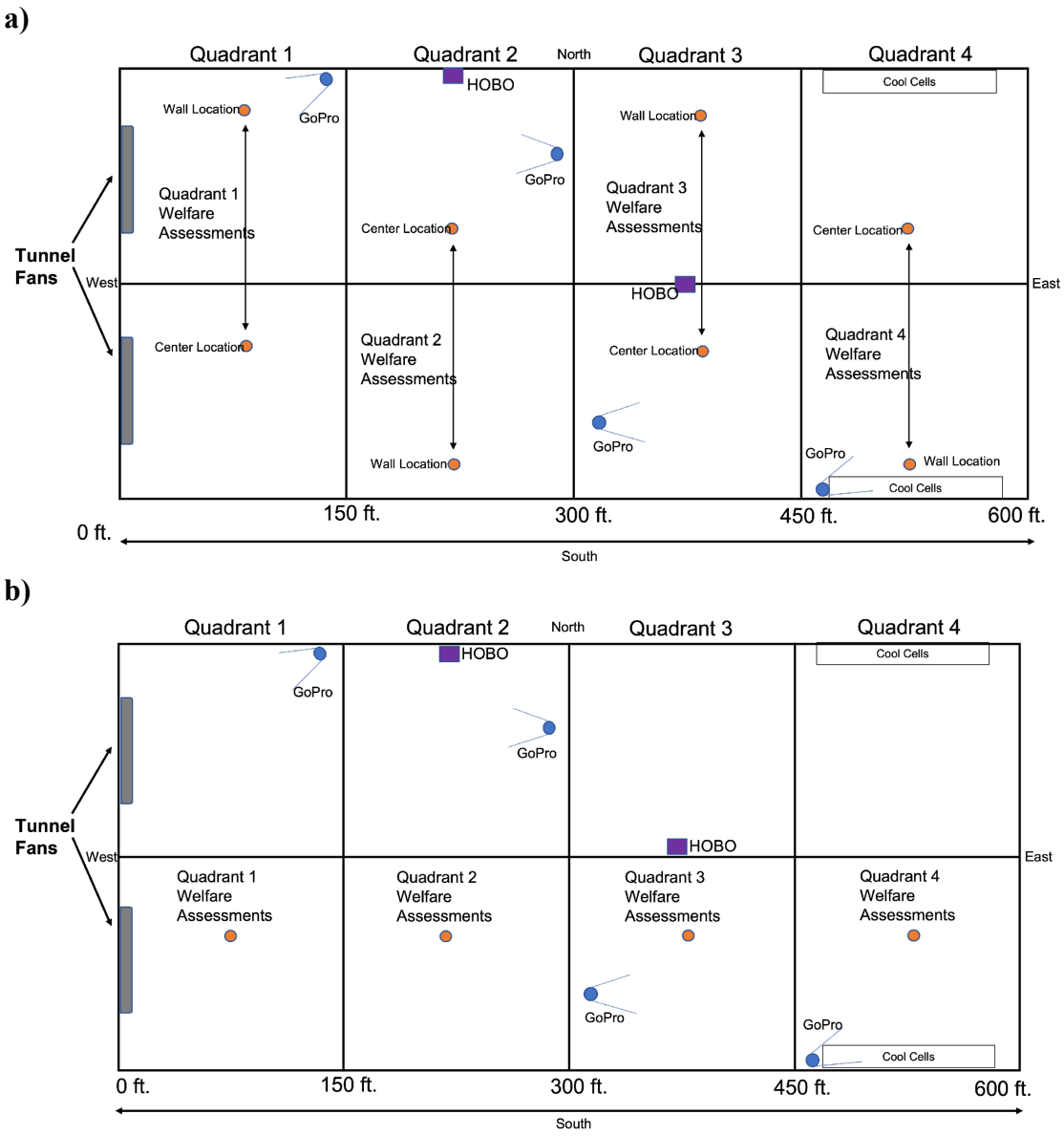


Figure 2.4. GoPro camera locations, HOBO data logger locations, house details, and welfare assessment locations in 4 commercial broiler houses. Besides welfare assessment locations, Flock 1 and Flock 2 houses had the same set up. a) Flock 1. b) Flock 2.

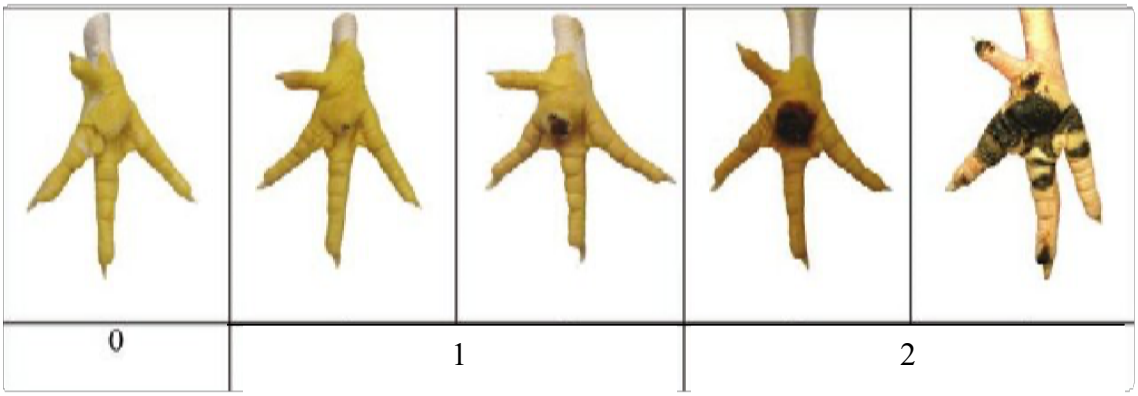


Figure 2.5. Scoring chart used for on-farm welfare assessments of footpad dermatitis in 4 commercial broiler houses. In this study, the first image on this scale was considered a FPD score of 0 (No FPD), the next two images on this scale were considered a FPD score of 1 (moderate), and the final two images on this scale were considered a FPD score of 2 (severe). Adapted from Welfare Quality, Assessment Protocol for Poultry, 2009.

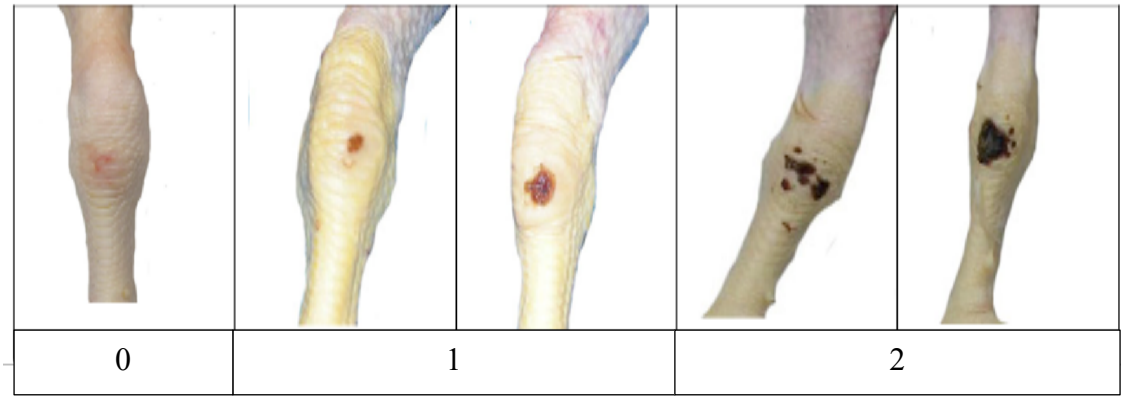


Figure 2.6. Scoring chart used for on-farm welfare assessments of hock burn in 4 commercial broiler houses. In this study, the first image on this scale was considered a HB score of 0 (No HB), the next two images on this scale were considered a HB score of 1 (moderate), and the final two images on this scale were considered a HB score of 2 (severe). Adapted from Welfare Quality, Assessment Protocol for Poultry, 2009.

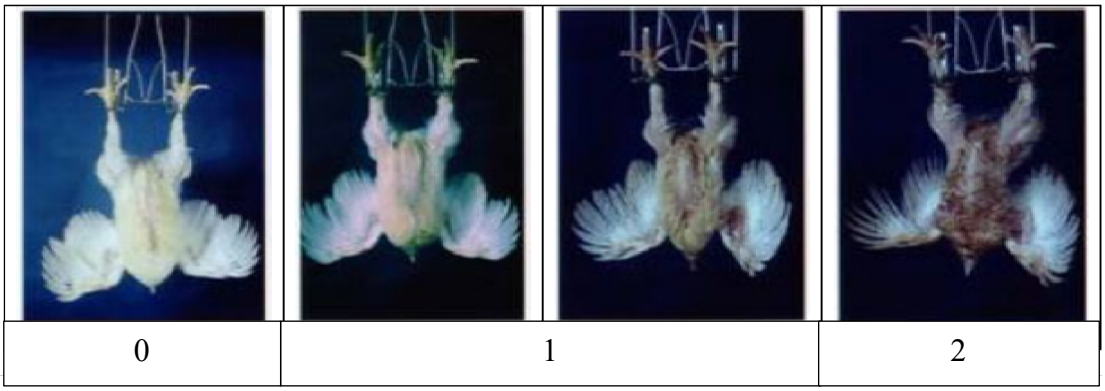


Figure 2.7. Scoring chart used for on-farm welfare assessments of feather cleanliness in 4 commercial broiler houses. In this study, the first image on this scale was considered a feather cleanliness score of 0 (Clean feathers), the next two images on this scale were considered a feather cleanliness score of 1 (moderate dirt), and the final image on this scale was considered a feather cleanliness score of 2 (severe dirt). Adapted from Welfare Quality, Assessment Protocol for Poultry, 2009.

Figure 2.8. a) Image portraying how birds were caught in a pen before being assessed for welfare in 4 commercial broiler houses. b) Image of a bird with FPD lesions, taken during on-farm welfare assessments.

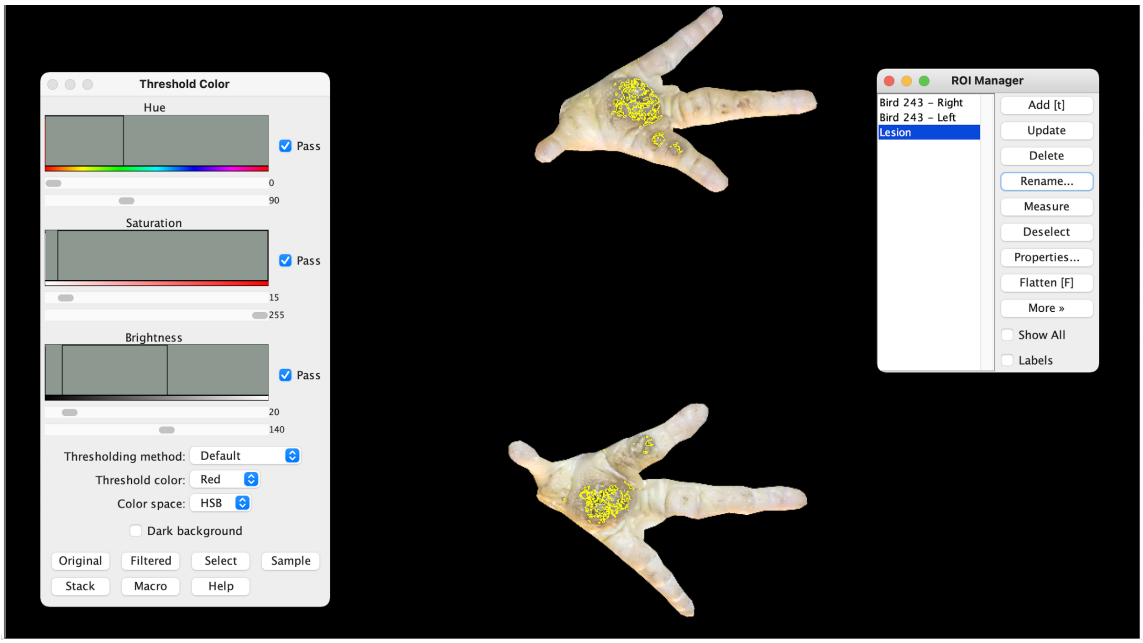


Figure 2.9. Digital image portraying how the feet of birds with FPD lesions in 4 commercial broiler houses were analyzed in ImageJ to determine lesion area (%).

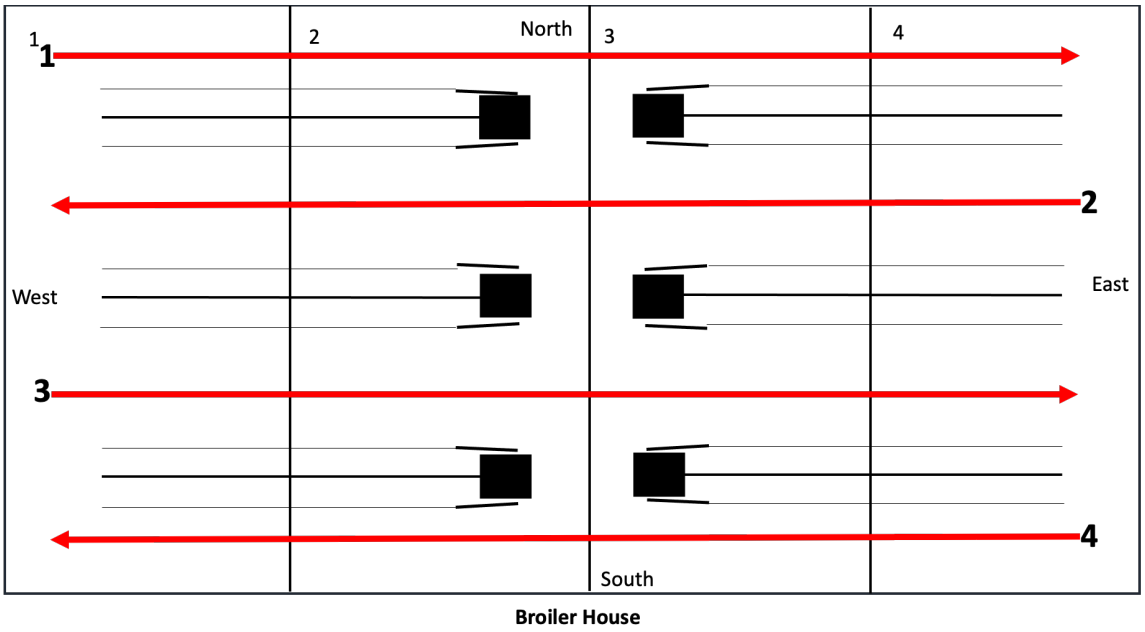


Figure 2.10. Diagram of placement and order of transect walks completed during the transect sampling method in 4 commercial broiler houses.

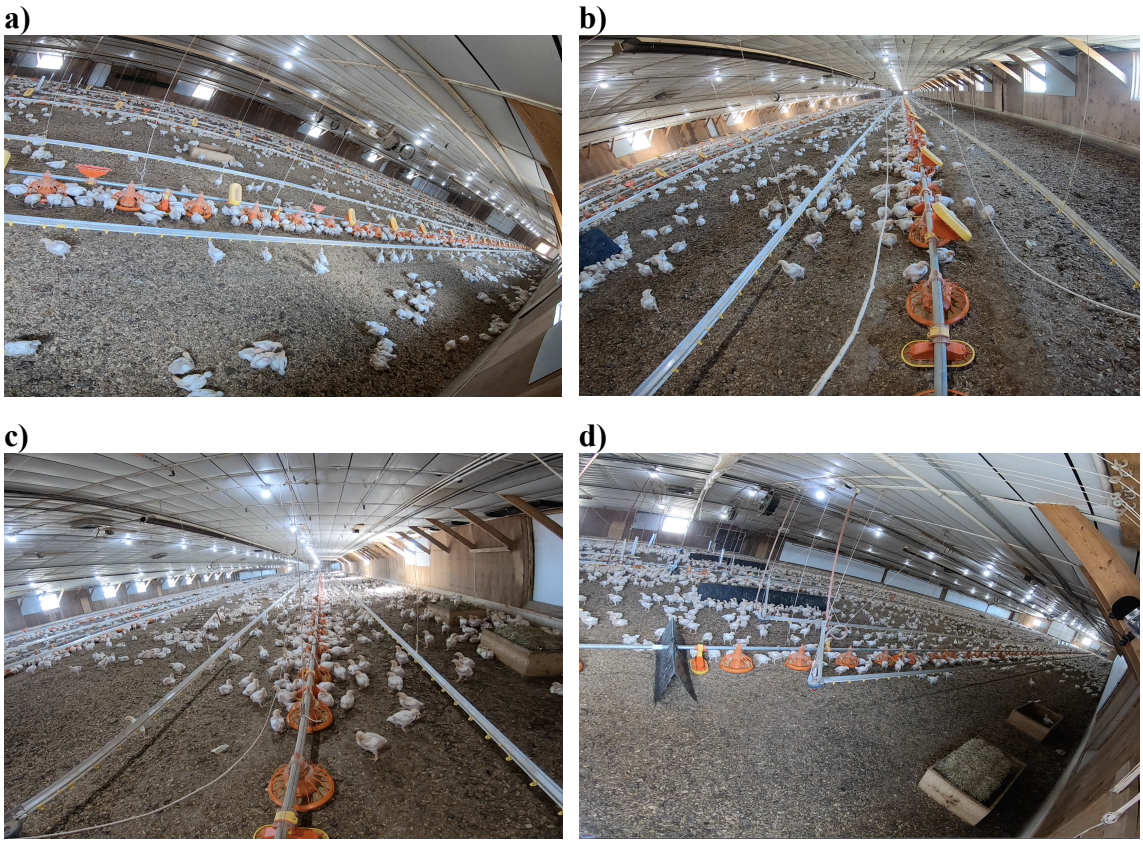


Figure 2.11. Image of video recorded from GoPro cameras mounted on the walls of quadrants 1 and 4, and hoppers of quadrants 2 and 3 in House 1 at Flock 1. All GoPros were set to record birds in the quadrant they were located in and Gopros were mounted in the same manner in each commercial broiler house. **a)** GoPro mounted on the northern wall in quadrant 1. **b)** GoPro mounted on the northernmost hopper in quadrant 2. **c)** GoPro mounted on the southernmost hopper in quadrant 3. **d)** GoPro mounted on the southern wall in quadrant 4.

a)

b)

Figure 2.12. Images of the standardized observation area (within the red lines) of GoPro videos in which researchers coded behavior of birds in 4 commercial broiler houses. a) Observation area for cameras mounted on the walls of the broiler houses. b) Observation area for cameras mounted on the hoppers in the broiler houses.

Table 2.5. House temperatures (°F) at week 0, 1, 2, 3, 4, 5, and 6 by treatment. Data are shown as the weekly temperature means and standard errors (SE) from both Flocks 1 and 2 combined.

Week[1]	Treatment[2]		P-Value
	No Fans[3]	Fans[4]	
0	79.01±0.49	79.58±0.49	0.4908
1	79.97±0.41	79.73±0.41	0.0936
2	81.78±0.15	81.07±0.15	0.0774
3	79.16±0.12[a]	78.04±0.12[b]	0.0214
4	77.15±0.17	76.73±0.17	0.2362
5	75.01±0.16	74.27±0.16	0.0859
6	74.41±0.11	73.92±0.18	0.0909

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Flock 1 bird ages differed: House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Weeks are organized according to the age of birds in Houses 2, 3, and 4. The first day of week 1 was 3/2/2021 in Houses 2, 3, and 4. Flock 2 bird age differed: House 1 and 2 broilers were 3 days older than broilers in Houses 3 and 4. Weeks are organized according to the age of birds in Houses 1 and 2. The first day of week 1 was 9/24/2021 in Houses 1 and 2.

[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.b**).

[3] There were no circulation fans in the control houses (House 3 and 4).

[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.6. Flock 1 house temperatures (°F) at week 0, 1, 2, 3, 4, 5, and 6 in 4 commercial broiler houses. Data are shown as the weekly temperature means and pooled standard errors of the mean (SEM).

Week[1]	House[2]				SEM	P-Value
	1	2	3	4		
0	87.19[d]	89.02[a]	88.16[b]	87.50[c]	0.07	< 0.0001
1	82.32[b]	83.92[a]	83.80[a]	82.18[b]	0.06	< 0.0001
2	80.34[d]	80.02[c]	81.24[a]	79.88[b]	0.06	< 0.0001
3	75.32[d]	75.98[c]	78.70[a]	77.49[b]	0.06	< 0.0001
4	76.78[b]	75.89[c]	78.19[a]	78.15[a]	0.11	< 0.0001
5	73.42[b]	72.99[c]	74.99[a]	74.95[a]	0.12	< 0.0001
6	76.06[ab]	75.51[b]	75.85[ab]	76.64[a]	0.33	< 0.0001

[abcd] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Flock 1 bird ages differed, and environmental data loggers were launched on different calendar dates. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Weeks are organized according to bird age in Houses 2, 3, and 4. The first day of week 1 was 3/2/2021 in Houses 2, 3, and 4.

[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.a**).

Table 2.7. Flock 2 mean (± SE) house temperatures (°F) at weeks 0,1,2,3,4,5, and 6 in 4 commercial broiler houses.

Week[1]	House[2]				P-Value
	1	2	3	4	
0	86.10 ± 0.06^{b}	86.26 ± 0.06^{b}	86.92 ± 0.12^{a}	87.16 ± 0.12^{a}	< 0.0001
1	83.02 ± 0.05^{d}	83.42 ± 0.05^{c}	84.53 ± 0.05^{b}	84.76 ± 0.05^{a}	< 0.0001
2	82.05 ± 0.07^{b}	82.17 ± 0.07^{b}	82.89 ± 0.07^{a}	82.97 ± 0.07^{a}	< 0.0001
3	79.08 ± 0.08^{c}	79.28 ± 0.08^{c}	80.34 ± 0.08^{b}	80.66 ± 0.08^{a}	< 0.0001
4	76.33 ± 0.14^{b}	76.16 ± 0.14^{b}	77.92 ± 0.14^{a}	77.60 ± 0.14^{a}	< 0.0001
5	74.00 ± 0.10^{d}	74.46 ± 0.10^{c}	76.42 ± 0.10^{b}	77.80 ± 0.10^{a}	< 0.0001
6	71.46 ± 0.20^{c}	71.68 ± 0.20^{c}	74.43 ± 0.08^{b}	74.80 ± 0.08^{a}	< 0.0001

[abcd] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Flock 2 bird age differed. House 1 and 2 broilers were 3 days older than broilers in Houses 3 and 4. Weeks are organized according to the age of birds in Houses 1 and 2. The first day of week 1 was 9/24/2021 and age 7 for birds in Houses 1 and 2.

[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.b**).

Table 2.8. House relative humidity (%) at week 0, 1, 2, 3, 4, 5, and 6 by treatment. Data are shown as the weekly temperature means standard errors (SE) from both Flocks 1 and 2 combined.

Week[1]	Treatment[2]		P-Value
	No Fans[3]	Fans[4]	
0	62.28±0.42	63.21±0.42	0.2474
1	54.24±0.92	54.28±0.92	0.9765
2	57.38±0.75	59.43±0.75	0.1926
3	65.52±0.19[b]	67.92±0.19[a]	0.0129
4	62.28±0.60	63.94±0.60	0.1885
5	63.46±0.85	64.07±0.85	0.6604
6	65.76±0.84	68.32±0.94	0.1515

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.
[1] Flock 1 bird ages differed: House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Weeks are organized according to the age of birds in Houses 2, 3, and 4. The first day of week 1 was 3/2/2021 in Houses 2, 3, and 4. Flock 2 bird age differed: House 1 and 2 broilers were 3 days older than broilers in Houses 3 and 4. Weeks are organized according to the age of birds in Houses 1 and 2. The first day of week 1 was 9/24/2021 in Houses 1 and 2.
[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.b**).
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.9. Flock 1 house relative humidity (%) at week 0, 1, 2, 3, 4, 5, and 6 in 4 commercial broiler houses. Data are shown as the weekly temperature means and pooled standard errors of the mean (SEM).

Week[1]	House[2]				SEM	P-Value
	1	2	3	4		
0	41.49[a]	38.39[c]	40.03[b]	41.84[a]	0.27	< 0.0001
1	48.97[a]	42.03[c]	45.68[b]	45.79[b]	0.14	< 0.0001
2	56.20[a]	51.39[c]	53.13[b]	53.00[b]	0.18	< 0.0001
3	65.44[a]	64.17[b]	62.62[c]	63.94[b]	0.22	< 0.0001
4	68.20[a]	66.21[b]	62.28[c]	68.19[a]	0.35	< 0.0001
5	64.24[a]	61.86[b]	57.95[c]	64.74[a]	0.37	< 0.0001
6	62.74[a]	65.32[a]	58.01[b]	64.70[a]	0.97	< 0.0001

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Flock 1 bird age differed, and environmental data loggers were launched on different calendar dates. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Weeks are organized according to bird age in Houses 2, 3, and 4. The first day of week 1 was 3/2/2021 in Houses 2, 3, and 4.

[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.a**).

Table 2.10. Flock 2 mean (± SE) house relative humidity (%) at weeks 0,1,2,3,4,5, and 6 in 4 commercial broiler houses.

Week[1]	House[2]				P-Value
	1	2	3	4	
0	66.52±0.27[a]	66.13±0.27[a]	63.82±0.51[b]	62.77±0.51[b]	< 0.0001
1	58.66±0.19[a]	58.88±0.19[a]	56.52±0.19[b]	52.83±0.19[c]	< 0.0001
2	66.56±0.26[b]	67.78±0.26[a]	66.20±0.26[b]	64.83±0.26[c]	< 0.0001
3	73.24±0.26[b]	74.42±0.26[a]	69.45±0.26[d]	71.88±0.26[c]	< 0.0001
4	63.03±0.32[b]	64.25±0.32[a]	60.03±0.32[d]	62.09±0.32[c]	< 0.0001
5	67.33±0.26[b]	68.64±0.26[a]	65.53±0.26[c]	67.45±0.26[b]	< 0.0001
6	74.45±0.84[a]	75.40±0.84[a]	69.22±0.33[b]	69.98±0.33[b]	< 0.0001

[abcd] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Flock 2 bird age differed. House 1 and 2 broilers were 3 days older than broilers in Houses 3 and 4. Weeks are organized according to the age of birds in Houses 1 and 2. The first day of week 1 was 9/24/2021 and age 7 for birds in Houses 1 and 2.

[2] Data were collected from loggers mounted on the northern wall of Quadrant 2 in each house (see **Figure 2.4.b**).

Table 2.11. Mean (± SE) litter moisture content (%) at week 0, 3, and 6. Data are shown as the weekly litter moisture means from both Flocks 1 and 2 in the houses without fans and with fans at week 0, 3 and 6 combined, week 0 only, week 3 only, and week 6 only.

Week[1]	No Fans[3]	Fans[4]	P-Value
0, 3 and 6[2]	18.01±0.61	18.42±0.61	0.6690
0	17.19±0.84	15.96±0.84	0.4121
3	14.75±0.37	15.94±0.37	0.1486
6	22.10±1.37	23.39±1.37	0.5749

[1] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-43 days in age.
[2] Values were obtained by averaging litter moisture from each welfare assessment location within each house and then each treatment group, from the 3 collection dates in Flock 1 and Flock 2.
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.12. Flock 1 mean (± SE) litter moisture content (%) by treatment group. Data are shown as the weekly litter moisture means in the houses with fans and no fans.

Week[1]	No Fans[2]	Fans[3]	P-Value
0	19.27±0.69[a]	18.96±1.17[b]	0.0150
3	11.36±0.58[b]	15.55±0.38[a]	< 0.0001
6	24.67±0.82[a]	22.46±0.63[b]	0.0378

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Values were obtained by averaging the litter moisture percentages from each quadrant within treatment and control houses, for the samples taken on the 3 collection dates.

[2] There were no circulation fans in the control houses (House 3 and 4).

[3] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.13. Weekly flock 1 mean (± SE) litter moisture content (%)**.** Data are shown as the weekly litter moisture means in all houses.

Week	Litter Moisture (%)[1]
0	19.11±0.66[b]
3	13.45±0.46[c]
6	23.57±0.54[a]
P-Value	< 0.0001

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$

[1] Values were obtained by averaging the litter moisture percentages from each quadrant in all houses, for the samples taken on the 3 collection dates.

Table 2.14. Flock 1 mean (± SE) litter moisture content (%) at week 0, 3, and 6. Data are shown as the weekly litter moisture means in 4 commercial broiler houses.

Week	House[1]				P-Value
	1	2	3	4	
0	16.68±2.14[b]	21.04±0.76[a]	18.47±0.55[ab]	20.07±1.23[ab]	0.1031
3	18.83±0.30[a]	14.27±0.47[b]	12.82±0.50[c]	13.53±0.44[bc]	< 0.0001
6	19.92±0.43[c]	25.00±0.53[b]	21.07±0.51[c]	28.27±0.48[a]	< 0.0001

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Values were obtained by averaging the litter moisture percentages from each quadrant within each house, for the samples taken on the 3 collection dates.

Table 2.15. Flock 2 mean (± SEM) litter moisture content (%) at week 0, 3, and 6 in 4 commercial broiler houses.

Week	House[1]				P-Value
	1	2	3	4	
0	12.94±0.46[b]	13.09±0.60[b]	15.00±0.50[a]	15.22±0.47[a]	0.0022
3	16.06±0.30[ab]	16.62±0.57[ab]	16.96±0.37[a]	15.67±0.33[b]	0.1336
6	24.38±0.79[a]	24.26±0.94[a]	20.14±0.67[b]	18.92±0.47[b]	< 0.0001

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Values were obtained by averaging the litter moisture percentages from each quadrant within each house, for the samples taken on the 3 collection dates.

Table 2.16. Flock 2 mean (± SEM) litter moisture content (%) by treatment group in 4 commercial broiler houses.

Week[1]	No Fans[2]	Fans[3]	P-Value
0	15.11±0.34[a]	13.01±0.37[b]	0.0001
3	16.32±0.28	16.34±0.32	0.9564
6	19.53±0.42[b]	24.32±0.60[a]	< 0.0001

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.
[1] Values were obtained by averaging the litter moisture percentages from each quadrant within treatment and control houses, for the samples taken on the 3 collection dates.
[2] There were no circulation fans in the control houses (House 3 and 4).
[3] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.17. Flock 2 mean (± SEM) litter moisture content (%) at weeks 0, 3, and 6**.**

Week	Litter Moisture (%)[1]
0	14.06±0.29[c]
3	16.33±0.21[b]
6	21.93±0.50[a]
P-Value	< 0.0001

[abc] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

1 Values were obtained by averaging the litter moisture percentages from each quadrant in all houses, for the samples taken on the 3 collection dates.

Table 2.18. Flock 1 and Flock 2 litter moisture (%) by treatment groups at weeks 0, 3, and 6. Data are shown as litter moisture (%) means (± SEM) in the houses without fans and with fans at week 0, 3 and 6 combined, week 0 only, week 3 only, and week 6 only.

Week[1]	Flock[2]	No Fans[3]	Fans[4]
0, 3 and 6	**1**	18.44±0.76	18.99±0.56
	2	16.98±0.30	17.89±0.62
	P-Value	0.0778	0.1907
0	**1**	19.27±0.68[a]	18.96±1.17[a]
	2	15.11±0.34[b]	13.01±0.37[b]
	P-Value	< 0.0001	< 0.0001
3	**1**	11.37±0.58[b]	15.55±0.38
	2	16.32±0.28[a]	16.34±0.32
	P-Value	< 0.0001	0.1208
6	**1**	24.67±0.82[a]	22.46±0.53[b]
	2	19.53±0.42[b]	24.32±0.60[a]
	P-Value	< 0.0001	0.0372

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-43 days in age.

[2] Values were obtained by averaging litter moisture from each welfare assessment location within each house and then each treatment group, from the 3 collection dates in Flock 1 and Flock 2.

[3] There were no circulation fans in the control houses (House 3 and 4).

[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.19. Noise volume (dB) by treatment groups at weeks 3, 6, and all weeks from Flocks 1 and 2 combined. Data are shown as noise volume (dB) means (± SEM) by treatment at week 3 and 6 combined, week 3 only, and week 6 only.

Week[1]	No Fans[3]	Fans[4]	P-Value
3 and 6[2]	58.02±0.83[b]	61.08±0.46[a]	0.0018
3	53.23±0.43[b]	59.33±0.49[a]	< 0.0001
6	62.81±0.80	62.83±0.61	0.9869

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$

[1] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.

[2] Values were obtained by averaging the noise volume from each welfare assessment location within treatment and control houses for all collection dates.

[3] There were no circulation fans in the control houses (House 3 and 4).

[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.20. Flock 1 and Flock 2 noise volume (dB) by treatment groups at weeks 0, 3, and 6. Data are shown as noise volume (dB) means (± SEM) in the houses without fans and with fans at week 3 and 6 combined, week 3 only, and week 6 only.

Week[1]	Flock[2]	No Fans[3]	Fans[4]
3 and 6	**1**	57.36±0.85	61.39±0.43
	2	59.34±1.84	60.47±1.10
	P-Value	0.2676	0.3555
3	**1**	53.36±0.40	59.97±0.46
	2	52.96±1.07	58.06±1.03
	P-Value	0.6742	0.0631
6	**1**	61.36±0.82[b]	62.81±0.53
	2	65.71±1.30[a]	62.88±1.58
	P-Value	0.0073	0.9592

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$

[1] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.

[2] Values were obtained by averaging the noise volume from each welfare assessment location within treatment and control houses for all collection dates.

[3] There were no circulation fans in the control houses (House 3 and 4).

[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.21. Flock 1 mean (± SEM) lame, sick, small, immobile, terminally ill, dead, and featherless bird count at week 6. Data are shown as mean bird count, per transect walk, observed in each commercial broiler house during the transect method of observation.

Characteristic	House[1]				P-Value
	1	2	3	4	
Lame	4.25±0.83[a]	1.75±0.83[ab]	1.50±0.83[b]	1.75±0.83[ab]	0.0376
Sick	0.25±0.19	0.50±0.19	0.00±0.19	0.00±0.19	0.2476
Small	4.25±1.60[b]	2.75±1.60[b]	3.25±1.60[b]	9.50±1.60[a]	0.0390
Immobile	2.75±1.10[ab]	1.75±1.10[b]	4.00±1.10[ab]	5.75±1.10[a]	0.0247
Terminally Ill	0.25±0.22	0.25±0.22	0.00±0.22	0.25±0.22	0.8015
Dead	2.00±0.61[a]	0.00±0.61[b]	0.50±0.61[ab]	1.25±0.61[ab]	0.0384
Featherless	0.25±0.32[b]	1.75±0.32[a]	0.25±0.32[b]	0.25±0.32[b]	0.0065

[ab] Columns not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Data were collected by performing four lengthwise walks in each house. Values were obtained by averaging the number of birds with each characteristic observed during each transect walk, within each house.

Table 2.22. Flock 2 mean (± SEM) lame, sick, small, immobile, terminally ill, dead, and featherless bird count at week 6. Data are shown as mean bird count, per transect walk, observed in each commercial broiler house during the transect method of observation.

Characteristic	House[1]				P-Value
	1	2	3	4	
Lame	1.25±0.76	2.00±0.76	1.50±0.76	1.00±0.76	0.8141
Sick	0.50±0.24	0±0.24	0.50±0.24	0.25±0.24	0.4262
Small	9.50±1.99[b]	7.00±1.99[b]	17.25±1.99[a]	16.50±1.99[a]	0.0288
Immobile	1.00±0.77	1.25±0.77	1.50±0.77	2.25±0.77	0.6949
Terminally Ill	0±0.13	0±0.13	0.00±0.13	0.25±0.13	0.4262
Dead	1.00±0.43	1.25±0.43	0±0.43	0±0.43	0.1216
Featherless	0.25±0.18	0±0.18	0±0.18	0.25±0.18	0.5885

[ab] Columns not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Data were collected by performing four lengthwise walks in each house. Values were obtained by averaging the number of birds with each characteristic observed during each transect walk, within each house.

Table 2.23. Footpad dermatitis (FPD) prevalence (%) and hock burn (HB) prevalence (%) by treatment group at week 6 in both Flocks 1 and 2. Data are shown as prevalence (%) means in the houses without fans and with fans in both flocks.

Welfare[1]	No Fans[3]	Fans[4]	P-Value
FPD[2]	72.03[a]	66.25[b]	0.0011
HB[2]	30.63[a]	18.13[b]	0.0002

[ab] Columns not sharing the same letters indicate a significant difference at $P \leq 0.05$.
[1] Welfare values were obtained by averaging the prevalence from each quadrant within each house and then each treatment group, from birds assessed on the 2 collection dates.
[2] At week 6, birds were between 41-43 days in age.
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.24. Flock 1 footpad dermatitis (FPD) prevalence (%) and hock burn (HB) prevalence (%) by treatment group at week 3 and week 6 in 4 commercial broiler houses.

Welfare[1]	Week[2]	No Fans[3]	Fans[4]	P-Value
FPD	**3**	8.75	10	0.428
	6	76.25	71.88	0.3717
HB	**3**	0	0	-
	6	4.38	8.75	0.1108

[1] Welfare values were obtained by averaging the prevalence from each quadrant within each house and then each treatment group, from birds assessed on the 2 collection dates.
[2] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.25. Flock 2 footpad dermatitis (FPD) prevalence (%) and hock burn (HB) prevalence (%) by treatment group at week 3 and week 6 in 4 commercial broiler houses. Data are shown as the weekly prevalence (%) means in the houses without fans and with fans.

Welfare[1]	Week[2]	No Fans[3]	Fans[4]	P-Value
FPD	**3**	6.25	3.75	0.3025
	6	79.38[a]	60.63[b]	0.0002
HB	**3**	0	0	-
	6	56.88[a]	27.50[b]	<0.0001

[ab] Columns not sharing the same letters indicate a significant difference at $P \leq 0.05$.
[1] Welfare values were obtained by averaging the prevalence from each quadrant within each house and then each treatment group, from birds assessed on the 2 collection dates.
[2] At week 3, birds were 21 days in age. At week 6, birds were 42 days in age.
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.26. Flock 1 and Flock 2 weekly footpad dermatitis (FPD) prevalence (%) and hock burn (HB) prevalence (%) at week 3 and week 6. Data are shown as the weekly prevalence (%) means in the houses without fans and with fans for both flocks.

Welfare[1]	Week[2]	Flock	No Fans[3]	Fans[4]
FPD	**3**	**1**	7.50	10[a]
		2	6.25	3.75[b]
		P-Value	0.6584	0.0246
	6	**1**	76.25	71.88[a]
		2	79.38	60.63[b]
		P-Value	0.5010	0.0330
HB	**3**	**1**	0	0
		2	0	0
		P-Value	-	-
	6	**1**	4.38[b]	8.75[b]
		2	56.88[a]	27.50[a]
		P-Value	< 0.0001	< 0.0001

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.
[1] Welfare values were obtained by averaging the prevalence from each welfare assessment location within each house and then each treatment group, from birds assessed on the 2 collection dates in Flock 1 and Flock 2.
[2] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-43 days in age.
[3] There were no circulation fans in the control houses (House 3 and 4).
[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

Table 2.27. Flock 1 behavior at week 3 and 6 by treatment. Data are shown as the mean (± SEM) percentage (%) of birds observed displaying a behavior within the mobility, comfort, play, drinking, or total behavior categories within each treatment group.

		Behavior Category[1]				
Week[2]	**Treatment[3]**	**Mobility**	**Comfort**	**Play**	**Drinking**	**Total**
3	**Fans[4]**	6.45±0.41	1.48±0.13	0.11±0.04[b]	8.17±0.35	8.04±0.41
	No Fans[5]	7.39±0.42	1.56±0.13	0.21±0.04[a]	8.93± 0.35	9.15±0.42
	P-Value	0.1139	0.7020	0.0402	0.1243	0.0595
6	**Fans[4]**	2.08±0.16	1.72±0.14	0.01±0.01	7.97± 0.36	3.81±0.20
	No Fans[5]	2.41±0.15	1.54±0.13	0.01±0.01	8.41± 0.34	3.97±0.19
	P-Value	0.1237	0.3375	0.5676	0.3820	0.5646

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$

[1] Mobility (walking, running, and flapping), comfort (dust bathing, and preening), play (sparring, food-running, and frolicking), drinking, and total (all behaviors besides drinking) behavior results are shown.

[2]At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.

[3] Values were obtained by averaging the percentage of birds observed performing each behavior category in each video collected from all 4 quadrants in both treatment and control houses.

[4] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

[5] There were no circulation fans in the control houses (House 3 and 4).

Table 2.28. Flock 1 behavior at week 3. Data are shown as the mean (± SEM) percentage (%) of birds observed displaying a behavior within each treatment group. Only individual behaviors with a significant difference between treatment groups are shown.

Treatment[1]	Running	Frolicking
Fans[2]	0.15±0.05[b]	0.07±0.03[b]
No Fans[3]	0.29±0.05[a]	0.15±0.03[a]
P-Value	0.0348	0.0425

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

1 Values were obtained by averaging the percentage of birds observed performing each behavior in each video collected from all 4 quadrants in both treatment and control houses.

[2] 16 circulation fans were hung from the ceiling in each house with fans (House 1 and 2).

[3] There were no circulation fans in the control houses (House 3 and 4).

Table 2.29. The effect of age on Flock 1 behavior. Data are shown as the mean (± SEM) percentage (%) of birds observed displaying a specific behavior at week 3 and week 6. Only individual behavior results with a significant difference between ages (weeks) are shown.

	Behavior[1]				
Week[2]	**Walking**	**Running**	**Flapping**	**Sparring**	**Frolicking**
3	6.58± 0.22[a]	0.22± 0.03[a]	0.11± 0.02[a]	0.05± 0.01[a]	0.11± 0.02[a]
6	2.21± 0.22[b]	0± 0.03[b]	0.05± 0.02[b]	0± 0.01[b]	0.01± 0.02[b]
P-Value	< 0.0001	< 0.0001	0.0072	0.0010	0.0001

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Values were obtained by averaging the percentage of birds observed performing each behavior in each video collected from all 4 quadrants in all houses.

[2] At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.

Table 2.30. The effect of age on Flock 1 behavior. Data are shown as the mean (± SEM) percentage (%) of birds observed displaying a behavior within the mobility, comfort, play, drinking, or total behavior categories within each treatment groups at week 3 and week 6.

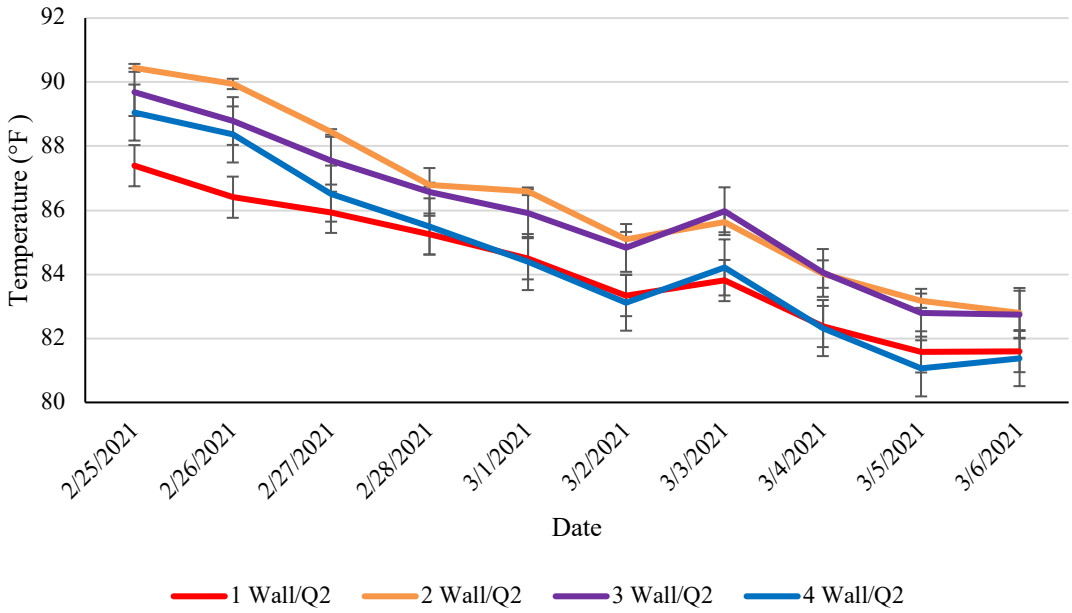
	Behavior Category[1]				
Week[2]	**Mobility**	**Comfort**	**Play**	**Drinking**	**Total**
3	6.91 ± 0.22[a]	1.52 ± 0.09	0.16 ± 0.02[a]	8.54± 0.25	8.59 ± 0.23[a]
6	2.25 ± 0.23[b]	1.63 ± 0.10	0.01 ± 0.02[b]	8.19± 0.25	3.89 ± 0.23b
P-Value	< 0.0001	0.4186	< 0.0001	0.3196	< 0.0001

[ab] Rows not sharing the same letters indicate a significant difference at $P \leq 0.05$.

[1] Mobility (walking, running, and flapping), comfort (dust bathing, and preening), play (sparring, food-running, and frolicking), drinking, and total (all behaviors besides drinking) behavior results are shown.

[2] Values were obtained by averaging the percentage of birds observed performing each behavior category in each video collected from all 4 quadrants in all houses. At week 3, birds were between 19-21 days in age. At week 6, birds were between 41-42 days in age.

a)



b)

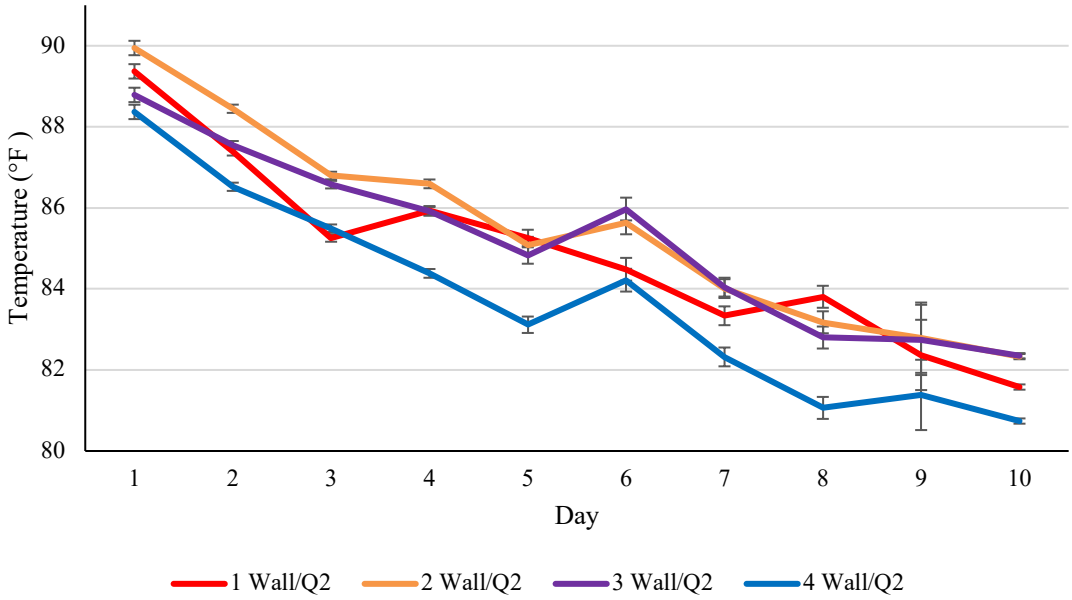
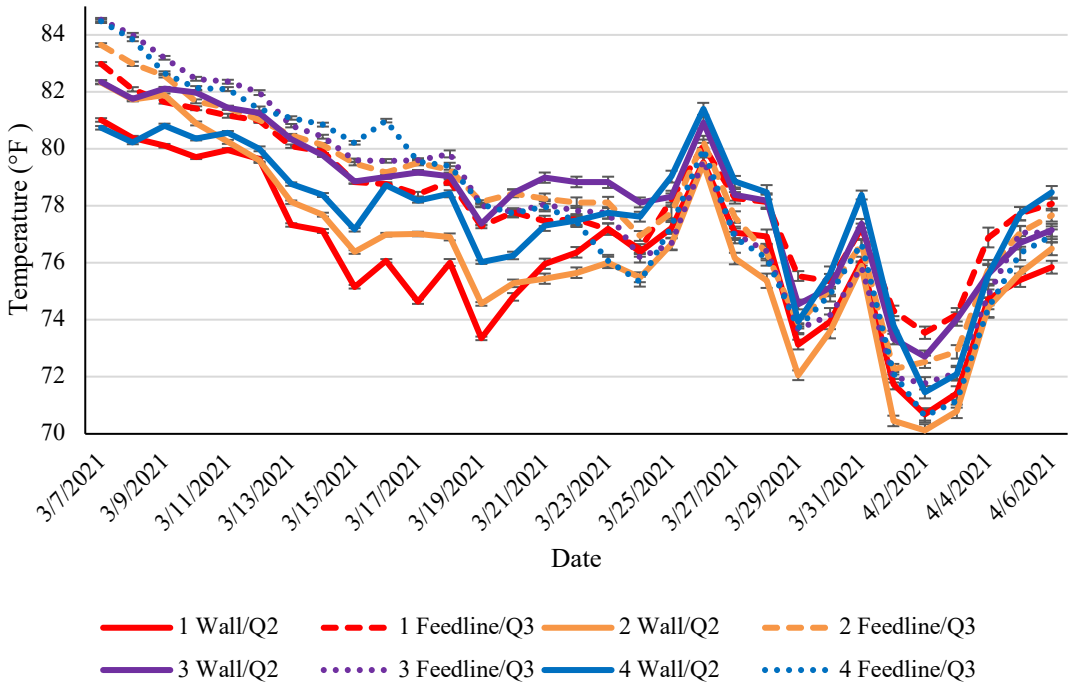


Figure 2.13. Flock 1 mean (± SE) daily temperature (°F) during the brooding period (days 1-10). Each line indicates 1 of the 4 houses used in the study. Brooding took place in quadrants 1 and 2 only, so the daily temperature averages from the data loggers located in the center of quadrant 3 are not shown. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Temperature (°F) by date **b)** Temperature (°F) by age. Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

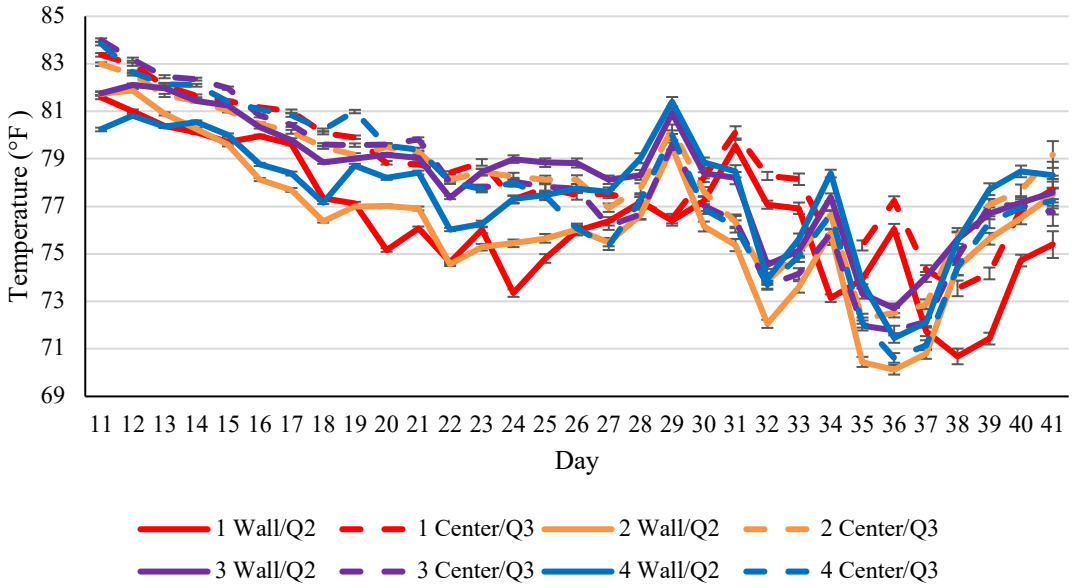
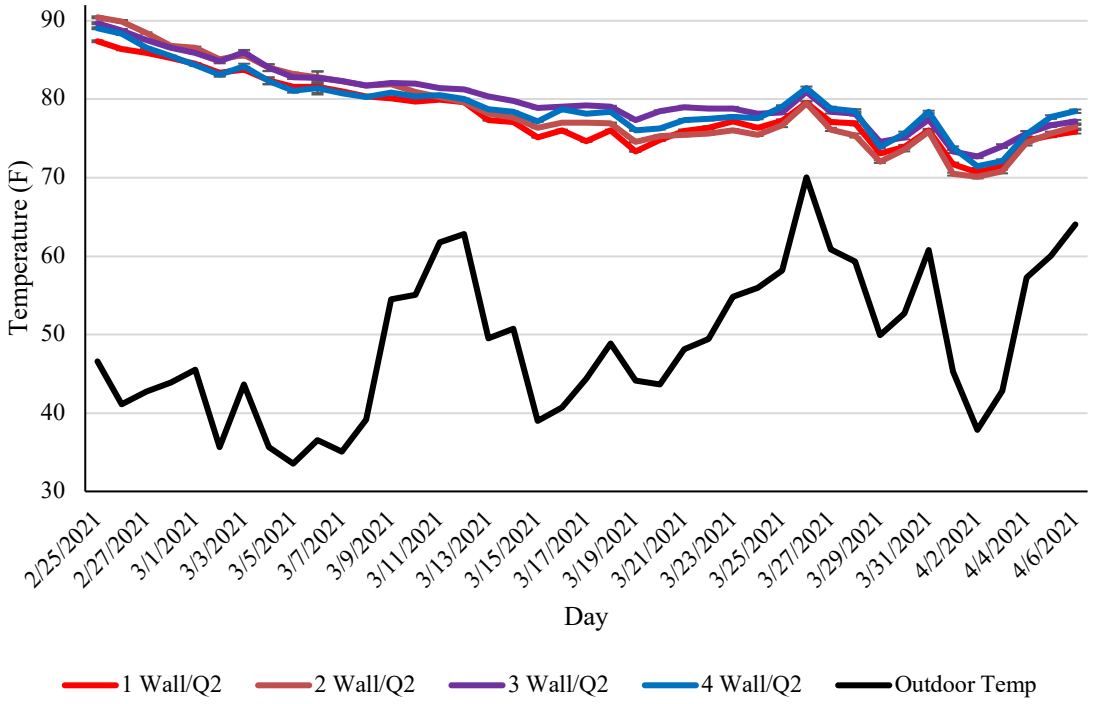


Figure 2.14. Flock 1 mean (± SE) daily temperature (°F) after the brooding period (days 11-41). Each line indicates 1 of the 4 houses used in the study. In the legend, the number indicates the house, dotted lines indicate the quadrant 3 locations, and solid lines indicate the quadrant 2 locations. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Temperature (°F) by date **b)** Temperature (°F) by age Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

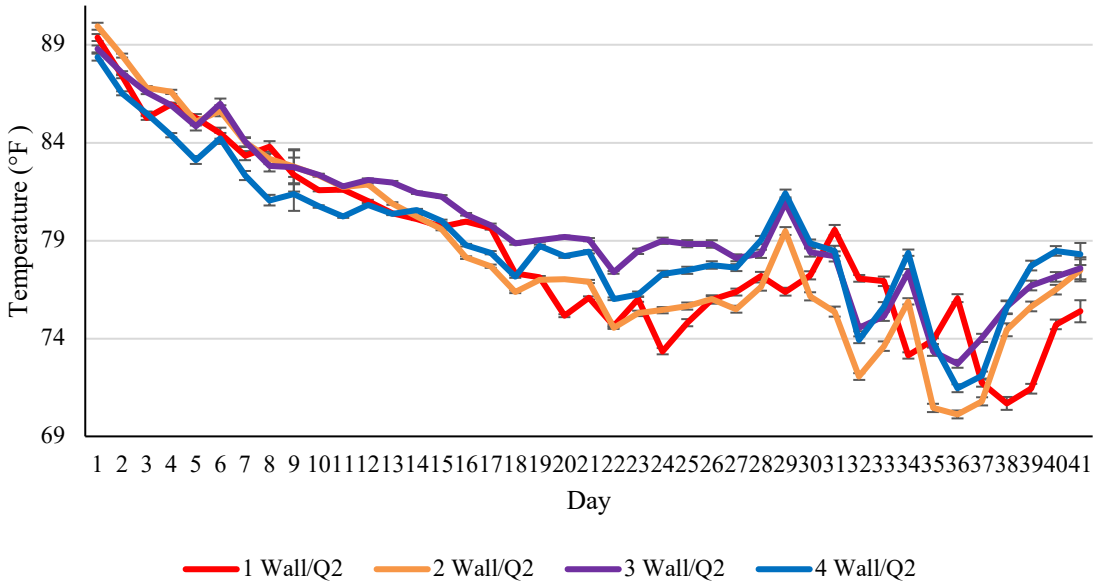
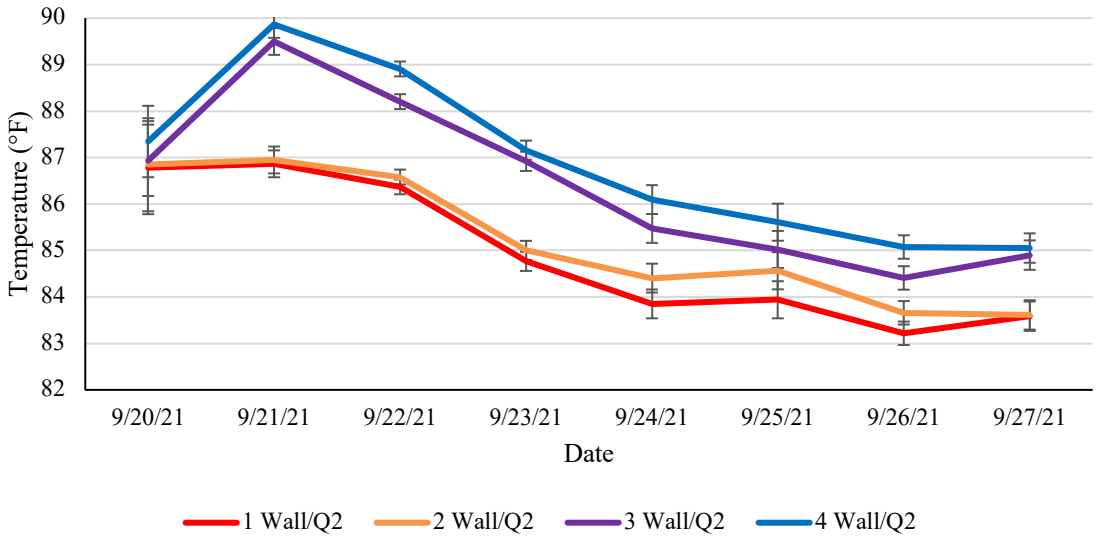


Figure 2.15. Flock 1 mean (± SE) daily temperature (°F) over the course of the entire growout. Each line indicates 1 of the 4 houses used in the study. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Temperature (°F) by date. The black line indicates outdoor daily weather means collected from Baltimore, Maryland (TWC Product and Technology) **b)** Temperature (°F) by age Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

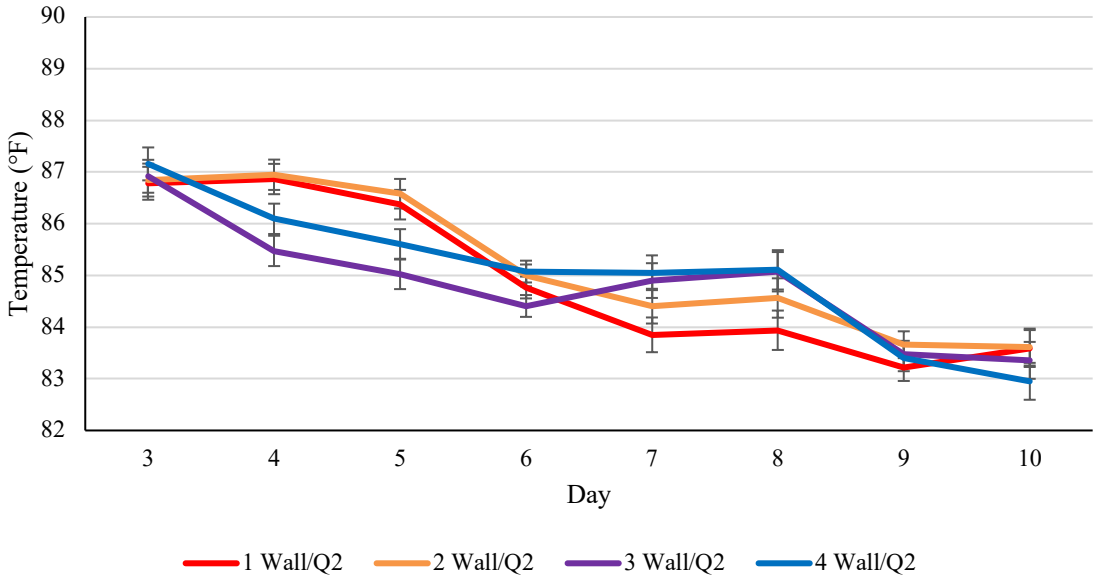
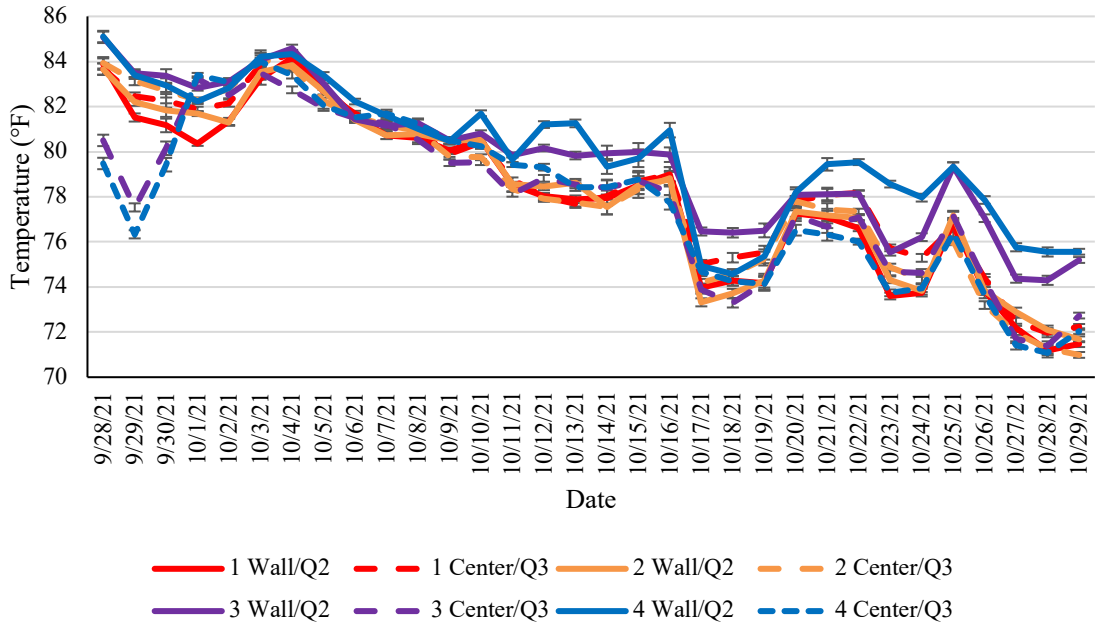


Figure 2.16. Flock 2 mean (± SE) daily temperature (°F) during the brooding period (days 3-10). Each line indicates 1 of the 4 houses used in the study. Brooding took place in quadrants 1 and 2 only, so the daily temperature averages from the data loggers located in the center of quadrant 3 are not shown. Broilers in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. Day is the age of birds in Houses 1 and 2. **a)** Temperature (°F) by date **b)** Temperature (°F) by age.

a)



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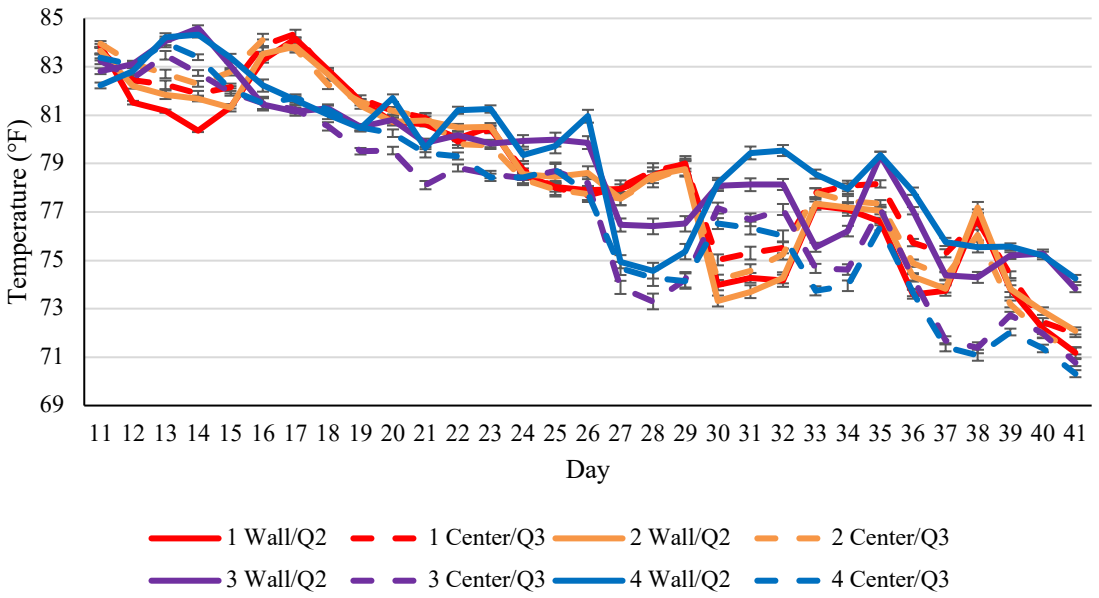
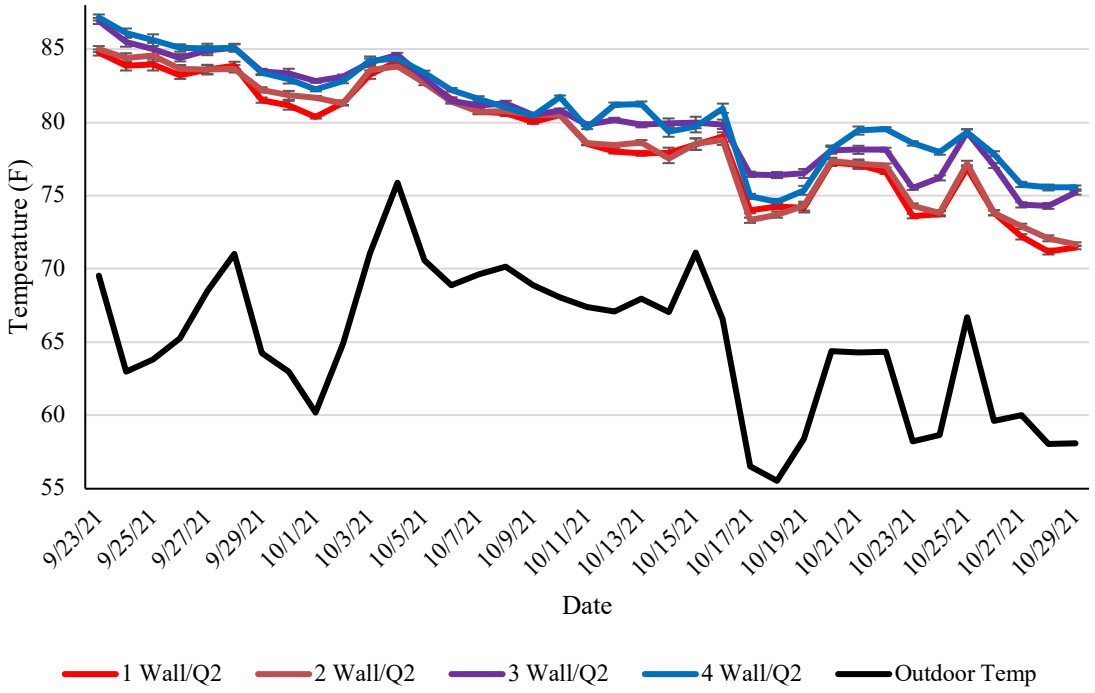


Figure 2.17. Flock 2 mean (± SE) daily temperature (°F) after the brooding period (days 11-41). Each line indicates 1 of the 4 houses used in the study. In the legend, the number indicates the house, dotted lines indicate the quadrant 3 locations, and solid lines indicate the quadrant 2 locations. Broilers in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. Day is the age of birds in Houses 1 and 2. **a)** Temperature (°F) by date **b)** Temperature (°F) by age Error bars are indicated by the small vertical lines above each datapoint

a)



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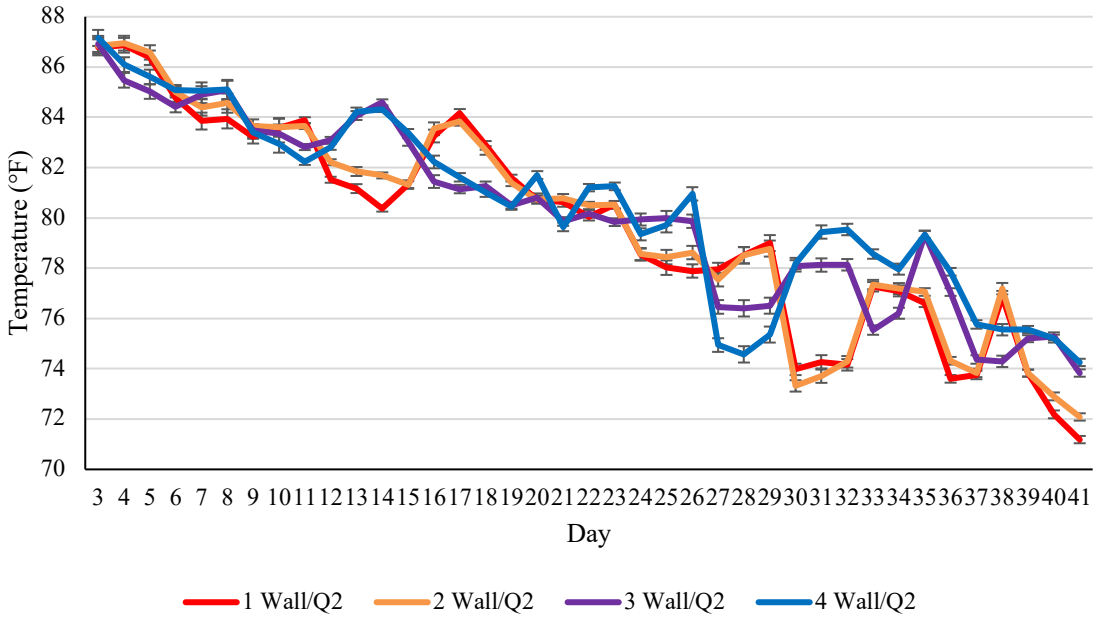
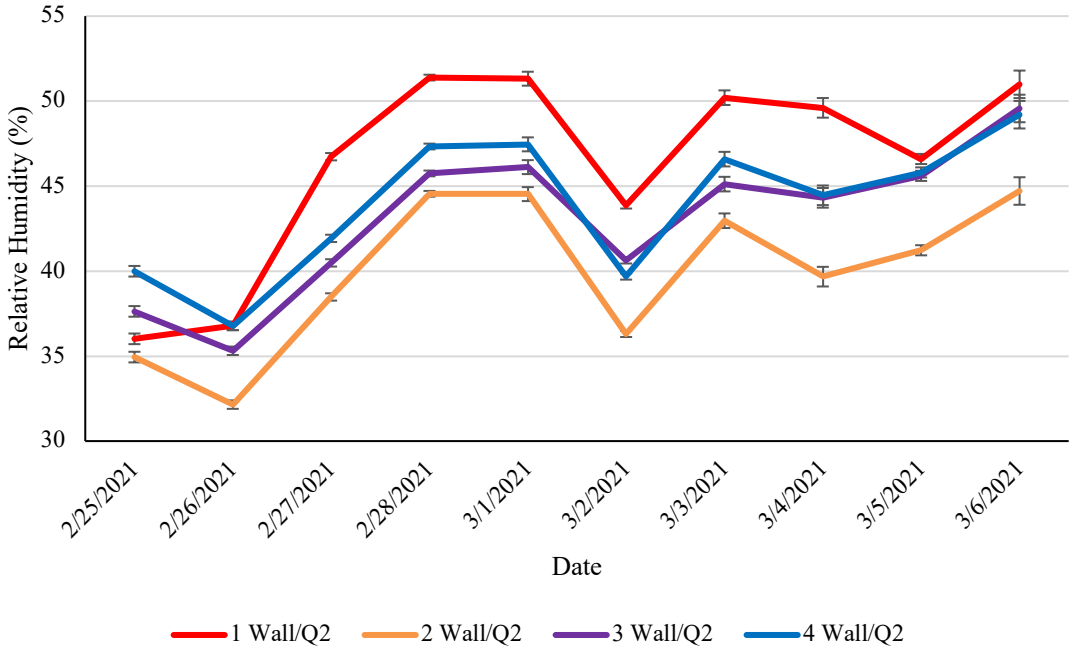


Figure 2.18. Flock 2 mean (± SE) daily temperature (°F) over the course of the entire growout. Each line indicates 1 of the 4 houses used in the study. Broilers in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. Day is the age of birds in Houses 1 and 2. **a)** Temperature (°F) by date. The black line indicates outdoor daily weather means collected from Baltimore, Maryland (TWC Product and Technology) **b)** Temperature (°F) by age Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

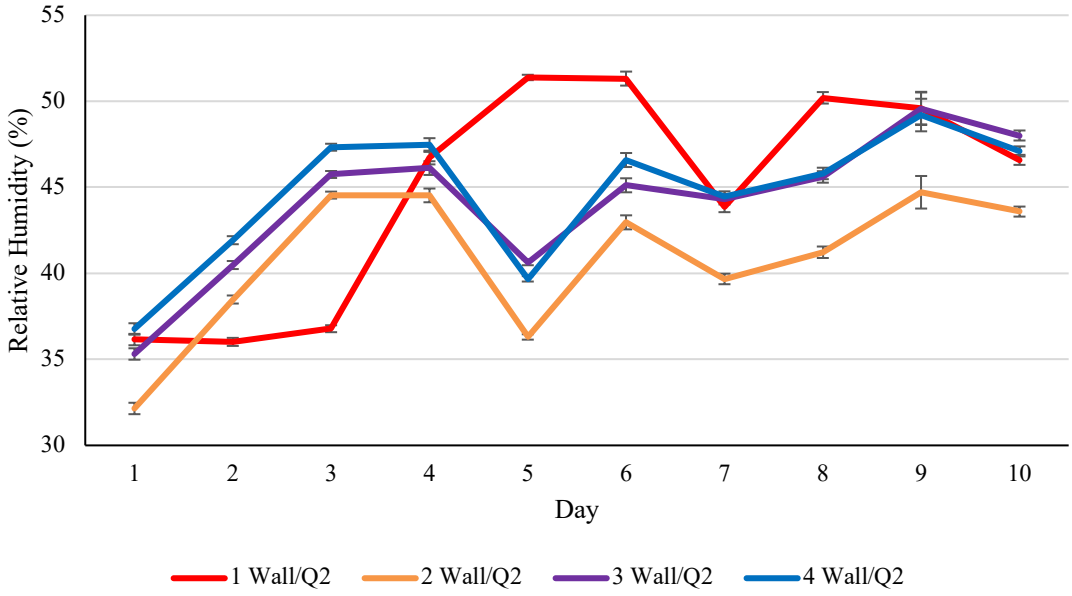
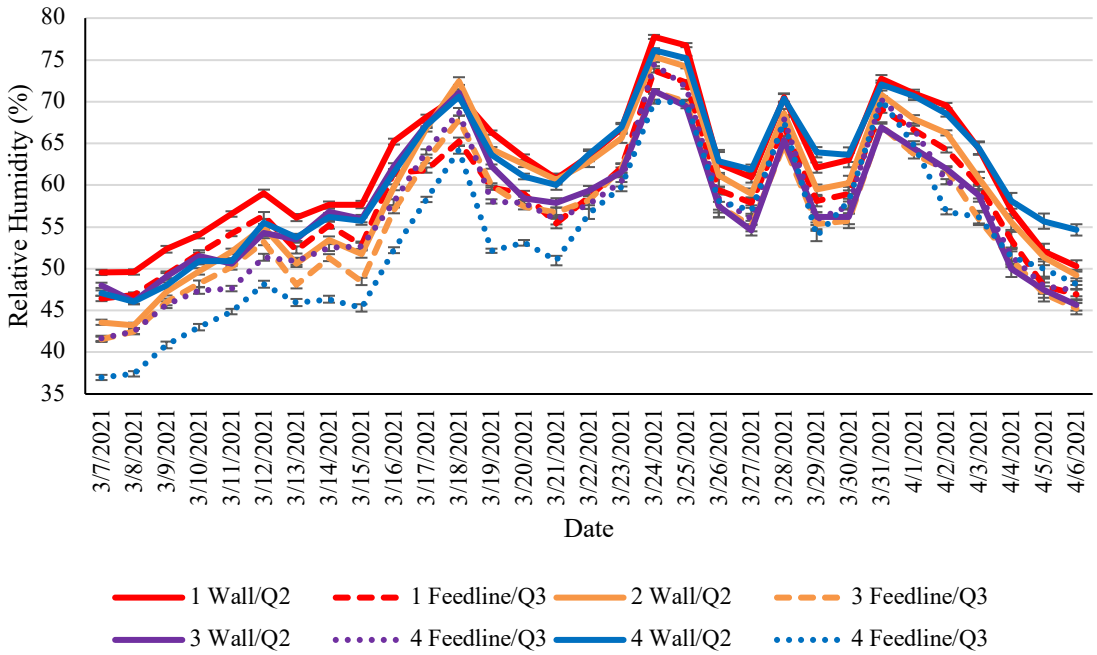


Figure 2.19. Flock 1 mean (± SE) daily relative humidity (%) during the brooding period (days 1-10). Each line indicates 1 of the 4 houses used in the study. Brooding took place in quadrants 1 and 2 only, so the daily humidity averages from the data loggers located in the center of quadrant 3 are not shown. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint

a)



b)

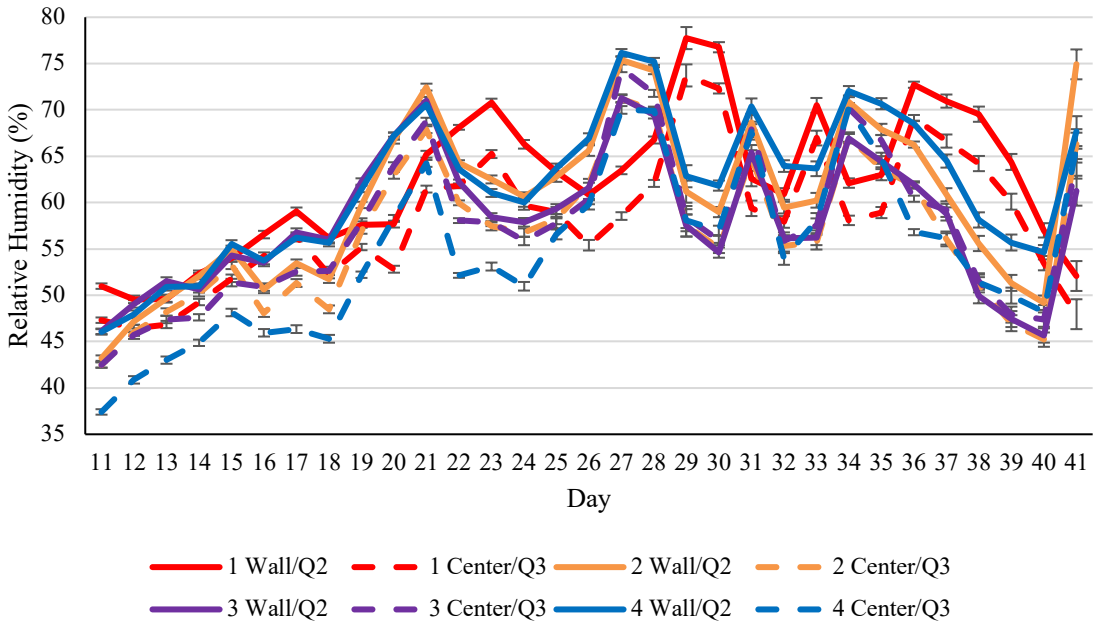
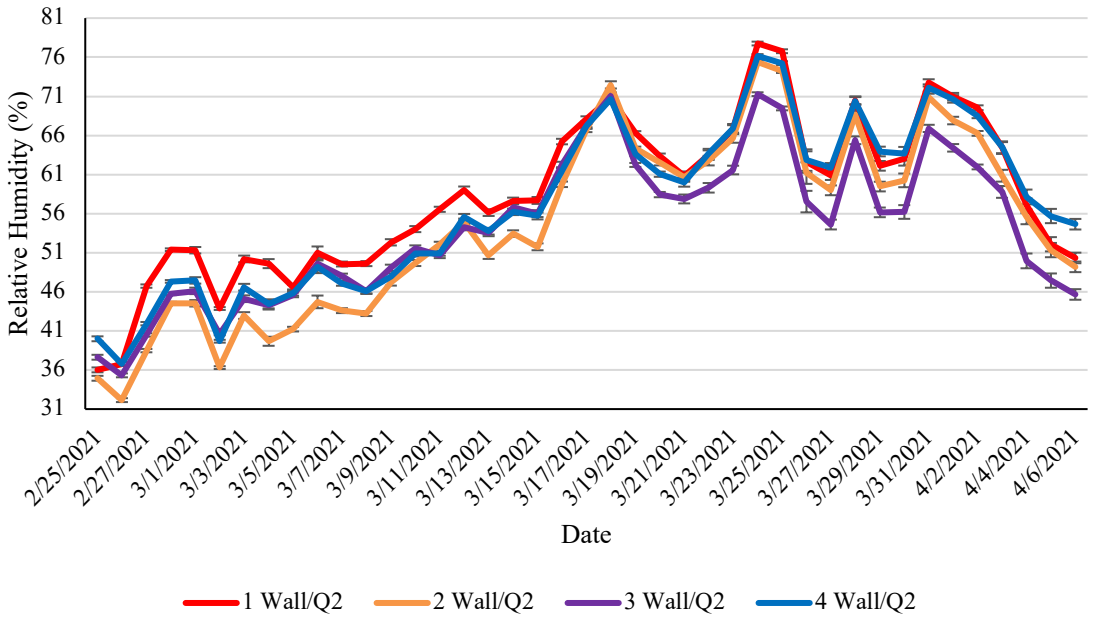


Figure 2.20. Flock 1 mean (± SE) daily relative humidity (%) after the brooding period (days 11-41). Each line indicates 1 of the 4 houses used in the study. In the legend, the number indicates the house, dotted lines indicate the quadrant 3 locations, and solid lines indicate the quadrant 2 locations. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

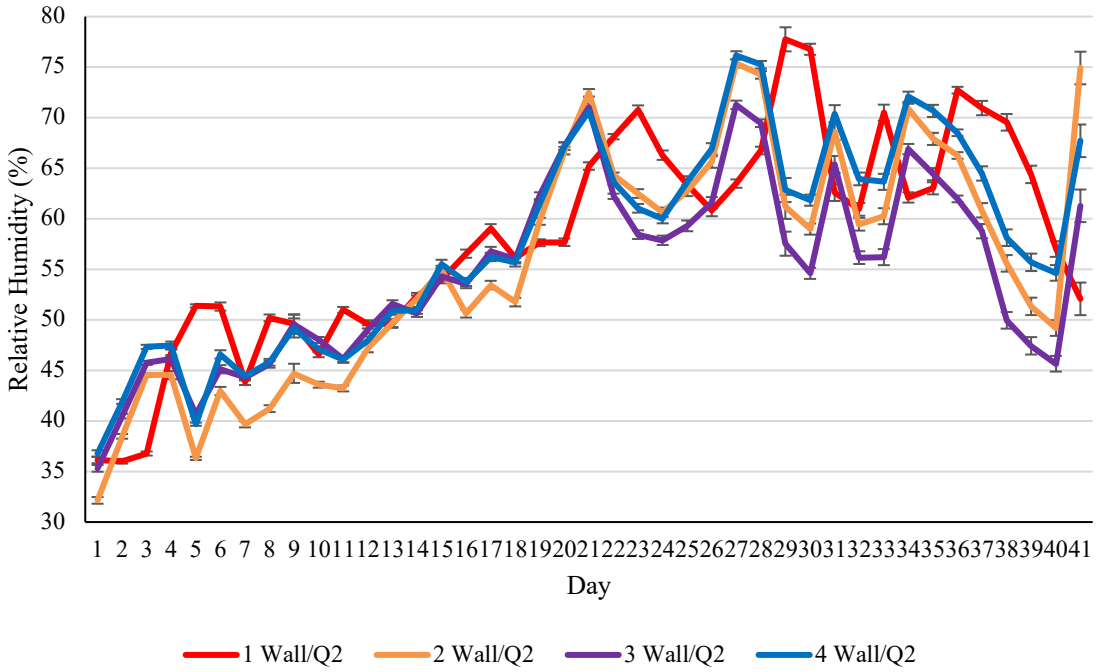
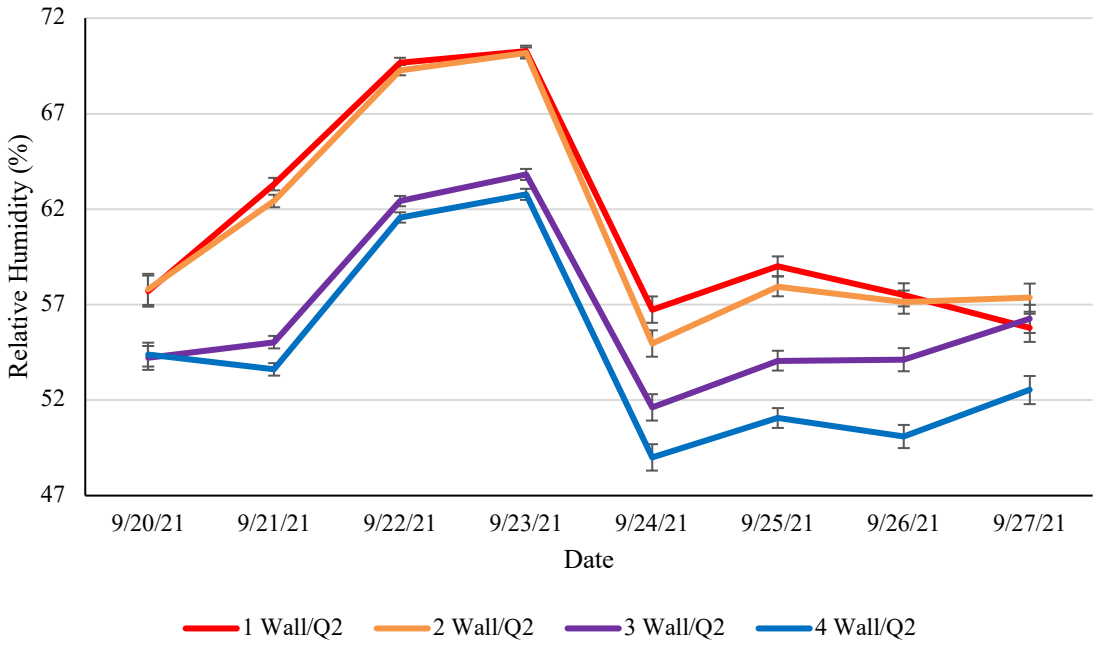


Figure 2.21. Flock 1 mean (± SE) daily relative humidity (%) over the course of the entire growout. Each line indicates 1 of the 4 houses used in the study. House 1 broilers were 2 days older than broilers in Houses 2, 3, and 4. Day is the age of the birds in Houses 2, 3, and 4. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint.

a)



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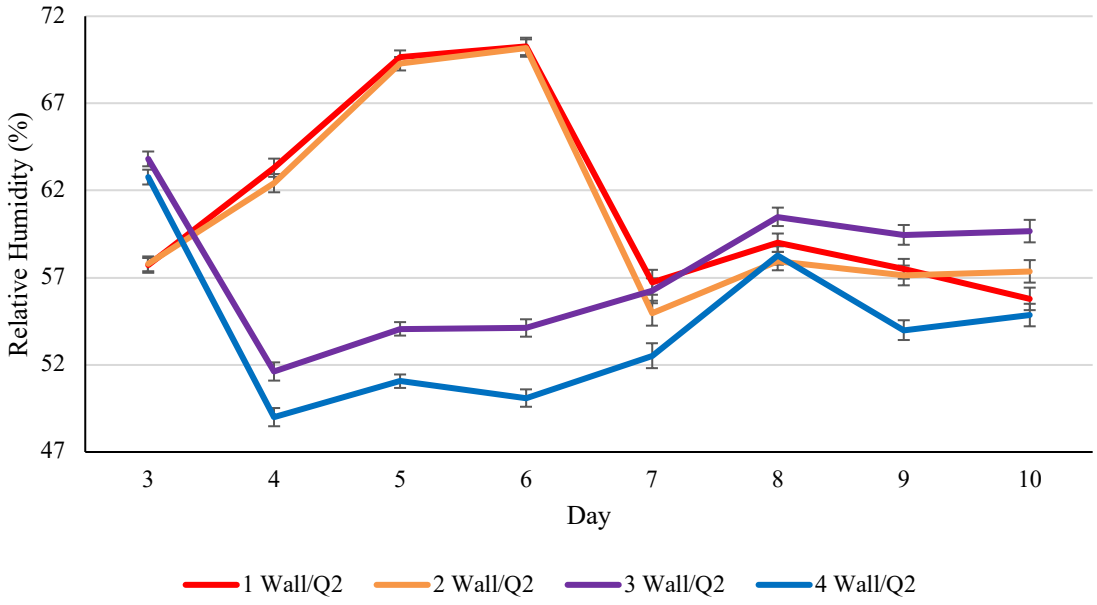


Figure 2.22. Flock 2 mean (± SE) daily relative humidity (%) during the brooding period (days 3-10). Each line indicates 1 of the 4 houses used in the study. Brooding took place in quadrants 1 and 2 only, so the daily humidity averages from the data loggers located in the center of quadrant 3 are not shown. Broilers in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. Day is the age of birds in Houses 1 and 2. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint.

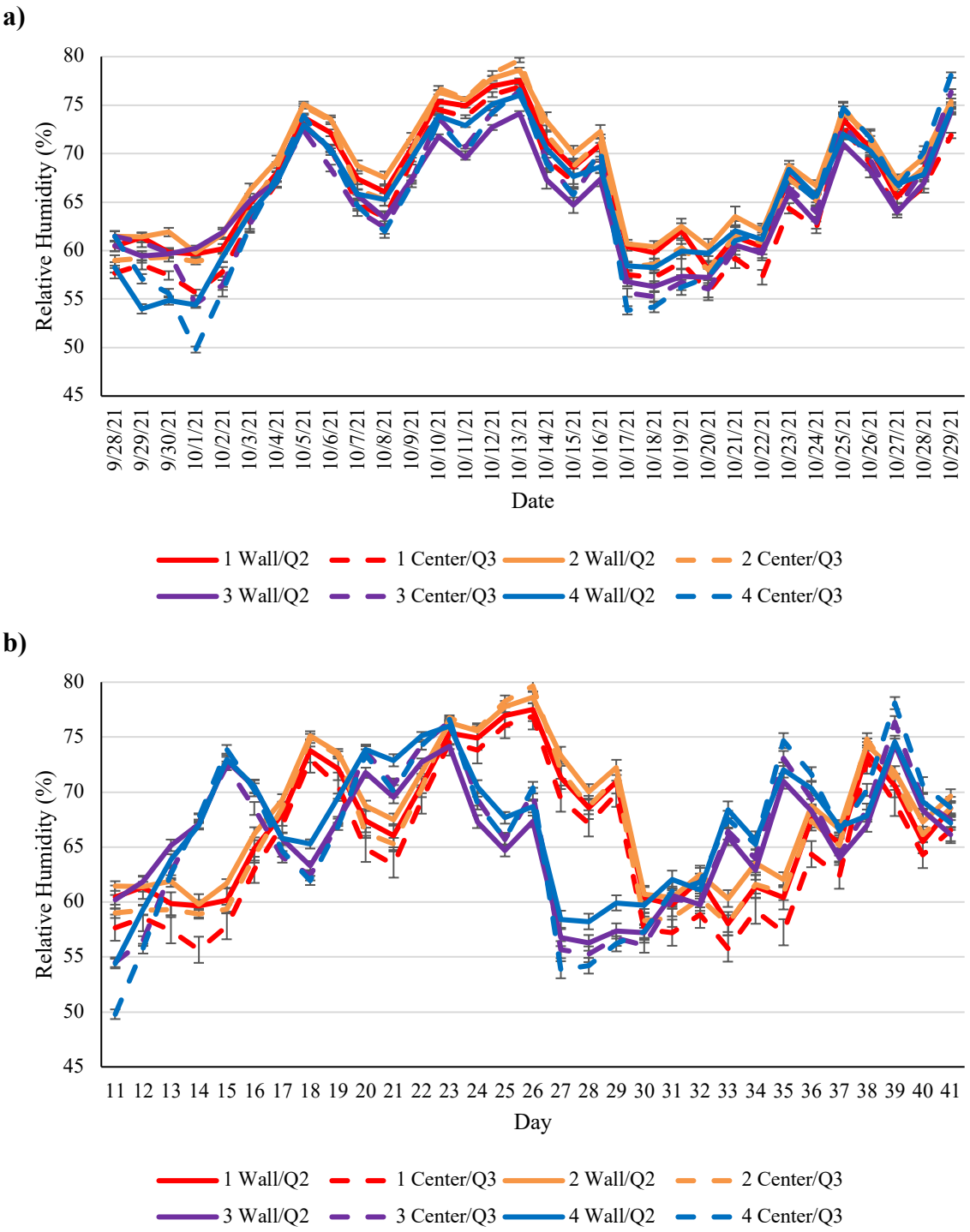
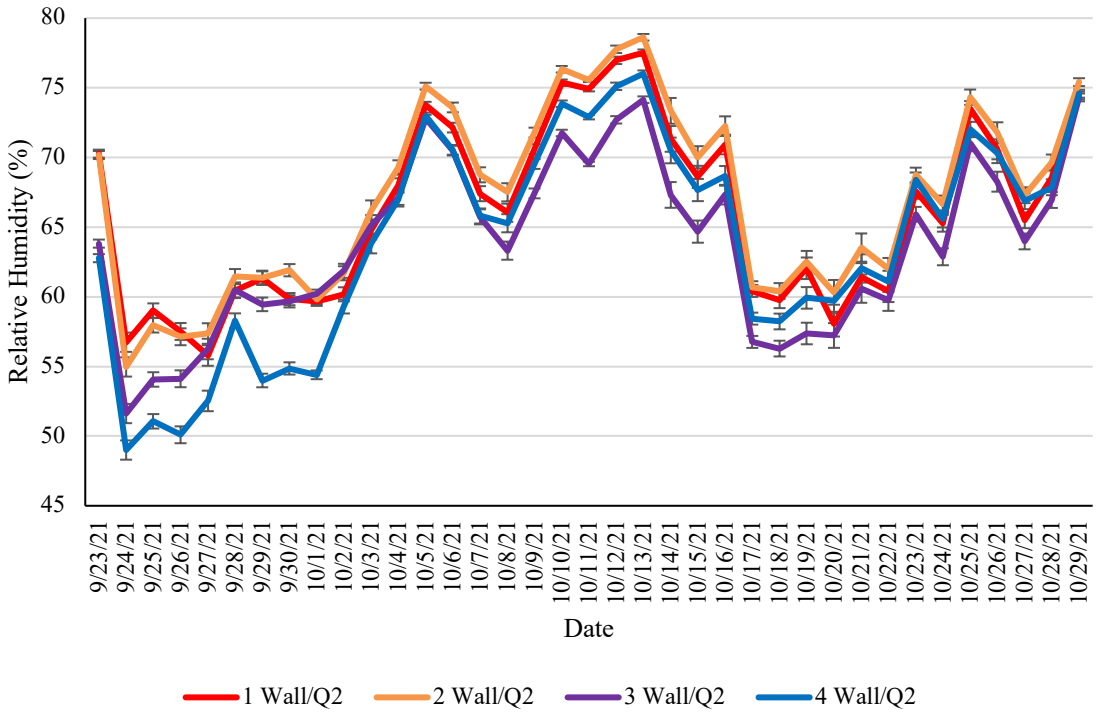


Figure 2.23. Flock 2 mean (± SE) daily relative humidity (%) after the brooding period (days 11-41). Each line indicates 1 of the 4 houses used in the study. In the legend, the number indicates the house, dotted lines indicate the quadrant 3 locations, and solid lines indicate the quadrant 2 locations. Broilers in Houses 1 and 2 were 3 days older than broilers in Houses 3 and 4. Day is the age of birds in Houses 1 and 2. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint.

a)



b)

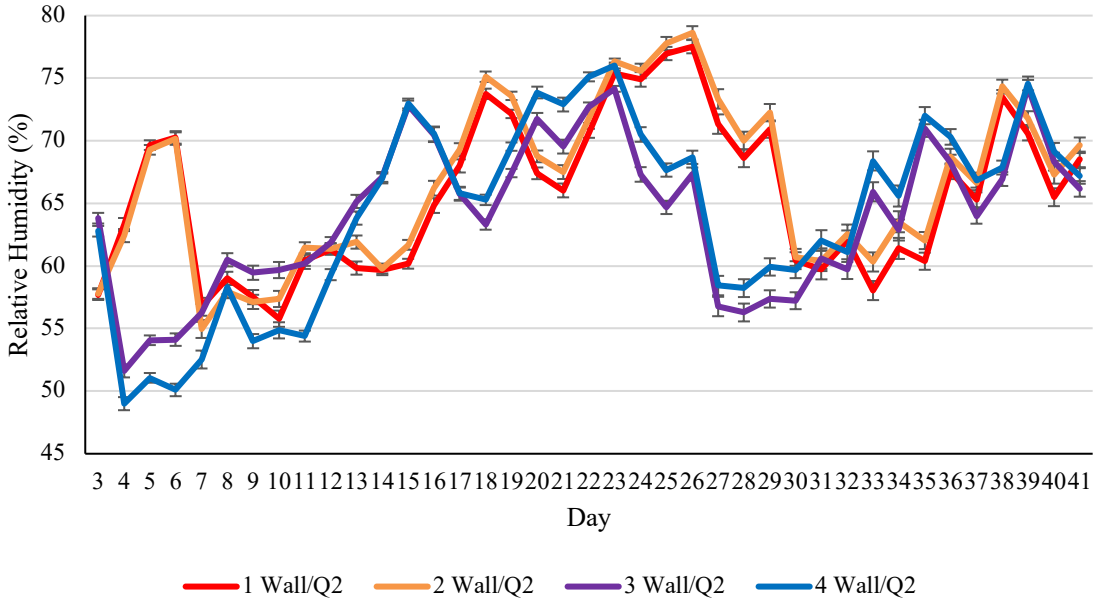


Figure 2.24. Flock 2 mean (± SE) daily relative humidity (%) over the course of the entire growout. Each line indicates 1 of the 4 houses used in the study. **a)** Relative humidity (%) by date **b)** Relative humidity (%) by age. Error bars are indicated by the small vertical lines above each datapoint.

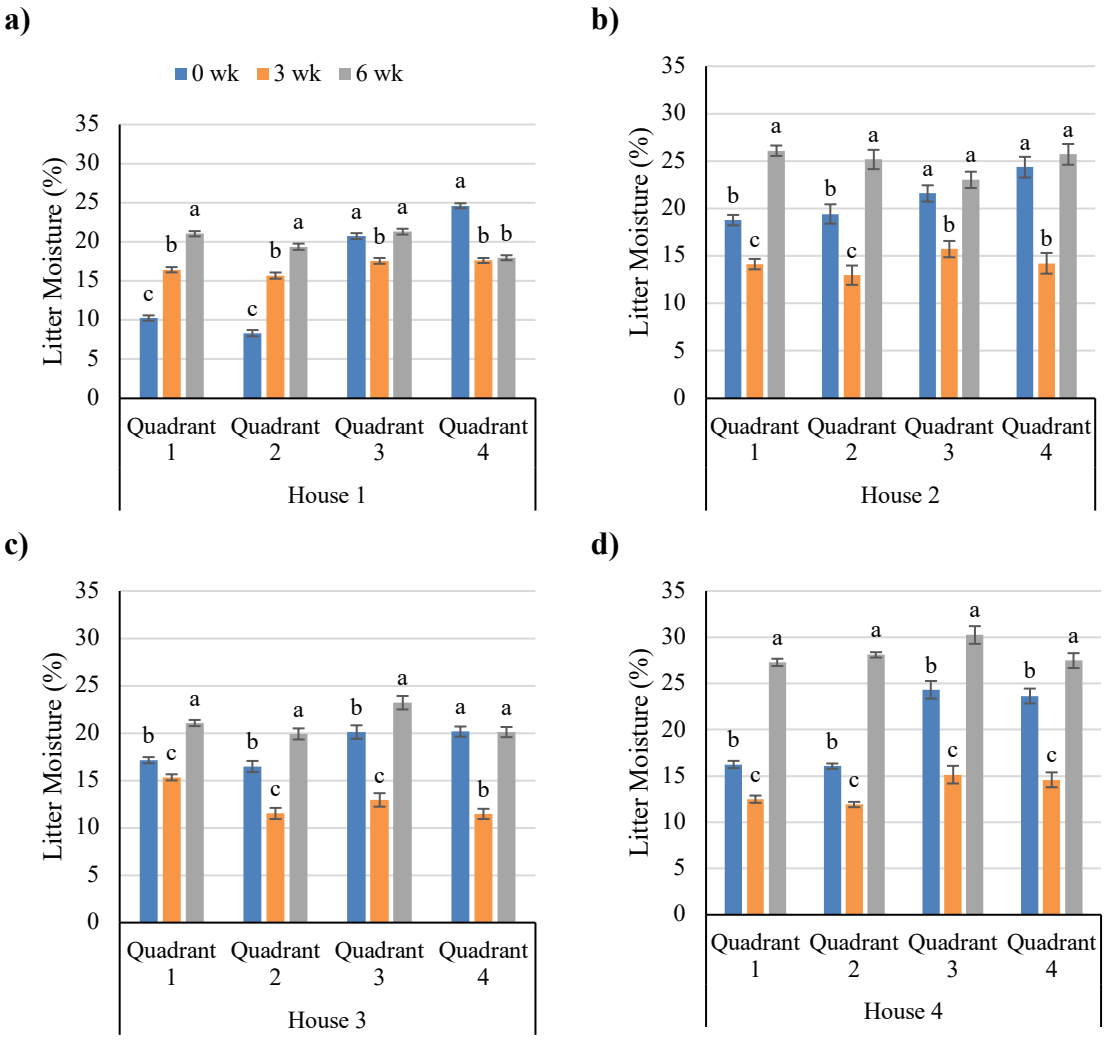


Figure 2.25. Flock 1 mean (± SE) litter moisture levels at week 0, 3, and 6 in each of 4 quadrants within 4 commercial broiler houses. The colors of the bars indicate the time the litter samples were collected. **a)** House 1. **b)** House 2. **c)** House 3. **d)** House 4. Error bars are indicated by the small vertical lines above each bar. [abc] Columns within each quadrant not sharing the same letters are significantly different at $P \leq 0.05$.

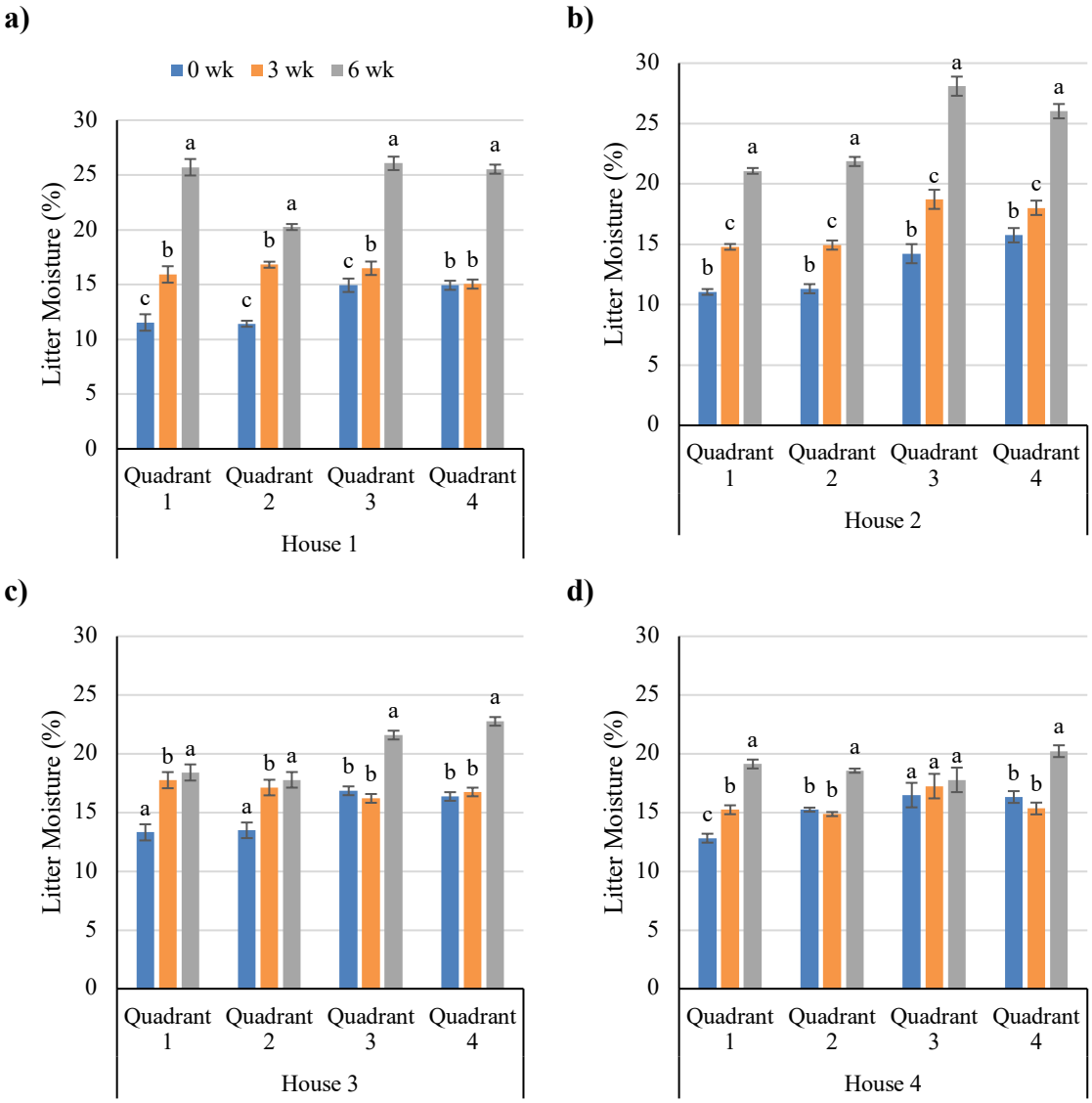
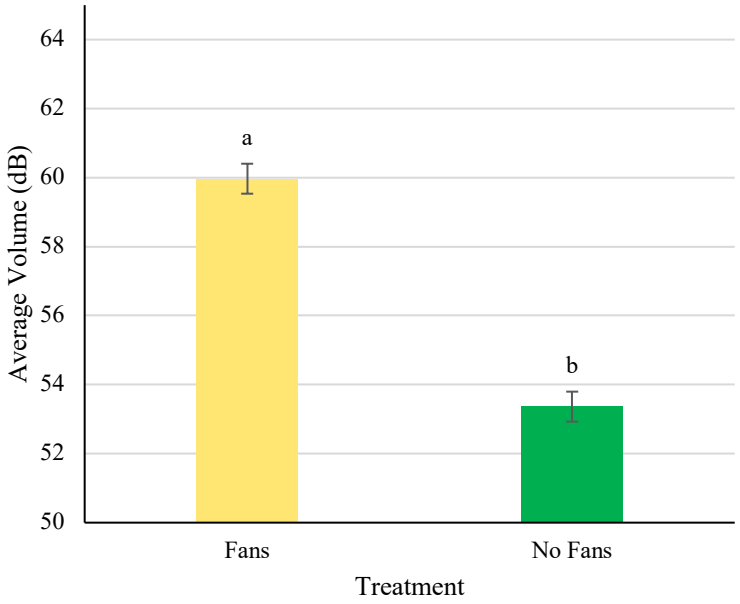


Figure 2.26. Flock 2 mean (± SE) litter moisture levels at week 0, 3, and 6 in each of 4 quadrants within 4 commercial broiler houses. The colors of the bars indicate the time the litter samples were collected. **a)** House 1. **b)** House 2. **c)** House 3. **d)** House 4. Error bars are indicated by the small vertical lines above each bar. [abc] Columns within each quadrant not sharing the same letters are significantly different at P≤0.05.

a)



b)

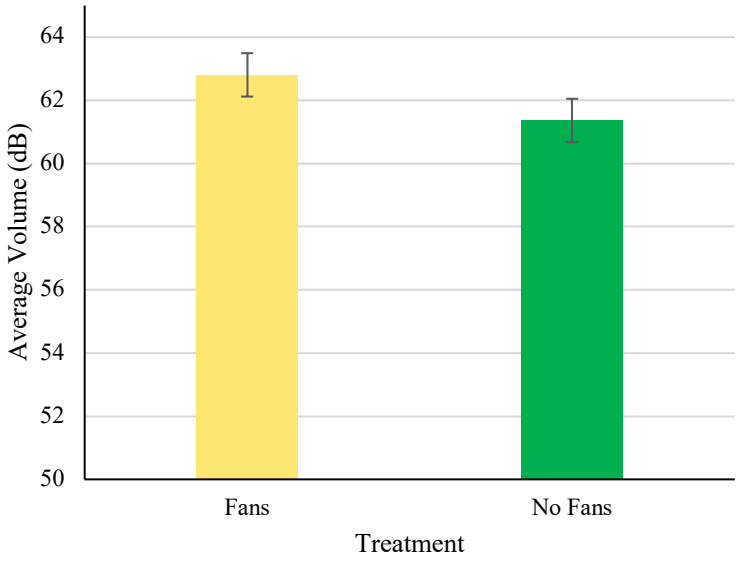
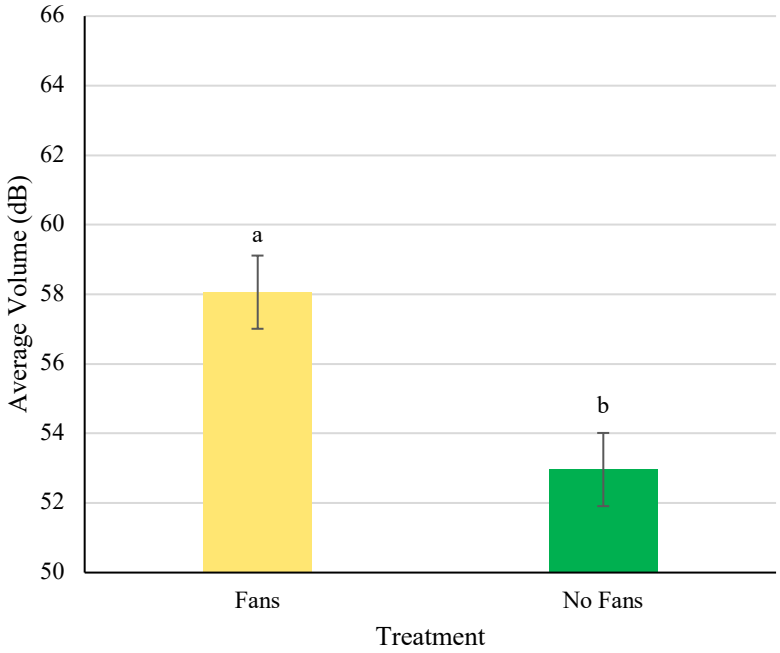


Figure 2.27. Flock 1 mean (± SE) noise volume (dB) levels in houses with fans (N=2) and without fans (N=2) at week 3 and 6. **a)** Volume at week 3. **b)** Volume at week 6. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

a)



b)

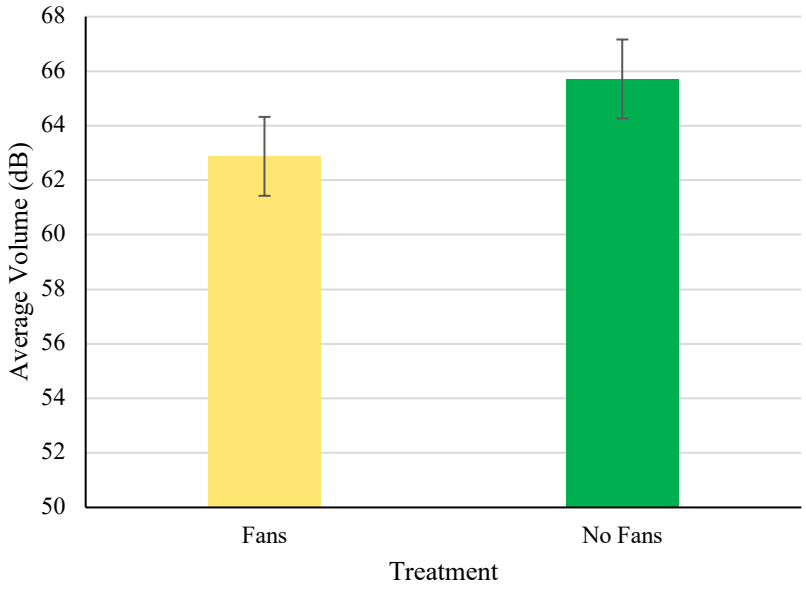


Figure 2.28. Flock 2 mean (± SE) noise volume (dB) levels in houses with fans (N=2) and without fans (N=2) at week 3 and 6. **a)** Volume at week 3. **b)** Volume at week 6. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

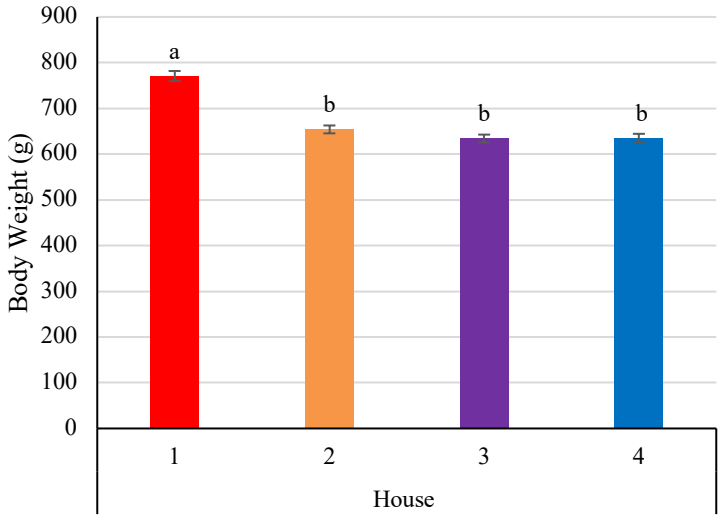


Figure 2.29. Flock 1 mean (± SE) body weight (g) of birds assessed in each house at week 3. Birds in House 1 were 2 days older than the birds in Houses 2, 3 and 4 when weighed. [ab] Bars not sharing the same letters are significantly different at P≤0.05.

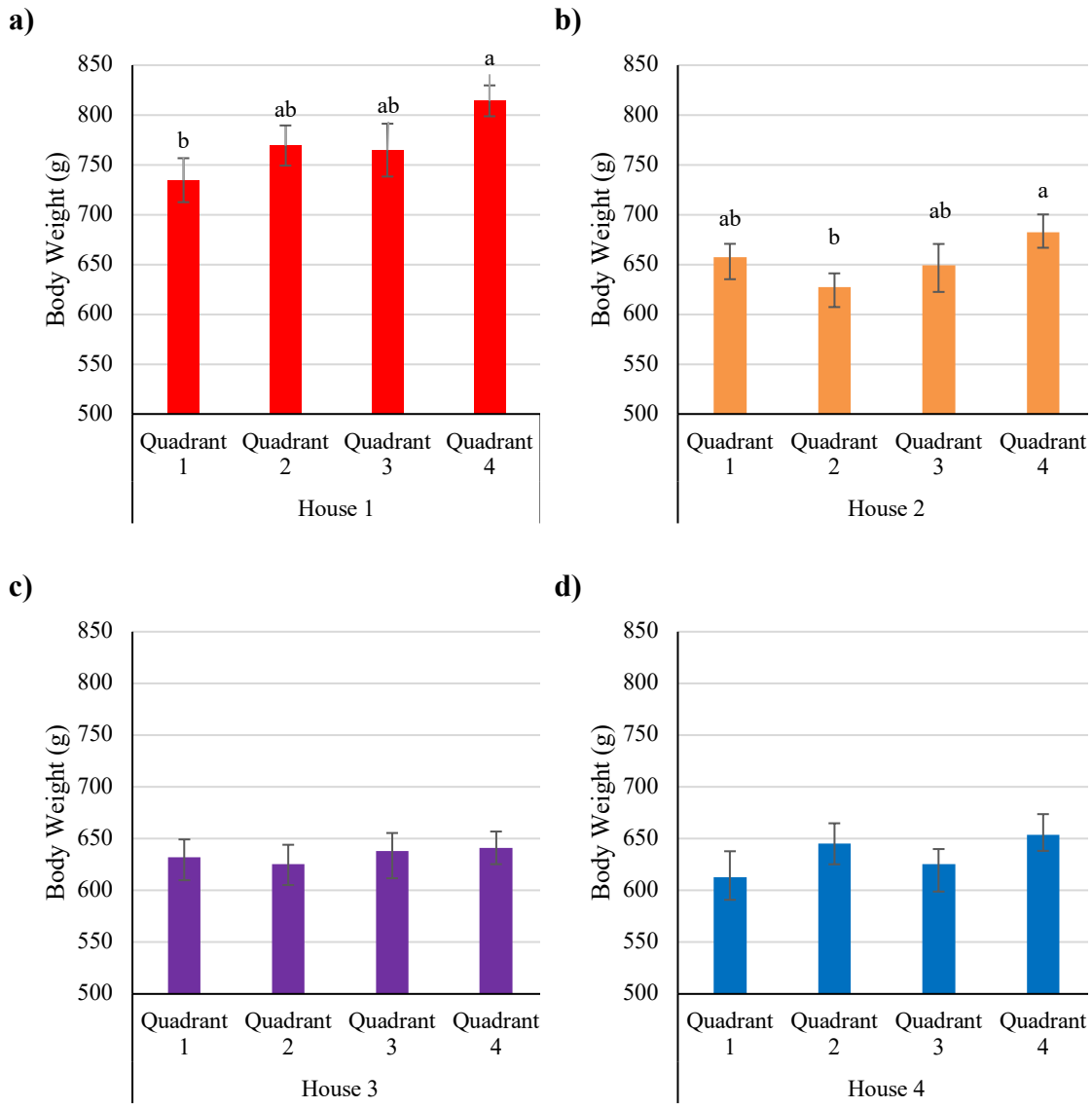


Figure 2.30. Flock 1 mean (± SE) body weight (g) of birds assessed in each house by quadrant at week 3. Birds in House 1 were 2 days older than the birds in Houses 2, 3 and 4 when weighed. [ab] Columns not sharing the same letters are significantly different within house at P≤0.05

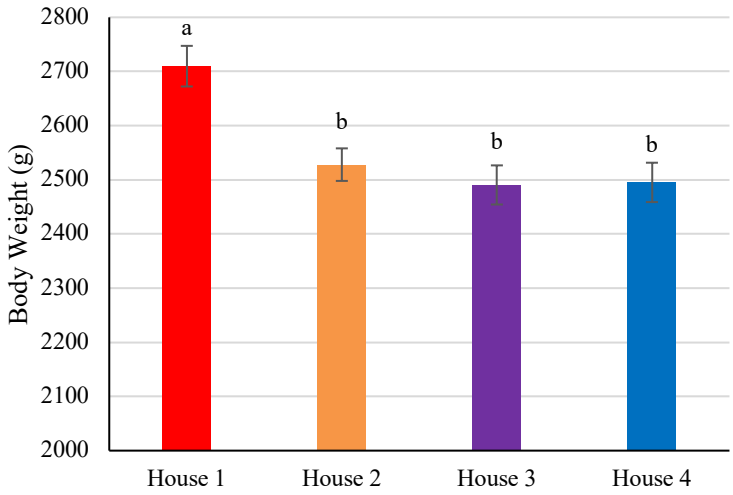


Figure 2.31. Flock 1 mean (± SE) body weight (g) of birds assessed in each house at week 6. Birds in House 1 were 2 days older than the birds in Houses 2, 3 and 4 when weighed. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

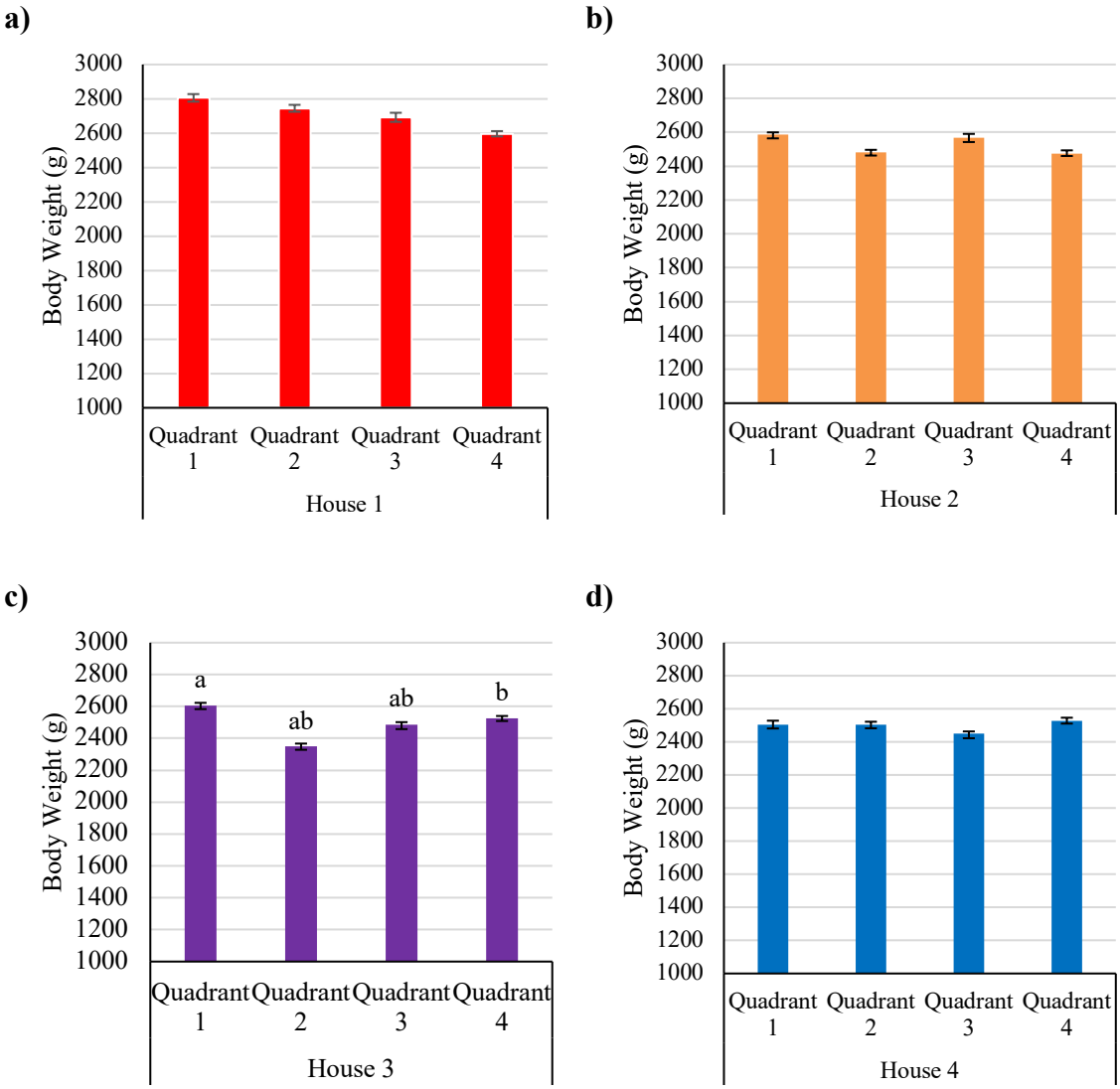


Figure 2.32. Flock 1 mean (± SE) body weight (g) of birds assessed in each house by quadrant at week 6. Birds in House 1 were 2 days older than the birds in Houses 2, 3 and 4 when weighed. [ab] Columns not sharing the same letters are significantly different within house at $P \leq 0.05$

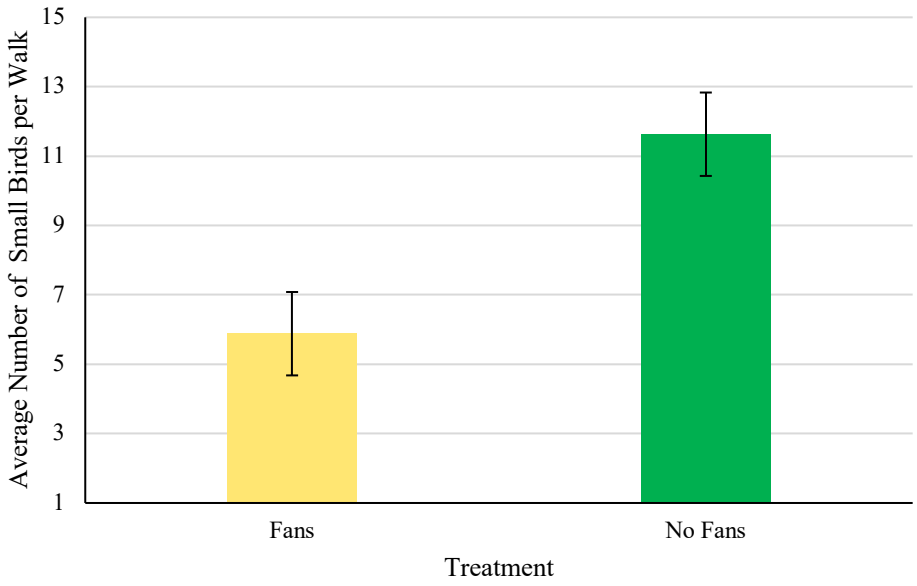


Figure 2.33. Mean (± SEM) small bird count at week 6 in both Flocks 1 and 2 combined. Data are shown as mean bird count, per transect walk, observed by treatment during the transect method of observation.

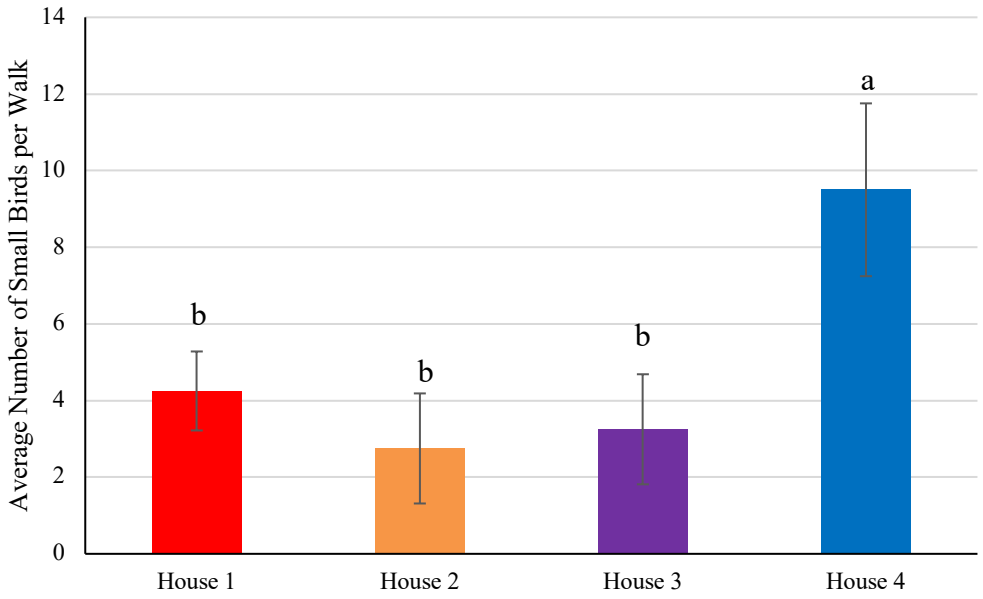


Figure 2.34. Flock 1 mean (± SE) small bird count observed in each house during the transect method of observation performed at week 6. Data were collected by performing four lengthwise walks in each house. The values were obtained by averaging the number of small birds observed during each transect walk, within each house. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

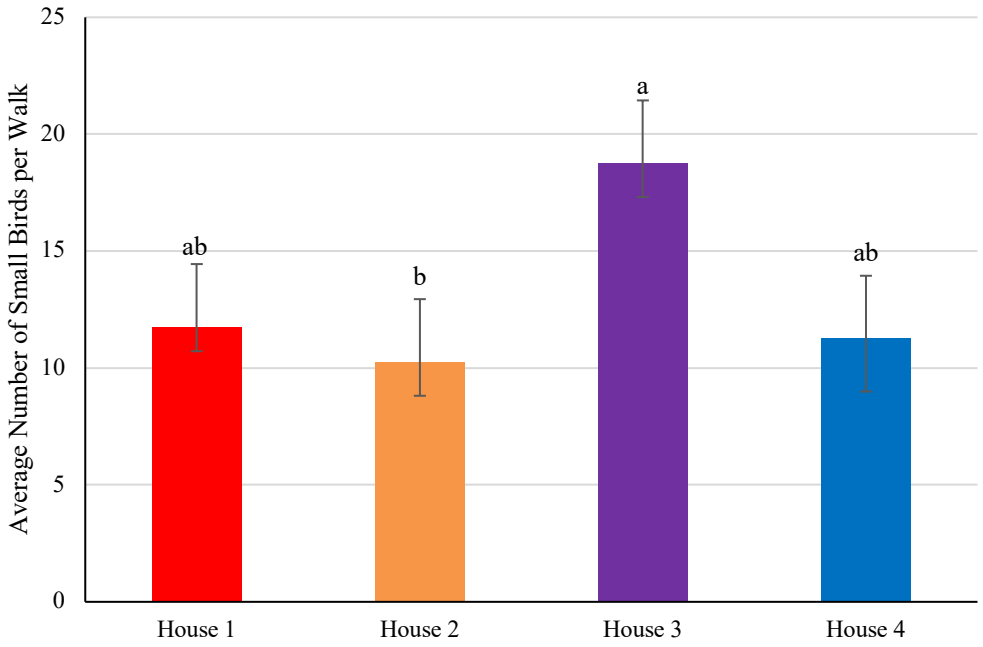


Figure 2.35. Flock 2 mean (± SE) small bird count observed in each house during the transect method of observation performed at week 3. Data were collected by performing four lengthwise walks in each house. The values were obtained by averaging the number of small birds observed during each transect walk, within each house. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

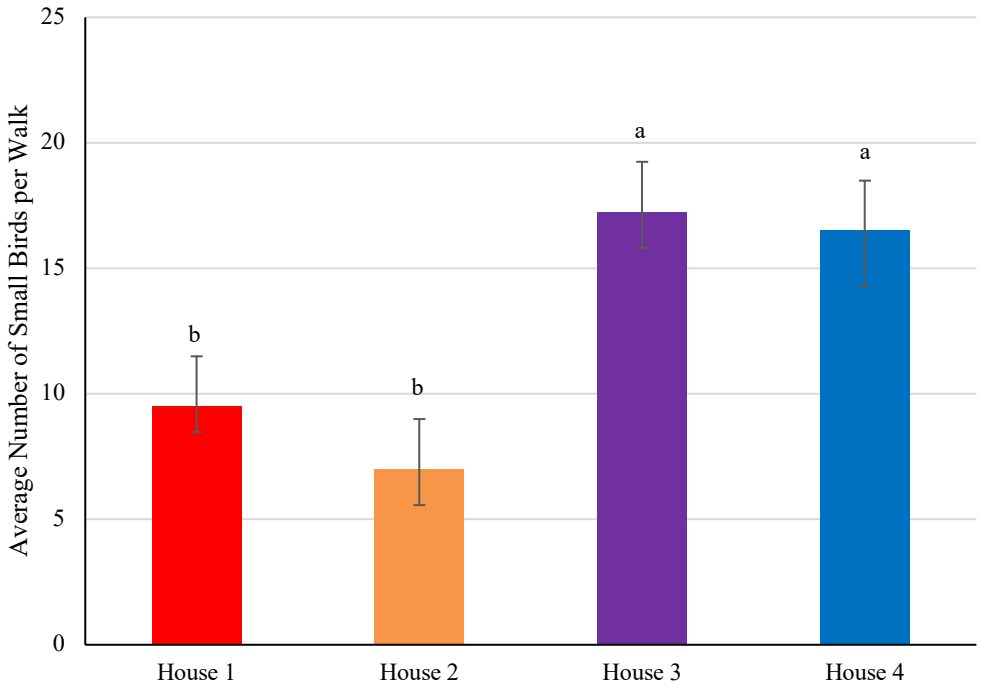


Figure 2.36. Flock 2 mean (± SE) small bird count observed in each house during the transect method of observation performed at week 6. Data were collected by performing four lengthwise walks in each house. The values were obtained by averaging the number of small birds observed during each transect walk, within each house. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

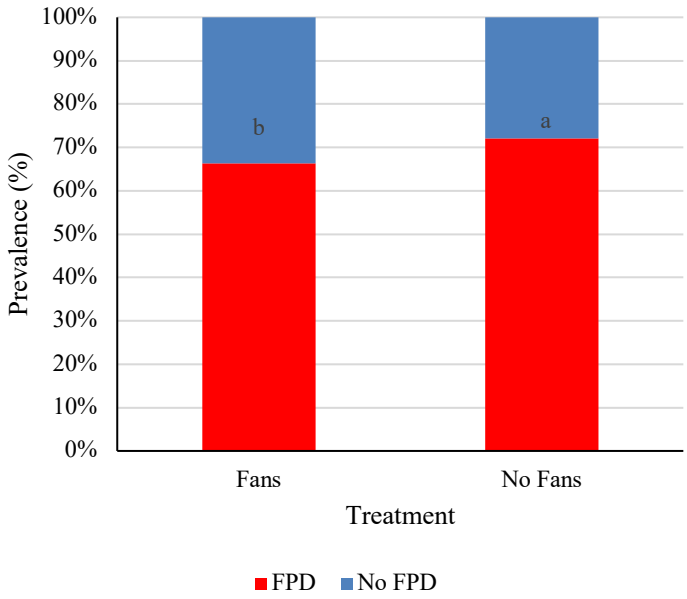
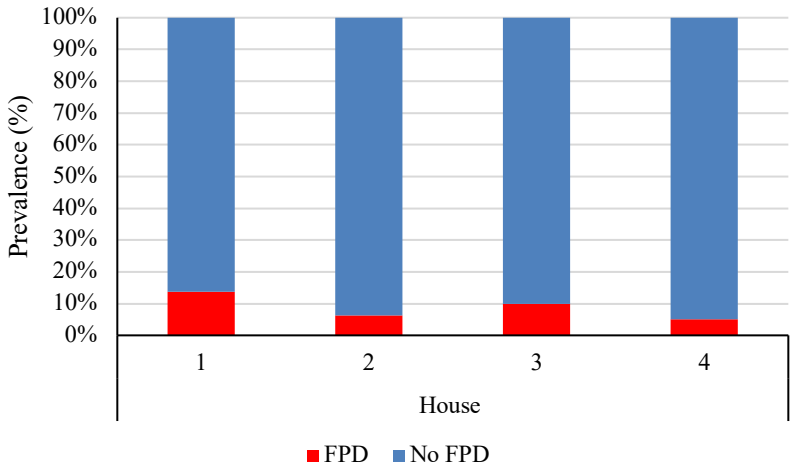


Figure 2.37. Footpad dermatitis (FPD) prevalence (%) by treatment group at week 6 in both Flocks 1 and 2 combined. Data are shown as percentages of birds that had any evidence of footpad dermatitis (a contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998) observed on-farm. [ab] Columns not sharing the same letters are significantly different at $P \leq 0.05$.

a)



b)

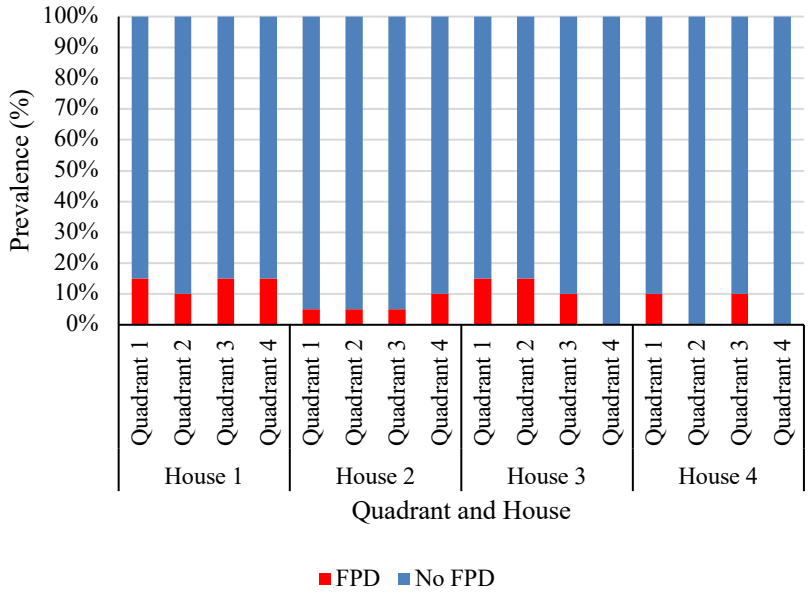
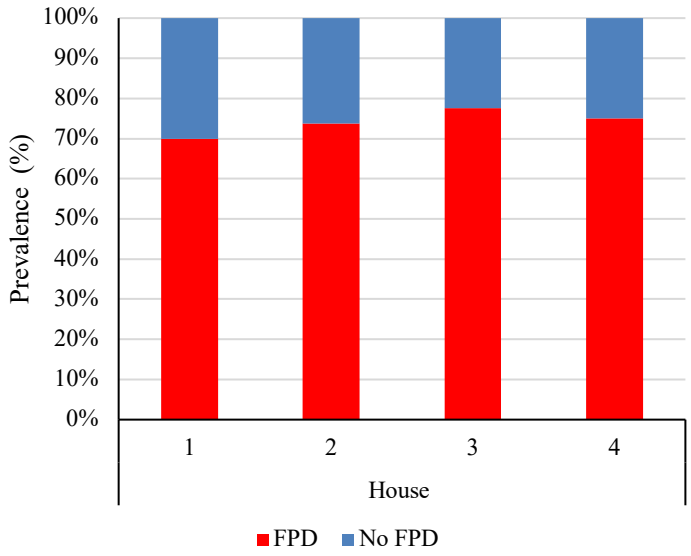


Figure 2.38. Flock 1 footpad dermatitis (FPD) prevalence (%) in 4 commercial broiler houses at week 3. Data are shown as percentages of birds that had any evidence of footpad dermatitis (a contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998) observed on-farm. **a)** Footpad dermatitis by house. **b)** Footpad dermatitis by quadrant.

a)



b)

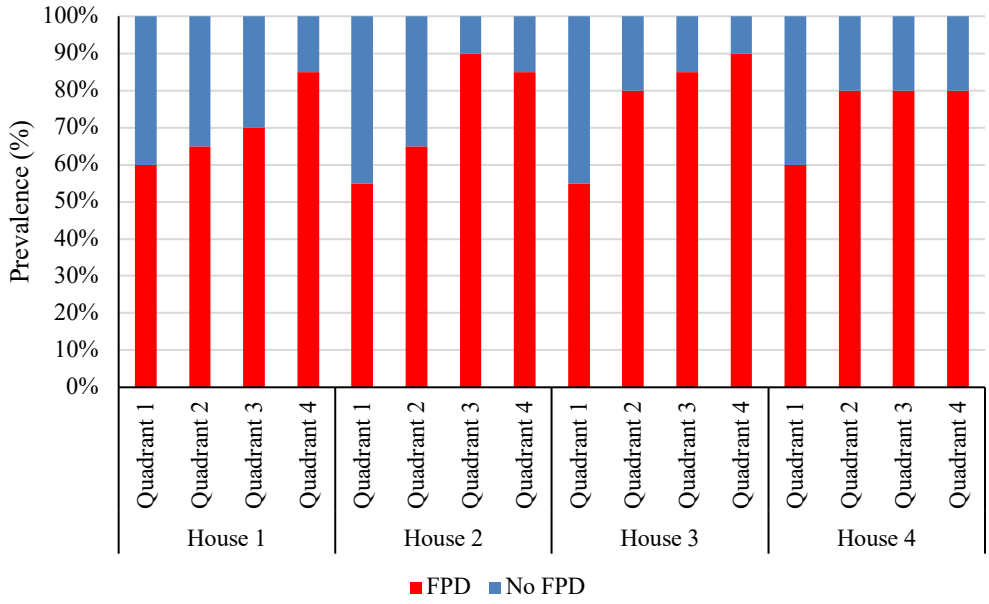


Figure 2.39. Flock 1footpad dermatitis (FPD) prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of footpad dermatitis (a contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998) observed on-farm. **a)** Footpad dermatitis by house. **b)** Footpad dermatitis by quadrant.

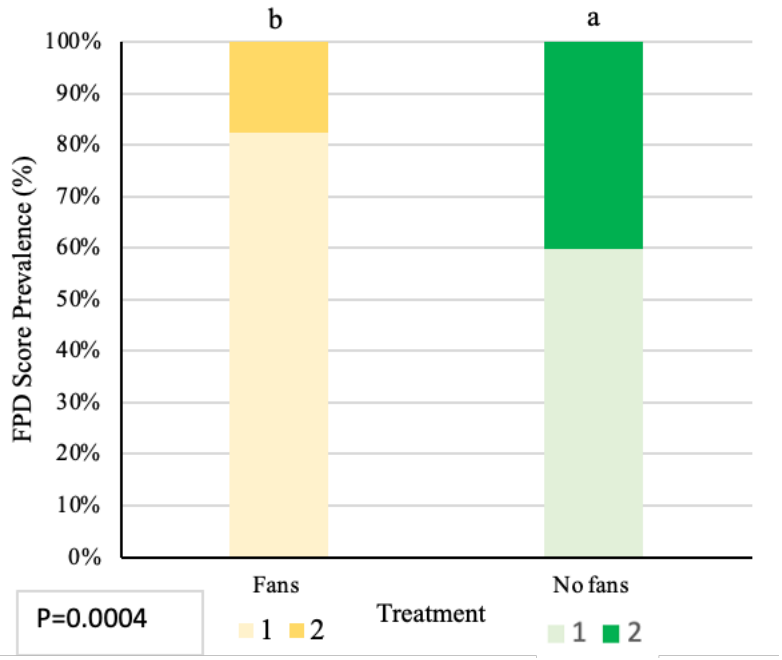


Figure 2.40. Flock 1 severity of footpad dermatitis (FPD) in 4 commercial broiler houses by treatment. Birds with 0 FPD scores were excluded. After exclusion, 204 birds either had a score of 1 (N = 144 birds) or 2 (N= 60 birds). Yellow bars indicate houses with fans and green bars indicate houses without fans. Lighter colors indicate a FPD score of 1 (moderate), while Darker colors indicate a FPD score of 2 (severe). [ab] Columns not sharing the same letters are significantly different at P≤0.05

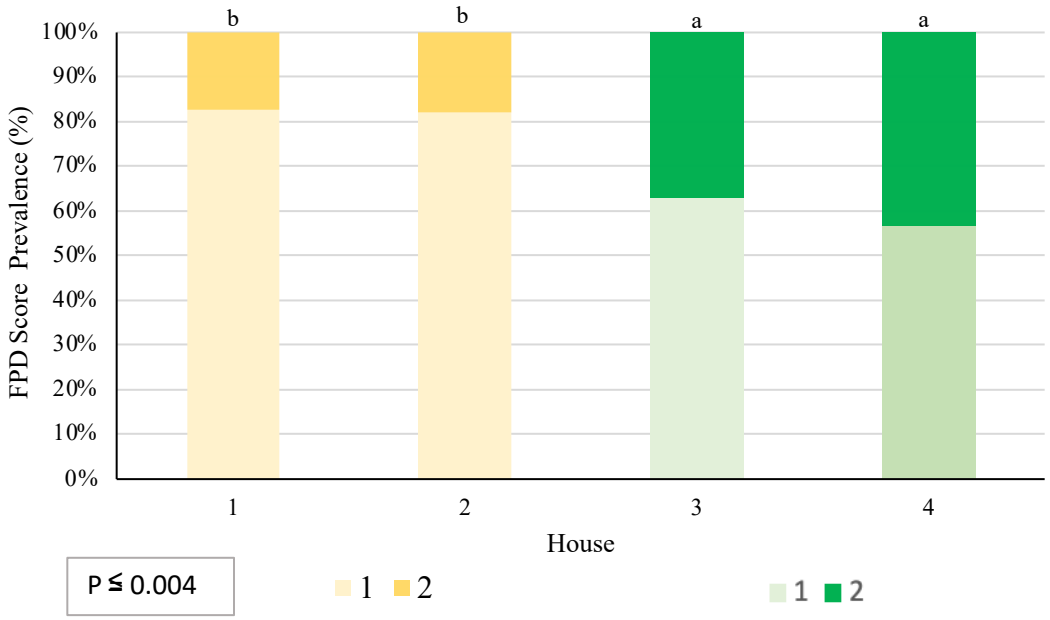


Figure 2.41. Flock 1 severity of footpad dermatitis (FPD) in 4 commercial broiler houses. Birds with 0 FPD scores were excluded. After exclusion, 204 birds either had a score of 1 (N = 144 birds) or 2 (N= 60 birds). Yellow bars indicate houses with fans and green bars indicate houses without fans. Lighter colors indicate a FPD score of 1 (moderate), while Darker colors indicate a FPD score of 2 (severe). [ab] Columns not sharing the same letters are significantly different at P≤0.05.

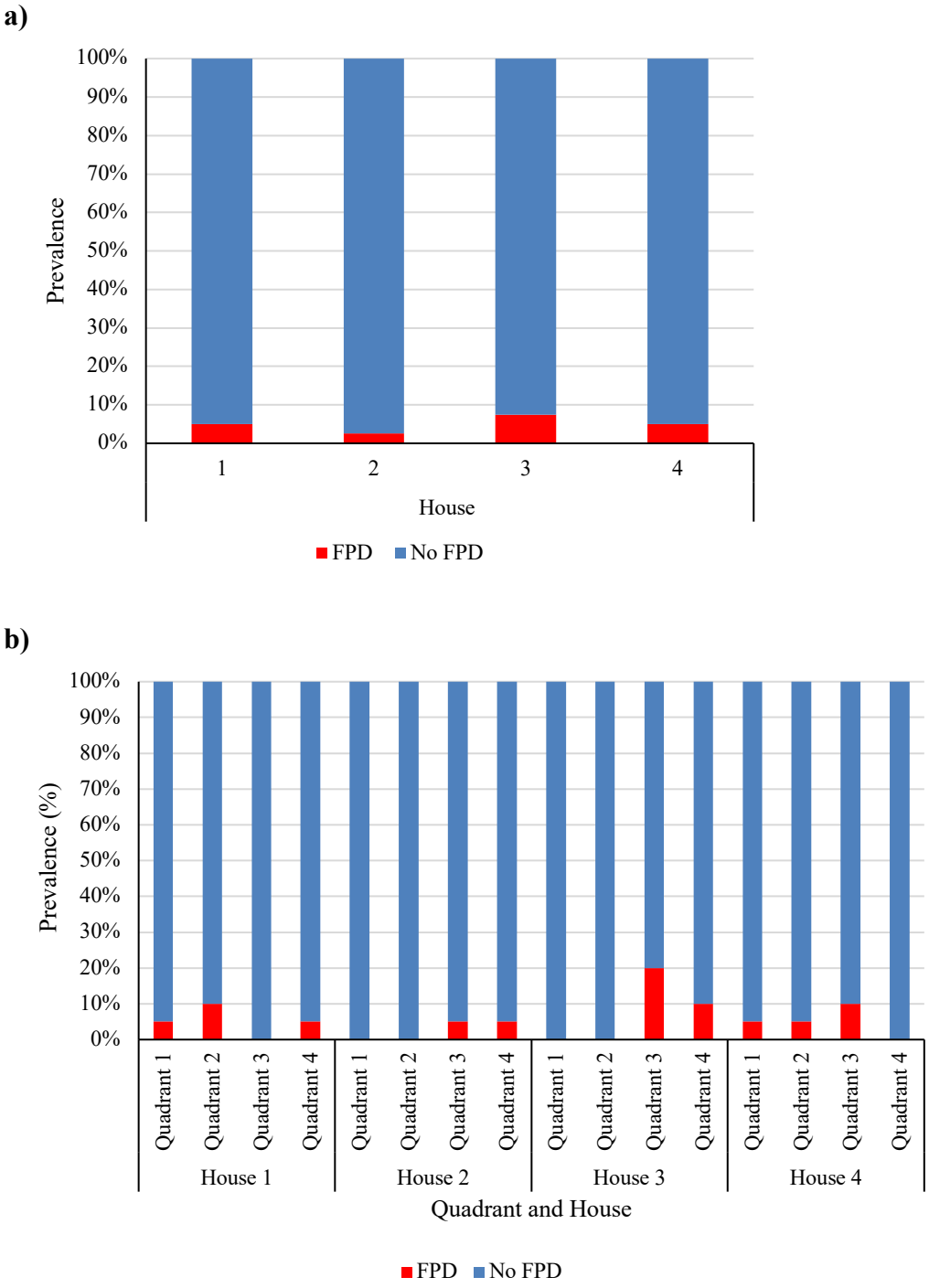
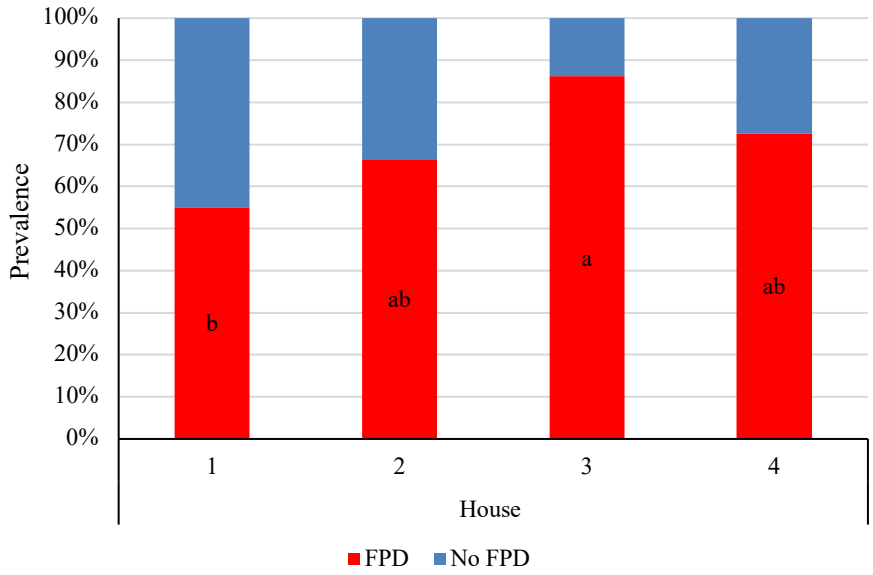


Figure 2.42. Flock 2 footpad dermatitis (FPD) prevalence (%) in 4 commercial broiler houses at week 3. Data are shown as percentages of birds that had any evidence of footpad dermatitis (a contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998) observed on-farm. **a)** Footpad dermatitis by house. **b)** Footpad dermatitis by quadrant.

a)



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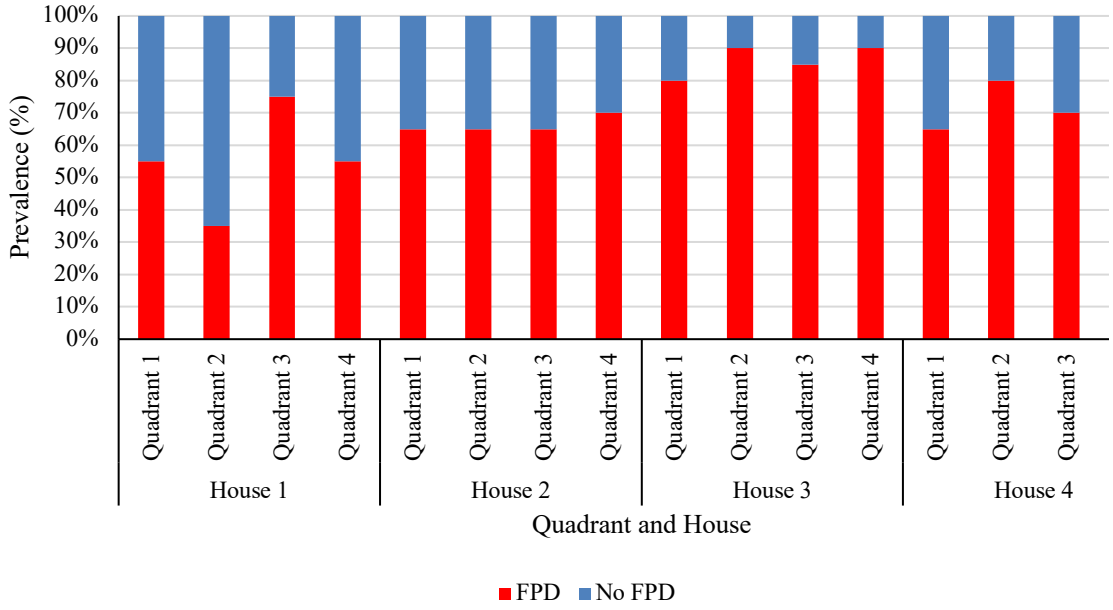


Figure 2.43. Flock 2 footpad dermatitis (FPD) prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of footpad dermatitis (a contact dermatitis seen in poultry that is known to cause lesions on the ventral footpads (Berg, 1998)) observed on-farm. **a)** Footpad dermatitis by house. **b)** Footpad dermatitis by quadrant. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

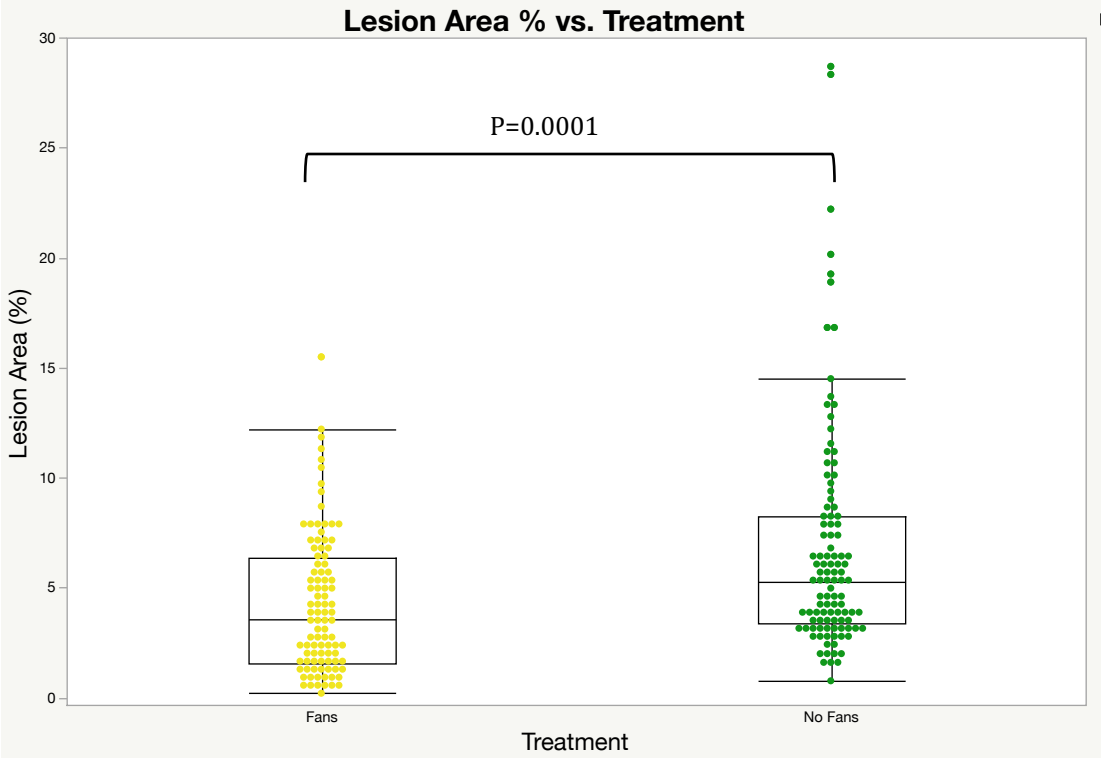


Figure 2.44. Flock 1 lesion size area (%) on broiler footpads in 4 commercial broiler houses is shown by treatment. Birds with 0 FPD scores were excluded. Yellow points indicate houses with fans and green points indicate houses without fans.

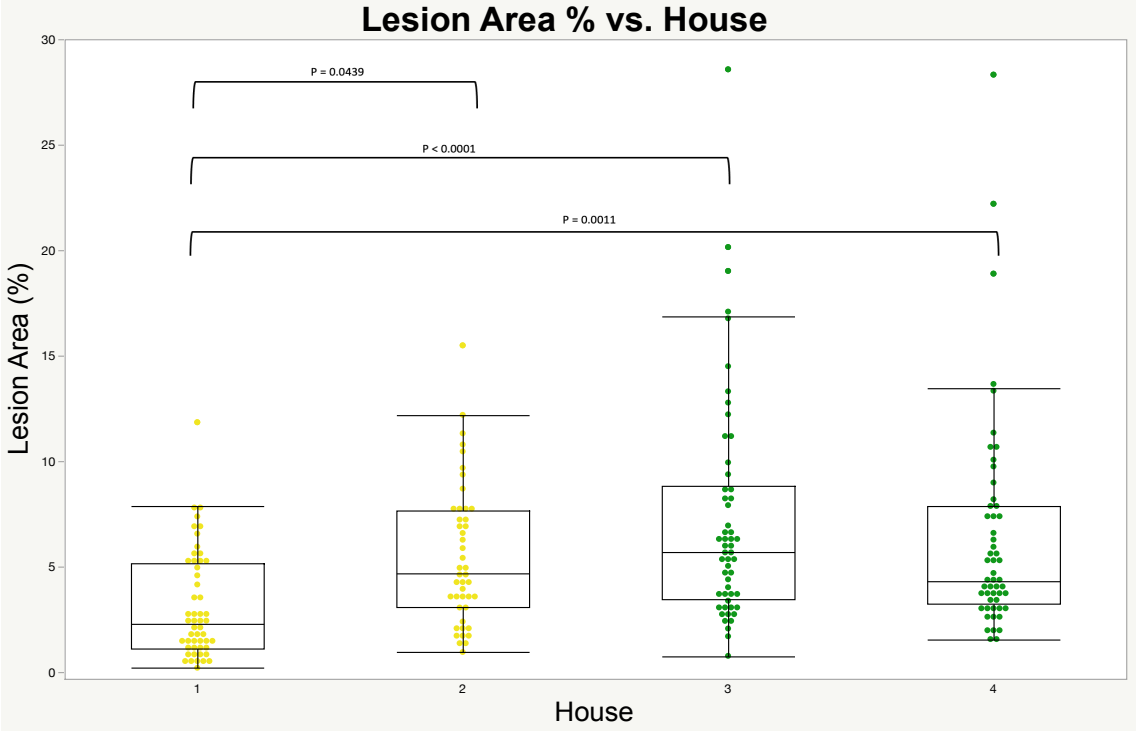


Figure 2.45. Flock 1 lesion size area (%) on broiler footpads in 4 commercial broiler houses. Birds with 0 FPD scores were excluded. Yellow points indicate houses with fans and green points indicate houses without fans.

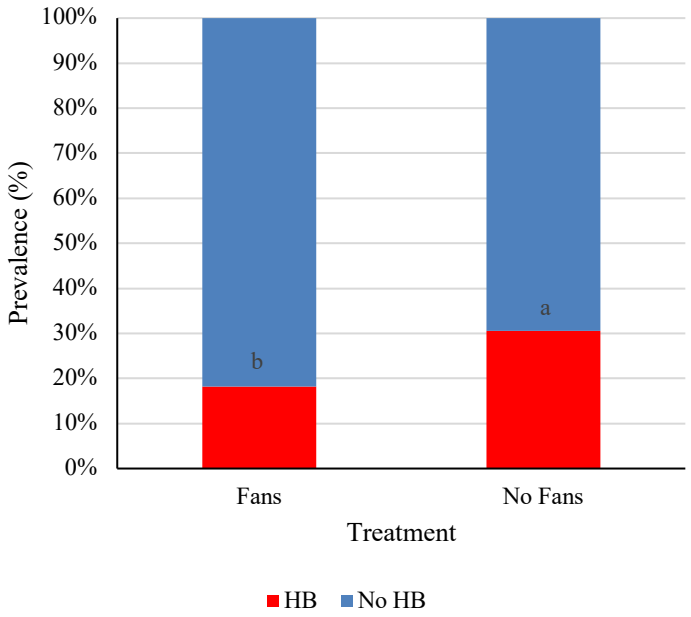
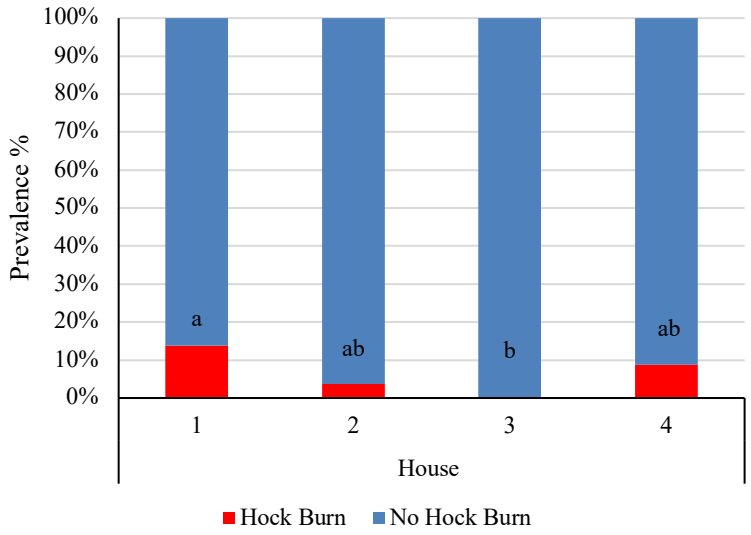


Figure 2.46. Hock burn (HB) prevalence (%) by treatment group at week 6 in both Flocks 1 and 2 combined. Data are shown as percentages of birds that had any evidence of hock burn (a contact dermatitis found on the skin of the caudal (back) part of the hock joint (Welfare Quality, Assessment Protocol for Poultry, 2009) observed on-farm. [ab] Columns not sharing the same letters are significantly different at $P \leq 0.05$.

a)



b)

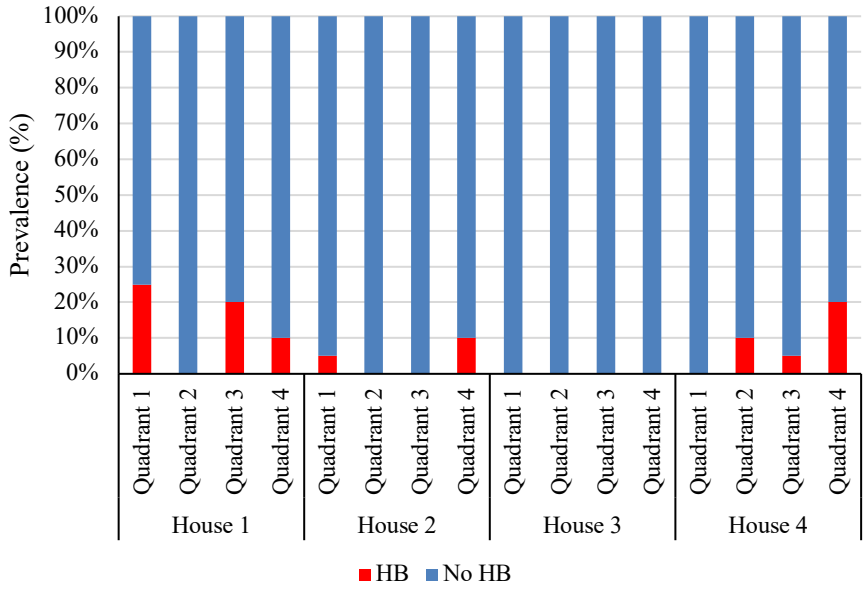
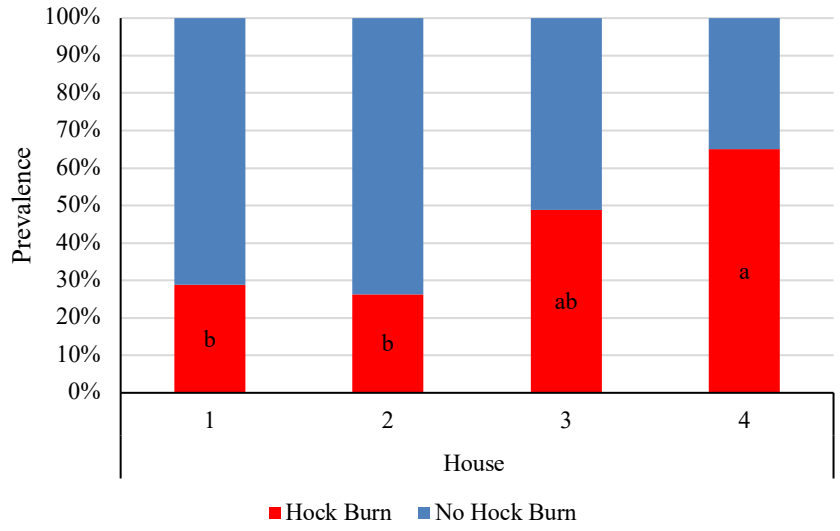


Figure 2.47. Flock 1 hock burn (HB) prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of hock burn (a contact dermatitis found on the skin of the caudal (back) part of the hock joint (Welfare Quality, Assessment Protocol for Poultry, 2009) observed on-farm. **A)** Hock burn by house. **b)** Hock burn by quadrant. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

a)



b)

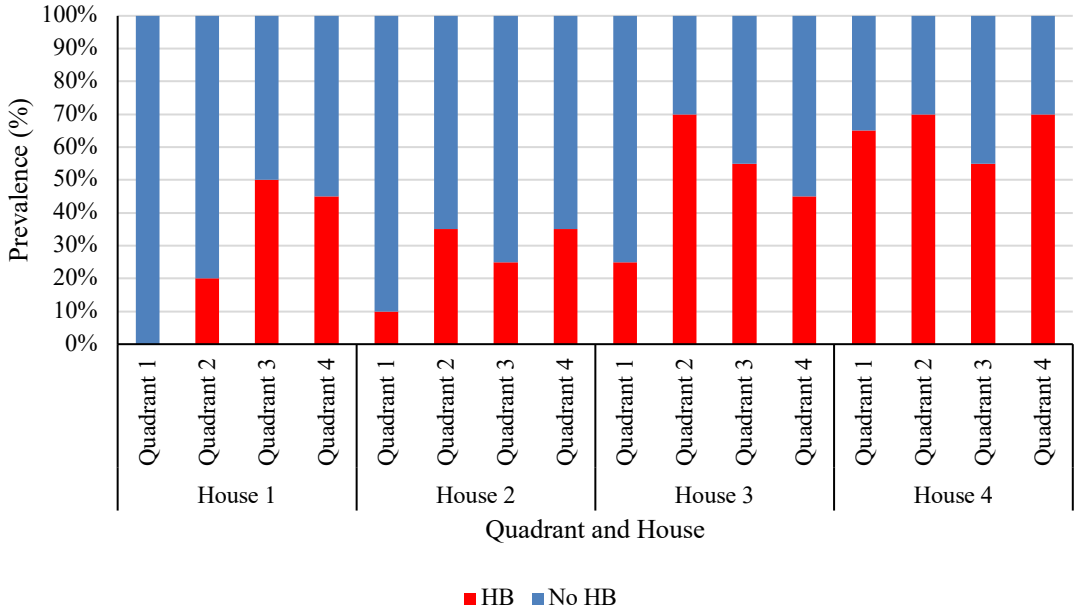
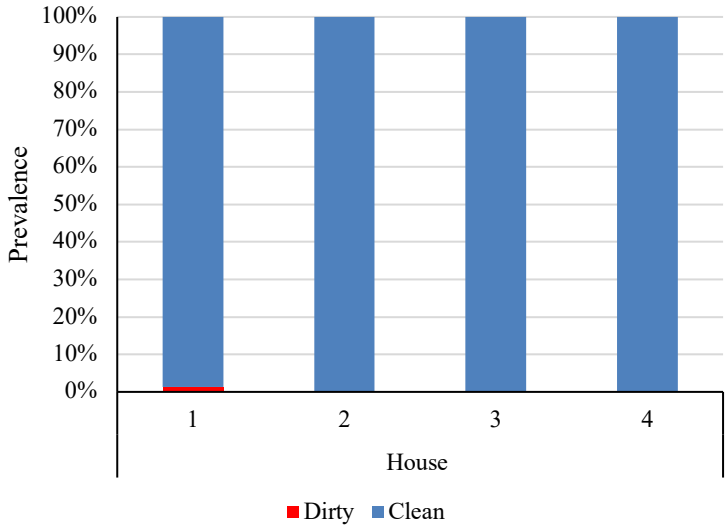


Figure 2.48. Flock 2 hock burn (HB) prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of hock burn (a contact dermatitis found on the skin of the caudal (back) part of the hock joint (Welfare Quality, Assessment Protocol for Poultry, 2009) observed on-farm. **A)** Hock burn by house. **b)** Hock burn by quadrant. [ab] Columns not sharing the same letters are significantly different at P≤0.05.

a)



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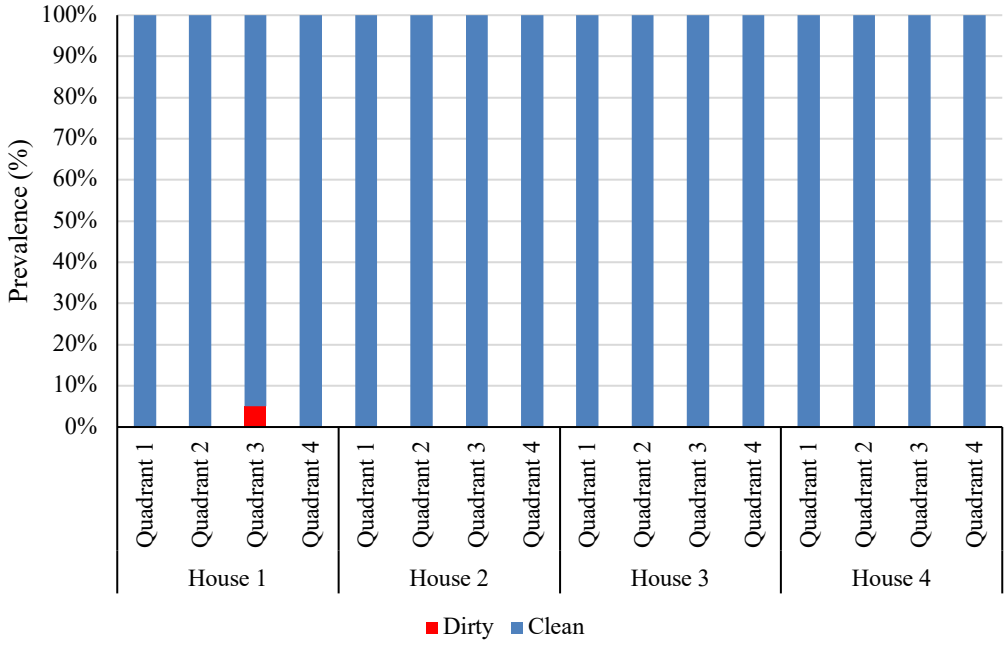
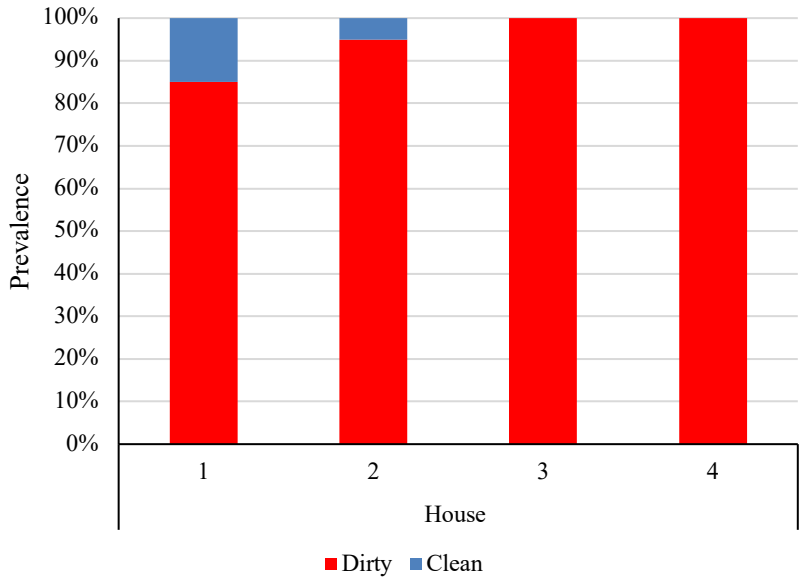


Figure 2.49. Flock 1 feather cleanliness prevalence (%) in 4 commercial broiler houses at week 3. Data are shown as percentages of birds that had any evidence of dirty feathers observed on-farm. **a)** Feather cleanliness by house. **b)** Feather cleanliness by quadrant.

a)



b)

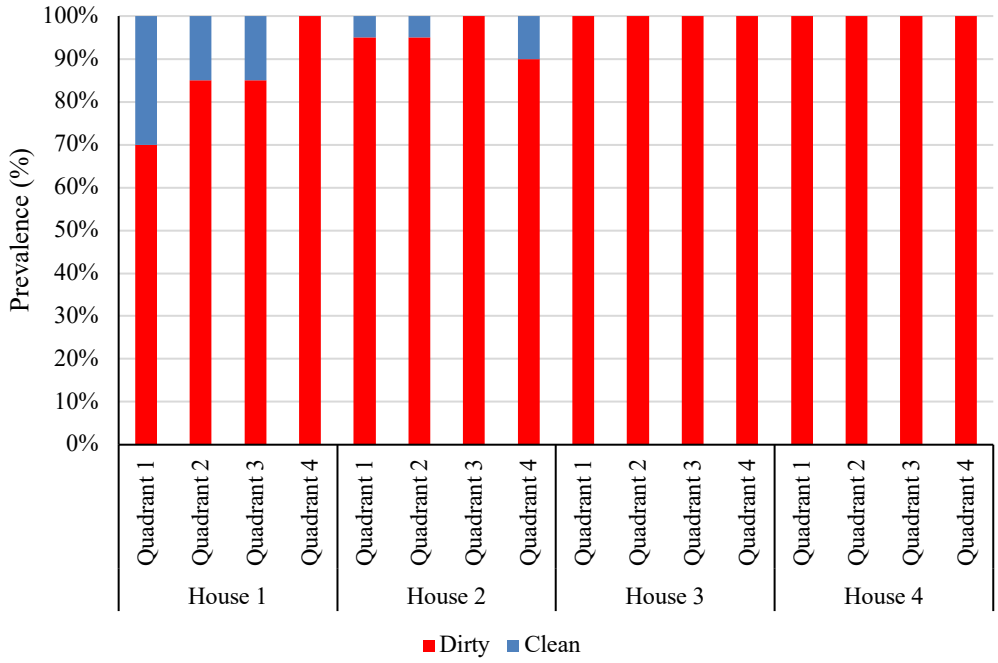
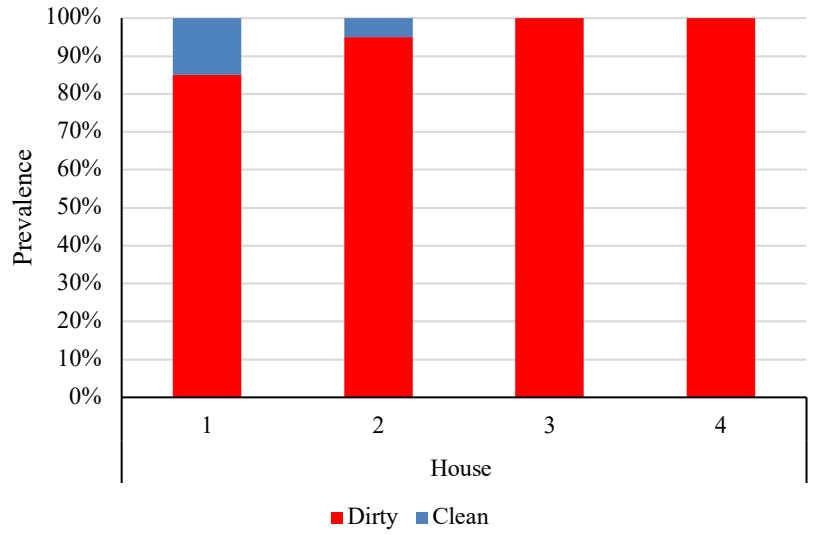


Figure 2.50. Flock 1 feather cleanliness prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of dirty feathers observed on-farm. **a)** Feather cleanliness by house. **b)** Feather cleanliness by quadrant.

a)



b)

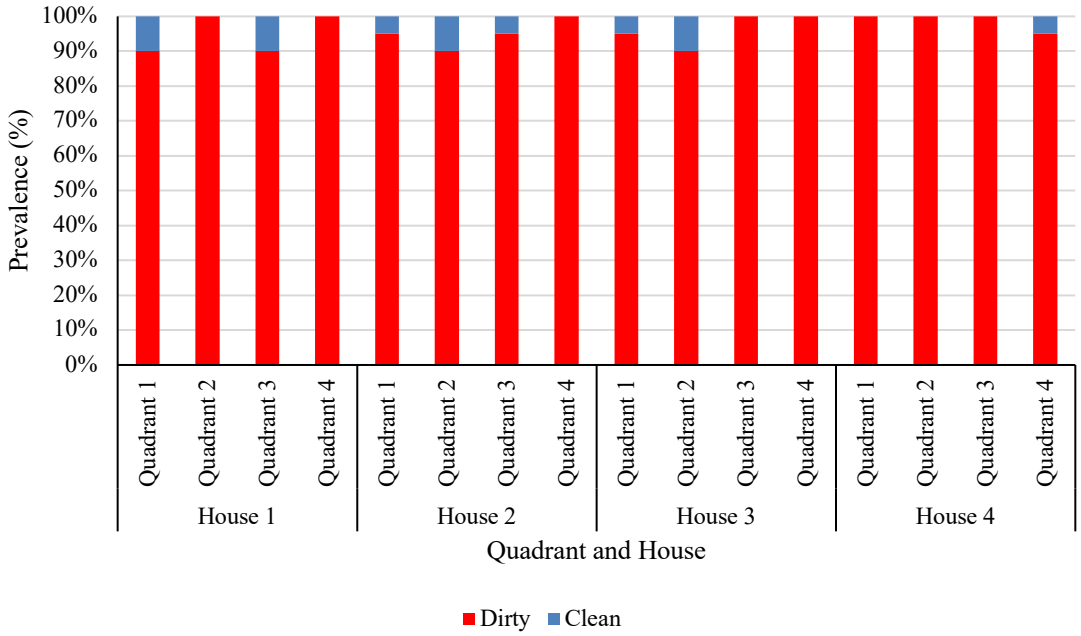


Figure 2.51. Flock 2 feather cleanliness prevalence (%) in 4 commercial broiler houses at week 6. Data are shown as percentages of birds that had any evidence of dirty feathers observed on-farm. **a)** Feather cleanliness by house. **b)** Feather cleanliness by quadrant.

CHAPTER 3: Conclusion

3.1 Summary and Implications

An animal's welfare can be affected by many factors, including management practices, environmental conditions, and health status. To protect chickens raised on farms for commercial meat consumption, it is essential that their welfare is prioritized. The results of this study indicate that additional ventilation from high-capacity circulation fans in broiler houses can have many potential welfare benefits. For example, proper ventilation can help ensure sufficient air exchange and stratification throughout the houses, control litter moisture, and keep temperature and humidity optimal. Footpad dermatitis (FPD), which can be caused by high litter moisture levels, is a broiler welfare concern because when severe, it can lead to a deteriorated state of health and intense pain for the animal (Berg, 1998). The results of this study indicate that high-capacity circulation fans in commercial broiler houses could positively impact footpad dermatitis prevalence, footpad dermatitis severity, and hock burn prevalence. The transect method of welfare observation showed that circulation fans could help improve flock uniformity as well. In addition, litter moisture levels and overheating in houses might be improved by circulation fans, but there was variation in these results and repeated trials are recommended. The objective of this study was to determine if welfare in 2 broiler flocks could be increased by adding large circulation fans to the ceiling of the commercial houses.

Throughout Flock 1, there was more variation in relative humidity over time when compared with temperature. Houses 1 and 2 had more similar temperature results while Houses 1 and 4 had more similar relative humidity results, although there was not a consistent similarity across all days or weeks. The difference in relative humidity levels

seen in the middle houses (Houses 2 and 3) and outside houses (Houses 1 and 4) on the farm could have been affected by the sun's heat coming through windows to affect relative humidity. Even though temperature and relative humidity levels were closely monitored in the broiler houses, the similarity in daily measurements by date could be a result of daily fluctuations in outdoor temperature and weather. When monitoring changes in broiler house temperature and humidity, outdoor weather should be considered an uncontrollable variable that can impact results.

In Flock 1, House 1 and House 4 were slightly more humid than the other houses throughout most weeks. This result was not reflected in Flock 2, during which Houses 1 and 2 were the most humid throughout most weeks, and that could have been a result of seasonal weather changes. House relative humidity was higher for Flock 2 compared with Flock 1. Previous studies indicate that relative humidity is easier to manage in cooler weather when houses are being heated with minimum ventilation settings (Mou, 2020).

Litter moisture results indicated that moisture increased from week 0 to week 6 in both flocks. With results from both flocks combined, there was no difference in litter moisture content (%) in the houses with and without fans at week 0, 3, or 6. Litter moisture content was significantly greater in the houses with circulation fans at week 3 in Flock 1, but that may not have been a result of the circulation fans because fresh dry litter was added to the houses at the time of the week 3 visit. Also, litter moisture content was consistently the lowest at week 3 compared with weeks 0 and 6 in all the houses during Flock 1. The circulation fans may have aided in keeping litter slightly dryer in Flock 1, despite the change in results observed at week 3 due to the addition of fresh litter at that time. Additionally, because growing birds block air movement across house floors with

their bodies as they increase in size, circulation fans are most effective when birds are younger. However, the benefits of drier litter can carry over to birds that have reached production weight/age.

Houses with fans had lower litter moisture than houses without fans at week 6 in Flock 1, but in Flock 2 where the houses with fans had higher litter moisture content compared to the houses without fans at week 6. Surprisingly, in Flock 2 there was a larger increase in litter moisture from week 3 to week 6 in the houses with fans compared with houses without fans. It is likely that rainy weather on the collection date for Houses 1 and 2 could have also contributed to increased litter moisture in those week 6 samples. Overall, the litter moisture results from both flocks were inconsistent. Trends in the results, however, indicate that the circulation fans could have reduced litter moisture. Further repeated trials are needed to determine the true impact of the circulation fans on litter moisture.

When comparing flocks, there was no difference in overall flock litter moisture in the houses with and without fans. However, Flock 1 litter had significantly more moisture than Flock 2 in both houses with and without fans at week 0, and in control houses at week 6. Flock 2 litter had significantly more moisture than Flock 1 in control houses at week 3. During colder months, outdoor air tends to have higher relative humidity levels than during warmer months; the warmer weather and decrease in outdoor relative humidity during Flock 2 could have contributed to the lower mean litter moisture observed at week 0 (in all houses) and week 6 (in control houses).

Body weight results were analyzed from Flock 1 only. The birds in House 1 were significantly heavier than the birds in the other 3 houses at both week 3 and week 6, but

that difference was due to the 3-day age difference between House 1 birds and birds from the other 3 houses. Body weight of birds in Houses 2, 3, and 4 was similar at both week 3 and week 6. Interestingly, Flock 1 birds were slightly lighter than performance objectives. When birds were caught on farm for welfare assessments, it is likely that our collected samples consisted of birds that were slower, less agile, and potentially less healthy than their flock mates (Koolhaas et al., 1999; Marchewka et al., 2013). Since the birds caught may not have been the strongest members of their flock, perhaps they were less likely to reach maximum performance expectations such as body weight.

Noise volume results showed that volume (dB) in in the houses with fans was louder on average than the volume in the houses without when both flocks and weeks were combined, indicating that high-capacity circulation fans could significantly increase house volume, although they are not as loud as the tunnel fans. When also considering the potential litter moisture maintenance benefits, noise pollution caused because of the circulation fans is likely not a significant threat to boiler welfare.

Noise volume was significantly louder in Flock 2 houses with no fans, a time when both circulation and tunnel fans were running. This is likely due to the proximity of the research to the tunnel fans at the time of noise volume measurement. Noise volume was taken at half as many locations in Flock 2 due to the change in welfare assessment location. It is also probable that more tunnel exhaust fans were running during Flock 2 compared with Flock 1 due to outdoor temperatures, leading to higher noise levels in Flock 2 houses.

The transect method of welfare assessment was performed at week 6 in Flock 1, and both week 3 and week 6 in Flock 2. Although it was not statistically significant, when transect results from both flocks were combined, more small birds were observed per transect walk in the houses without fans than in the houses with fans. For both flocks, the difference in the number of small birds observed in each treatment group was more significant than the other characteristic differences in the houses. For Flock 1, there were more small birds in House 4 than the other houses, but that result was not reflected in House 3, the other fan treatment house. Perhaps there were more small birds in House 4 because at week 6, House 4 had the greatest litter moisture content compared to the other houses House 4 had the greatest mean temperature compared with the other houses at week 6 as well. Because litter moisture is often related to increased stress and smaller body weights (Martland, 1985; Ekstrand et al., 1998; Dawkins et. al, 2004), the higher levels of heat and litter moisture in House 4 might have affected bird uniformity and future studies should also collect measures of stress (e.g., corticosterone). In Flock 2, significantly more small birds were observed per transect walk in Houses 3 and 4 than Houses 1 and 2 at week 6. There were more small birds in one of the houses without fans at week 3 and in both houses without fans at week 6 in Flock 2. Overall, there were significantly more runts in the houses without fans in Flock 2. These results indicate that there could be some benefit of the fans that improve flock uniformity.

One of the most interesting welfare results was that, out of the birds with footpad dermatitis (FPD score of 1 or 2), the birds in the houses without the circulation fans (Houses 3 and 4) had greater FPD severity scores and lesion areas at week 6. Birds in the houses without fans also had greater lesion area variation than birds in the houses with

fans and both houses had 3 birds with large lesion areas (between 20% and 30%). When both flocks were combined, more footpad dermatitis (P=0.0011) and hock burn (P=0.0002) was observed in the houses without fans than in the houses with fans at week 6. In both flocks, FPD prevalence increased with bird age; it was greater at week 6 compared to week 3. Ideally, there should be no FPD; however, the increase observed is not surprising. When comparing flocks, there was significantly higher FPD prevalence in Flock 1 at both week 3 and week 6, but only in the houses with fans.

These contact dermatitis results indicate that high-capacity circulation fans could aid in reducing FPD severity and prevalence, and hock burn prevalence. Because footpad dermatitis and hock burn are indicators of poor welfare, these results support our hypothesis that birds in the houses with circulation fans would have higher welfare than birds in the houses without circulation fans.

Flock 1 behavior results showed that birds in the fan houses displayed more play behaviors (sparring, food-running, and frolicking) at week 3. This was surprising to because play behaviors can be indicators of positive welfare. There was no significant difference in mobility, comfort, play, or total active behaviors at week 6 and frequency of observed behaviors was low. Running and frolicking were the only individual behaviors with significant differences in treatment group from either week; a greater percentage of birds in the houses without fans were observed running and frolicking at week 3, compared to the houses with fans. Fans and de-stratified air might cause young birds to be less inclined to play or move around, but for producers, the benefit of dry litter and reduced FPD prevalence is worth the potential decrease in play and mobility behaviors.

As expected, active behaviors decreased as the birds aged. At week 3, birds performed more walking, running, flapping, sparring, and frolicking behaviors than they did at week 6. At week 3, birds performed more mobility, play, and active behaviors than they did at week 6. These results were expected because previous research indicates that overall activity decreases as broilers age (Baxter et al., 2019). Also, high daily body weight gain typically seen in broilers, in combination with their low levels of activity, could make it more difficult for them to perform active behaviors as they age.

Although there are often multiple uncontrollable variables associated with field studies, like the current study, results can provide insight into the effectiveness of management strategies in real word settings. Overall, the results of this study indicate that installing high-capacity circulation fans in commercial broiler houses could positively impact footpad dermatitis prevalence, footpad dermatitis severity, hock burn prevalence, and potentially flock uniformity as well. This information can assist producers in maintaining profitable broiler operations while also prioritizing broiler health and welfare.

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