BROILER WELFARE AND BEHAVIOR AS AFFECTED BY MANAGEMENT PRACTICES

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ABSTRACT

The U.S. broiler industry is a cornerstone of the nation's food system and economy, leading global production and delivering affordable, high-quality protein. However, its rapid growth presents challenges, particularly regarding animal welfare. Key gaps include the economic and resource impacts of slower-growing strains, inconsistent research on stocking density and lighting effects, and limited adoption of advanced welfare technologies due to high costs. Addressing these challenges requires collaboration, targeted research, and sustainable solutions.

This dissertation examines the effects of growth rate, stocking density, and lighting intensity on broiler welfare and behavior, offering strain-specific management strategies to enhance production performance and welfare in the poultry industry.

Chapter one reviews gaps in balancing productivity and animal welfare. While slower-growing strains improve welfare, they increase costs and resource use, raising food security concerns. Research on stocking density reveals strain-specific responses but emphasizes environmental management's role over density effects. Similarly, lighting intensity studies show inconsistent results. Emerging technologies like computer vision show potential for welfare assessment but face adoption barriers due to cost. Bridging these gaps demands rigorous research and practical, economically viable solutions.

Chapter two explores how growth rate and stocking density impact welfare. Reduced densities improve feather coverage, gait scores, and activity but may compromise feed conversion ratio (FCR) and lengthen production cycles.

Chapter three compares Ross 708 and Cobb 700 broilers under varying stocking densities. Lower densities improve feather cleanliness and footpad health but show minimal effects on production and welfare, supporting current stocking density standards (44 kg/m^2).

Chapter four analyzes density and age effects on activity. High density increases early activity but reduces mobility by 56 days, with strain-specific behavioral responses.

Chapter five investigates lighting intensity. Higher light intensity improves activity, gait scores, and thermal regulation but increases feather loss, while lower intensity preserves feather coverage and reduces dermatitis but limits activity.

Chapter six highlights strain-specific lighting strategies. Ross broilers benefit from 20 lux, enhancing behaviors like stretching and preening, while Cobb 700 broilers adapt better to 5 lux, particularly during later growth stages. These findings emphasize tailored management strategies to optimize broiler welfare.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

The U.S. broiler industry is crucial in meeting the protein needs and has been the most productive animal agriculture sector by weight over the past two decades, leading global broiler production (USDA-NASS, 2024). In 2022, per capita consumption of broiler products in the United States reached 44.1 kg, nearly double the consumption of beef or pork (USDA, 2022). To meet this demand, the industry produced 60 billion pounds of live broilers, with a market value exceeding $50 billion (USDA, 2022). Beyond production, the broiler industry plays a crucial role in the U.S. economy, directly employing 367,515 individuals and supporting an additional one million jobs in related industries, amounting to 1.3 million jobs overall. These positions offer an average salary of $66,100, contributing to a total wage impact of $90.9 billion. The industry's overall economic contribution is estimated at $449.5 billion (National Chicken Council, 2022a). However, the industry's remarkable growth has also brought challenges, particularly regarding animal welfare. Animal welfare is typically defined across five domains (Webster, 1994): good nutrition, a healthy environment, good health, appropriate behavior, and positive mental experience (Mellor, 2016). As public concern about broiler welfare grows, more attention is being placed on the quality of life experienced by broilers (Hall and Sandilands, 2007; Cornish et al., 2016), the industry faces increasing pressure to balance productivity with ethical and sustainable management practices. This study examines key factors: growth rate, stocking density, lighting intensity, and advancements in welfare assessment, impacting broiler welfare and performance, offering insights into sustainable solutions for the future.

1.2 Balancing Growth Rate and Broiler Welfare

Commercial broiler chickens grow rapidly and convert feed efficiently, providing affordable and high-quality animal protein. Modern commercial broiler strains achieve nearly four times the body weight (**BW**) at day 56 compared to strains from six decades ago, along with a significant 40% improvement in feed conversion ratio (**FCR**) (Zuidhof et al., 2014a). However, this fast growth and efficiency-oriented feeding and management procedures can present challenges for maintaining optimal animal welfare (Bessei, 2006). The rapid growth of modern commercial broilers is the result of decades of genetic selection, and growth rate is a key economic driver. Research suggests that slower-growing broilers may have better locomotion, feather coverage, footpad health, breast condition, leg and hock health, and bone strength compared to standard commercial strains (Bizeray et al., 2000; Sanotra et al., 2001; Shim et al., 2012; Rayner et al., 2020; Weimer et al., 2020; Abeyesinghe et al., 2021). As a result, some studies advocate for slower-growing strains to improve welfare.

However, transitioning to slower-growing strains presents challenges, as production costs for slower-growth birds are 11 to 25% higher than those of conventional strains (Lusk et al., 2019). Additionally, switching to slower growth methods would require significant increases in water, land, and fuel resources, potentially raising chicken prices and reducing supply. For example, if one-third of U.S. broiler producers switched to slower-growing breeds, 1.5 billion additional birds would be needed to meet current production levels, increasing resource usage and raising production costs by an estimated $9 billion. Such a shift could lead to food insecurity, especially in regions dependent on U.S. chicken exports (National Chicken Council, 2017).

Slowing the growth of current fast-growing commercial broilers may offer a more economically viable and environmentally sustainable way to improve welfare without drastically increasing costs. Decisions on chicken growth rates should be informed by rigorous scientific research, rather than driven by activist pressures. More research is needed to evaluate the health and welfare implications of varying growth rates to ensure that changes in production methods strike a balance between sustainability, animal welfare, and affordability for consumers.

1.3 The Role of Stocking Density in Welfare and Productivity

Stocking density (**SD**) is a key factor in broiler production, influencing both welfare and profitability. SD affects bird health, environmental conditions, and productivity. Research shows that higher SDs reduce bird movement, increase oxidative stress, and lead to issues like footpad dermatitis, scratches, and poorer feathering (Estevez, 2007; Simitzis et al., 2012). When SD exceeds 34 to 38 kg/m², broiler welfare suffers, with increased litter moisture and footpad dermatitis, though feed conversion ratio (**FCR**) generally remains unchanged (Thomas et al., 2004; Ahmed et al., 2018). High SD also raises ammonia levels and worsens ventilation efficiency, leading to heat stress (Rayner et al., 2020). But the broiler market is very sensitive to price. lowering SD will increase production costs and compromise profitability. Studies also showed that the environment provided to broilers had a greater impact on welfare than the SD itself, meaning that good environmental management can reduce the adverse effects of high stocking densities (Stamp Dawkins et al., 2004).

In the U.S., recommended SDs vary. The National Chicken Council (**NCC**) suggests 32 to 44 kg/m², balancing profitability with feeder and drinker access (National Chicken Council, 2022b), while welfare groups like the Global Animal Partnership (**GAP**) advocate for lower SDs of 27 to 29 kg/m² to support natural behaviors. Lower SDs improve welfare but increase costs and land use, which contributes to low adoption (only 2.4% of U.S. broiler farms meet these requirements) of GAP standards (Mckenna, 2016; National Chicken Council, 2021).

Broiler strains like Ross and Cobb respond differently to SD. Ross broilers perform best at 13–15 birds/m² (32.5–37.5 kg/m²) for optimal body weight and FCR (Son, 2013; Vargas-Galicia et al., 2017; Kryeziu et al., 2018), while Cobb broilers yield higher economic returns at 17 birds/m² (Houshmand et al., 2012; Yanai et al., 2018; Gholami et al., 2020), despite slight reductions in body weight and FCR (Gholami et al., 2020). More research is needed to compare the effects of NCC- and GAP-recommended SDs across different strains under similar conditions. In conclusion, SD is crucial in balancing broiler welfare, environmental conditions, and profitability.

1.4 Lighting Intensity on Broiler Performance and Welfare

Lighting, encompassing light intensity, photoperiod, and wavelength, is a crucial component in commercial broiler management, shaping broiler physiology, behavior, and welfare outcomes. Light intensity, in particular, significantly influences broiler activity and production efficiency. Broilers are commonly raised in low-light conditions under the assumption that dim environments enhance productivity.

Research supports this, indicating that broilers reared in low-intensity settings achieve higher body weights, improved FCR, and faster growth rates compared to those exposed to brighter light (Lien et al., 2008). This is often attributed to reduced activity levels, which enable more efficient energy utilization (Proudfoot and Sefton, 1978). Lower lighting intensities are also associated with reduced activity and aggression (Olanrewaju et al., 2006; Pal et al., 2019).

However, low-light conditions pose welfare concerns. They have been linked to eye-related issues, including increased eye size and a heightened susceptibility to eye diseases (Blatchford et al., 2009; Deep et al., 2010), higher carcass fat content (Alvino et al., 2009b), leg problems (Weeks and Butterworth, 2004) and may interfere with the broilers' vision and natural behavior rhythms, ultimately impacting welfare (Blatchford et al., 2009).

Broilers raised in environments with minimal contrast between light and dark phases, such as at 5 lux, exhibit less distinct circadian rhythms, displaying uniform activity throughout the day. In contrast, higher light intensities (e.g., 50 lux and 200 lux) encourage well-defined behavioral patterns, with activity peaks during transitions between light and dark periods (Alvino et al., 2009b). Brighter environments also promote natural behaviors such as preening and walking (Vandenbert and Widowski, 2000), which are indicators of comfort and welfare. Notably, preening plays an essential role in feather maintenance and overall health, suggesting that higher light intensities may support welfare by encouraging these beneficial behaviors.

Current recommended lighting intensities in the U.S. vary. Broiler producers typically use 5 lux or less after brooding to improve the growth rate and feed efficiency (National Chicken Council, 2022b), while animal welfare advocates and food chain companies demand 20-50 lux throughout the entire production cycle (Better Chicken Commitment, 2024). The impact of light intensity on broiler chicken production performance remains a subject of debate. While some studies have found that lower light conditions (5 lux) can improve BW and FCR (Ahmad et al., 2011; Rault et al., 2017; Aldridge et al., 2022), a larger body of research indicates no significant effect of light intensity on broiler performance metrics (Deep et al., 2010; Olanrewaju et al., 2010; Olanrewaju et al., 2011;

Olanrewaju et al., 2012; Deep et al., 2013; Olanrewaju et al., 2016; Fİdan et al., 2017; Wu et al., 2023). Additionally, research predominantly focuses on the Ross strain (Deep et al., 2010; Olanrewaju et al., 2010; Olanrewaju et al., 2011; Deep et al., 2012; Olanrewaju et al., 2012; Olanrewaju et al., 2016; Fİdan et al., 2017; Rault et al., 2017; Wu et al., 2023), despite Ross and Cobb being the two most widely used commercial broiler strains. Only a limited number of studies have explored the effects of lighting on Cobb (Blatchford et al., 2009; Aldridge et al., 2022), underscoring the need for more balanced research across strains to better understand strain-specific responses to light intensity.

1.5 Advancing Broiler Welfare Assessment with Natural Behavior Indicators and Precision Livestock Farming Technologies

Natural behavior expression is a key metric in poultry welfare assessment (Webster, 2001), with preening and stretching recognized as essential comfort behaviors in poultry. These actions indicate that broilers are engaging in natural activities suited to their needs and therefore can serve as valuable welfare indicators. Stretching, involving the extension of one wing and leg on the same side, supports muscle tone, joint health, and overall well-being. A lack of stretching can signal health issues, particularly in leg health and skeletal development, as it often requires enough space for proper movement (Li et al., 2021). Preening, where broilers preening feathers with their beaks to distribute oil and remove dirt, dust, and parasites, is essential for feather maintenance and health (Zhao et al., 2020). The frequency and duration of preening can reflect environmental suitability and welfare levels; for instance, the number of broilers preening simultaneously may signal adequate space availability, indicating reduced competition and greater comfort. These comfort behaviors are traditionally assessed manually by farmers and auditors based on industry protocols. While manual observation remains the standard, it is labor-intensive, time-consuming, and subjective, making it difficult to perform comprehensively across large facilities or over extended production cycles. However, advancements in Precision Livestock Farming (**PLF**) technologies, particularly computer vision, enable automated, continuous behavior measurement in commercial poultry production.

Automated systems like video-action recognition have shown promise for objectively estimating drinking time (Nasiri et al., 2024a) and automatically detecting and counting preening and stretching behaviors on commercial farms (Nasiri et al., 2024b). This technology uses machine learning algorithms to monitor and classify behaviors in digital images or video, offering objective, scalable assessment that supports animal welfare. Radio frequency identification (**RFID**) technology has been widely applied for behavior tracking of group-housed animals, including broilers (Li et al., 2020; van der Sluis et al., 2020), laying hens (Richards et al., 2011; Li et al., 2017), turkeys (Tu et al., 2011), pigs (Zhu et al., 2010; Brown-Brandl et al., 2013; Adrion et al., 2018), and cattle (Schirmann et al., 2012; Wolfger et al., 2015).

Image processing techniques also enable the evaluation of broiler activity levels by analyzing pixel differences between consecutive images (Silvera et al., 2017), footpad dermatitis by estimating dermatitis area (Vanderhasselt et al., 2013), and feather coverage in both broilers and laying hens, often using thermography for added accuracy (Cook et al., 2006; Cangar et al., 2008) to measure footpad dermatitis by estimating the percentage of the affected area, and assess feather coverage of broilers and laying hens (Cook et al., 2006) combined with thermography technology. For instance, insufficient exercise has been linked to leg abnormalities in broilers (Haye and Simons, 1978). To quantify activity levels, an activity index is often calculated as the displacement area (the non-overlapping bird-representative pixels before and after movement) divided by the area representing the bird (Bloemen et al., 1997).

These objective, technology-driven approaches offer valuable insights into broiler welfare and have the potential to improve management practices in commercial poultry production. However, adoption remains limited due to high costs and technical challenges. Collaborative efforts between industry and academia are needed to refine and implement these tools widely.

1.6 Conclusions

The U.S. broiler industry faces the dual challenge of maintaining productivity while addressing growing concerns over animal welfare. By optimizing growth rates, stocking densities, and lighting conditions, and leveraging advanced technologies for welfare assessment, the industry can achieve a sustainable balance between economic and ethical goals. Continued research is critical to guide these efforts, ensuring welfare improvements align with the realities of commercial production.

1.7 Preview

In the first part of the experiment (Chapter 2), we investigated the interactive effects of growth rate and stocking density on broiler performance and welfare. With growing concerns about animal welfare in recent years, slower-growing broiler breeds are often associated with better welfare outcomes. However, a large-scale shift to slower-growing broiler production poses significant challenges, including increased production costs, higher resource consumption, and potential food security risks. Additionally, lower stocking densities are often correlated with slower growth rates in the broiler industry. To address these complexities, we reduced the growth rate of commercially fast-growing broiler breeds and examined their performance under varying stocking densities. By integrating precision livestock farming (PLF) technology and a computer vision system, we aimed to develop an objective and quantitative method to evaluate the impact of growth rate and stocking density on both production performance and welfare.

In the second part of the experiment (Chapters 3 and 4), we focused on stocking density as a key management practice, examining its effects on broiler production, welfare, activity levels, and welfare-related behaviors. Using PLF, image processing technology, and computer vision systems, we continuously, automatically, and objectively monitored differences in production, welfare, and activity across various stocking densities. This work provides a foundation for real-time, dynamic monitoring of production and welfare in future smart broiler farms.

In the third part of the experiment (Chapters 5 and 6), we investigated the impact of light intensity—another critical management factor—on broiler production, welfare, activity levels, and welfare-related behaviors. Again, we employed PLF, image processing technology, and computer vision systems to automatically and continuously monitor broiler performance under different light intensity conditions. This research lays the groundwork for real-time, indoor, dynamic monitoring of production and welfare in smart broiler farms, offering valuable information to support decision-making by future farm managers using advanced technologies.

CHAPTER TWO

EVALUATING BROILER WELFARE AND BEHAVIOR AS AFFECTED BY GROWTH RATE AND STOCKING DENSITY

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ABSTRACT This study evaluated the welfare and behaviors of Cobb 700 broilers as affected by growth rate (**GR**) and stocking density (**SD**). Slower-growth (weight gain < 50 g day^{-1}) and medium-growth (weight gain = 50 to 60 g day^{-1}) broilers were produced by providing 57.1% and 78.6% of the feed intake listed in the Cobb 700 production manual for standard (fed ad libitum) broilers (weight gain > 60 g day^{-1}). Broilers at all 3 GRs were reared at 2 SDs of 30 and 40 kg/m^2. Broiler welfare indicators, including gait score, tibia strength, feather coverage, and footpad condition were evaluated when birds reached 1, 2, and 3 kg of body weight. The activity index was determined by overhead cameras and image processing, and the time spent at feeders was recorded using the radio-frequency identification (**RFID**) systems. The results show that it took 45 days for standard, 52 days for medium-growth, and 62 days for slower-growth broilers to reach a 3 kg market body weight. Feed conversion ratios (**FCR**, kg/kg) were 1.57 for standard, 1.67 for medium-growth, and 1.80 for slower-growth broilers. GR and SD had an interaction effect on feather cleanliness (P=0.03), and belly feather coverage (P=0.02). Slower-growth broilers were more active and had better feather coverage and gait scores than medium-growth and standard broilers (all P<0.01) but may feel hungry and depressed, medium-growth broilers spent the most time at the feeder among the 3 growth groups (P=0.02), and standard broilers showed the best production performance. Broilers at 30 kg/m^2 showed better bone strength (P=0.04), and footpad condition (P<0.01) compared to those at 40 kg/m^2. In conclusion, reducing GR and SD may slightly improve broiler leg health at the high expense of compromised production performance and prolonged production cycles.

Keywords: broiler; growth rate; stocking density; welfare; behavior

2.1 Introduction

Global broiler production has risen over the past few decades, with increased body weight, muscle yield (Havenstein et al., 2003a), and production efficiency (Havenstein et al., 2003b). Broiler production, compared to other animal production systems, has a lower environmental impact (De Vries and de Boer, 2010), as the broiler industry continues to increase growth rates and feed efficiency, reducing energy expenditure for maintenance (Zuidhof et al., 2014b; Tallentire et al., 2016).

Public concerns about the welfare of broilers continue to grow (Hall and Sandilands, 2007; Cornish et al., 2016), and people are more discerning regarding the quality of life these birds undergo. Animal welfare has been defined into five domains (Webster, 1994), i.e., good nutrition, good environment, good health, appropriate behavior, and positive mental experience (Mellor, 2016). Growth rate (GR) and stocking density (SD) are two factors that may affect broiler welfare. Achieving good welfare is often incompatible with high growth rates in commercial broilers (Dawkins and Layton, 2012). There is evidence to suggest slower-growth broilers have better locomotor ability, feather coverage, footpad quality, breast condition, leg and hock health, and bone strength than standard strains (Bizeray et al., 2000; Sanotra et al., 2001; Shim et al., 2012; Rayner et al., 2020; Weimer et al., 2020; Abeyesinghe et al., 2021). Therefore, some studies suggest using slower-growing strains instead of fast-growing ones to improve broiler welfare (Wilhelmsson et al., 2019; Rayner et al., 2020). However, the rapid growth of modern commercial broilers is achieved through decades of genetic selection (Tallentire et al., 2016), and growth is a primary economic factor, so there are challenges with the acceptance of using slower-growth strains in commercial broiler production (Bessei, 2006). The study by Lusk et al. (2019) shows production costs per pound for slower-growth strains are 11%-25% higher compared to modern broilers. Customers would need to pay 10.8% more just to offset the producer’s losses. In addition, transitioning to welfare-friendly production systems that rely on slower-growing strains will require an additional 1.5 billion slower-growth birds annually to replace just one-third of broiler chickens in America, resulting in increased demands for water, land, and fuel (National Chicken Council, 2017).

Slowing down the current fast-growing (commercial) birds may be a more economical and environmentally sustainable way to improve broiler welfare. Moreover, the advantages exhibited by the slower-growing strains could be attributed to the genetic discrepancy rather than the growth rate. The study by Bizeray et al. (2000) shows that 3-day-old slower-growing broilers spent twice as much time walking and standing as fast-growing birds, indicating genetic discrepancies already affect locomotor behavior in broilers' early stages. However, the impacts of the growth rate on welfare have rarely been scientifically evaluated for the same strain of broilers. Existing research mainly focuses on the impact of the reduced growth rate of commercial broilers on the activity (Nielsen et al., 2003) and corticosterone (Trocino et al., 2020). Still, it lacks research on other welfare indicators such as gait score, footpad condition, feather health, etc. Stocking density is another confounder because the slower-growing strains are usually reared at lower SDs than their counterparts. Stocking density is directly related to profitability and therefore has critical implications for the broiler industry. In general, broilers raised in higher SD show decreased locomotion and increased indicators of oxidative stress (SD: 27.2 kg/m^2) (Simitzis et al., 2012), greater incidence of footpad dermatitis, scratches, bruising, poorer feathering, and condemnations (SD: 34-38 kg/m^2) (Estevez, 2007). Published research has indicated that stocking density exceeding 34 to 38 kg/m^2 (depending on final BW) will compromise the health and welfare of broilers (Estevez, 2007). As SD increased, litter moisture, gait scores, footpad dermatitis, and hock burn scores were adversely affected (Thomas et al., 2004; Son, 2013), while SD exhibited no impact on FCR (Thomas et al., 2004; Ahmed et al., 2018). Current recommended densities in the US are rather variable. The National Chicken Council (**NCC**) recommends a stocking density of 32 to 44 kg/m^2 in consideration of both producer profitability and the bird space requirement for feeder and drinker access, while animal welfare allies like Global Animal Partnership (**GAP**) emphasize accommodation of bird natural behaviors using lower stocking densities (27 to 29 kg/m^2). Clearly, there is a huge discrepancy between the broiler industry and animal welfare group standards, with the latter taking little consideration of producer profitability and industry sustainability.

An important reason for this lack of consensus is the absence of a more objective and neutral measurement method.

Time and labor intensive, and subjectivity suggests manual welfare assessment is not easy to perform. Therefore, precision agriculture technologies have been increasingly considered and used for objective and automatic measurements. Radio frequency identification (**RFID**) and image processing are 2 examples of precision livestock farming (**PLF**) technologies. RFID technology has been successfully used to measure behaviors of group-housed individual animals like broilers (Li et al., 2020; van der Sluis et al., 2020), laying hens (Richards et al., 2011; Li et al., 2017), turkeys (Tu et al., 2011), pigs (Zhu et al., 2010; Brown-Brandl et al., 2013; Adrion et al., 2018), and cattle (Schirmann et al., 2012; Wolfger et al., 2015). Image processing technology has demonstrated abilities to evaluate broilers' activity level by determining differences in pixels between consecutive images of birds (Silvera et al., 2017), measure footpad dermatitis by estimating the percentage of dermatitis area (Vanderhasselt et al., 2013), and assess feather coverage of broilers (Cangar et al., 2008) and laying hens (Cook et al., 2006) combined with thermography technology. Lack of exercise in broilers has been reported as a cause of abnormal legs (Haye and Simons, 1978). The activity index has been used to quantify animal activity and is equal to the area of non-overlapping bird-representative pixels before and after the broiler movement (displacement area) divided by the area of the full broiler pixels (Bloemen et al., 1997).

Feathers are unique to birds, and their delicate microstructure helps to form a tough outer skin that provides an insulating layer for birds to trap warm air and protect birds from external mechanical damage (Lingham, 2014; Lingham, 2017). Zhao et al. (2013) proposed that body surface temperature can be used as an indicator for evaluating feather coverage. The body surface temperature covered by feathers is significantly lower than that of bare skin, so the lower the average body temperature, the higher the degree of feather coverage. The use of infrared thermal imaging allows us to measure surface temperature undisturbed and precisely, especially on feathers that have low heat capacities (Naas et al., 2010). The Gait Score (GS) serves as a standardized approach for evaluating the lameness and walking proficiency of broilers. Gait disorders may be linked to discomfort, decreased activity, and a diminished display of motivated behaviors, all contributing to compromised welfare. Consequently, the assessment of gait scores emerges as a crucial tool for identifying and screening gait disorders within broiler flocks, playing a pivotal role in monitoring and promoting animal welfare standards (Kittelsen et al., 2017). The condition of the footpad serves as a crucial indicator of walking abilities and constitutes a significant aspect of broiler welfare. The presence of severe footpad dermatitis can lead to pain and lameness (Shepherd and Fairchild, 2010). Reduced bone strength is associated with fractures that occur during the capture and transportation (Rath et al., 2000). Furthermore, increased leg deformation can diminish the broiler's walking ability or cause pain (Bradshaw et al., 2002), posing welfare concerns even in the absence of fractures.

The objective of this study was to evaluate the interaction of GR and SD on bird welfare and behavior within the same commercial broiler strain using animal-based measures. Some animal-based measures were monitored using various PLF systems for objective and continuous results.

2.2 Material and Methods

2.2.1 Birds, Diets, and Management

A total of 267 day old Cobb 700 straight runs were used in this study (obtained from a local commercial hatchery), of which 252 birds were randomly placed in 18 pens while 15 backup birds were fed ad libitum and used in the first 14 days of mortality replacements. Two birds were used in the medium-growth SD-40 group (days 5 and 11), 2 birds were used in the standard-growth SD-30 group (days 7 and 9), and 2 birds were used in the standard-growth SD-40 group (days 7 and 14). They were all raised in the same room and same conditions but separated by pens. Each pen had 1.5 m^2 of available floor space and was equipped with one 36-cm-diameter tube feeder and 2 nipple drinkers. Feeder space and drinker availability can satisfy the highest SD in all pens. There were 3 growth rates, body weight gain < 50 g/day for slower-growing, 50 to 60 g/day for medium-growing, and > 60 g/day for standard broilers (based on average weight gain to reach 3 kg). Standard-growth birds were fed ad libitum through the flock, medium and slower-growth broilers were fed ad libitum during the first 14 days, then medium-growth birds were fed 78.6%, and slower-growth birds were fed 57.1% of the recommended Cobb700 as hatched daily feed consumption objectives (Cobb, 2020). There were 2 stocking densities (30 kg/m^2 and 40 kg/m^2), yielding 6 treatment combinations with 3 pen replicates per treatment combination. Sixteen birds were placed in pens with 40 kg/m^2 stocking density, and 12 birds were placed in pens with 30 kg/m^2 stocking density. Broilers were feather- and vent-sexed and assigned to each experimental pen at a 1:1 (male: female) sex ratio. Broilers were fed feed (crude protein: 19%, metabolizable energy: 2851 kcal/kg) throughout the flock. Once a day, same time every day, feed was added to feeders. Light intensity, temperature, and humidity were adjusted according to the Cobb700 broilers management guide (Cobb, 2021) by bird age. Topsoil (Farmer Green topsoil, 5 cubic feet per pen) with black mulch (Earthgro black wood shredded mulch, 1.5 cubic feet per pen) was applied as bedding at the start of the study and was never replaced. The topsoil and mulch used in this setup, rather than the shavings or rice hulls commonly used in the commercial poultry industry, serve a specific purpose. When using overhead cameras to monitor broiler activities, it is essential to distinguish the broilers from their background (the bedding material) for effective image processing of the recorded video. To achieve this, black topsoil and mulch are used instead of the light yellow shavings or rice hulls, providing a contrasting background against the white bodies of the broilers. All birds in each experimental pen were weighted together to obtain a total pen weight twice a week. The feed consumption was measured every week to calculate the weekly feed conversion ratio. All broilers were kept until their body weights reached 3 kg. Five randomly selected broilers (3 males and 2 females) in each pen were measured for welfare indicators, then they were euthanized to measure the tibia-breaking strength. Broilers that were not selected will be adopted by local farmers the next day. Birds got adopted and left the experimental room on day 46 for the standard-growth, day 53 for the medium-growth, and day 63 for the slower-growth birds. The carbon dioxide euthanasia method was used to euthanize broilers. Broilers were euthanized via carbon dioxide (CO_2), CO_2 tank pressure > 500 psi, CO_2 flow rate = volume of container * 0.4, and duration of CO_2 exposure = 7-10 minutes. The experiments followed the Guide for the Care and Use of Agriculture Animals in Research and Teaching (Federation of Animal Science Societies, 2010) and the University of Tennessee Institution Animal Care and Use Committee (**IACUC** Protocol #2847-0821). Research investigating growth rate effects on broilers of the same commercial strain is limited. To slow down the growth rate of commercial broiler strains, nutritional manipulation, i.e., providing ad libitum feed with lower amino acid (AA) and metabolizable energy (ME), was examined by this group (Zhang et al., unpublished data). The results showed that commercial broilers provided feed with low AA and ME ate more to compensate for AA and ME deficiencies, which made it impossible to produce broilers at desired slower growth rates through nutritional manipulation. As such, slower-growing and medium-growing broilers were produced by limiting the feed rationing in this study.

2.2.2 Welfare and Behavior Measurement

All measured items, sampling time, and methods are summarized in **A score** of 2 for feather cleanliness, feather coverage, and footpad dermatitis may be considered a welfare issue. Gait scores higher than 3 can be generally considered a welfare issue (Sørensen et al., 2000).

Table 2.1. Feather coverage and cleanliness, footpad dermatitis, gait score, activity index, the time spent at feeders, and bone strength were evaluated using a variety of precision agriculture technologies, including an overhead camera system, thermography, image processing, and ultra-high frequency RFID (**UHF-RFID**) system.

Broiler feather, footpad, and gait score were also manually assessed following the Welfare Quality® assessment protocol (Welfare Quality®, 2009). The welfare score range for feather cleanliness and feather coverage is from 0–3, footpad dermatitis is from 0-4, and gait score is from 0-5. A score of 0 represents the best welfare for all indicators.

A score of 2 for feather cleanliness, feather coverage, and footpad dermatitis may be considered a welfare issue. Gait scores higher than 3 can be generally considered a welfare issue (Sørensen et al., 2000).

Table 2.1 The summary of measured items, sampling time, and methods

Measurement frequency	Measurement items	Measurement method
Three-time in total (When broilers reached 1, 2, and 3 kg)	Feather coverage score	Measured manually
	Feather cleanliness score	
	Gait score	
	Footpad dermatitis score	
	Body temperature	Thermal camera
	Bare skin ratio	
Only when broilers reached 3 kg	Tibia breaking strength	Three-point bending method
Continually and automatically all days	Time spent at the feeder	RFID
	Activity index	Overhead camera system
Weekly	FCR	Measured manually
	Feed consumption	
Twice a week	Total pen weight	

2.2.2.1 Feather Coverage

When broilers reached 1, 2, and 3 kg of body weight, 5 birds per pen were randomly selected for feather coverage measurement, and selected birds were removed from the pens for the measurements. In addition to manual evaluation, a thermal camera (T865, Teledyne FLIR, Wilsonville, OR) was used to measure the back and belly surface temperature of the broilers to determine both back and belly bare skin ratio and feather coverage. Broilers were hung on a chicken shackle to shoot thermal images and the whole process took less than 1 minute. Broilers selected for welfare assessment were put into a large tote after measuring the gait score. We completed the current pen measurement before moving to the next pen. The broilers were handled at roughly the same time. The "FLIR Thermal Studio Pro" software determined both back and belly bare skin ratio and feather coverage. This software can measure the temperature of individual pixels within thermal images. The process involves delineating the entire broiler body by leveraging distinctions between its temperature and the background temperature. In each image, three temperatures at the intersection of feathers and exposed skin are randomly chosen, and their average is established as the threshold. Subsequently, the software autonomously computes the proportion of the broiler's surface area exceeding this threshold temperature, representing the bare skin percentage. Conversely, the percentage of the area below the threshold temperature corresponds to the feather cover percentage. Scores used for the feather coverage classification were described as 0, 1, 2, or 3 where 0 represented full feather coverage and 3 represented a large amount of visible skin (Welfare Quality®, 2009).

2.2.2.2 Feather cleanliness

Feather cleanliness was assessed simultaneously with feather coverage. The breast or belly side feather cleanliness was scored visually from 0 (very clean and dry) to 3 (very dirty, wet, or soiled with litter, feces, or dirt) (Welfare Quality®, 2009).

2.2.2.3 Footpad Dermatitis

When broilers reached 1, 2, and 3 kg of body weight, 5 birds per pen were randomly selected for footpad dermatitis measurement. The scoring scale allows an assessment of the severity of these lesions. A five-scale scoring (from 0 to 4) protocol was used, with a score of 0 being no evidence of footpad dermatitis and a score of 4 being severe footpad dermatitis (Welfare Quality®, 2009).

2.2.2.4 Gait Score

When broilers reached 1, 2, and 3 kg of body weight, 5 birds (3 males and 2 females) per pen were randomly selected and the gait score was manually assessed and recorded. Birds were classified according to these criteria: 0: normal, dexterous, and agile; 1: Slight abnormality, but difficult to define; 2: Definite and identifiable abnormality; 3: Obvious abnormality, affects the ability to move; 4: Severe abnormality, only takes a few steps; and 5: Incapable of walking (Welfare Quality®, 2009).

2.2.2.5 Bone Strength

Bone strength was determined in 5 randomly collected birds (3 males and 2 females) in each pen at the end of the flock. Broilers were euthanized via the CO_2 method. The left tibia was collected, connective tissues were removed, bones were weighed, and frozen (-20 °C) until further analysis (Karaarslan and Nazlıgül, 2018). The breaking strength of tibias was determined by the three-point bending method using MTS Alliance RT/30 (MTS Systems Corporation, Eden Prairie, MN). The distance between the 2 supporting points of the tibia was 4 cm. The maximum force required to break the tibia was determined as the breaking strength.

2.2.2.6 The Time Spent at Feeders

The UHF-RFID antenna panels (Impinj Mini-guardrail and Times-7 A6034, TransTech System Inc., Aurora, OR) were placed under the feeder and connected to the RFID reader to automatically evaluate bird utilization of feeders continuously. At 21 days of age, 3 broilers per pen had a small RFID tag (Atlas RFID Solutions LLC, Birmingham, AL) attached to the neck. Tags were adjusted daily at about 9 a.m. to reduce any discomfort to the broilers. When the tagged broiler came to the feeder and bowed its head to feed, the RFID system detected the feeding behavior of the broiler and converted this into real-time data. When the broiler stopped eating and raised its head or left the feeder, the tag signal disappeared. The antenna was on the surface of litter, and the feeder was placed on the top surface of the antenna, The distance between the feed and the ground was about 4 cm. When chickens were feeding, the distance from the tag on their neck to the ground continued to increase as they grew, reaching about 12 cm at 42 days of age. The antenna was set to receive signals from tags with a maximum vertical height of 15 cm from the ground. In the horizontal direction, the tag was difficult to detect when it was 4 cm away from the edge of the antenna. In this study, when the interval between 2 detected signals (the feeding behavior records in the data file) from the same tag was less than 20 seconds, it was considered a continuous feeding behavior, When the interval was greater or equal to 20 seconds, the feeding behavior was considered finished. Using the 20-second interval as a threshold to determine two feeding events has been previously published in a peer-reviewed journal (Li et al., 2019a).

2.2.2.7 Activity Index

Activity indices were measured by overhead cameras installed over each pen. High-performance security cameras (IP5M-B1186EB-28MM, Amcrest Technologies, Houston, TX) were installed approximately 3 meters above each pen to monitor broilers' activities. Each overhead camera covered 2 pens. The overhead camera recorded videos in the first 15 minutes of each hour from the start of the experiment to the end of the experiment. Images were extracted from the video every 0.2 seconds to analyze the activity index of broilers (Yang et al., 2020).

2.2.3 Statistical Analysis

All the analyses were performed by JMP, version 16.0.0 (SAS Institute, Cary, NC). Growth rates at slower, medium, or standard and stocking densities at 30 or 40 kg/m^2 were used in a 2 x 3 factorial arrangement in 3 randomized complete designs. The individual chicken was considered as the experimental unit for feather coverage, feather cleanliness, bone strength, footpad dermatitis, gait score, and feeding behaviors. Broilers were randomly selected at different weights, so the broiler chicken selected at 1 kg, and the broiler chicken selected at 2 kg or 3 kg may not be the same. The pen was considered as the experimental unit for the weight gain, FCR, and activity index. The continuous variables including the time spent at feeders, activity index, bone-breaking strength, and average temperature were analyzed by two-way ANOVA to test the effect of growth rate, stocking density, and interactions. Bare skin ratio and scored variables including gait score, footpad dermatitis, feather coverage, and feather cleanliness were analyzed using two-way ANOVA on ranks to test the effect of growth rate, stocking density, and the interactions. Least squares means were computed and separated with Tukey's HSD for the post-hoc analysis at the 0.05 significance level. The normality of the residuals was tested using the Shapiro-Wilk normality test. The Shapiro-Wilk normality test results show that welfare-related scores, and back and belly skin ratio were not normally distributed. The time spent at feeders, bone strength, activity index, FCR, back temperature, and belly temperature were normally distributed. The Kruskal-Wallis test was used to test the difference of body weight (1, 2, and 3 kg) in scoring and continuous variables. $P < 0.05$ was considered significant.

2.3 Results

2.3.1 Interaction Effect of Growth Rate by Stocking Density

The results in **Table 2.2** show that growth rate and stocking density had an interaction effect on feather cleanliness ($P = 0.03$), and belly feather coverage ($P = 0.02$). Feather cleanliness and belly feather coverage of broilers raised in SD-30 and SD-40 responded differently to increasing GR. SD-40 broiler feathers became significantly dirty when the GR was increased from slower to medium.

At the same time, SD-30 broiler feathers became noticeably dirty only when the GR increased from medium to standard. When the GR was increased from medium to standard, the belly feather coverage scores of the SD-40 broiler increased significantly faster than that of the SD-30 broiler.

Growth rate and stocking density had no interaction effect on bone strength ($P = 0.56$), the time spent at feeders ($P = 0.51$), back feather coverage ($P = 0.58$), footpad ($P = 0.73$), gait score (*P* = 0.65), activity index (*P* = 0.97), FCR (*P* = 0.83), belly temperature (*P* = 0.73), back temperature (*P* = 0.91), belly skin ratio (*P* = 0.93) and back skin ratio (*P* = 0.32).

2.3.2 Production Performance

The average growth rate for slower-growing, medium-growing, and standard broilers were 48, 60, and 66 g/day respectively. The body weight and feed intake of the standard birds (fed ad libitum) approached the commercial standard throughout the experimental period (See **Figure 2.1**). Due to the feed ration, the medium-growing and slower-growing

Table 2.2 Interaction effect of growth rate (GR) by stocking density (SD) on feather cleanliness and belly feather coverage score

Parameter	**Treatment**						**Std Error**	***P*-value**
GR	Slow	Slow	Medium	Medium	Standard	Standard		
SD	30	40	30	40	30	40		
Feather cleanliness	0.00[b]	0.29[b]	0.20[b]	0.80[a]	0.73[a]	0.93[a]	0.08	0.03
Belly feather coverage	0.09[d]	0.11[cd]	0.16[cd]	0.40[bc]	0.47[b]	0.89[a]	0.07	0.02

[a, b, c] Means in the same row with no common superscripts differ (*P*<0.05).

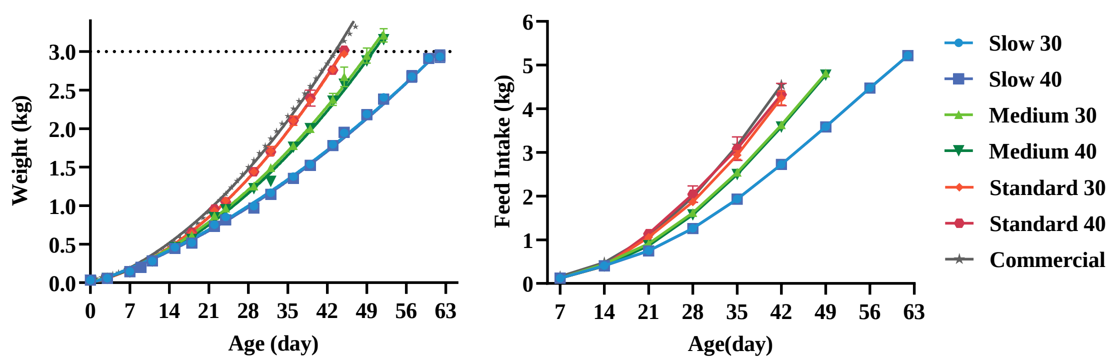

Figure 2.1 Body weight (kg) and accumulated feed intake (kg, measured and added up weekly) of broilers in different growth rates. These broilers were raised under two stocking densities (30 and 40 kg/m^2). Additionally, the dataset incorporates bird body weight and feed intake information sourced from the Cobb700 commercial manual (Cobb, 2020) for a comprehensive and comparative analysis.

broilers in both stocking densities grew slower and consumed more feed to reach the 3 kg target weight compared to the standard birds ($P < 0.01$).

As shown in

Table 2.3, the final FCRs were 1.80 for slower-growing, 1.67 for medium-growing, and 1.57 for standard broilers ($P < 0.01$). Stocking density had no significant effect on the FCR ($P = 0.48$).

2.3.3 Feather Coverage, Body Temperature, Bare Skin Ratio and Feather Cleanliness

The results in Error! Not a valid bookmark self-reference. show that the average belly temperature and back skin ratio of broilers in the slow-growing group were lower ($P <$ 0.01) than those in medium-growing and standard broilers. The slower-growing birds' average belly temperature dropped by 1.2 degrees and the back skin ratio was 1.6% lower than the other 2 groups. Standard broilers had the lowest belly feather coverage, with 3% more exposed skin area than the other 2 groups. For the impact of body weight, broilers reaching 1 kg demonstrated the

cleanest plumage but had the lowest feather coverage, and their bare skin ratio was higher ($P < 0.01$) than older birds.

Standard broilers had the lowest belly feather coverage, with 3% more exposed skin area than the other 2 groups. For the impact of body weight, broilers reaching 1 kg demonstrated the cleanest plumage but had the lowest feather coverage, and their bare skin ratio was higher ($P < 0.01$) than older birds. As body weight increased from 1 kg to 3 kg, the average body surface temperature gradually decreased alongside improved feather coverage, resulting in a 7-degree drop in back temperature and a 5-degree drop in belly temperature. Similarly, broilers reaching 2 kg had cleaner plumage but lower feather coverage, with belly bare skin ratios 1.26% higher (P < 0.01) compared to when they were 3 kg. The temperature trends persisted, with a 7-degree decrease in back temperature and a 5-degree decrease in belly temperature as body weight increased from 1 kg to 3 kg. Stocking density had a significant effect on the feather cleanliness and feather coverage score of broilers. Broilers from SD 30 kg/m^2 had cleaner feathers (P < 0.01), better belly feather coverage (P < 0.01), and better back feather coverage (P = 0.03) compared to birds from SD 40 kg/m^2. However, the results from the infrared camera show that SD had no significant effect on the average body surface temperature and bare skin ratio.

Table 2.3 Final FCR and days to reach 1, 2, and 3 kg body weight for slow-growing, medium-growing, and standard broilers reared at 2 stocking densities (30 and 40 kg/m^2)

Target Body Weight	**Slow**		**Medium**		**Standard**		**Std Error**	***P*-value**
	SD 30	**SD 40**	**SD 30**	**SD 40**	**SD 30**	**SD 40**		
1 kg	28 d	28 d	25 d	25 d	23 d	23 d		
2 kg	47 d	47 d	39 d	39 d	36 d	36 d		
3 kg	62 d	62 d	50 d	50 d	45 d	45 d		
Final FCR	1.8^{A}	1.8^{A}	1.65^{B}	1.68^{B}	1.55^{C}	1.59^{C}	0.02	< 0.01

$^{A, B, C}$ Means in the same row with no common superscripts differ (P<0.01).

Table 2.4 Effects of growth rate (GR), weight, and stocking density (SD) on feather coverage, back and belly body temperature, bare skin ratio, and feather cleanliness. Scores of feather coverage and cleanliness were determined following the Welfare Quality® (2009) assessment protocol

Measurement Items	**Treatment**			**DF total**	**F**	**Std Error**	***P*-value**
GR	Slower	Medium	Standard				
Back feather coverage score	0.11^{B}	0.54^{A}	0.04	269	13.02	< 0.01	< 0.01
Belly feather coverage score	0.10^{C}	0.28^{B}	0.05	269	37.53	< 0.01	< 0.01
Back temperature (°C)	24.74	25.84	0.34	269	4.59	0.34	0.01
Belly temperature (°C)	26.51^{B}	27.78^{A}	0.28	269	7.24	0.28	< 0.01
Back skin ratio %	1.89^{B}	3.76^{A}	0.39	269	1.37	8.22	0.26
Belly skin ratio %	6.10^{B}	7.26^{B}	0.65	269	10.35	7.99	< 0.01
Feather cleanliness score	0.14^{C}	0.50^{B}	0.05	269	44.01	< 0.01	< 0.01
Weight	1 kg	2 kg	3 kg				
Back feather coverage score	0.68^{A}	0.08^{B}	0.05	269	59.42	< 0.01	< 0.01
Belly feather coverage score	0.51^{A}	0.29^{B}	0.06	269	12.72	< 0.01	< 0.01
Back temperature (°C)	29.57^{A}	24.31^{B}	0.08	269	605.0	< 0.01	< 0.01
Belly temperature (°C)	30.59^{A}	26.40^{B}	0.08	269	388.0	< 0.01	< 0.01
Back skin ratio %	5.93^{A}	1.18^{C}	0.29	269	85.10	< 0.01	< 0.01

Belly skin ratio %	14.50^{A}	5.30^{B}	0.38	269	173.2	< 0.01	< 0.01
Feather cleanliness score	0.29^{B}	0.52^{A}	0.06	269	16.39	< 0.01	< 0.01
SD	30	40					
Back feather coverage score	0.21^{b}	0.36^{a}		269	4.70	0.05	0.03
Belly feather coverage score	0.24^{B}	0.47^{A}		269	16.06	0.04	< 0.01
Back temperature (°C)	25.49	25.64		269	0.15	0.27	0.69
Belly temperature (°C)	27.33	27.43		269	0.09	0.23	0.76
Back skin ratio %	3.05	2.82		269	0.15	6.72	0.70
Belly skin ratio %	7.75	8.13		269	0.84	6.52	0.36
Feather cleanliness score	0.31^{B}	0.67^{A}		269	38.61	0.04	< 0.01

$^{a, b, c}$ Means in the same row with no common superscripts differ (P<0.05).
$^{A, B, C}$ Means in the same row with no common superscripts differ (P<0.01).

2.3.4 Gait Score, Footpad Dermatitis, Bone Strength, Activity Index, and Feeding Hours

The results in **Reducing** stocking density only improved the belly feather coverage of standard broilers (P = 0.02). Because standard broilers were fed ab libitum, they were growing fast and spent more time lying (Savory and Mann, 1999; Yan et al., 2021). Crowded conditions combined with wet litter with large amounts of manure result in standard broilers with dirty belly feathers and low feather coverage. Reducing the stocking density in this condition can directly reduce

Table 2.5 show that slower-growing broilers had better gait scores, and their activity index increased (P < 0.01) when the growth rate of broilers was reduced.

The medium-growing broilers, compared to the slower-growing ones, had higher bone strength (P = 0.01) and spent 1.1 hours more per day eating (P = 0.02). The growth rate had no significant effect on footpad dermatitis.

When comparing the results to birds weighing 1 kg, the gait and footpad dermatitis scores were worse (P < 0.01) when broilers reached 3 kg market weight, and the activity index and feeding time were reduced (P < 0.01). The average gait score for each group in this trial was within the score of 1.

2.4 Discussion

2.4.1 Effects of GR by SD Interactions on Feather Cleanliness and Belly Feather Coverage

Reducing stocking density only improved feather cleanliness in medium-growth broilers (*P* = 0.03). In both SDs, slower-growth broilers had cleaner plumage, and standard birds had dirtier feathers. For medium-growth broilers, restricted feeding resulted in increased activity levels, which is consistent with more drinking, walking, standing, and litter pecking reported in broiler breeders (Savory and Maros, 1993), which compromised the feather cleanliness of broilers raised on SD-40.

However, the reduced amount of manure excreted and litter moisture due to reduced stocking density results in cleaner plumage in medium-growth broilers at SD-30. This suggests that limiting feeding to 78% may be the threshold at which changes in SD can have a significant impact on feather cleanliness. Reducing stocking density only improved the belly feather coverage of standard broilers (*P* = 0.02). Because standard broilers were fed ab libitum, they were growing fast and spent more time lying (Savory and Mann, 1999; Yan et al., 2021). Crowded conditions combined with wet litter with large amounts of manure result in standard broilers with dirty belly feathers and low feather coverage. Reducing the stocking density in this condition can directly reduce

Table 2.5 Effects of growth rate (GR), weight, and stocking density (SD) on gait score, footpad dermatitis, bone breaking strength (pound-force, lbf), activity index, and daily Time spent at the feeder. Scores of gait score and footpad dermatitis were determined following the Welfare Quality® (2009) assessment protocol

Measurement Items	**Treatment**			**DF total**	**F**	**Std Error**	***P*-value**
GR	Slower	Medium	Standard				
Gait score	0.18^{B}	0.43^{A}	0.38^{A}	269	6.49	0.06	< 0.01
Footpad dermatitis	0.13	0.22	0.23	269	1.71	0.05	0.31
Bone strength (lbf)	86.23^{b}	98.20^{a}	89.34^{ab}	89	4.43	2.95	0.01
Activity index	0.027^{A}	0.020^{AB}	0.014^{B}	38	8.54	< 0.01	< 0.01
Time spent at the feeder (h/day)	3.44^{b}	4.61^{a}	3.82^{ab}	103	4.77	0.27	0.02
Weight	1 kg	2 kg	3 kg				
Gait score	0.11^{B}	0.42^{A}	0.46^{A}	269	20.74	0.06	< 0.01
Footpad dermatitis	0.00^{C}	0.22^{B}	0.37^{A}	269	33.49	0.05	< 0.01
Activity index	0.030^{A}	0.018^{B}	0.017^{B}	38	11.01	< 0.01	< 0.01

Time spent at the feeder (h/day)	4.63^{A}	3.86^{AB}	3.36^{B}	103	6.22	0.28	< 0.01
SD	30		40				
Gait score	0.27a		0.39b	269	5.03	0.05	0.03
Footpad dermatitis	0.08^{B}		0.31^{A}	269	18.24	0.04	< 0.01
Bone strength (lbf)	94.77^{a}		87.74^{b}	89	4.25	2.41	0.04
Activity index	0.021		0.020	38	0.35	< 0.01	0.56
Time spent at the feeder (h/day)	3.79		4.15	103	1.37	0.21	0.24

$^{a, b, c}$ Means in the same row with no common superscripts differ (*P*<0.05).
$^{A, B, C}$ Means in the same row with no common superscripts differ (*P*<0.01).

manure excretion and topsoil moisture also improves air circulation, so it is beneficial to the belly feather coverage of standard-growth broilers

2.4.2 Effects of Growth Rate on Broiler Production Performance

Reducing the growth rate of the Cobb 700 commercial broiler strain by restricting feeding was demonstrated to be a feasible approach for slowing the growth rate of broilers in this study. Our results show that limiting broiler feed intake from ad libitum (100%) to 78.6% and 57.1% from day 15 to the end of the trial in the medium-growing and slower-growing groups reduced the average daily gain of broilers from 67 g/d, respectively to 58 and 48 g/d. Feed restriction slowed the growth rate of birds, impaired FCR, and increased activity levels. As a result of restricted feeding to 78.6% (medium-growing) and 57.1% (slower-growing) of recommended feed intake, both resulted in broilers consuming all the feed offered before the end of the day. Furthermore, limiting feeding to 60% causes birds to be hungry most of the day (Nielsen et al., 2003). Slowing down the growth rate of broilers compromises FCR, mainly because the energy intake from the food, after digestion and metabolism, is first used to support the animal's basal metabolic function to keep it alive, and the rest goes into body tissues or secretions (Zuidhof, 2019). Liu et al. (2017) determined the maintenance net energy of fast-growing strain broilers to be 404 kj/kg^$^{0.75}$, which is the energy that broilers must allocate to the body every day. Decreasing the growth rate of broilers prolongs the feeding period, increasing the proportion of energy required for maintenance, which in turn reduces overall production efficiency.

2.4.3 Effects of Stocking Density on Broiler Production Performance

Stocking density had no significant effect on average weight gain and feed intake. For the same growth rate, broilers of different stocking densities reach 1, 2, and 3 kg at the same age. Feed intake of the standard broiler approached the standards described in the commercial standards. Since the feed provided to the medium-growing and slower-growing birds was completely consumed every day, there was no difference in feed intake between the two SDs. Stocking density had no significant effect on the overall FCR. Similar results were reported by Franco-Rosselló et al. (2022), with no significant difference in average daily gain and FCR between 30 and 40 kg/m^2 stocking densities. However, increasing the stocking density still influenced the weight uniformity in the slow-growing group, because the male broilers (3.44 kg) in the slower-growing-SD-40 group weighed more than the females (2.81 kg) when the average broiler weight was 3 kg. Since there were only 3 replicates in both slower-growing-SD-30 and slower-growing-SD-40, further experiments with more replicates need to be conducted. Differences in body size between males and females are well known, with males exhibiting higher final body weight and lower FCR than females (Trocino et al., 2015; Trocino et al., 2020). As social animals, broilers generally begin to establish social hierarchies at 5 to 6 weeks of age (Olukosi et al., 2002). Dominant birds have priority to access the feeder while subordinate birds may not access resources at will (Diarra and Devi, 2014). With limited feed and limited feeding area, increasing stocking density can make broilers very crowded when feeding, especially as broilers become larger and heavier. Males monopolized the feeders and crowded out relatively weak females, and this effect was reinforced by the prolonged feeding period caused by restricted feeding, resulting in slower-growing males in the SD-40 group being heavier than females.

2.4.4 Effects of Growth Rate on Broiler Welfare

Slowing down the growth rate of broilers improves the bird's feather coverage and feather cleanliness. Feather coverage is an important component of the bird welfare (Nicol et al., 2006; Tactacan et al., 2009; Lay et al., 2011). In our experiment, the group of slow-growing broilers exhibited consistently lower average surface temperatures and bare skin ratios on both the belly and back in comparison to the medium-growing and standard broilers. The impact of feed restriction leads to reduced dietary energy and protein intake, consequently slowing down both weight gain and feather development (Moreira et al., 2006). It is crucial to highlight that when comparing feather coverage among broilers with different growth rates, the comparison is made at the same weight but at different ages. This discrepancy in feather growth can be attributed to the extended duration required by slow-growing birds to reach 2 and 3 kg of body weight, resulting in a more robust feather development compared to their faster-growing counterparts. Consequently, slower-growing broilers consistently benefit from additional time to grow more feathers, offsetting the impact of feed restriction. This insight underscores the nuanced interplay between ages, weight, and feather development in broilers subjected to feed restriction. Plumage cleanliness is important for thermoregulation. When feathers become wet or clumped by litter, the feathers lose their protective properties and harm broiler welfare (Saraiva et al., 2016). Feather cleanliness was significantly improved with a decrease in growth rate, which may be related to the increased activity level of chickens due to feed restriction. Birds under feeding restriction have been reported to exhibit more walking, pecking, and less lying behavior (Nielsen et al., 2003; Trocino et al., 2020; Yan et al., 2021).

Slower-growing birds had lower gait scores, confirming that the reduction in growth rate improved gait scores. The higher activity index in the slower-growing group also suggested that increasing the activity level of the birds improved leg health. Similar results were reported by Brickett et al. (2007).

The average gait score for each group in this trial was within the score of 1, which is lower than that reported by Sanotra et al. (2001). Significant differences in movement and skeletal pathology were observed when broiler gait scores were higher than 3, which is generally considered a welfare issue (Sørensen et al., 2000). Although litter quality (moisture content) deteriorated with the rearing period's duration, as Bergmann et al. (2016) reported, the growth rate in this study had no significant effect on footpad dermatitis. Excessive litter moisture, rather than the growth rate, has been reported to be the main cause of footpad dermatitis (de Jong et al., 2014; Taira et al., 2014). Previous studies have shown no significant correlation between bone-breaking strength and gait scores (Yalcin et al., 1998; Brickett et al., 2007; Ruiz-Feria et al., 2014). Slowing growth to medium growth produced the strongest bones, which is similar to the results reported by Van Wyhe et al. (2014) Controlling the growth rate through diet (restricted diet protein and energy to 80% of NRC, compared to 60% and 100% NRC) can improve turkey's bone shear strength at 1kg. The cortical thickness and density in both proximal and distal regions of turkeys from different growth groups at the age of 111 days show no significant differences. This suggests that bone maturation is more closely correlated with age than diet (Van Wyhe et al., 2014). In addition, Van Wyhe et al. (2014) also reported that turkeys with 80% NRC had a higher bone turnover rate compared with 60% NRC. This is probably due to the reduced nutrients in the diet rather than the age or feed intake differences. This report is consistent with our finding that the slow-growing broilers have the lowest bone strength, which may be evidence of nutritional deficiencies in slow-growing birds. Although our results show that the activity level of medium-growth broilers has increased, previous reports have shown that leg health is not significantly related to the activity level of broilers (Sherlock et al., 2010), the possible explanation is that commercial broilers may not engage in adequate exercise to make a difference in bone quality.

2.4.5 Effects of Stocking Density on Broiler Welfare

Footpad dermatitis and feather cleanliness are closely related to litter moisture (Shepherd and Fairchild, 2010; de Jong et al., 2014; Taira et al., 2014). Footpad dermatitis is a contact dermatitis found on the skin of the foot, most commonly on the central pad, sometimes also on the toes. The inflamed skin turns dark following contact with wet litter and consequently, deep skin lesions may occur. Increased stocking density increases broiler manure excretion, and water spillage onto the litter during drinking, which leads to increased litter moisture content (Astaneh et al., 2018). In addition, broilers at slaughter weights have plump feathers, and when they gather together, they inhibit heat and gas exchange between the litter and the air above the broiler (Saraiva et al., 2016), making the litter more difficult to dry, thereby increasing the footpad dermatitis score and reducing feather cleanliness. Decreasing stocking density improved bone strength. The tibia-breaking strength of the standard-growing-SD-40 group in this experiment was similar to the value determined by Liu et al. (2021). An increase in tibia-breaking strength accompanied by a decrease in stocking density has also been reported (Buijs et al., 2012; Vargas-Galicia et al., 2017; Ma et al., 2020), although the range of stocking densities in this experiment was small and the differences in bone strength values were not large.

2.4.6 Effects of Growth Rate on Broiler Behavior

Decreasing the growth rate can increase the activity level of broilers. Similar conclusions have also been reported in slower-growing broiler strains (Bokkers and Koene, 2003; Zupan et al., 2003; Rayner et al., 2020; Abeyesinghe et al., 2021) or restricted feeding studies (Trocino et al., 2020; Yan et al., 2021). Standard-growing birds prefer to lie down, while medium-growing and slower-growing broilers may be driven by hunger to forage and thus display more motor behaviors. In addition, slower-growing broilers weigh less than medium-growth and standard broilers at the same age. The results of the weight on broiler activity index also show that heavier broilers are less willing to move, and slow-growing broilers are therefore more active. Standard-growing broilers spent an average of 3.82 hours per day on feeding, and there were no significant differences between ages. The average daily feeding time of the medium-growing group was 4.61 hours, which was significantly higher than that of the slower-growing group by about 1.1

hours per day. Medium-growing birds spent about 5 hours per day around the feeder at 1 and 2 kg, then dropped to 3.9 hours per day at 3 kg. The slower-growing group was quite different. Due to the hunger, they feel, when they first adapt to restricted feeding at 1kg, they will spend 5.24 hours around the feeder, even if the food in the feeder has been eaten, and then the feeding time drops sharply to 3.0, and 2.2 at 2 and 3 kg, respectively. Feed-restricted birds might already know and be accustomed to having so little food each day that they prefer to move around to other areas after the limited food has been eaten. Research on food restriction in broiler breeders shows that restricting feed intake to 30% makes breeders more active, exhibiting more drinking, stereotyped pecking of empty feeders, litter pecking, and feather preening behaviors (Savory and Maros, 1993). This feed restriction can control their weight at 2.2kg at 21 weeks, helping them to maintain optimal reproductive status. However, long-term feed restrictions can also make them hungry, frustrated, and bored (Savory and Mann, 1999). Nielsen et al. (2011) reported that using high-fiber diets can reduce the hunger of broiler breeders for a limited time, which helps to improve breeders' welfare, but feeding high-fiber diets will cause broilers to drink more water, which will compromise the litter quality and reduce the welfare of breeders. Welfare concerns triggered by breeder feed restrictions may raise similar welfare concerns about feed restrictions for commercial broilers, but it may not be appropriate to transfer such concerns directly to broilers because breeders generally only provide one-third of their ad libitum feed intake to maintain optimal reproduction performance, which is very different from the lowest 57% and the more recommended 78% feed restriction in this experiment.

2.4.7 Effects of Stocking Density on Broiler Behavior

Different stocking densities had no significant effect on feeding time and activity index. We hypothesized that there would be a difference in the activity index of broilers due to the significant effect of SD on reducing gait scores and improving bone strength. However, no such difference was observed. This is consistent with a previous report by Son (2013), which also found no significant change in the time broilers spent resting, standing, and walking (SD 44 vs. 30 kg/m^2). However, there was a tendency towards increased activity index with reduced stocking densities. Broilers have plenty of space to move around when they are young, and the impact of stocking density on their behavior usually does not appear until birds get bigger and heavier. As broilers grow in weight, their motivation to move decreases significantly, and the relative distance of movement for larger birds becomes smaller (Sherlock et al., 2010). These could be the main reasons explaining why stocking density did not have a significant effect on the activity index.

2.5 Conclusions

Effects of growth rate and stocking density on broiler welfare and behavior were researched. The results show that slowing the growth rate of broilers can be achieved through feed restriction. Reducing the growth rate of broilers improved feather coverage, gait score, and increased activity index, although compromised the FCR and prolonged the production cycle and they may feel hungry and depressed. Additionally, reducing stocking density can improve bone strength, feather cleanliness, and footpad condition in broilers. Overall, this study can be valuable for the development of more sustainable and welfare-friendly practices in the broiler industry.

CHAPTER THREE

IMPACT OF STOCKING DENSITY ON WELFARE AND PERFORMANCE OF ROSS 708 AND COBB 700 BROILERS

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Abstract: Stocking density (SD) may affect broiler productivity and welfare. This study investigated the performance and welfare of Ross 708 and Cobb 700 broilers as affected by four SDs (27, 29, 32, and 44 kg/m^2) until day 56. A total of 432 birds per strain were used, with 10, 12, 14, and 18 birds per pen (1.1 m × 1.5 m), corresponding to the respective SDs. Each SD treatment comprised eight replicates. The target SD was

determined based on the projected market weight of 4 kg at 56 days of age. The average body weight (BW), feed intake, and feed conversion ratio (FCR) were measured biweekly. Welfare indicators (four broilers per pen), including gait score, feather cleanliness, feather coverage, body temperature, and footpad condition, were evaluated on days 28 and 56. Tibia strength (two broilers per pen) was measured on day 56. The results show that the BW and FCR of both broiler strains were not affected by SD. For both strains, the male broilers exhibited greater bone strength compared to that of the female broilers (129.06 lbf M vs. 91.70 lbf F for Ross, and 130.86 lbf M vs. 117.40 lbf F for Cobb), but the influence of SD on bone strength was found to be significant only for the Ross male broilers. Most welfare indicators were not affected by the SD on days 28 and 56 for either broiler strain, except for feather cleanliness in Ross broilers and footpad in Cobb broilers on day 56, which improved at lower SDs. Strong age and sex effects on the welfare indicators were also identified for both broiler strains. It was concluded that the SD is not a significant factor for broiler productivity, and it has a minor influence on broiler welfare compared to those of age and sex.
Keywords: broiler; stocking density; production performance; welfare

3.1 Introduction

The broiler industry is crucial in meeting the protein needs of the U.S. In 2022, per capita consumption of broiler products in the United States reached 44.1 kg, nearly double the consumption of beef or pork (USDA, 2022). To meet this high demand, 20.6 billion kg of live broilers were produced, with a total market value exceeding $66 billion (USDA, 2022). Additionally, the broiler industry significantly contributed to the U.S. economy, generating over 1.5 million jobs and adding $417 billion in economic impact (National Chicken Council, 2022a).

The broiler industry has made significant reductions in the environmental footprint (De Vries and de Boer, 2010) through improvements in productivity and efficiency over the years (Scanes, 2007), providing a vital source of affordable yet high-quality animal protein. Modern commercial broiler strains achieve nearly four times the body weight (**BW**) at day 56 compared to strains from six decades ago, along with a significant 40% improvement in feed conversion ratio (**FCR**) (Zuidhof et al., 2014a). However, rapid growth rates and intensive commercial production systems have raised growing public concerns regarding animal welfare (Hall and Sandilands, 2007; Cornish et al., 2016). Animal welfare is guided by the "five freedoms" (Webster, 1994), which Mellor (2016) later refined to include good nutrition, a healthy environment, good health, appropriate behavior, and a positive mental experience. Fast growth and efficiency-oriented feeding and management procedures have led to welfare issues in modern broilers (Bessei, 2006). Welfare issues in broilers are multifaceted, including lameness, footpad dermatitis, metabolic disorders (Bessei, 2006), poor environmental conditions (Tainika et al., 2023), etc. Some major welfare concerns are related to stocking density (**SD**). The SD may affect the litter and air quality which are major welfare, environmental, and management concerns at commercial broiler farms. High SD can restrict normal behavior in birds and lead to increased moisture in litter due to higher manure production per unit area. High moisture in the litter may foster microbial growth and increase ammonia levels in broiler houses (Rayner et al., 2020), consequently posing the risk of contact footpad dermatitis. Furthermore, high SD restricts heat transfer from the litter to the surrounding space, reducing the effectiveness of ventilation systems in managing heat stress (Bessei, 2006). Current recommended SD in the U.S. vary. The National Chicken Council (**NCC**) Broiler Welfare Guidelines, widely recognized as the standard for broiler welfare in the U.S. (Meyer et al., 2020), suggest a range of 32 to 44 kg/m^2. This range is based on the birds' final market weight and takes into account the space needed for broilers to express normal behaviors (National Chicken Council, 2022b). In comparison, animal welfare programs like Global Animal Partnership (**GAP**) recommended lower SDs, from 27 to 29 kg/m^2, to accommodate bird natural behaviors. According to Mckenna (2016) , only 600 farms (2.4%) out of 25,000 in the U.S. (National Chicken Council, 2021) have adopted GAP SDs for broiler production. The low adoption rate is possibly a result of high production costs. In addition, lower SD may also be associated with an increase in land use and a greater environmental footprint (Chan et al., 2022). Although lower SD has the potential to enhance welfare, it is essential to balance sustainable production, land use, environmental impact, and animal welfare.

The market share of commercial broilers is mainly dominated by Ross and Cobb strains in the United States (Dozier III and Gehring, 2014). The production responses of these two strains to SD are different. For Ross broilers raised to approximately 42 days of age, a SD of 13–15 birds/m^2 (equivalent to 32.5–37.5 kg/m^2, based on an average weight of 2.5 kg at 42 days) was recommended for achieving higher BWs (Son, 2013; Vargas-Galicia et al., 2017; Kryeziu et al., 2018) and lower FCR (Zuowei et al., 2011; Cengiz et al., 2015; Palizdar et al., 2017). In comparison, Cobb broilers raised at a density of 10 birds/m^2 (28.5 kg/m^2, calculated based on an average weight of 2.85 kg at 42 days) are suggested for maximizing BW (Houshmand et al., 2012; Yanai et al., 2018; Gholami et al., 2020). However, an SD of 17 birds/m^2 for Cobb broilers provided the best economic return of \$3.98/m^2, despite slightly lower BW and FCR (Gholami et al., 2020). Currently, there is a lack of research comparing the NCC and GAP-recommended SDs under similar production conditions. As such, investigating the impacts of NCC and GAP-recommended SDs on major broiler strains under similar production conditions is warranted.

The objective of this study was to evaluate the performance and welfare of Ross 708 and Cobb 700 broilers under different SDs. Precision livestock farming (**PLF**) technologies were utilized for an objective assessment of feather coverage through temperature analysis.

3.2 Materials and Methods

3.2.1 Birds, Diets, and Management

A total of 432 one-day-old straight run broilers from each strain (obtained from a local commercial hatchery) were raised under four stocking densities (SDs) of 27, 29, 32, and 44 kg/m^2 until day 56. To achieve these target SDs, identical pens (1.1 m x 1.5 m) were used, with varying numbers of birds per pen: 10, 12, 14, and 18 birds were housed to reach SDs of 27, 29, 32, and 44 kg/m^2, respectively. Each SD treatment had 8 replicates. The desired market body weight of 4 kg and the targeted SD were reached by day 56. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in September 2022 and the trial with Cobb 700 broilers in January 2023. All birds were reared under identical room conditions but housed separately in pens. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The feeder space and the number of drinkers were sufficient for all treatments based on the NCC recommendation (National Chicken Council, 2022b). Broilers were feather-sexed (for Ross birds) or vent-sexed (for Cobb birds) and distributed evenly in experimental pens at a 1:1 male-to-female ratio. Environment management, including light intensity and temperature, in the experimental room was adjusted according to the Ross 708 (Aviagen, 2018) and the Cobb 700 (Cobb, 2021) broiler management guides by bird age. At the study's commencement, each pen was bedded with Topsoil (Farmer Green topsoil, 0.14 cubic feet per pen) and covered with black mulch (Earthgro black wood shredded mulch, 0.04 cubic feet per pen) which remained unchanged throughout the study period. The topsoil and mulch used in this setup, rather than the shavings or rice hulls commonly used in the commercial poultry industry, serve a specific purpose. When using overhead cameras to monitor broiler activities, it is essential to distinguish the broilers from their background (the bedding material) for effective image processing of the recorded video. To achieve this, black topsoil and mulch are used instead of the light yellow shavings or rice hulls, providing a contrasting background against the white bodies of the broilers. Every two weeks, the total weight of all birds in each experimental pen was recorded. Feed intake was also measured biweekly to calculate the FCR. Broilers were reared to a target market weight of 4.0 kg for 56 days.

Four hundred thirty-two (432) day-old broilers from each strain (obtained from a local commercial hatchery) were raised under four SDs. The initial weight of the Ross 708 birds was about 38 g, and that of the Cobb 700 birds was about 36 g. Identical pens (1.1 m x 1.5 m) were stocked with 10, 12, 14, or 18 birds, and each SD treatment had 8 replicate pens. The target SD was determined based on the projected market weight of 4 kg at 56 days of age. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in September-October 2022 and the trial with Cobb 700 broilers in January-February 2023. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The feeder space and the number of drinkers were sufficient for all treatments based on the NCC recommendation (National Chicken Council, 2022b). Broilers were feather-sexed (for Ross birds) or vent-sexed (for Cobb birds) and distributed evenly in experimental pens at a 1:1 male-to-female ratio. Environment management, including light intensity and temperature, in the experimental room was adjusted according to the Ross 708 (Aviagen, 2018) and the Cobb 700 (Cobb, 2021) broiler management guides by bird age. At the study's commencement, each pen was bedded with topsoil (Farmer Green topsoil, 0.14 cubic feet per pen) and covered with black mulch (Earthgro black wood shredded mulch, 0.04 cubic feet per pen) which remained unchanged throughout the study period. Every two weeks, the total weight of all birds in each experimental pen was determined. Feed intake was also measured biweekly to calculate the FCR (feed intake/body weight gain). The empty feed bucket is weighed initially. Feed is added daily, and the amount provided is recorded. Every two weeks, the bucket with any remaining feed is weighed, and the total feed intake for the pen over that period is calculated by subtracting the final feed weight from the total feed added during the two weeks. Broilers were raised over a 56-day production cycle.

3.2.2 Welfare and Behavior Measurement

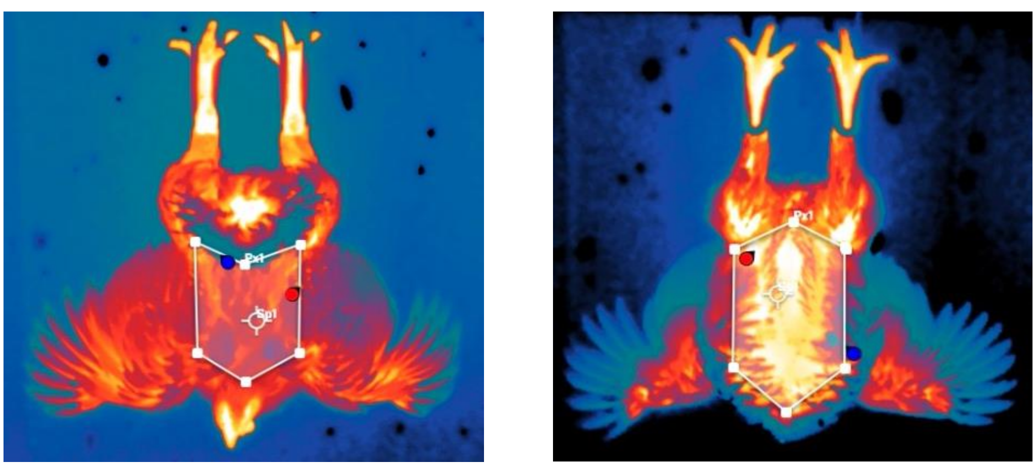
Broiler welfare was assessed manually based on feather cleanliness, footpad dermatitis, gait score, and bone strength according to Zhou et al. (2024), and the Welfare Quality® assessment protocol (Welfare Quality®, 2009). Scores for each indicator reflected varying degrees of welfare, with lower scores representing better conditions. For feather cleanliness, scores ranged from 0 (clean) to 3 (severely soiled), and for footpad dermatitis, the scale extended from 0 (no lesions) to 4 (severe lesions). Gait scores ranged from 0 (normal mobility) to 5 (unable to walk), with gait scores of 3 and above signaling a welfare concern (Sørensen et al., 2000).

Precision agriculture technologies, including thermography and image processing (Zhao et al., 2013), were utilized to measure bare-skin ratio and surface body temperature (**Figure 3.1**). For Ross and Cobb broilers at 28 days of age, a threshold of 33.5°C was used to calculate the bare skin ratio. At 56 days of age, the threshold was set at 35°C for the calculation. The back and belly parts correspond to the back and breast regions illustrated by Zhao et al. (2013).

At 28 days of age, four birds (two males and two females) per pen were randomly selected for assessments of feather cleanliness, footpad dermatitis, and gait score. At 56 days of age, four birds (two males and two females) were randomly selected for the same assessments. During measurements, selected birds were temporarily removed from their pens. A thermal camera (T865, Teledyne FLIR, Wilsonville, OR) was used to measure the back and belly surface temperatures, allowing for the calculation of the ratio of bare skin to feather coverage. Additionally, two broilers (one male and one female) per pen were euthanized using the carbon dioxide method for tibia-breaking strength assessment at the trial's conclusion. The left tibia breaking strength was measured using a three-point bending method with an MTS Alliance RT/30 apparatus (MTS Systems Corporation, Eden Prairie, MN), maintaining a 4 cm distance between the two supporting points (Zhou et al., 2024). All procedures followed the guidelines in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (Federation of Animal Science Societies, 2010) and were approved by the University of Tennessee's Institutional Animal Care and Use Committee (IACUC Protocol #2876-1221).

3.2.3 Statistical Analysis

All statistical analyses were performed using JMP, version 16.0.0 (SAS Institute, Cary, NC). A Randomized Complete Block Design was employed, with SDs of 27, 29, 32, and



(**a**) (**b**)

Figure 3.1 These thermal images depict a Cobb broiler (SD-44 treatment, Pen 31, Bird #5) on day 56. (**a**) A thermal image of the broiler's back, with the white polygon outlining the back area. Using a 35 °C threshold, the average temperature of the area was calculated to be 25.4 °C, and no bare skin was detected (0% bare-skin ratio). (**b**) A thermal image of the broiler’s belly, with the white polygon outlining the belly area. With the same 35 °C threshold, the average temperature was measured at 34.2 °C, and the bare-skin ratio was 55.5%. The red dots in the figure indicate the highest temperature points within the selected range, while the blue dots represent the lowest temperature points. These measurements were automatically determined using the "FLIR Thermal Studio Pro" software. Any overlapping content in the figure was generated automatically by the software's measurement tools and can be disregarded.

44 kg/m^2, each having eight replications. Broilers were randomly selected at different ages, meaning that the individuals selected at days 28 and 56 were not necessarily the same. A Mixed Analysis of Variance (**ANOVA**) was used to assess the impact of SD on continuous variables (bone breaking strength, average temperature, and bare skin ratio), with pens as the random block effect. All scored variables including gait score, footpad dermatitis, feather coverage, and feather cleanliness were analyzed using a Mixed ANOVA on ranks with pens as the random block effect to assess the effect of SD. Tukey’s HSD test was used for post-hoc pairwise comparisons, with significance set at the 0.05 level, following the calculation of least squares means. The normality of residuals was assessed using the Shapiro-Wilk normality test. Additionally, the Kruskal-Wallis test was utilized to evaluate differences between ages (days 28 and 56) in scoring and continuous variables, with significance set at $P<0.05$.

3.3 Results

The intention of this study was not to compare the Ross 708 and Cobb 700 strains, but rather to evaluate the responses of each strain independently. Despite our efforts to maintain similar personnel, management, and environmental conditions for both strains, some variation in management was inevitable. Furthermore, breeder hen age plays a crucial role in the performance of their offspring. Since we only had one batch of chicks from each strain without considering their parent age, it would neither be feasible nor appropriate to compare them due to the lack of replication.

3.3.1 Effects of SD on body weight and FCR

Table 3.1 shows the effects of SD on BW and FCR for Ross and Cobb broilers. Stocking density did not significantly affect the BW and FCR of Ross 708 and Cobb 700 broilers. At 28 days, Ross 708 broilers had an average weight of 1.01 kg (P=0.57) and an FCR of 1.81 (P=0.57). At 56 days, Ross birds reached an average weight of 3.59 kg (*P*=0.57), with an FCR of 1.90 (*P*=0.57). Cobb broilers weighed 1.42 kg at day 28 (*P*=0.69), with an FCR of 1.62 (*P*=0.15). By day 56, their average BW had increased to 4.31 kg (*P*=0.15). Due to accidental data missing, it was not possible to calculate FCR on day 56. The significant differences in weight and FCR can be attributed to the environmental

Table 3.1 Effect of stocking density (SD, kg/m^2) on the body weight (BW, kg) and feed conversion ratio (FCR) of Ross 708 and Cobb 700 broilers.

			Ross 708				
BW (kg) or FCR	SD 27	SD 29	SD 32	SD 44	Average	Std Error	P-value
BW (Day 14)	0.33	0.34	0.33	0.33	0.33	<0.01	0.35
BW (Day 28)	1.00	1.10	0.97	0.97	1.01	0.02	0.48
BW (Day 42)	2.10	2.06	2.02	2.06	2.06	0.04	0.61
BW (Day 56)	3.66	3.56	3.54	3.60	3.59	0.07	0.57
FCR (Day 0-28)	1.83	1.77	1.75	1.88	1.81	0.03	0.06
FCR (Day 0-56)	1.92	1.93	1.89	1.87	1.90	0.03	0.57
			Cobb 700				
BW (kg) or FCR	SD 27	SD 29	SD 32	SD 44	Average	Std Error	P-value
BW (Day 14)	0.39	0.40	0.40	0.39	0.40	0.01	0.40
BW (Day 28)	1.44	1.40	1.42	1.41	1.42	0.02	0.69
BW (Day 42)	2.80	2.80	2.77	2.67	2.76	0.05	0.20
BW (Day 56)	4.38	4.35	4.35	4.15	4.31	0.08	0.15
FCR (Day 0-28)	1.64	1.66	1.56	1.63	1.62	0.03	0.15

conditions during rearing: the Ross poultry was raised in hot weather, while the Cobb poultry was raised in cold weather. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in September-October 2022 and the trial with Cobb 700 broilers in January-February 2023.

3.3.2 Effects of SD, Sex, and SD by Sex Interactions on Bone Breaking Strength

Table 3.2 and

Table 3.3 show the effects of SD, sex, and the SD by sex interactions on bone breaking strength for Ross and Cobb broilers. Reducing the SD from 32 to 27 reduced the bone breaking strength of male Ross broilers from 142.95 to 101.82 lbf (P=0.01), while the bone strength of female Ross birds was not affected by SD with an average bone breaking strength of 91.70 lbf. There was no interaction effect of SD and Sex on Cobb broilers (P=0.79). The bone strength of Ross (average 110.38 lbf, P=0.14) and Cobb (average 124.12 lbf, P=0.11) broilers was not affected by SD. The bone strength of male broilers was higher than that of females for both Ross (37.36 lbf higher, P<0.01) and Cobb (13.46 lbf higher, P<0.01) birds.

3.3.3 Effects of SD on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare Skin Ratio

Table 3.4 and **Table 3.5** show the effects of SD on gait score, footpad dermatitis, feather cleanliness, back and belly temperature, and bare skin ratio for Ross and Cobb broilers. The welfare values in these tables represent the average welfare scores for birds under each treatment.

For Ross 708 broilers, the gait score (0.31, *P*=0.93) and footpad dermatitis (1.84, *P*=0.77) on day 28 and the gait score (1.36, *P*=0.38) and footpad dermatitis (1.19, *P*=0.08) on day 56 were not affected by SD. Lowering the SD improved feather cleanliness for SD-27 (1.34), SD-29 (1.41), and SD-32 (1.59) groups compared with SD-44 (2.19) birds on day 56 (*P*<0.01). On day 28, SD did not affect back or belly temperature, or bare skin ratio. The belly temperature was 4.68 °C higher, and the bare skin ratio was 43.85% higher than the back. Similarly, on day 56, SD had no significant effect on these parameters, with the belly temperature 6.94 °C higher and the bare skin ratio 53.53% higher than the back.

Table 3.2 Effects of stocking density (SD, kg/m^2), sex, and SD by sex interaction on Ross 708 broiler's bone breaking strength (lbf).

Effect of SD on bone strength of Ross						
SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
99.19	114.63	116.33	111.36	110.38	5.65	0.14
Effect of sex on bone strength of Ross						
	Male		Female		Std Error	*P*-value
	129.06^a		91.70^b		3.89	<0.01
SD by sex interaction effects of Ross						
	SD 27	SD 29	SD 32	SD 44	Std Error	*P*-value
Male	101.82^{bc}	135.49^{ab}	142.95^a	135.99^{ab}	7.72	0.01
Female	96.56^c	93.78^c	89.72^c	86.73^c		

$^{a, b, c}$ Means in the same row with no common superscripts differ (P<0.05).

Table 3.3 Effects of stocking density (SD, kg/m2), sex, and SD by sex interaction on Cobb 700 broiler's bone breaking strength (lbf).

Effect of SD on bone strength of Cobb

SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
120.27	131.98	116.07	128.16	124.12	5.02	0.11

Effect of sex on bone strength of Cobb

Male	Female	Std Error	*P*-value
130.86[a]	117.40[b]	3.55	<0.01

SD by sex interaction effects of Cobb

	SD 27	SD 29	SD 32	SD 44	Std Error	*P*-value
Male	125.64	138.58	120.13	139.11	7.09	0.79
Female	114.89	125.40	112.02	117.21		

[a, b] Means in the same row with no common superscripts differ (P<0.05).

Table 3.4 Effects of stocking density (SD, kg/m2) on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare skin ratio (%) of Ross 708 broilers. Scores of feather cleanliness, gait score, and footpad dermatitis were determined following the Welfare Quality® (2009) assessment protocol.

Measurement items			**Ross 708**				
On day 28	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
Gait score	0.31	0.34	0.32	0.25	0.31	0.09	0.93
Footpad	1.84	2.16	1.91	2.16	1.84	0.25	0.77
Feather cleanliness	0.06	0.00	0.00	0.03	0.06	0.03	0.35
Back temperature	31.96	31.88	32.68	32.46	32.25	0.37	0.36
Belly temperature	36.62	36.99	37.21	36.91	36.93	0.18	0.17
Back skin ratio	19.73	19.27	27.25	22.50	22.19	3.15	0.28
Belly skin ratio	64.61	65.77	69.08	64.69	66.04	1.89	0.32
On day 56	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
Gait score	1.56	1.16	1.50	1.22	1.36	0.16	0.38
Footpad	0.94	1.09	1.22	1.50	1.19	0.15	0.08
Feather cleanliness	1.34[b]	1.41[b]	1.59[b]	2.19[a]	1.63	0.15	<0.01

Back temperature	25.03	24.80	25.15	24.89	24.97	0.28	0.82
Belly temperature	31.75	31.82	32.23	31.82	31.91	0.24	0.46
Back skin ratio	2.35	3.29	3.49	3.30	3.11	0.84	0.77
Belly skin ratio	54.49	55.66	59.43	56.99	56.64	1.98	0.35

[a, b] Means in the same row with no common superscripts differ (P<0.05).

Table 3.5 Effects of stocking density (SD, kg/m2) on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare skin ratio (%) of Cobb 700 broilers.

Measurement items				**Cobb 700**			
On day 28	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
Gait score	0.41	0.19	0.56	0.47	0.41	0.12	0.18
Footpad	1.16	1.47	1.53	1.56	1.43	0.26	0.62
Feather cleanliness	0.72	0.44	0.47	0.63	0.56	0.13	0.47
Back temperature	31.29	30.28	31.23	30.63	30.86	0.38	0.20
Belly temperature	35.12	34.52	34.66	34.67	34.74	0.28	0.45
Back skin ratio	28.91	22.93	30.64	26.80	27.32	3.35	0.41
Belly skin ratio	71.61	66.85	65.93	66.10	67.62	2.37	0.30
On day 56	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*P*-value
Gait score	1.97	2.00	2.00	1.87	1.96	0.13	0.89
Footpad	1.22^{b}	1.81^{ab}	1.86^{ab}	2.27^{a}	1.79	0.24	0.04
Feather cleanliness	2.09	2.44	2.22	2.45	2.30	0.18	0.57
Back temperature	24.55	24.48	24.62	24.33	24.50	0.24	0.84

Belly temperature	32.00	31.48	31.62	31.58	31.67	0.28	0.57
Back skin ratio	0.80	0.93	0.96	0.48	0.80	0.25	0.55
Belly skin ratio	59.03	55.69	56.97	57.21	57.23	2.82	0.87

[a, b] Means in the same row with no common superscripts differ (P<0.05).

For Cobb 700 broilers, SD affected footpad on day 56 (P = 0.04), with birds at 27 kg/m² (1.22) had healthier footpads than those at 44 kg/m² (2.27). The gait scores, feather cleanliness, back and belly temperature and bare skin ratio of Cobb were unaffected by SD on either day 28 or day 56. On day 28, belly temperature was 3.88 °C higher, and the belly bare skin ratio was 40.3% greater than the back. Similarly, on day 56, belly temperature exceeded back temperature by 7.17 °C, and the belly bare skin ratio was 56.43% higher than the back.

3.3.4 Effect of Age on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare Skin Ratio

Error! Not a valid bookmark self-reference. highlights the significant effects of age on broiler welfare indicators. From day 28 to day 56, footpad health in Ross birds improved by 0.78, while in Cobb birds, it declined by 0.36 (both P<0.01). Gait scores worsened, and feather cleanliness declined for both Ross and Cobb broilers over this period.

However, average back and belly temperatures, along with bare skin ratios, decreased, indicating improved feather coverage with age (all P<0.01).

3.3.5 Effect of Sex on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare Skin Ratio

Table 3.7 illustrates the effects of sex on welfare indicators in Ross 708 and Cobb 700 broilers. At 28 days of age, no significant differences were observed between males and females for any welfare parameters in either strain. By 56 days of age, however, several significant differences emerged. In Ross 708 broilers, females exhibited lower back temperatures (24.58°C vs. 25.35°C; P<0.01) and a reduced back skin ratio (1.70% vs. 4.52%; P<0.01) compared to males. No significant differences were found in gait score, footpad condition, feather cleanliness, belly temperature, or belly skin ratio for Ross 708 broilers. In Cobb 700 broilers at 56 days of age, females showed improved gait scores (1.78 vs. 2.14; P=0.01), healthier footpad scores (1.63 vs. 1.95; P=0.04), and cleaner feathers (2.21 vs. 2.39; P=0.04) compared to males. However, no significant differences were observed between males and females for back temperature, belly temperature, back skin ratio, or belly skin ratio in Cobb 700 broilers.

Table 3.6 Effects of age on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare skin ratio (%) of Ross 708 and Cobb 700 broilers.

Measurement items	**Ross 708**			
	Day 28	Day 56	Std Error	*P*-value
Gait score	0.30[b]	1.36[a]	0.16	<0.01
Footpad	1.97[a]	1.19[b]	0.10	<0.01
Feather cleanliness	0.02[b]	1.63[a]	1.27	<0.01
Back temperature	32.24[a]	24.97[b]	0.95	<0.01
Belly temperature	36.93[a]	31.90[b]	0.07	<0.01
Back skin ratio	22.19[a]	3.11[b]	0.11	<0.01
Belly skin ratio	66.04[a]	56.64[b]	0.05	<0.01
Measurement items	**Cobb 700**			
	Day 28	Day 56	Std Error	*P*-value
Gait score	0.41[b]	1.95[a]	0.06	<0.01
Footpad	1.43[b]	1.79[a]	0.12	<0.01
Feather cleanliness	0.56[b]	2.30[a]	0.08	<0.01
Back temperature	30.86[a]	24.49[b]	0.15	<0.01
Belly temperature	27.32[a]	0.81[b]	1.20	<0.01
Back skin ratio	34.74[a]	31.67[b]	0.13	<0.01
Belly skin ratio	67.62[a]	57.24[b]	1.13	<0.01

a, b Means in the same row with no common superscripts differ (P<0.05).

Table 3.7 Effects of Sex on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare skin ratio (%) of Ross 708 and Cobb 700 broilers.

Measurement items	Ross 708				Cobb 700			
On day 28	Male	Female	Std Error	*P*-value	Male	Female	Std Error	*P*-value
Gait score	0.33	0.28	0.06	0.58	0.38	0.44	0.09	0.37
Footpad	2.01	1.92	0.16	0.65	1.27	1.59	0.16	0.07
Feather cleanliness	0.02	0.03	0.02	0.58	0.63	0.50	0.08	0.22
Back temperature	32.04	32.45	0.28	0.34	30.65	31.06	0.08	0.30
Belly temperature	36.96	36.91	0.12	0.74	30.65	31.06	0.27	0.87
Back skin ratio	20.31	24.07	2.53	0.34	25.26	29.38	0.27	0.23
Belly skin ratio	67.07	65.00	1.32	0.26	34.76	34.73	0.17	0.72
On day 56	Male	Female	Std Error	*P*-value	Male	Female	Std Error	*P*-value
Gait score	1.45	1.27	0.12	0.38	2.14[a]	1.78[b]	0.09	0.01
Footpad	1.17	1.20	0.12	0.78	1.95[a]	1.63[b]	0.15	0.04
Feather cleanliness	1.63	1.64	0.09	0.82	2.39[a]	2.21[b]	0.10	0.04
Back temperature	25.35[a]	24.58[b]	0.18	<0.01	24.56	24.42	0.14	0.43
Belly temperature	31.94	31.87	0.15	0.73	31.50	31.83	0.17	0.13
Back skin ratio	4.52[a]	1.70[b]	0.60	<0.01	0.97	0.62	0.18	0.19
Belly skin ratio	56.71	56.57	1.30	0.93	55.40	59.05	1.70	0.06

a, b Means in the same row with no common superscripts differ (P<0.05).

3.4 Discussion

3.4.1. Effects of Stocking Density on Body Weight and FCR

The SD had no significant effect on the BW or FCR of Ross and Cobb broilers, with final BW averaging 3.59 kg for Ross and 4.31 kg for Cobb birds. These results align with Weimer et al. (2020) also found that the broiler's BW (2.714 kg) and FCR (1.55) on day 42 were unaffected by SD, specifically comparing with 29 kg/m² and 37 kg/m². These findings suggest that precise control of SD can allow poultry producers to optimize space usage without compromising growth performance. However, contrasting studies have reported that higher SDs can negatively impact broiler BW and feed intake under specific conditions (Abudabos et al., 2013; Yanai et al., 2018; Goo et al., 2019; Li et al., 2019b; Gholami et al., 2020). Son et al. (2022) demonstrated that increased densities (23–26 birds/m²) under heat stress conditions led to reduced BW and increased oxidative stress markers. Consistent with this, Goo et al. (2019) found that high SDs combined with heat stress significantly impaired broiler growth performance. These findings highlight the importance of considering environmental factors, such as temperature and ventilation, alongside SD. Differences in results across studies may stem from variations in feeding strategies, rearing environments, or genetic strains. As noted by Ekstrand and Carpenter (1998), the impact of SD on broiler performance is strongly influenced by environmental conditions, such as litter quality and ventilation. Therefore, a holistic management approach addressing both density and environmental variables is essential to mitigate potential adverse effects. Our findings reinforce the efficacy of SD recommendations, such as the NCC's recommended 44 kg/m² (National Chicken Council, 2022b). Adherence to such guidelines supports consistent production outcomes while maintaining bird welfare. This approach allows producers to optimize economic returns without negatively affecting animal welfare or growth performance, making it a practical strategy for sustainable poultry production.

3.4.2. Effects of SD, Sex, and SD by Sex Interactions on Bone Breaking Strength

Generally speaking, broilers raised at higher densities exhibit lower bone breaking strength compared to those raised at lower densities (Hall, 2001; Buijs et al., 2012; Vargas-Galicia et al., 2017; Ma et al., 2020). The limited space affects their movement and bone development, leading to weaker bones and higher susceptibility to leg issues (Bradshaw et al., 2002; Ma et al., 2020). However, lowering SD was sometimes related to compromised leg health. Tablante et al. (2003) reported that reducing SD from 20 to 10 birds/pen increased the incidence of tibial dyschondroplasia by 10.6%. Buijs et al. (2009) found an unexpected latency to lie improvement (related to better leg health and walking ability) in birds under SD of 47 kg/m^2 compared to birds at SD from 23 to 41 kg/m^2. The significance reported in this study was from males, reducing the SD from 32 to 27 reduced the bone breaking strength of male Ross broilers, while the bone strength of female Ross birds was not affected by the reduction of SD. Although broilers raised at lower SD had more space to move around, the lack of competition for feeding between male broilers due to the decreased SD may be the reason for the reduced bone breaking strength.

The bone strength of Cobb broilers was not affected by SD. This is inconsistent with the previous report that increasing SD will reduce bone breaking strength at around 45 days of age (Buijs et al., 2012; Vargas-Galicia et al., 2017; Zhou et al., 2024). Broilers selected at different ages for measuring the bone strength may explain this discrepancy. The bone breaking strength in this experiment was measured at 56 days of age, the additional 11 days may have allowed bones to become stronger and eliminated the potential impact of SD. The bone breaking strength of the Cobb birds at 56 days of age in this experiment was 124.12 lbf, which was higher than the 91.25 lbf of the Cobb at 45 days reported by Zhou et al. (2024). The bone strength of male broilers was higher than that of females for both Ross and Cobb birds. This is in line with our expectations and consistent with previously reported results (Rath et al., 1999; Applegate and Lilburn, 2002; Alkhtib et al., 2021). Mönch et al. (2020) suggested that hormonal differences, which affect skeletal development, might explain the variance in bone strength between male and female broilers.

3.4.3. Effects of SD on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare Skin Ratio

Reducing SD improved Ross's feather cleanliness at 56 days. Feathers serve as a protective layer, maintaining body temperature and shielding birds from physical damage (Lingham, 2019). Clean feathers are a critical welfare indicator, and improving feather cleanliness through optimized SD could enhance overall welfare. Higher SD, such as SD-44 in Ross broilers, compromised feather cleanliness at 56 days, likely due to overcrowding. Overcrowding increases feeding, drinking, and excretion activities, leading to elevated moisture and ammonia levels in litter, which are known to negatively affect feather and footpad health (Stamp Dawkins et al., 2004; Meluzzi et al., 2008). Adjusting SD during specific growth phases may help maintain better feather and litter quality, minimizing welfare issues.

Lowering the SD improved Cobb's footpad health at 56 days, as higher SD was associated with wetter litter, compromising footpad conditions (Stamp Dawkins et al., 2004). Integrating litter management systems to control moisture and ammonia levels could enhance footpad health outcomes, reducing potential welfare issues. In contrast, the footpad health of Ross broilers was unaffected by SD. Other welfare indicators, including gait score, back and belly temperature, and bare skin ratio, were not significantly influenced by SD in either strain. These findings suggest that welfare is generally maintained well within the SD-44 kg/m² recommended by NCC (National Chicken Council, 2022b).

3.4.4. Effects of Age and Sex on Broiler Welfare

Age significantly impacts all welfare indicators in broilers. As broilers mature, feather coverage increases, but feather cleanliness declines, and gait scores worsen due to increasing BW and pressure on joints. These trends align with typical broiler growth patterns and are consistent with findings from Taira et al. (2014). The average footpad dermatitis score of Ross broilers was lower at 56 days than at 28 days, likely due to changes in litter conditions. At 28 days, wet litter adhered to the birds' feet, contributing to footpad dermatitis. By 56 days, litter naturally dried and caked litter fell off, allowing partial healing of footpad damage without manual intervention. Although litter moisture was not measured in this study, this observation underscores the importance of litter management in controlling footpad dermatitis. Similar findings by Taira et al. (2014) suggest that transitioning broilers from wet to dry litter slows the progression of footpad issues. Future studies should include continuous monitoring of litter moisture to confirm its relationship with footpad health and overall welfare. These findings reinforce the role of litter management in mitigating footpad issues and improving broiler welfare as birds age.

The impact of sex on broiler welfare indicators becomes increasingly significant as birds age, with females consistently showing advantages across multiple welfare parameters by 56 days of age. Females tend to have lighter BW, which reduces the stress on their legs and likely contributes to improved gait scores and footpad condition. These differences may result from inherent physiological or behavioral variations between sexes, including disparities in BW, activity levels, and metabolism. Given that commercial broilers are typically raised as mixed-sex flocks, managing production separately for males and females may not be practical. However, understanding these sex-based differences can inform strategies to optimize overall flock welfare.

3.4.5. Limitations and Future Research Directions

The range of SDs tested may not fully capture the variety found in commercial settings, and trials with higher densities could offer additional insights. Further exploring practical applications such as tailored density strategies across different growth stages can provide producers with actionable insights. Developing adaptable management systems that adjust densities dynamically based on age or seasonal conditions could enhance production efficiency. The trials for Ross 708 and Cobb 700 were conducted months apart, which might have introduced seasonal variability, affecting results. While some welfare indicators were measured objectively, others, like gait score and feather cleanliness, were manually assessed, introducing subjectivity. Additionally, litter quality, which significantly impacts welfare, was not systematically measured.

Future research should explore a broader range of SDs, both higher and lower, to identify welfare and performance thresholds. More precise measurements of litter conditions, including moisture and ammonia levels, could provide deeper insights. Cross-seasonal studies would help assess the interaction between SD and varying environmental conditions. Incorporating automated technologies for welfare assessment, such as image analysis, could reduce bias and improve accuracy.

3.5 Conclusions

This study comparatively investigated the effect of SD on the production performance and welfare of Ross 708 and Cobb 700 broilers. Results indicated that reducing SD improved feather cleanliness in Ross broilers and footpad health in Cobb broilers on day 56, although it led to a decrease in bone breaking strength in male Ross birds. However, other key production parameters, including BW, FCR, gait score, body temperature, and bare skin ratio, were unaffected by variations in SD. Overall, the current SD practices commonly used by farmers did not compromise the production performance or overall welfare of Ross and Cobb broilers, suggesting that existing guidelines remain effective in balancing productivity and animal welfare.

CHAPTER FOUR

IMPACT OF STOCKING DENSITY ON ACTIVITY INDEX, STRETCHING AND PREENING BEHAVIOR OF ROSS 708 AND COBB 700 BROILERS

Abstract: Stocking density (SD) is crucial for profitability and impacts broiler welfare. The activity index, stretching, and preening behaviors in broilers reflect their comfort, welfare, and environmental suitability, offering valuable insights into their welfare. This study investigated the activity index% (AI%), stretching, and preening behaviors of Ross 708 and Cobb 700 broilers as affected by four SDs (27, 29, 32, and 44 kg/m²) on day 28 and 56. The target SD was determined based on the projected market weight of 4 kg at 56 days of age. Broilers activities were monitored through the computer vision system continuously. Activity index, stretching and preening behavior of broilers at the fourth and eighth weeks of age were analyzed. Results showed that Ross broilers raised at 44 kg/m² increased their activity index (AI) and stretching behavior at 28 days ($P < 0.01$) but reduced AI at 56 days ($P < 0.01$) likely due to crowding. Stretching ($P = 0.12$) and preening ($P = 0.89$) behavior were unaffected by SD on day 56. Ross broilers exhibited more stretching and preening in morning than afternoon on day 28. For Cobb broilers, increasing stocking density to 44 kg/m² slightly raised AI ($P < 0.01$) but significantly reduced stretching and preening behaviors ($P < 0.01$) on day 28. the AI ($P = 0.06$) and stretching ($P = 0.79$) behavior of Cobb were unaffected by SD on day 56. the AI, stretching and preening patten (by hour) of Cobb were relatively stable throughout the daytime. In conclusion, SD of 44 kg/m^2 promoted Ross's activity and expression of welfare-related behaviors in the early stage but had a negative impact on Cobb's welfare-related behaviors.

Keywords: broiler; stocking density; activity index; stretching; preening

4.1 Introduction

Natural behavior expression is a key metric in poultry welfare assessment (Webster, 2001), with preening and stretching recognized as essential comfort behaviors in poultry. These behaviors indicate that broilers are engaging in natural activities suited to their needs and therefore can serve as valuable welfare indicators. Stretching, involving the extension of one wing and leg on the same side, supports muscle tone, joint health, and overall well-being. A lack of stretching can signal health issues, particularly in leg health and skeletal development, as it often requires enough space for proper movement (Li et al., 2021). Preening, where broilers groom feathers with their beaks to distribute oil and remove dirt, dust, and parasites, is essential for feather maintenance and health (Zhao et al., 2020). Ahmed et al. (2018) examined the effects of stocking density on the welfare and behavior of Arbor Acres broiler chickens, highlighting that comfort-related behaviors, such as leg and wing stretching and preening, decreased as stocking density increased over the first five weeks. In particular, the control group at lower stocking density (12 birds/m^2) displayed a higher frequency of leg and wing stretching compared to the high-density group (20 birds/m^2), suggesting that greater space allows broilers more freedom to stretch comfortably. Preening, a key self-care behavior, also occurred less frequently in high-density environments. Broilers in crowded conditions engaged in significantly less preening than those in low-density environments, indicating that high stocking density may induce stress and limit natural self-care behaviors.

The frequency and duration of preening can reflect environmental suitability and welfare levels, these comfort behaviors are traditionally assessed manually and auditors based on industry protocols. While manual observation remains the standard, it is labor-intensive, time-consuming, and subjective, making it difficult to perform comprehensively across large facilities or over extended production cycles. However, advancements in Precision Livestock Farming (PLF) technologies, particularly computer vision, enable automated, continuous behavior measurement in commercial poultry production.

Automated systems like video-action recognition have shown promise for objectively estimating drinking time (Nasiri et al., 2024a) and automatically detecting and counting preening and stretching behaviors on commercial farms (Nasiri et al., 2024b). This technology uses machine learning algorithms to monitor and classify behaviors in digital images or video, offering objective, scalable assessment that supports animal welfare. Our research uses PLF technologies to simultaneously and continuously observe multiple welfare-related behaviors, collecting a large amount of data that cannot be achieved through human observation.

The objective of this study was to use precision agriculture techniques to evaluate how stocking density affects broiler activity index, stretching and preening behaviors, as well as the diurnal patterns of these welfare-related behaviors.

4.2 Materials and Methods

4.2.1 Birds, Diets, and Management

The birds, diets, and management used here were identical to those described in Chapter Three (3.2.1). Four hundred thirty-two (432) day-old straight run broilers from each strain were raised under four stocking densities (SDs) of 27, 29, 32, and 44 kg/m^2 until day 56. using identical 1.1 x 1.5 m pens with 10, 12, 14, and 18 birds per pen, respectively, for each SD treatment with 8 replicates. The desired market body weight of 4 kg and the targeted SD were reached by day 56. Each pen had a 36-cm tube feeder and three nipple drinkers, and broilers were evenly distributed by sex (1:1 ratio). Environmental management followed the Ross 708 (Aviagen, 2018) and the Cobb 700 (Cobb, 2021) broiler management guides.

4.2.2 Continuous Behavior Monitoring

High-performance security cameras (IP5M-B1186EB-28MM, Amcrest Technologies, Houston, TX) were installed approximately 3 meters above each pen to monitor broilers' activities. Each overhead camera covered 2 pens. The overhead camera recorded videos in the first 15 minutes of each hour from the start of the experiment to the end of the experiment. The activity index, as well as stretching and preening behaviors, were analyzed from videos recorded on days 28 and 56. On these days, broiler chickens were provided with lights from 7:00 to 22:59, and lights were turned off from 23:00 to 6:59. Activity indices were measured by overhead cameras installed over each pen. Images were extracted from the video every 0.2 seconds to analyze the activity index of broilers (Yang et al., 2020).

The automated video-action recognition algorithm developed by Nasiri et al. (2024b) was used to automatically detecting and counting preening and stretching behaviors. The algorithm demonstrated identification performance with an accuracy of 96.7% (Nasiri et al., 2024b).

4.3 Results

4.3.1 Effect of Stocking Density, Age on the Activity Index% and the 24-hour AI% Patterns.

The results in **Table 4.1** and **Figure 4.1** indicate that high stocking density (SD-44) increases the activity index% (AI%) of Ross 708 broilers at 28 days of age, suggesting that crowding may stimulate movement in younger birds. However, as broilers grow to 56 days, the space requirement per bird rises, resulting in a significantly lower overall AI% for the SD-44 group compared to other stocking densities, as space constraints become more restrictive. In terms of hourly AI% patterns, at 28 days of age, Ross 708 broilers show increased activity in the early hours after the lights turn on (7:00) and before they turn off (22:59), aligning with their diurnal activity pattern. By 56 days of age, nighttime AI% levels are higher than those at 28 days, likely due to age-related behavioral changes. Additionally, daytime AI% at 56 days remains relatively steady across hours, with minimal fluctuations, indicating a more uniform activity pattern as the birds mature.

For Cobb 700 broilers, as shown in **Table 4.2** and **Figure 4.2**, high stocking density (SD-44) at 28 days of age led to increased activity (AI%), indicating that crowding stimulated movement in younger birds. By 56 days, however, the influence of stocking density on AI% diminished, with the average AI% decreasing from approximately 3% at 28 days to around 2% at 56 days. This reduction in activity was primarily due to a lower AI% during the daytime at 56 days. Additionally, Cobb broilers displayed relatively stable AI% levels

Table 4.1 The effect of stocking density (SD, kg/m^2), age on the activity index% (AI%) and the hourly AI% patterns of the Ross 708 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on AI% of Ross 708 on day 28

SD	27	29	32	44	Std Error	*P*-value
AI %	3.70^{b}	4.16^{b}	3.74^{b}	4.83^{a}	0.14	<0.01

The 24-hour AI% patterns of Ross 708 on day 28

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
AI %	0.86^{f}	0.78^{f}	1.09^{f}	0.52^{f}	0.71^{f}	0.49^{f}	7.47^{ab}	6.90^{abc}		
Hour	9	10	11	12	13	14	15	16		
AI %	5.81^{bcde}	5.51^{cde}	4.93^{de}	4.54^{e}	4.84^{de}	4.97^{de}	4.68^{e}	4.92^{de}	0.36	<0.01
Hour	17	18	19	20	21	22	23	24		
AI %	5.04^{cde}	6.67^{abcd}	5.81^{bcde}	6.63^{abcd}	8.07^{a}	5.67^{bcde}	0.75^{f}	0.90^{f}		

Effect of SD on AI% of Ross 708 on day 56

SD	27	29	32	44	Std Error	*P*-value
AI %	4.21^{ab}	4.16^{ab}	4.48^{a}	3.81^{b}	0.13	<0.01

The 24-hour AI% patterns of Ross 708 on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
AI %	2.33^{de}	2.15^{de}	1.98^{e}	2.28^{de}	1.88^{e}	1.59^{e}	4.46^{abc}	4.13^{bc}		
Hour	9	10	11	12	13	14	15	16		
AI %	4.28^{bc}	4.22^{bc}	3.75^{cd}	5.66^{ab}	5.62^{ab}	5.10^{abc}	5.15^{abc}	5.14^{abc}	0.31	<0.01
Hour	17	18	19	20	21	22	23	24		
AI %	5.08^{abc}	5.08^{abc}	5.23^{abc}	4.89^{abc}	5.49^{ab}	5.94^{a}	4.40^{abc}	4.13^{bc}		

Effect of age on AI% of Ross 708

Age	Day 28	Day 56	Std Error	*P*-value
AI %	4.11	4.16	0.07	0.55

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them (P<0.05).

Table 4.2 The effect of stocking density (SD, kg/m^2), age on the activity index% (AI%) and the 24-hour AI% patterns of the Cobb 700 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on AI% of Cobb 700 on day 28

SD	27	29	32	44	Std Error	*P*-value
AI %	2.76^{b}	2.88^{ab}	2.80^{b}	3.17^{a}	0.07	<0.01

The 24-hour AI% patterns of Cobb 700 on day 28

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
AI %	0.78^{e}	1.01^{e}	0.52^{e}	0.75^{e}	0.59^{e}	0.69^{e}	4.54^{ab}	4.69^{a}		
Hour	9	10	11	12	13	14	15	16		
AI %	4.33^{abc}	3.96^{abcd}	3.96^{abcd}	3.84^{abcd}	3.98^{abcd}	3.73^{bcd}	4.18^{abcd}	3.97^{abcd}	0.18	<0.01
Hour	17	18	19	20	21	22	23	24		
AI %	3.52^{cd}	3.33^{d}	3.66^{bcd}	3.66^{bcd}	4.16^{abcd}	4.16^{abcd}	0.79^{e}	0.87^{e}		

Effect of SD on AI% of Cobb 700 on day 56

SD	27	29	32	44	Std Error	*P*-value
AI %	2.16	2.13	2.01	2.17	0.05	0.06

The 24-hour AI% patterns of Cobb 700 on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
AI %	0.61^{e}	0.56^{e}	0.47^{e}	0.57^{e}	0.42^{e}	0.60^{e}	3.44^{a}	3.38^{ab}		
Hour	9	10	11	12	13	14	15	16		
AI %	3.06^{abcd}	2.68^{d}	2.70^{d}	2.77^{cd}	2.84^{bcd}	2.60^{d}	2.62^{d}	2.77^{cd}	0.11	<0.01
Hour	17	18	19	20	21	22	23	24		
AI %	3.31^{abc}	2.75^{cd}	2.82^{bcd}	2.91^{abcd}	3.18^{abcd}	2.79^{bcd}	0.58^{e}	0.38^{e}		

Effect of age on AI% of Cobb 700

Age	Day 28	Day 56	Std Error	*P*-value
AI %	2.90^{a}	2.12^{b}	0.08	<0.01

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them (P<0.05).

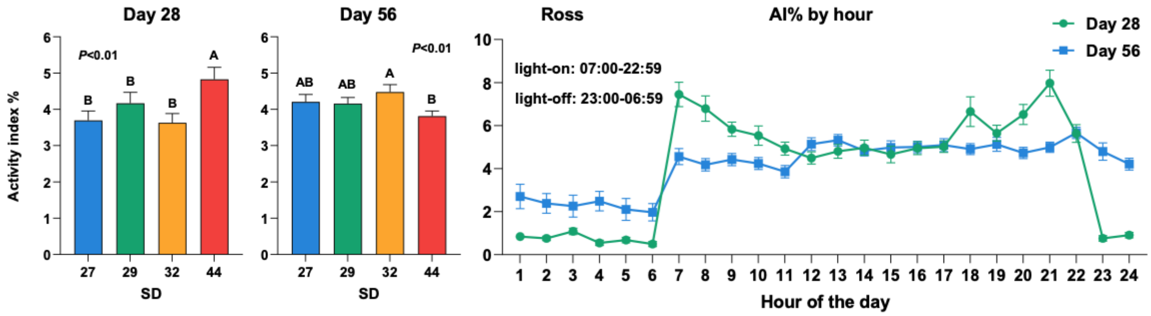


Figure 4.1 The effect of stocking density (SD, kg/m^2) on activity index% (AI%) of Ross 708 broilers on days 28 and 56, and the 24-hour AI% patterns for Ross on days 28 and 56.

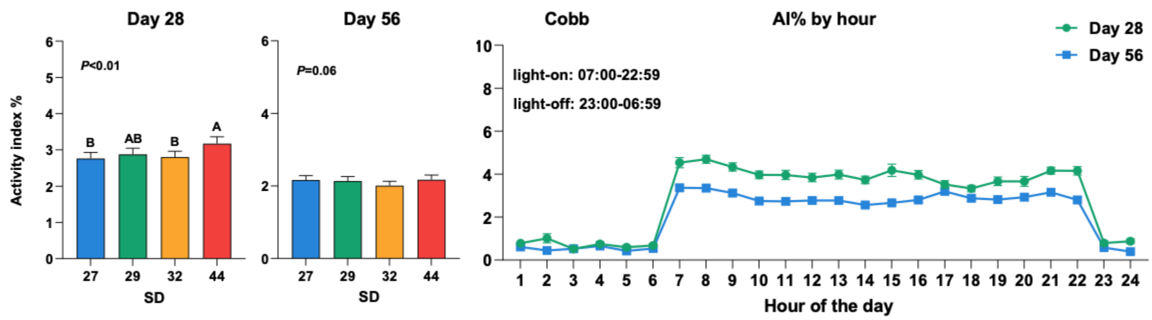


Figure 4.2 The effect of stocking density (SD, kg/m^2) on activity index% (AI%) of Cobb 700 broilers on days 28 and 56, and the 24-hour AI% patterns for Cobb on days 28 and 56.

throughout the day, without significant fluctuations, suggesting a consistent activity pattern across different stocking densities as they aged.

4.3.2 Effect of Stocking Density, Age on the Number of Stretching Behavior and the 24-hour stretching Patterns.

The results in

Table 4.3 and **Figure 4.3** indicate that increasing stocking density to 44 kg/m² at 28 days of age encourages more stretching behavior in Ross broilers, suggesting that higher density at a young age promotes movement. By 56 days, the stretching behavior of broilers was unaffected by SD. The average number of stretches decreased from 3.86 times per bird per hour at 28 days to 2.71 times at 56 days. At 28 days, broilers exhibited significantly more stretching behaviors immediately after the lights were turned on, with more activity observed in the morning than in the afternoon. Even during dark periods, broilers maintained an average of one stretch per hour.

For Cobb 700 broilers (see **preening behavior** among Ross broilers immediately after the lights are turned on, with more preening observed in the morning compared to the afternoon.

Table 4.3 The effect of stocking density (SD, kg/m^2), age on the number of stretching behavior (times per bird per hour) and the 24-hour stretching behavior patterns of the Ross 708 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on the number of stretching of Ross on day 28						
SD	27	29	32	44	Std Error	*P*-value
Stretching	3.16^{b}	3.70^{b}	3.64^{b}	4.95^{a}	0.21	<0.01

The 24-hour stretching patterns of Ross on day 28										
Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	1.35^{def}	1.03^{f}	2.28^{bcdef}	1.26^{def}	0.82^{f}	1.18^{ef}	4.76^{ab}	5.95^{a}		
Hour	9	10	11	12	13	14	15	16		
Stretching	6.47^{a}	5.85^{a}	6.28^{a}	5.97^{a}	6.42^{a}	5.38^{a}	4.22^{abc}	4.79^{ab}	0.52	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	4.65^{abc}	4.56^{abc}	4.41^{abc}	4.13^{abc}	3.95^{abcd}	3.79^{abcde}	2.00^{cdef}	1.24^{ef}		

Effect of SD on the number of stretching of Ross on day 56						
SD	27	29	32	44	Std Error	*P*-value
Stretching	2.33	2.66	2.82	3.05	0.21	0.12

The 24-hour stretching patterns of Ross on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	1.78^{bcd}	1.96^{bcd}	1.21^{bcd}	1.65^{bcd}	1.07^{bcd}	2.28^{bcd}	3.10^{bcd}	3.17^{bcd}		
Hour	9	10	11	12	13	14	15	16		
Stretching	3.44^{bcd}	3.16^{bcd}	3.69^{b}	6.74^{a}	3.78^{b}	3.47^{bcd}	2.34^{bcd}	2.78^{bcd}	0.52	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	3.05^{bcd}	3.75^{b}	2.25^{bcd}	2.22^{bcd}	2.86^{bcd}	3.60^{bc}	0.96^{cd}	0.83^{d}		

Effect of age on the number of stretching of Ross

Age	Day 28	Day 56	Std Error	*P*-value
Stretching	3.86^{a}	2.71^{b}	0.13	<0.01

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them (P<0.05).

Table 4.4 and **Figure 4.4**), high stocking density (SD-44) at 28 days of age led to a decrease in stretching (1.96), while the lower-density group (SD-29) exhibited the highest number (3.32) of stretches. This finding suggests strain-specific responses to stocking density. By 56 days of age, the stretching was unaffected by SD, with average stretching episodes decreasing from 2.48 at 28 days to 1.14 at 56 days. Additionally, Cobb broilers displayed no significant differences in stretching behavior between morning and afternoon hours throughout the day.

4.3.3 Effect of Stocking Density, Age on the Number of Preening Behavior and the 24-hour preening Patterns.

The results in **Table 4.5** and **Figure 4.5** indicate that increasing the stocking density does not impact the preening behavior of Ross broilers, suggesting that preening is not particularly sensitive to stocking density. Recent research by our team supports this finding, showing that the space occupied by broilers during preening is comparable to the space occupied when they lie down, which may explain the lack of sensitivity to density changes. The hourly preening pattern at 28 days of age reveals a significant increase in preening behavior among Ross broilers immediately after the lights are turned on, with more preening observed in the morning compared to the afternoon.

Table 4.3 The effect of stocking density (SD, kg/m^2), age on the number of stretching behavior (times per bird per hour) and the 24-hour stretching behavior patterns of the Ross 708 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on the number of stretching of Ross on day 28

SD	27	29	32	44	Std Error	*P*-value
Stretching	3.16^{b}	3.70^{b}	3.64^{b}	4.95^{a}	0.21	<0.01

The 24-hour stretching patterns of Ross on day 28

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	1.35^{def}	1.03^{f}	2.28^{bcdef}	1.26^{def}	0.82^{f}	1.18^{ef}	4.76^{ab}	5.95^{a}		
Hour	9	10	11	12	13	14	15	16		
Stretching	6.47^{a}	5.85^{a}	6.28^{a}	5.97^{a}	6.42^{a}	5.38^{a}	4.22^{abc}	4.79^{ab}	0.52	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	4.65^{abc}	4.56^{abc}	4.41^{abc}	4.13^{abc}	3.95^{abcd}	3.79^{abcde}	2.00^{cdef}	1.24^{ef}		

Effect of SD on the number of stretching of Ross on day 56

SD	27	29	32	44	Std Error	*P*-value
Stretching	2.33	2.66	2.82	3.05	0.21	0.12

The 24-hour stretching patterns of Ross on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	1.78^{bcd}	1.96^{bcd}	1.21^{bcd}	1.65^{bcd}	1.07^{bcd}	2.28^{bcd}	3.10^{bcd}	3.17^{bcd}		
Hour	9	10	11	12	13	14	15	16		
Stretching	3.44^{bcd}	3.16^{bcd}	3.69^{b}	6.74^{a}	3.78^{b}	3.47^{bcd}	2.34^{bcd}	2.78^{bcd}	0.52	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	3.05^{bcd}	3.75^{b}	2.25^{bcd}	2.22^{bcd}	2.86^{bcd}	3.60^{bc}	0.96^{cd}	0.83^{d}		

Effect of age on the number of stretching of Ross

Age	Day 28	Day 56	Std Error	*P*-value
Stretching	3.86^{a}	2.71^{b}	0.13	<0.01

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them (P<0.05).

Table 4.4 The effect of stocking density (SD, kg/m^2), age on the number of stretching behavior (times per bird per hour) and the 24-hour stretching patterns of the Cobb 700 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on the number of stretching of Cobb on day 28										
SD	27		29		32		44		Std Error	*P*-value
Stretching	2.54^{b}		3.32^{a}		2.61^{b}		1.96^{c}		0.17	<0.01
The 24-hour stretching patterns of Cobb on day 28										
Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	1.54^{fgh}	1.70^{efgh}	1.57^{fgh}	1.27^{gh}	0.60^{h}	3.04^{abcdefg}	3.34^{abcdefg}	4.06^{abcd}		
Hour	9	10	11	12	13	14	15	16		
Stretching	2.73^{bcdefgh}	2.98^{abcdefg}	3.15^{abcdefg}	4.46^{abc}	4.60^{ab}	1.36^{fgh}	5.00^{a}	3.51^{abcdef}	0.41	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	3.83^{abcde}	2.44^{cdefgh}	2.68^{bcdefgh}	1.56^{fgh}	2.55^{bcdefgh}	2.21^{defgh}	0.84^{h}	1.60^{fgh}		
Effect of SD on the number of stretching of Cobb on day 56										
SD	27		29		32		44		Std Error	*P*-value
Stretching	1.10		1.22		1.08		1.15		0.10	0.79
The 24-hour stretching patterns of Cobb on day 56										
Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Stretching	0.50^{def}	0.62^{bcdef}	0.76^{abcdef}	0.53^{cdef}	0.33^{ef}	0.78^{abcdef}	2.01^{a}	1.74^{abcd}		
Hour	9	10	11	12	13	14	15	16		
Stretching	1.47^{abcdef}	1.61^{abcd}	1.14^{abcdef}	1.26^{abcdef}	1.78^{abc}	1.38^{abcdef}	1.13^{abcdef}	1.09^{abcdef}	0.24	<0.01
Hour	17	18	19	20	21	22	23	24		
Stretching	1.57^{abcde}	1.22^{abcdef}	1.36^{abcdef}	1.29^{abcdef}	1.86^{ab}	1.48^{abcdef}	0.17^{f}	0.24^{f}		
Effect of age on the number of stretching of Cobb										
Age	Day 28				Day 56				Std Error	*P*-value
Stretching	2.48^{a}				1.14^{b}				0.08	<0.01

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them ($P<0.05$).

Table 4.5 The effect of stocking density (SD, kg/m^2), age on the number of preening behavior and the 24-hour preening patterns of the Ross 708 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on the number of preening of Ross on day 28

SD	27	29	32	44	Std Error	*P*-value
Preening	9.68	10.75	10.04	10.49	0.57	0.56

The 24-hour preening patterns of Ross on day 28

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Preening	0.82^{j}	0.96^{j}	2.04^{ij}	1.57^{ij}	3.63^{hij}	3.43^{hij}	19.73^{ab}	16.05^{abcde}		
Hour	9	10	11	12	13	14	15	16		
Preening	19.21^{abc}	18.76^{abcd}	18.06^{abcd}	17.42^{abcd}	21.58^{a}	15.30^{abcdef}	12.48^{bcdefg}	14.37^{abcdef}	1.40	<0.01
Hour	17	18	19	20	21	22	23	24		
Preening	12.31^{cdefg}	9.68^{efgh}	11.49^{defg}	8.35^{fghi}	6.63^{ghij}	9.79^{efgh}	1.32^{ij}	0.77^{j}		

Effect of SD on the number of preening of Ross on day 56

SD	27	29	32	44	Std Error	*P*-value
Preening	5.90	5.55	6.03	5.68	0.47	0.89

The 24-hour preening patterns of Ross on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Preening	1.04^{f}	2.24^{def}	1.01^{f}	2.27^{def}	2.14^{def}	3.79^{cdef}	7.61^{bcd}	6.72^{bcdef}		
Hour	9	10	11	12	13	14	15	16		
Preening	5.56^{bcdef}	6.71^{bcdef}	9.29^{abc}	14.48^{a}	7.81^{bcd}	7.61^{bcd}	6.63^{bcdef}	7.17^{bcde}	1.15	<0.01
Hour	17	18	19	20	21	22	23	24		
Preening	9.08^{abc}	10.22^{ab}	6.59^{bcdef}	6.30^{bcdef}	5.81^{bcdef}	6.53^{bcdef}	1.10^{f}	1.23^{ef}		

Effect of age on the number of preening of Ross

Age	Day 28	Day 56	Std Error	*P*-value
Preening	10.24^{a}	5.79^{b}	0.37	<0.01

When comparing groups, superscript letters indicate whether there are significant differences between them. If two groups share any of the same superscript letters (even just one), it means there is no significant difference between them. Conversely, if two groups do not share any superscript letters, it means there is a significant difference between them (P<0.05).

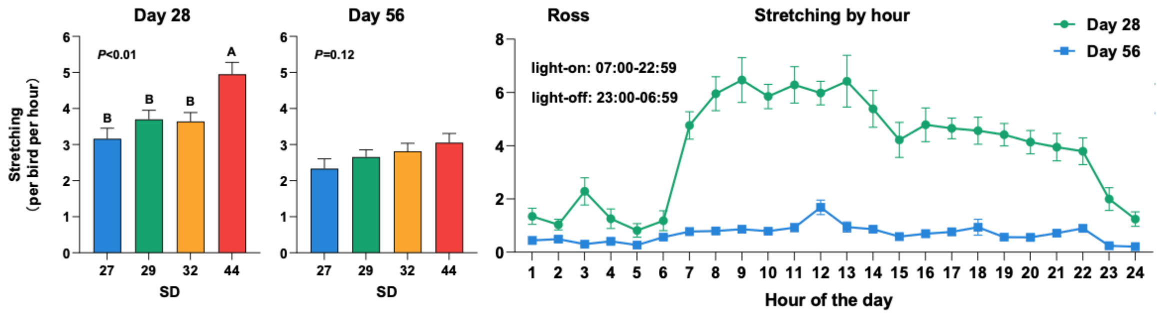


Figure 4.3 The effect of stocking density (SD, kg/m^2) on the number of stretching behavior (times per bird per hour) of Ross 708 broilers on days 28 and 56, and the 24-hour stretching patterns for Ross on days 28 and 56.

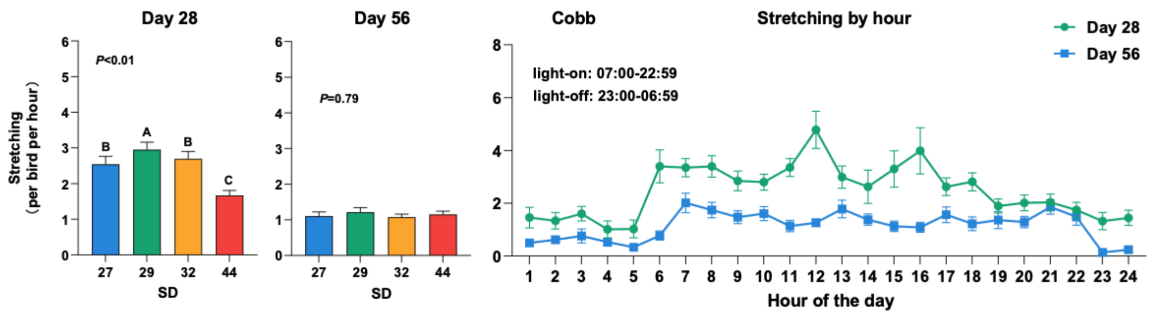


Figure 4.4 The effect of stocking density (SD, kg/m^2) on the number of stretching behavior (times per bird per hour) of Cobb 700 broilers on days 28 and 56, and the 24-hour stretching patterns for Cobb on days 28 and 56.

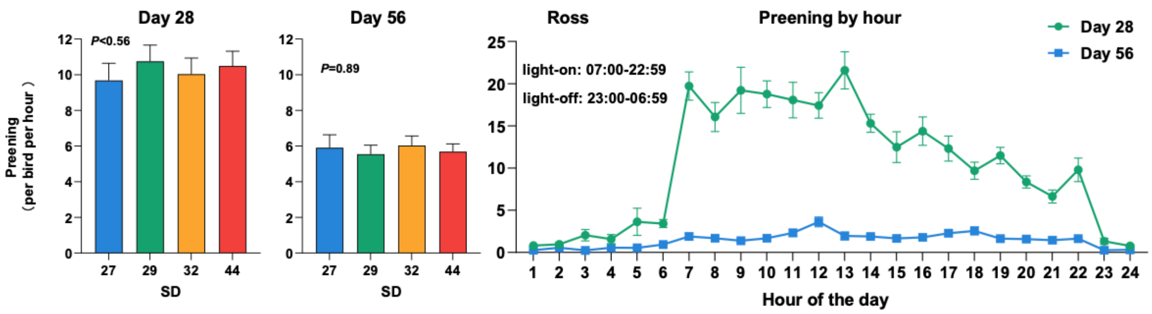


Figure 4.5 The effect of stocking density (SD, kg/m^2) on the number of preening behavior (times per bird per hour) of Ross 708 broilers on days 28 and 56, and the 24-hour preening patterns for Ross on days 28 and 56.

For Cobb 700 broilers, as shown in Error! Not a valid bookmark self-reference. and **Figure 4.6**, increasing stocking density at 28 days of age resulted in a decrease in preening behavior, while the SD-27 group displayed the highest frequency of preening. This suggests that, although Cobb broilers have sufficient space for movement, an increase in bird density can disrupt preening behavior. This may indicate that welfare-related behaviors in Cobb broilers are more easily interrupted by disturbances from other individuals. Additionally, the average frequency of preening decreased from around 6.80 at 28 days to approximately 3.07 at 56 days, indicating a reduction in preening as broilers age. Unlike Ross broilers, Cobb broilers showed no significant difference in preening frequency between morning and afternoon, indicating a more consistent level of preening behavior throughout the day.

4.4 Discussion

4.4.1 Effect of Stocking Density, Age on the Activity Index% and the 24-hour AI% Patterns.

Higher stocking density (SD-44) significantly increased Ross and Cobb broilers' AI% at 28 days of age compared to lower-density groups. Coupled with the production performance data in **Table 3.1**, which shows that broilers at 28 days achieve approximately 30% of their final weight at 56 days, this suggests that, at this younger age, even under the highest stocking density (44 kg/m²), the birds retain adequate space for movement within the pen. These conditions appear to facilitate higher activity levels Interestingly, these findings diverge from those of previous studies. For example, Shynkaruk et al. (2023) found that at 20 days of age, Ross broilers housed at a lower stocking density (31 kg/m²) exhibited more active behaviors, such as walking and running, while spending less time resting. Similarly, Abdelgaber et al. (2023) reported that at four weeks, broilers in high-density environments (18 birds/m²) showed an increased social interactions among broilers, potentially due to the closer proximity of birds enhancing behavioral stimulation.

Significantly reduced walking, eating, and preening behaviors compared to those at medium (15 birds/m²) or low (10 birds/m²) densities. These studies suggest that lower densities promote more natural and diverse activity patterns, while high densities may

Table 4.6 The effect of stocking density (SD, kg/m^2), age on the number of preening behavior (times per bird per hour) and the 24-hour preening patterns of the Cobb 700 broilers. 5 Lux lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of SD on the number of preening of Cobb on day 28

SD	27	29	32	44	Std Error	*P*-value
Preening	8.55^{a}	7.65^{a}	7.67^{a}	4.14^{b}	0.56	<0.01

The 24-hour preening patterns of Cobb on day 28

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Preening	2.11^{fg}	2.74^{efg}	4.80^{bcdefg}	4.52^{cdefg}	3.40^{defg}	5.27^{bcdefg}	10.15^{abcd}	7.92^{abcdefg}		
Hour	9	10	11	12	13	14	15	16		
Preening	8.40^{abcdefg}	7.80^{abcdefg}	9.78^{abcde}	13.00^{a}	11.49^{abc}	9.30^{abcdef}	11.39^{abc}	10.05^{abcde}	1.40	<0.01
Hour	17	18	19	20	21	22	23	24		
Preening	12.05^{ab}	9.77^{abcde}	8.13^{abcdefg}	5.02^{bcdefg}	3.55^{defg}	3.46^{defg}	1.59^{g}	2.36^{fg}		

Effect of SD on the number of preening of Cobb on day 56

SD	27	29	32	44	Std Error	*P*-value
Preening	2.59^{b}	3.59^{a}	2.81^{ab}	3.30^{ab}	0.22	0.01

The 24-hour preening patterns of Cobb on day 56

Hour	1	2	3	4	5	6	7	8	Std Error	*P*-value
Preening	2.60	2.86	2.41	2.27	2.45	2.17	3.85	3.01		
Hour	9	10	11	12	13	14	15	16		
Preening	2.06	4.32	3.90	3.56	3.16	4.50	3.88	2.91	0.55	0.06
Hour	17	18	19	20	21	22	23	24		
Preening	3.52	3.19	2.83	2.26	3.43	2.92	2.80	2.83		

Effect of age on the number of preening of Cobb

Age	Day 28	Day 56	Std Error	*P*-value
Preening	6.80^{a}	3.07^{b}	0.24	<0.01

Shared letters mean no difference, while distinct letters signify the difference (P<0.05).

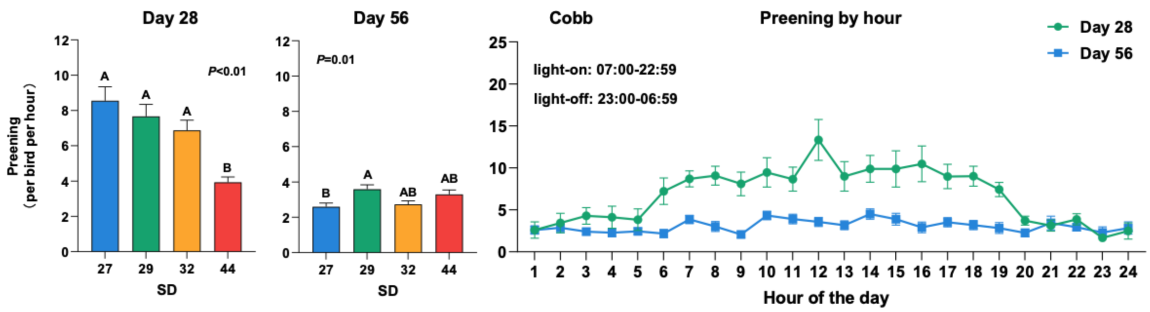


Figure 4.6 The effect of stocking density (SD, kg/m²) on the number of preening behavior (times per bird per hour) of Cobb 700 broilers on days 28 and 56, and the 24-hour preening patterns for Cobb on days 28 and 56.

suppress these behaviors. Additionally, van der Eijk et al. (2022) observed that Ross broilers stocked at lower densities (24 and 30 kg/m²) displayed greater locomotion, comfort, and foraging behaviors, reflecting enhanced welfare compared to those in higher-density conditions (36 and 42 kg/m²).

Conversely, other studies offer alternative perspectives. McLean et al. (2002) reported that while reducing stocking density from 40 to 28 kg/m² improved thermal comfort at six weeks, it did not significantly influence overall activity levels. The resting behavior of broilers was observed to be less frequent in groups with higher SD (Ahmed et al., 2018; Abdelgaber et al., 2023). Increasing SD increases the chances of broiler chickens being disturbed (Li et al., 2021). Such disturbances could drive greater social interactions and movement, potentially explaining the higher AI% observed in the SD-44 group in the current study.

As broilers grow and approach 56 days of age, however, their spatial requirements increase substantially. This results in a marked decline in AI% of Ross birds in the SD-44 group compared to lower-density groups, as space constraints become more restrictive. Bokkers et al. (2011) highlighted that high stocking densities can physically limit movement, leading broilers to congregate near walls and reducing their overall use of the available space. These constraints impede the expression of natural behaviors and elevate social stress. Additionally, Abdelgaber et al. (2023) suggested that higher densities exacerbate competition, further reducing physical activity and negatively impacting welfare outcomes. These findings suggest that while high SD may initially stimulate increased social interactions and activity levels in younger broilers, these benefits diminish as the birds grow larger and require more space. Ultimately, the spatial limitations associated with higher stocking densities hinder natural behavior expression, compromise welfare, and emphasize the need to carefully manage stocking densities across different stages of broiler growth.

The activity levels of broiler chickens are influenced by light and exhibit a circadian rhythm, with activity significantly increasing during periods of light exposure. At 56 days of age, Ross broilers showed a lower daytime AI% compared to their levels at 28 days, while their nighttime AI% was higher than at 28 days. Nielsen et al. (2004) observed that broilers exhibited increased activity during periods of darkness as they aged, with this effect being particularly pronounced in fast-growing strains. Similarly, Blatchford et al. (2012) reported a comparable rise in nocturnal activity with age, attributing it to a combination of factors, including nighttime feeding and drinking behaviors as well as the birds' continued growth. This pattern suggests an overall decline in activity as the birds age, with a compensatory increase in nighttime activity. Similarly, Cobb broilers displayed a drop in average AI% from approximately 3% at 28 days to 2% at 56 days, primarily driven by a decline in daytime activity levels. These findings indicate reduced mobility with age and a shift in activity patterns toward greater consistency across the day and night.

The AI% levels of both Ross and Cobb broilers were relatively stable throughout the day at 56 days, without significant fluctuations. This more consistent activity pattern contrasts with earlier ages when activity levels might have been more variable. This observation aligns with findings from McLean et al. (2002), who reported that general inactivity increased with age across all stocking densities, with broilers spending approximately 75% of their time sitting or resting by six weeks of age. Further evidence supports these trends. Son (2013) observed that locomotor capacity declines with age, particularly at higher stocking densities. The study compared three stocking densities: low (30–32 kg/m^2), medium (36–38 kg/m^2), and high (42–44 kg/m^2), demonstrating that higher densities exacerbate the reduction in mobility as broilers mature. This decline likely reflects not only the physical constraints imposed by higher stocking densities but also increased physical discomfort experienced by the birds. These findings are consistent with the current study, which observed decreased activity and restricted mobility in broilers at 56 days of age, especially under conditions of high stocking density. In summary, as broilers age, their overall activity decreases, with a notable decline in daytime activity and relatively stable activity patterns across the day and night. These changes are further influenced by stocking density, which compounds the reduction in locomotor capacity and mobility, emphasizing the need to optimize rearing conditions to maintain bird welfare as they mature.

4.4.2 Effect of Stocking Density, Age on the Number of Stretching Behavior and the 24-hour stretching Patterns.

Increasing SD to 44 kg/m² at 28 days of age prompted Ross broilers to exhibit more stretching behaviors, suggesting that higher stocking densities at a young age may stimulate movement in broiler chickens. Febrer et al. (2006) observed that broilers tend to cluster more densely than expected under random distribution, even at high stocking densities of 46 kg/m², likely due to their natural social tendencies. As juveniles with an inherent preference for close proximity, broilers may adapt to higher densities by maintaining social interactions. However, it is important to note that stocking density had minimal influence on most behaviors and health indicators. Instead, environmental factors such as air quality and litter moisture appeared to play a more significant role in their overall welfare. Contrasting results from other studies highlight the complexity of stretching behavior in broilers. Abdelgaber et al. (2023) reported that stretching behavior was not affected by SD, while Shynkaruk et al. (2023) found that stretching and ruffling behaviors in Ross broilers at 34 days of age were more common at lower SDs (31 kg/m²), indicating improved comfort and freedom to express natural behaviors. Similarly, Li et al. (2021) observed that birds at medium SDs (29 and 33 kg/m²) stretched more frequently than those at low (27 kg/m²) or high (39 kg/m²) densities. In high-density environments, stretching was reduced, likely due to interference from other birds, whereas at lower densities, stretching duration increased, possibly because of reduced competition and less physical obstruction. Additionally, stretching behavior generally declined with age, but the duration of individual stretches tended to increase.

In this study, stretching behavior in Ross broilers was not significantly influenced by SD at 56 days of age. The frequency of stretching decreased from an average of 3.86 stretches per bird per hour at 28 days to 2.71 stretches per bird per hour at 56 days. At 28 days, stretching was most pronounced immediately after lights were turned on, with greater activity in the morning compared to the afternoon. Even during the dark period, broilers averaged one stretch per hour. This observation aligns with findings by Nielsen et al. (2004) and Blatchford et al. (2012), who reported measurable nocturnal activity in broilers, which increased as the birds aged.

For Cobb 700 broilers, stocking density appeared to have a more pronounced impact on stretching behavior at 28 days. Birds housed at the highest density (SD-44) exhibited fewer stretches (1.96 stretches per bird per hour) compared to those at lower densities, with the SD-29 group showing the highest stretching frequency (3.32 stretches per bird per hour). Behaviors such as stretching and dust bathing, which require adequate space, are often restricted in high-density environments (Bokkers et al., 2011). Ahmed et al. (2018) further highlighted that welfare-related behaviors, including leg stretching, preening, and dust bathing, are negatively affected by higher stocking densities.

These findings suggest that different breeds respond differently to stocking density. By 56 days of age, stretching behavior in Cobb broilers was no longer influenced by SD, with the frequency of stretches declining from 2.48 stretches per bird per hour at 28 days to 1.14 stretches per bird per hour at 56 days. Unlike Ross broilers, Cobb broilers did not exhibit significant differences in stretching behavior between morning and afternoon hours.

Stocking density has a significant impact on broiler stretching behavior at younger ages, with lower densities generally promoting greater freedom of movement and expression of natural behaviors. However, as broilers age, stretching behavior decreases and becomes less influenced by stocking density. Differences between breeds further underscore the importance of tailoring management practices to specific genetic lines to optimize welfare and behavioral outcomes.

4.4.3 Effect of Stocking Density, Age on the Number of Preening Behavior and the 24-hour preening Patterns.

Increasing stocking density did not significantly affect preening behavior in Ross broilers, suggesting that preening is not particularly sensitive to stocking density changes. Recent findings from our group support this observation, indicating that broiler chickens occupy similar amounts of space while preening as they do when lying down, which may explain the minimal impact of density on this behavior. Guinebretiere et al. (2024) similarly found no significant differences in preening, standing, or foraging behaviors between high-density (HD) and low-density (LD) groups. The absence of behavioral changes in these scenarios may be attributed to the relatively small density reduction (22%), which may not have been sufficient to induce substantial differences. Furthermore, Son (2013) reported that preening behaviors, along with pecking, eating, and drinking, were not significantly affected by stocking density, highlighting the robustness of certain behaviors across varying densities.

For Cobb 700 broilers the results differed. Increasing stocking density at 28 days of age led to a reduction in preening behavior, with the SD-27 group exhibiting the highest preening frequency. This finding aligns with Collins (2008), who observed that fewer birds obstructing access to feeders at lower stocking densities promoted increased preening behavior. This suggests that while Cobb broilers generally have sufficient space to conduct the preening behavior, higher SD may disrupt this behavior due to increased competition and physical interference. Abdelgaber et al. (2023) reported similar trends, noting that reduced preening and locomotor behaviors in high-density groups are often associated with poorer leg health and lameness, common challenges in overcrowded environments. Ahmed et al. (2018) also observed that welfare-related behaviors, including preening, leg stretching, and dust bathing, were negatively impacted by higher densities, further supporting the idea that Cobb broilers may be more sensitive to the effects of overcrowding on welfare-related behaviors.

Additionally, the preening frequency of the Ross bird decreased as broilers aged. This age-related reduction in preening behavior may reflect both physiological changes and environmental constraints as the birds grow larger. Unlike Ross broilers, Cobb broilers demonstrated no significant difference in preening frequency between morning and afternoon hours, indicating a more consistent level of preening behavior throughout the day. Preening behavior appears relatively resilient to changes in SD for Ross broilers but is more affected in Cobb broilers, particularly at higher densities. This breed-specific sensitivity suggests that management strategies should consider genetic differences when determining optimal stocking densities to support welfare-related behaviors.

4.5 Conclusions

This study highlights the effects of SD and age on broiler chickens' activity and behavior, with notable breed-specific differences. At 28 days, higher SD (44 kg/m^2) increased AI% in both Ross and Cobb broilers, likely due to closer proximity fostering social interactions. However, by 56 days, AI% declined, especially at higher SDs, reflecting limited mobility and welfare challenges. While high SD encourages activity in younger birds, it restricts natural behaviors as they grow. At 28 days, high SD promoted stretching in Ross broilers but suppressed it in Cobb broilers, with lower SD (29 kg/m^2) enabling more frequent stretching. Stretching declined with age in both breeds, although individual stretches lasted longer. By 56 days, SD had minimal impact, underscoring the age-related decline in stretching. Cobb broilers exhibited more consistent stretching patterns across the day than Ross broilers. Preening in Ross broilers was unaffected by SD, requiring minimal space. However, Cobb broilers preened less at high SD, indicating sensitivity to competition. Preening declined with age in both breeds, but Cobb broilers maintained consistent daily patterns, unlike Ross broilers. These findings underscore the need to adjust rearing practices based on broiler age and breed. Higher SD may suit younger birds but should decrease as they grow to mitigate welfare issues and support natural behaviors. Breed-specific responses to SD and environmental conditions should guide ethical and effective poultry management strategies.

CHAPTER FIVE

IMPACT OF LIGHTING INTENSITY ON WELFARE AND PERFORMANCE OF ROSS 708 AND COBB 700 BROILERS

Abstract: Light intensity (LI) is crucial in commercial broiler management, shaping broiler physiology, behavior, and welfare. Light intensity influences various behaviors and circadian rhythms in broiler chickens, impacting both their welfare and production performance. However, there are currently no studies utilizing precision livestock farming (PLF) technologies to explore and quantify the effects of light intensity on broiler welfare, production performance, and activity levels. This study investigated the performance and welfare of Ross 708 and Cobb 700 broilers as affected by Three LIs (5, 20, and 50 lux) from day 8 to day 56. Each LI treatment has six replicates. During the first week, all treatments were exposed to 50 lux lighting to help the chicks locate feed and water efficiently. The average body weight (BW), feed intake, and feed conversion ratio (FCR) were measured biweekly. Welfare indicators (four broilers per pen), including gait score, feather cleanliness, feather coverage, body temperature, and footpad condition, were evaluated on days 28 and 56. Tibia strength (two broilers per pen) was measured on day 56. The results show that increasing LI reduced BW in Ross at 42 days ($P<0.05$), decreasing from 2.70 kg (20 lux) to 2.54 kg (50 lux), but had no effect by 56 days. BW was unaffected by LI for Cobb birds, though 5 lux LI improved FCR to 1.66 at 42 days. LI did not affect bone strength, but males exhibited 1.25 times higher strength than females ($P<0.01$). Ross broilers exposed to 50 lux at 28 days had 1.5°C higher back temperatures than 20 lux ($P<0.05$), while Cobb broilers at 56 days in 5 lux had lower belly temperatures and better feather coverage ($P<0.05$). Feather cleanliness was best at 20 lux, while 50 lux improved gait scores ($P<0.01$) in both strains. Age significantly worsened feather cleanliness, gait, and footpad health across both strains ($P<0.01$).
Keywords: broiler; lighting intensity; production performance; welfare

5.1 Introduction

In 2022, the United States produced 27.2 billion kg of broilers, making a 50% increase in broiler production since 2000, surpassing hogs and cattle production (USDA-NASS, 2023). Such growth in the broiler industry, driven by improvements in production efficiency, has made high-quality chicken more affordable. However, rising public concern and criticism regarding the welfare of birds raised in crowded and dim environments that restrict bird activity and natural behavior is also becoming an issue (Hall and Sandilands, 2007; Cornish et al., 2016).

Animal welfare is guided by the "five freedoms" (Webster, 1994), which Mellor (2016) later refined to include good nutrition, a healthy environment, good health, appropriate behavior, and a positive mental experience. Efficiency-driven feeding and management practices have inadvertently led to welfare issues in modern broilers. Lighting, including light intensity (LI), photoperiod, and wavelength, is a crucial component in commercial broiler management, shaping broiler physiology, behavior, and welfare outcomes. Light intensity, in particular, significantly influences broiler activity and production efficiency. Broilers are commonly raised in low-light conditions under the assumption that dim environments enhance productivity.

Research supports this, indicating that broilers reared in low-intensity settings achieve higher body weights, improved feed conversion ratios (FCR), and faster growth rates compared to those exposed to brighter light (Lien et al., 2008). This is often attributed to reduced activity levels, which enable more efficient energy utilization (Proudfoot and Sefton, 1978). Lower lighting intensities are also associated with reduced activity and aggression (Olanrewaju et al., 2006; Pal et al., 2019). However, low-light conditions pose welfare concerns. They have been linked to eye-related issues, including increased eye size and a heightened susceptibility to eye diseases (Blatchford et al., 2009; Deep et al., 2010), higher carcass fat content (Alvino et al., 2009b), leg problems (Weeks and Butterworth, 2004) and may interfere with the broilers' vision and natural behavior rhythms, ultimately impacting welfare (Blatchford et al., 2009).

Broilers raised in environments with minimal contrast between light and dark phases, such as at 5 lux, exhibit less distinct circadian rhythms, displaying uniform activity throughout the day. In contrast, higher light intensities (e.g., 50 lux and 200 lux) encourage well-defined behavioral patterns, with activity peaks during transitions between light and dark periods (Alvino et al., 2009b). Brighter environments also promote natural behaviors such as preening and walking (Vandenbert and Widowski, 2000), which are indicators of comfort and welfare. Notably, preening plays an essential role in feather maintenance and overall health, suggesting that higher light intensities may support welfare by encouraging these beneficial behaviors.

Current recommended lighting intensities in the U.S vary. Broiler producers typically use 5 lux or less after brooding to improve the growth rate and feed efficiency (National Chicken Council, 2022b), while animal welfare advocates and food chain companies demand 20-50 lux throughout the entire production cycle (Better Chicken Commitment, 2024). The impact of light intensity on broiler chicken production performance remains a subject of debate. While some studies have found that lower light conditions (5 lux) can improve BW and FCR

Some studies suggest that lower light conditions (5 lux) can enhance BW and FCR (Ahmad et al., 2011; Rault et al., 2017; Aldridge et al., 2022), while other research indicates that light intensity has no significant impact on broiler production performance (Deep et al., 2010; Olanrewaju et al., 2010; Olanrewaju et al., 2011; Olanrewaju et al., 2012; Deep et al., 2013; Olanrewaju et al., 2016; Fİdan et al., 2017; Wu et al., 2023). Additionally, most research on the impact of LI on broilers has primarily focused on the Ross strain (Deep et al., 2010; Olanrewaju et al., 2010; Olanrewaju et al., 2011; Deep et al., 2012; Olanrewaju et al., 2012; Olanrewaju et al., 2016; Fİdan et al., 2017; Rault et al., 2017; Wu et al., 2023), despite Cobb being another widely used commercial breed in the United States. Only a limited number of studies have explored the effects of lighting on Cobb (Blatchford et al., 2009; Aldridge et al., 2022), underscoring the need for more balanced research across strains to better understand strain-specific responses to light intensity.

The objective of this study was to comparatively evaluate the production performance and welfare of Ross 708 and Cobb 700 broilers as affected by LI. As manual welfare assessment is subjective, we used precision livestock farming (**PLF**) technologies to perform objective evaluation on feather coverage via temperature analysis.

5.2 Materials and Methods

5.2.1 Birds, Diets, and Management

A total of 648 straight-run broilers, consisting of 324 Ross-708 and 324 Cobb-700 birds, were obtained from local commercial hatcheries and reared at a 44 kg/m^2 stocking density (18 birds per pen, pen size: 1.1m x 1.5m) until day 56. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in July 2023 and the trial with Cobb 700 broilers in October 2023. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The tested lighting intensities were 5, 20, and 50 lux applied from day 8 to day 56. Each LI treatment has 6 replicates. During the first week, all treatments were exposed to 50 lux lighting to help the chicks locate feed and water efficiently. All birds were reared in one room with areas of varying light intensity distinguished by black tarps (TEZONG black waterproof plastic tarps, 10x20ft each). To achieve lighting levels of 50, 20, and 5 Lux, 6, 4, and 3 light bulbs (Overdrive A19 Dimmable Omni LED Bulb - 9.8 Watts 5000K) were used respectively to provide lighting. To ensure even distribution of light, bulbs were spaced uniformly, and black tapes (Lichamp black electrical tape) were applied to the bulbs to fine-tune the lighting levels. The lighting intensities at the bird level were measured using a HATO ONE spectrometer (item code: 6776). Measurements were taken at three points in each pen: the right-up corner, center area, and left-down corner. All birds were reared under identical room conditions but housed separately in pens. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The feeder space and the number of drinkers were sufficient for all treatments based on the NCC recommendation (National Chicken Council, 2022b). Broilers were feather-sexed (for Ross birds) or vent-sexed (for Cobb birds) and distributed evenly in experimental pens at a 1:1 male-to-female ratio. The experimental room temperature was adjusted according to the Ross 708 (Aviagen, 2018) and the Cobb 700 (Cobb, 2021) broiler management guides by bird age. At the study's commencement, each pen was bedded with Topsoil (Farmer Green topsoil, 0.14 cubic feet per pen) and covered with black mulch (Earthgro black wood shredded mulch, 0.04 cubic feet per pen) which remained unchanged throughout the study period. The topsoil and mulch used in this setup, rather than the shavings or rice hulls commonly used in the commercial poultry industry, serve a specific purpose. When using overhead cameras to monitor broiler activities, it is essential to distinguish the broilers from their background (the bedding material) for effective image processing of the recorded video. To achieve this, black topsoil and mulch are used instead of the light yellow shavings or rice hulls, providing a contrasting background against the white bodies of the broilers. Every two weeks, the total weight of all birds in each experimental pen was recorded. Feed intake was also measured biweekly to calculate the FCR. Broilers were reared to a target market weight of 4.0 kg for 56 days. broilers in this study were provided with a diet containing 19% crude protein and 2851 kcal/kg metabolizable energy (Co-op Chick Starter/Grower Crumble - AMP BMD, Tennessee Farmers Cooperative, La Vergne, TN) throughout the entire study. Broilers in this study were provided with a diet containing 19% crude protein and 2851 kcal/kg metabolizable energy (Co-op Chick Starter/Grower Crumble - AMP BMD, Tennessee Farmers Cooperative, La Vergne, TN) throughout the entire study. Subsequently, five randomly chosen broilers (3 males and 2 females) from each pen underwent measurement for welfare indicators, and two broilers (1 male and 1 female) were euthanized via carbon dioxide method to assess tibia-breaking strength at the end of the trial. These procedures adhered to the guidelines outlined in the Guide for the Care and Use of Agriculture Animals in Research and Teaching (Federation of Animal Science Societies, 2010), as well as the University of Tennessee's Institutional Animal Care and Use Committee (**IACUC** Protocol #2876-1221).

5.2.2 Welfare and Behavior Measurement

Broiler welfare indicators including feather cleanliness, footpad dermatitis, and gait score were manually evaluated on days 28 and 56, following the methods described by Zhou et al. (2024) and the Welfare Quality® assessment protocol (Welfare Quality®, 2009). Precision agriculture technologies, including thermography and image processing, were utilized to measure the bare-skin ratio and surface body temperature. The thermal camera (T865, Teledyne FLIR, Wilsonville, OR) captured surface temperatures of the back and belly regions, which correspond to the back and belly areas as defined by Zhao et al.

(2013). These measurements were then used to calculate the bare skin ratio. At the end of the flock, bone strength was assessed in two randomly selected birds from each pen. The left tibia breaking strength was measured using the three-point bending method on an MTS Alliance RT/30 apparatus (MTS Systems Corporation, Eden Prairie, MN), with a 4 cm distance between the two supporting points.

5.2.3 Statistical Analysis

All the analyses were conducted using JMP, version 16.0.0 (SAS Institute, Cary, NC). Lighting intensities of 50, 20, and 5 lux were used in a complete randomized design with 6 replications. The individual chicken served as the experimental unit for assessments of feather coverage, feather cleanliness, bone strength, footpad dermatitis, and gait score. Broilers were randomly selected at different ages, so the birds chosen on day 28 may not have been the same individuals selected on day 56. The pen was regarded as the experimental unit for the weight gain and FCR. For continuous variables, one-way ANOVA was employed to examine the impact of LI. All scored variables were analyzed using one-way ANOVA on ranks to assess the effect of LI. Tukey's HSD test was applied for post-hoc analysis at the 0.05 significance level after computing least squares means. The normality of residuals was assessed using the Shapiro-Wilk normality test. Additionally, the Kruskal-Wallis test was utilized to evaluate differences between ages (days 28 and 56) in scoring and continuous variables, with significance set at $P<0.05$.

5.3 Results

5.3.1 Effect of Lighting Intensity on the Body Weight and FCR.

According to

Table 5.1 and **Figure 5.1**, increased light intensity negatively impacted the body weight of Ross broilers at 42 days. Specifically, as light intensity rose from 20 lux to 50 lux, body weight decreased from 2.70 kg to 2.54 kg. However, by 56 days, light intensity no longer affected body weight. The FCR at 42 days remained unaffected by light intensity, averaging 1.73. Due to accidentally missing data, it was not possible to calculate FCR on day 56.

For Cobb broilers, body weight remained unaffected by LI, with averages of 2.88 kg at 42 days and 4.16 kg at 56 days. However, reducing light intensity to 5 lux at 42 days slightly raised the FCR to 1.66, though by 56 days, light intensity did not influence the

Table 5.1 Effect of lighting intensity (LI, lux) on the body weight (BW, kg) and feed conversion ratio (FCR) of Ross 708 and Cobb 700 broilers.

		Ross 708				
BW (kg) or FCR	50 lux	20 lux	5 lux	Average	Std Error	P-value
BW (Day 14)	0.34	0.35	0.35	0.35	0.01	0.10
BW (Day 28)	1.10	1.18	1.15	1.14	0.03	0.13
BW (Day 42)	2.54^{b}	2.70^{a}	2.61^{ab}	2.62	0.04	0.03
BW (Day 56)	4.04	3.84	3.97	3.95	0.06	0.14
0-42 FCR	1.75	1.73	1.72	1.73	0.02	0.45
		Cobb 700				
BW (kg) or FCR	50 lux	20 lux	5 lux	Average	Std Error	P-value
BW (Day 14)	0.44	0.44	0.45	0.44	0.01	0.76
BW (Day 28)	1.44	1.47	1.49	1.46	0.02	0.26
BW (Day 42)	2.88	2.79	2.98	2.88	0.06	0.13
BW (Day 56)	4.17	4.03	4.28	4.16	0.07	0.07
0-42 FCR	1.75^{ab}	1.80^{a}	1.66^{b}	1.74	0.03	0.01
0-56 FCR	2.04	1.96	2.00	2.00	0.04	0.44

[a, b, c] Means in the same row with no common superscripts differ (P<0.05).

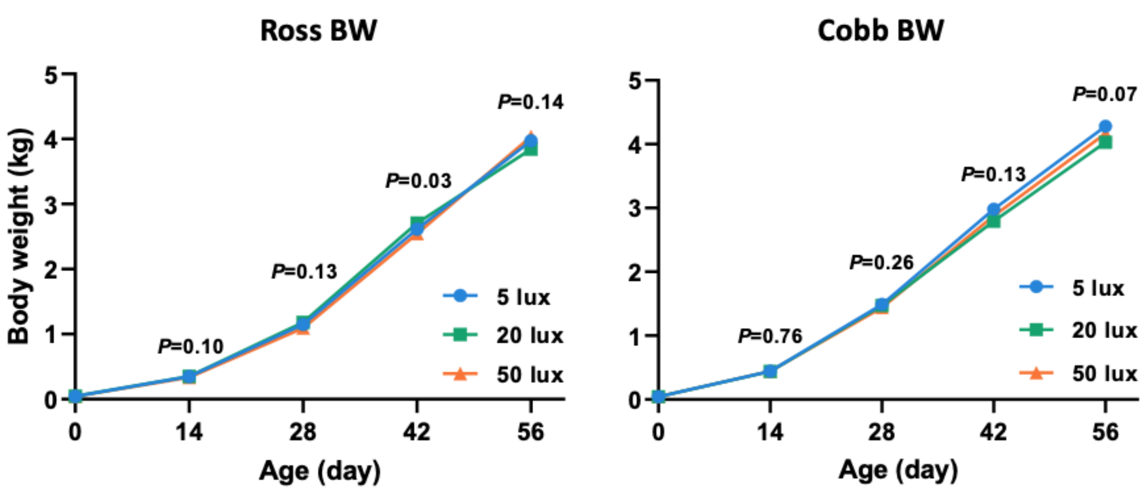


Figure 5.1 Effect of lighting intensity (LI, lux) on the body weight (BW, kg) of Ross 708 and Cobb 700 broilers.

FCR.

5.3.2 Effect of Lighting Intensity on the Bone Breaking Strength.

According to **Table 5.2** and **Table 5.3**, light intensity does not affect the bone breaking strength in either Ross or Cobb broilers. However, within both strains, male broilers exhibit significantly higher bone strength than females, with male bone strength approximately 1.25 times that of females.

5.3.3 Effect of Lighting Intensity and Age on Body Temperature and Bare Skin Ratio.

As shown in **Table 5.4**, light intensity influenced the back temperature of Ross broilers at 28 days of age. Broilers exposed to 50 lux light had back temperatures 1.5 degrees higher than those in the 20 lux group. This increase may result from higher activity levels under more intense light, as greater exercise and competition can reduce back feather coverage. As broilers mature, feather coverage improves, particularly over the back and abdomen, thereby reducing exposed skin areas, which aligns with typical growth and development patterns in broilers.

Cobb broilers at 56 days of age in the 5 lux lighting group had a significantly lower belly bare skin ratio compared to those in the 20 and 50 lux groups as shown in **Table 5.5**. This increased feather coverage in the 5 lux group also resulted in a belly temperature 1 °C lower than in the higher LI groups. The improved belly feather coverage is likely due to reduced friction with the litter, as lower light intensity may decrease movement, thereby preserving feather integrity. Feather coverage on both the back and abdomen improves with age, consistent with observations in Ross broilers.

5.3.4 Effect of Lighting Intensity on Gait Score, Footpad and Feather Cleanliness.

As shown in **Table 5.6** and **Table 5.7**, lighting intensity influenced feather cleanliness and gait scores in Ross 708 broilers. At 28 days, broilers under 20 lux showed the cleanest feathers (1.07), while those under 50 lux had the lowest cleanliness score (0.80). At 56 days, the 50 lux group had a better gait score (1.72) than the 20 lux (2.26) and 5 lux (2.25) groups, suggesting higher light may improve gait, while 20 lux benefited feather cleanliness.

Table 5.2 Effects of lighting intensity (LI, lux), and sex on Ross 708 broiler's bone breaking strength (lbf).

Effect of LI on bone strength of Ross					
50 lux	20 lux	5 lux	Average	Std Error	*P*-value
122.30	119.00	140.19	127.16	7.43	0.11

Effect of sex on bone strength of Ross			
Male	Female	Std Error	*P*-value
142.26[a]	112.06[b]	6.07	<0.01

[a, b, c] Means in the same row with no common superscripts differ ($P<0.05$).

Table 5.3 Effects of lighting intensity (LI, lux), and sex on Cobb 700 broiler's bone breaking strength (lbf).

Effect of LI on bone strength of Cobb					
50 lux	20 lux	5 lux	Average	Std Error	*P*-value
103.17	107.58	111.65	107.47	7.19	0.71

Effect of sex on bone strength of Cobb			
Male	Female	Std Error	*P*-value
120.56[a]	94.88[b]	5.87	<0.01

[a, b, c] Means in the same row with no common superscripts differ ($P<0.05$).

Table 5.4 Effects of lighting intensity (LI, lux), age, and LI by age interaction on Ross 708 broiler's back and belly temperature (°C) and bare skin ratio (%).

Effect of LI on Ross

	50 lux	20 lux	5 lux	Std Error	*P*-value
Back skin ratio	19.06	13.32	17.08	1.18	0.09
Belly temperature	35.19	35.01	34.93	0.12	0.30
Belly skin ratio	66.87	66.43	67.49	1.22	0.83

Effect of age on Ross

	Day 28	Day 56	Std Error	*P*-value
Back skin ratio	31.88[a]	1.10[b]	1.54	<0.01
Belly temperature	35.85[a]	34.22[b]	0.10	<0.01
Belly skin ratio	66.72	67.13	1.00	0.77

LI by age interaction effects of Ross

		50 lux	20 lux	5 lux	Std Error	*P*-value
Back temperature	D 28	33.08[a]	31.51[b]	32.31[ab]	0.32	0.03
	D 56	27.00[c]	27.06[c]	26.70[c]		

[a, b, c] Means in the same row with no common superscripts differ (*P*<0.05).

Table 5.5 Effects of lighting intensity (LI, lux), age, and LI by age interaction on Cobb 700 broiler's back and belly temperature (°C) and bare skin ratio (%).

Effect of LI on Cobb

	50 lux	20 lux	5 lux	Std Error	*P*-value
Back temperature	27.57	27.31	27.74	1.19	0.28
Back skin ratio	9.38	8.71	10.33	0.11	0.59

Effect of age on Cobb

	Day 28	Day 56	Std Error	*P*-value
Back temperature	30.24^{a}	24.84^{b}	1.53	<0.01
Back skin ratio	18.69^{a}	0.26^{b}	0.91	<0.01

LI by age interaction effects of Cobb

		50 lux	20 lux	5 lux	Std Error	*P*-value
Belly temperature	D 28	34.85^{ab}	34.34^{bc}	34.82^{ab}	0.21	<0.01
	D 56	35.23^{a}	34.99^{ab}	33.92^{c}		
Belly skin ratio	D 28	61.03^{b}	57.97^{b}	60.79^{b}	1.83	<0.01
	D 56	76.52^{a}	73.42^{a}	64.36^{b}		

$^{a, b, c}$ Means in the same row with no common superscripts differ (P<0.05).

Table 5.6 Effects of lighting intensity (LI, lux) on the gait score, footpad dermatitis, and feather cleanliness of Ross 708 broilers. Scores of feather cleanliness, gait score, and footpad dermatitis were determined following the Welfare Quality® (2009) assessment protocol.

Measurement items	**Ross 708**					
On day 28	50 lux	20 lux	5 lux	Average	Std Error	*P*-value
Gait score	0.19	0.43	0.31	0.31	0.09	0.18
Footpad	0.67	0.81	0.35	0.61	0.14	0.09
Feather cleanliness	0.80[b]	1.07[a]	1.00[ab]	0.96	0.06	<0.01
On day 56	50 lux	20 lux	5 lux	Average	Std Error	*P*-value
Gait score	1.72[b]	2.26[a]	2.25[a]	2.08	0.12	<0.01
Footpad	1.81	2.38	1.86	2.02	0.18	0.11
Feather cleanliness	2.25[b]	2.68[a]	2.22[b]	2.38	0.11	0.01

[a, b, c] Means in the same row with no common superscripts differ ($P<0.05$).

Table 5.7 Effects of lighting intensity (LI, lux) on the gait score, footpad dermatitis, and feather cleanliness of Cobb 700 broilers. Scores of feather cleanliness, gait score, and footpad dermatitis were determined following the Welfare Quality® (2009) assessment protocol.

Measurement items	**Cobb 700**					
On day 28	50 lux	20 lux	5 lux	Average	Std Error	*P*-value
Gait score	0.50	0.47	0.46	0.48	0.09	0.96
Footpad	1.46	1.71	1.47	1.55	0.19	0.74
Feather cleanliness	0.01	0.05	0.01	0.02	0.03	0.13
On day 56	50 lux	20 lux	5 lux	Average	Std Error	*P*-value
Gait score	2.04[b]	2.81[a]	2.43[ab]	2.43	0.17	<0.01
Footpad	2.46[ab]	2.93[a]	2.13[b]	2.51	0.17	<0.01
Feather cleanliness	1.78	2.03	1.86	1.89	0.09	0.16

[a, b, c] Means in the same row with no common superscripts differ ($P<0.05$).

In Cobb 700 broilers at 56 days, light intensity affected both gait and footpad dermatitis scores. The 50 lux group had the best gait score (2.04), whereas the 5 lux group showed the lowest footpad dermatitis score (2.13), suggesting higher light improves gait, while lower light supports footpad health.

Lighting intensity had no significant effect on the gait score at day 28 or footpad condition at both 28 and 56 days in Ross broilers. Similarly, in Cobb broilers, lighting intensity did not influence the gait score or footpad condition at day 28, nor feather cleanliness at both 28 and 56 days.

5.3.5 Effect of Age on Gait Score, Footpad and Feather Cleanliness.

As shown in **Table 5.8**, age significantly affects all welfare indicators (all $P<0.01$) in both Ross and Cobb broilers. Feather cleanliness declines with age, while gait scores and footpad health deteriorate as the birds gain weight in both strains.

5.4 Discussion

5.4.1 Effect of Lighting Intensity on the Body Weight and FCR.

In this study, the effect of different lighting intensities (LI) on broiler production performance was evaluated. Our results indicated that increasing LI from 20 lux to 50 lux negatively impacted the BW of Ross broilers at 42 days. However, by 56 days, LI no longer influenced BW. Similarly, the FCR at 42 days remained unaffected by LI. For Cobb broilers, BW remained stable regardless of LI, averaging 2.88 kg at 42 days and 4.16 kg at 56 days. Reducing LI to 5 lux slightly raised the FCR to 1.66 at 42 days, but by 56 days, LI did not influence FCR. Our findings align with previous studies that suggest LI within a moderate range has limited effects on BW and FCR. For instance, Olanrewaju et al. (2014) reported no significant impact of LI (ranging from 25 to 0.2 lux) on BW and FCR, supporting the adoption of lower LI (e.g., 5–10 lux) in commercial broiler production to conserve energy while maintaining performance. Similarly, Buyse et al. (1996) observed no significant differences in BW or feed intake of male broilers under LI ranging from 0.7 to 46.5 lux, although higher intensities (e.g., 150 lux) slightly decreased growth and fat deposition. The marginal increase in FCR at 5 lux observed in our study might reflect changes in activity levels. According to Aldridge et al. (2022), broilers

Table 5.8 Effects of age on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare skin ratio (%) of Ross 708 and Cobb 700 broilers.

Measurement items	**Ross 708**			
	Day 28	Day 56	Std Error	*P*-value
Gait score	0.31[b]	2.08[a]	0.06	<0.01
Footpad	0.61[a]	2.01[b]	0.09	<0.01
Feather cleanliness	0.96[b]	2.38[a]	0.05	<0.01
Measurement items	**Cobb 700**			
	Day 28	Day 56	Std Error	*P*-value
Gait score	0.48[b]	2.43[a]	0.08	<0.01
Footpad	1.55[b]	2.50[a]	0.10	<0.01
Feather cleanliness	0.02[b]	1.88[a]	0.04	<0.01

[a, b, c] Means in the same row with no common superscripts differ ($P<0.05$).

raised at 5 lux exhibited a higher FCR (1.69) compared to 20 lux (1.76), attributed to reduced activity and energy expenditure, which improved feed utilization. However, excessively low LI (<1 lux) may adversely affect growth, as Arowolo et al. (2019) demonstrated that such conditions severely limited feed and water intake, causing stunted growth and poor FCR. Higher LI (e.g., 20 lux or more) can stimulate early exploratory behavior and adaptability to feed and water, particularly during the brooding stage, as noted by Wu et al. (2022). However, sustained high LI may increase activity and energy expenditure, potentially diminishing growth rates over time. This trade-off underscores the importance of adjusting LI according to developmental stages. For instance, Pal et al. (2019) recommended using higher LI (around 20 lux) during the first week to enhance early activity and feed intake, followed by a reduction to 3–5 lux to improve energy efficiency and FCR. Additionally, lower LI (e.g., 5–10 lux) has been associated with reduced hyperactivity and energy conservation, allowing more energy to be allocated toward growth and improving FCR (Ahmad et al., 2011; Wu et al., 2022). However, prolonged exposure to very low LI (<5 lux) could pose health risks such as eye problems or footpad dermatitis, potentially offsetting the benefits (Olanrewaju et al., 2016; Wu et al., 2022).

Overall, our results support the implementation of moderate LI (5–10 lux) in broiler production as a sustainable and efficient management strategy. This range appears optimal for conserving energy, improving FCR, and maintaining production performance, aligning with earlier findings (Olanrewaju et al., 2016). The absence of significant BW differences across LI levels further suggests that lower intensities can be effectively utilized without compromising growth, providing an economically and environmentally sustainable solution for modern broiler production systems.

5.4.2 Effect of Lighting Intensity on the welfare of broilers.

Lighting intensity does not affect bone breaking strength in either Ross or Cobb broilers. This finding aligns with published research, which suggests that variations in LI have minimal impact on skeletal health and bone strength. Deep et al. (2010) reported no significant differences in skeletal scores or gait ability across different LIs, suggesting that LI alone does not directly influence skeletal development or walking ability.

Similarly, Škrbić et al. (2019) found that high LI did not significantly affect tibial measurements, including weight, length, and cross-sectional area, across different stocking densities (10, 13, or 15 birds/m²). Interestingly, at higher stocking densities, high LI slightly improved tibial hardness, potentially due to increased activity mitigating some negative effects of crowding.

LI significantly influenced broiler back and belly temperatures, likely due to interactions between activity levels, feather wear, and thermal regulation. For Ross broilers at 28 days, back temperatures were 1.5°C higher in the 50 lux group compared to the 20 lux group, likely due to increased activity leading to feather loss, particularly on the back (Buyse et al., 1996). Enhanced activity under brighter light, such as increased standing and walking, aligns with findings from Deep et al. (2010) and (Wu et al., 2022), who observed that higher LI encourages activity but may also increase risks of overstimulation and social stress.

Conversely, Cobb broilers at 56 days showed lower belly bare skin ratios under 5 lux compared to 20 and 50 lux, highlighting the protective effect of reduced movement in low LI environments. This reduced activity likely minimized friction with the litter, preserving feather integrity and resulting in a 1°C lower belly temperature. Ahmad et al. (2011) supported this, linking better feather coverage with lower activity levels under reduced LI. Additionally, lower LI effectively reduces aggressive behaviors such as feather pecking, contributing to improved feather coverage and welfare outcomes (Arowolo et al., 2019; Pal et al., 2019).

Our findings support previous recommendations for transitioning broilers to lower LI after the first week to balance production performance with welfare (Buyse et al., 1996). While higher LI (>25 lux) promotes early feed intake and activity, prolonged exposure can stimulate aggressive behaviors, increase social stress, and compromise welfare. Moderate LI (5–10 lux) achieves a balance between activity and rest, promoting healthy behavior patterns while minimizing risks of anxiety or skin damage (Wu et al., 2022). However, high LI (20–50 lux) may lead to energy wastage, feather loss, and stress, while excessively low LI (<5 lux) may cause lethargy or inadequate preening.

At 28 days, Ross broilers exposed to 20 lux had the cleanest feathers, while the 50 lux group had the lowest cleanliness scores, suggesting moderate light levels (20 lux) might better support feather cleanliness by reducing dust and litter disturbance. At 56 days, however, the 50 lux group demonstrated better gait scores, aligning with findings that higher LI promotes activity and improves leg health (Škrbić et al., 2019). Increased activity under higher LI may reduce contact with wet litter, mitigating footpad issues.

For Cobb broilers at 56 days, LI significantly influenced both gait and footpad dermatitis scores. The 50 lux group achieved the best gait scores, supporting the hypothesis that higher LI enhances leg development (Škrbić et al., 2019; Aldridge et al., 2022). Conversely, the 5 lux group had the lowest footpad dermatitis scores, likely due to reduced litter disturbance, as noted by (Pal et al., 2019). However, prolonged exposure to low LI may pose long-term risks from excessive contact with litter, underscoring the need for balance.

Our results suggest that younger broilers may be less sensitive to LI variations. At 28 days, LI had no significant impact on gait scores, footpad conditions, or feather cleanliness in either strain, indicating that other environmental factors, such as litter quality or stocking density, may play a more prominent role in early growth stages. These findings emphasize the trade-offs associated with different LIs. High LI (e.g., 50 lux) improves gait scores and stimulates activity, which can enhance leg health but may compromise feather cleanliness due to increased litter disturbance. Low LI (e.g., 5 lux) supports footpad health by reducing litter interaction but may suppress natural behaviors, limiting welfare.

5.5 Conclusions

In conclusion, LI impacts broiler growth performance and welfare differently based on age, strain, and specific welfare metrics. In Ross broilers, increased LI (50 lux) at 42 days reduced body weight, though this effect disappeared by 56 days, with FCR remaining stable across all LIs. Conversely, Cobb broilers' body weight was unaffected by LI at both 42 and 56 days, but lower LI (5 lux) slightly increased FCR at 42 days. Bone strength was consistent across LIs for both strains, with males exhibiting stronger bones than females. LI influenced thermal regulation and feather coverage, as higher LI increased back temperature in Ross broilers at 28 days due to enhanced activity, while lower LI preserved belly feather coverage and reduced belly temperature in Cobb broilers at 56 days by minimizing friction with litter. Welfare outcomes showed that moderate LI (20 lux) optimized feather cleanliness in Ross broilers, while higher LI (50 lux) improved gait scores for both strains at 56 days. Lower LI (5 lux) reduced footpad dermatitis in Cobb broilers but may limit activity and natural behaviors. Across all metrics, age significantly influenced welfare, with feather cleanliness, gait, and footpad health declining as broilers matured. These findings emphasize the trade-offs associated with different LIs, with high LI promoting activity and leg health but risking feather loss, while low LI supports footpad health and feather preservation but may suppress natural behaviors.

CHAPTER SIX

IMPACT OF LIGHTING INTENSITY ON ACTIVITY INDEX, STRETCHING AND PREENING BEHAVIOR OF ROSS 708 AND COBB 700 BROILERS

Abstract: Light intensity (LI) is crucial in broiler management, shaping broiler physiology, behavior, and welfare. The activity index, stretching, and preening behaviors in broilers reflect their comfort, welfare, and environmental suitability, offering valuable insights into their welfare. This study investigated the activity index% (AI%), stretching, and preening behaviors of Ross 708 and Cobb 700 broilers as affected by Three LIs (5, 20, and 50 lux) on days 28 and 56. Each LI treatment has six replicates. During the first week, all treatments were exposed to 50 lux lighting to help the chicks locate feed and water efficiently. Broiler activities were monitored through the computer vision system continuously. Activity index, stretching, and preening behavior of broilers at the fourth and eighth weeks of age were analyzed. Results shows that increasing LI significantly raised the AI% in Ross at 28 days ($P<0.01$), peaking at 50 lux (7.20%). In Cobb broilers, AI% was highest at 5 lux (4.45%) at 28 days, with no significant differences by 56 days. Stretching behavior in Ross broilers peaked at 20 lux (4.71 stretches per bird per hour) at 28 days, declining to 1.91 at 56 days, while Cobb broilers showed increased stretching at 20 lux only at 56 days ($P<0.01$). Preening in Ross broilers increased with light intensity at 28 days (8.40 events/hour) but decreased with age (4.34/hour at 56 days), while Cobb broilers showed no light-related changes, highlighting better adaptability to low light.
Keywords: broiler; lighting intensity; activity index; stretching; preening

6.1 Introduction

Natural behavior expression is a key metric in poultry welfare assessment (Webster, 2001), with preening and stretching recognized as essential comfort behaviors. These activities indicate that broilers are engaging in behaviors suited to their needs, making them valuable welfare indicators.

Lighting intensity plays a critical role in influencing broiler behavior, impacting their levels of physical engagement and comfort behaviors. Various intensities of light, measured in lux, directly affect behaviors such as stretching, preening, and general activity, which are crucial indicators of both physical and psychological welfare in broilers.

At lower light intensities, such as 5 to 20 lux, broilers exhibit decreased stretching behaviors, with a noticeable shift towards inactivity and increased resting. Stretching, involving the extension of a wing and leg on the same side (Li et al., 2021), a natural comfort behavior that supports muscle tone, circulation, and joint flexibility, is minimized in dim environments. This reduction suggests that birds in low light are less physically engaged, possibly due to reduced motivation and stimulation (Senaratna et al., 2016).

Preening behaviors, where broilers groom their feathers, is essential for body maintenance and feather alignment (Zhao et al., 2020), also fluctuate with light intensity. Under high-intensity lighting, broilers preen more frequently, particularly while lying down, as increased visibility may enhance their ability to perform this body-care activity effectively (Alvino et al., 2009a). Brighter conditions support higher visibility, which stimulates preening and may even encourage social engagement through visual mimicry of peers. Conversely, in medium to low light conditions, preening is less frequent, indicating that birds may experience diminished comfort or social interaction.

The activity index, or general movement level within the flock, also shows a strong correlation with lighting intensity. High-intensity light environments encourage active movement, with behaviors such as walking, standing, and social interactions more prominent in well-lit spaces (Manser, 1996). Broilers exposed to higher light intensity demonstrate increased exploration and interaction with their surroundings and each other, a trend that persists even in later growth stages. In contrast, lower light intensities promote sedentary behavior, characterized by resting and inactivity, which can lead to physical issues like reduced muscle tone and leg health challenges. Overall, while lower light intensities are sometimes implemented to reduce aggression or conserve energy, they may also inhibit natural behaviors essential for broiler welfare. Providing adequate lighting is crucial for encouraging behaviors like stretching, preening, and movement, which contribute to the physical health and psychological comfort of broilers. Traditionally, the frequency and duration of these behaviors are assessed manually, which, although standard, is labor-intensive, time-consuming, and subjective. Precision Livestock Farming technologies, such as computer vision, now enable automated, continuous behavior monitoring in commercial settings. Automated systems, like video-action recognition, have shown promise in objectively measuring behaviors, including drinking, preening, and stretching(Nasiri et al., 2024a; Nasiri et al., 2024b), offering scalable, objective assessments to enhance welfare monitoring. The object of this study is to leverage precision agriculture techniques to examine how lighting intensity affects broiler activity index, stretching, and preening behaviors.

6.2 Materials and Methods

6.2.1 Birds, Diets, and Management

A total of 648 straight-run broilers, consisting of 324 Ross-708 and 324 Cobb-700 birds, were obtained from local commercial hatcheries and reared at a 44 kg/m^2 stocking density (18 birds per pen, pen size: 1.1m x 1.5m) until day 56. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in July 2023 and the trial with Cobb 700 broilers in October 2023. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The tested lighting intensities were 5, 20, and 50 lux applied from day 8 to day 56. Each LI treatment has 6 replicates. During the first week, all treatments were exposed to 50 lux lighting to help the chicks locate feed and water efficiently. All birds were reared in one room with areas of varying light intensity distinguished by black tarps (TEZONG black waterproof plastic tarps, 10x20ft each). To achieve lighting levels of 50, 20, and 5 Lux, 6, 4, and 3 light bulbs (Overdrive A19 Dimmable Omni LED Bulb - 9.8 Watts 5000K) were used respectively to provide lighting. To ensure even distribution of light, bulbs were spaced uniformly, and black tapes (Lichamp black electrical tape) were applied to the bulbs to fine-tune the lighting levels. The lighting intensities at the bird level were measured using a HATO ONE spectrometer (item code: 6776). Measurements were taken at three points in each pen: the right-up corner, center area, and left-down corner. All birds were reared under identical room conditions but housed separately in pens. Each pen was equipped with one 36-centimeter-diameter tube feeder and three nipple drinkers. The feeder space and the number of drinkers were sufficient for all treatments based on the NCC recommendation (National Chicken Council, 2022b). Broilers were feather-sexed (for Ross birds) or vent-sexed (for Cobb birds) and distributed evenly in experimental pens at a 1:1 male-to-female ratio. The experimental room temperature was adjusted according to the Ross 708 (Aviagen, 2018) and the Cobb 700 (Cobb, 2021) broiler management guides by bird age. At the study's commencement, each pen was bedded with Topsoil (Farmer Green topsoil, 0.14 cubic feet per pen) and covered with black mulch (Earthgro black wood shredded mulch, 0.04 cubic feet per pen) which remained unchanged throughout the study period. The topsoil and mulch used in this setup, rather than the shavings or rice hulls commonly used in the commercial poultry industry, serve a specific purpose. When using overhead cameras to monitor broiler activities, it is essential to distinguish the broilers from their background (the bedding material) for effective image processing of the recorded video. To achieve this, black topsoil and mulch are used instead of the light yellow shavings or rice hulls, providing a contrasting background against the white bodies of the broilers. Every two weeks, the total weight of all birds in each experimental pen was recorded. Feed intake was also measured biweekly to calculate the FCR. Broilers were reared to a target market weight of 4.0 kg for 56 days. broilers in this study were provided with a diet containing 19% crude protein and 2851 kcal/kg metabolizable energy (Co-op Chick Starter/Grower Crumble - AMP BMD, Tennessee Farmers Cooperative, La Vergne, TN) throughout the entire study. Broilers in this study were provided with a diet containing 19% crude protein and 2851 kcal/kg metabolizable energy (Co-op Chick Starter/Grower Crumble - AMP BMD, Tennessee Farmers Cooperative, La Vergne, TN) throughout the entire study. Subsequently, five randomly chosen broilers (3 males and 2 females) from each pen underwent measurement for welfare indicators, and two broilers (1 male and 1 female) were euthanized via carbon dioxide method to assess tibia-breaking strength at the end of the trial. These procedures adhered to the guidelines outlined in the Guide for the Care and Use of Agriculture Animals in Research and Teaching (Federation of Animal Science Societies, 2010), as well as the University of Tennessee's Institutional Animal Care and Use Committee (**IACUC** Protocol #2876-1221).

6.2.2 Continuous Behavior Monitoring

High-performance security cameras (IP5M-B1186EB-28MM, Amcrest Technologies, Houston, TX) were installed approximately 3 meters above each pen to monitor broilers' activities. Each overhead camera covered 2 pens. The overhead camera recorded videos in the first 15 minutes of each hour from the start of the experiment to the end of the experiment. The activity index, as well as stretching and preening behaviors, were analyzed from videos recorded on days 28 and 56. On these days, broiler chickens were provided with lights from 7:00 to 22:59, and lights were turned off from 23:00 to 6:59. Activity indices were measured by overhead cameras installed over each pen. Images were extracted from the video every 0.2 seconds to analyze the activity index of broilers (Yang et al., 2020).

The automated video-action recognition algorithm developed by Nasiri et al. (2024b) was used to automatically detecting and counting preening and stretching behaviors. The algorithm demonstrated identification performance with an accuracy of 96.7% (Nasiri et al., 2024b).

6.3 Results

6.3.1 Effect of Lighting Intensity, Age on the Activity Index% and the Hourly AI% Patterns.

According to

Table 6.1 and **Figure 6.1**, the Activity Index of Ross broilers raised significantly when the light intensity went up at 28 days of age. The highest AI% was seen when 50 lux of light was used. By 56 days, while increased LI continued to positively affect AI%, the overall AI% had decreased significantly, from an average of 6.27% at 28 days to 1.63%. The hourly activity pattern at 28 days revealed that AI% in Ross broilers initially declined gradually after lights were turned on, followed by

Table 6.1 The effect of lighting intensity (LI, lux), age on the activity index% (AI%) and the hourly AI% patterns of the Ross 708 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on AI% of Ross on day 28										
LI	5			20			50		Std Error	*P*-value
AI %	5.44^{c}			6.18^{b}			7.20^{a}		0.16	<0.01
The hourly AI% patterns of Ross on day 28										
hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
AI %	8.33^{a}	8.19^{a}	8.19^{a}	8.10^{a}	7.30^{ab}	6.95^{ab}	6.78^{abc}	5.87^{bcd}		
hour	15	16	17	18	19	20	21	22	0.38	<0.01
AI %	5.68^{bcd}	5.65^{bcd}	5.51^{bcd}	5.06^{cd}	4.79^{d}	4.74^{d}	4.63^{d}	4.61^{d}		
Effect of LI on AI% of Ross on day 56										
LI	5			20			50		Std Error	*P*-value
AI %	1.00^{b}			2.07^{a}			1.83^{a}		0.09	<0.01
The hourly AI% patterns of Ross on day 56										
hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
AI %	2.26^{a}	2.15^{ab}	2.05^{ab}	1.89^{ab}	1.81^{ab}	1.61^{ab}	1.60^{ab}	1.58^{ab}		
hour	15	16	17	18	19	20	21	22	0.22	0.01
AI %	1.57^{ab}	1.54^{ab}	1.49^{ab}	1.44^{ab}	1.37^{ab}	1.33^{ab}	1.27^{ab}	1.13^{b}		
Effect of age on AI% of Ross										
Age	Day 28					Day 56			Std Error	*P*-value
AI %	6.27^{a}					1.63^{b}			0.07	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

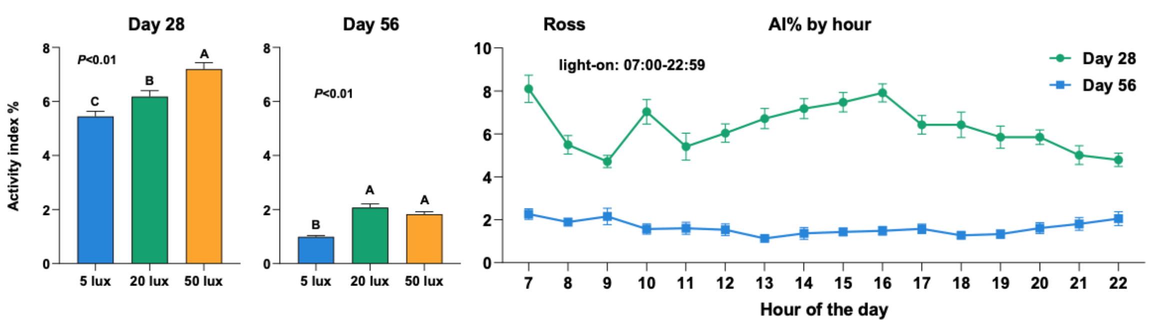


Figure 6.1 The effect of lighting intensity (LI, lux) on activity index% (AI%) of Ross 708 broilers on days 28 and 56, and the hourly AI% patterns for Ross on days 28 and 56.

fluctuations, possibly due to the presence of staff entering the room to monitor health and feeding. At 56 days, the hourly activity pattern remained stable.

For Cobb 700 broilers (see

Table 6.2 and **Figure 6.2**), high lighting intensity (50 lux) at 28 days resulted in a lower AI%, while the 5 lux group displayed the highest AI% (4.45%). This suggests that at 28 days, Cobb broilers may experience discomfort under higher light levels (50 lux), leading to reduced activity. Additional experiments are necessary to provide a more comprehensive understanding of this phenomenon. These findings underscore the variation in optimal welfare conditions required by different broiler strains. By day 56, light intensity had no notable impact on AI% in Cobb broilers. The daily activity pattern of Cobb broilers was consistently stable, showing no variation between morning and afternoon, and the difference in activity levels between 28 and 56 days was less pronounced than in Ross broilers.

6.3.2 Effect of Lighting Intensity, Age on the Number of Stretching Behavior and the Hourly Stretching Patterns.

According to **Table 6.3** and **Figure 6.3**, the stretching behavior of Ross broilers at 28 days of age increased significantly with higher light intensity, reaching a maximum frequency of 4.71 stretches per bird per hour at 20 lux. At 56 days, increasing the light intensity to 20 lux continued to positively influence stretching behavior, although the overall frequency declined from an average of 4.03 stretches at 28 days to 1.91 times at 56 days. The hourly stretching pattern at 28 days showed that Ross broilers were most active in the early afternoon, while at 56 days, stretching behavior stabilized at a consistently low level throughout the day.

For Cobb 700 broilers (see **Table 6.4** and **Figure 6.4**), stretching behavior at 28 days was unaffected by light intensity, indicating good adaptability to lower lighting (5 lux). By 56 days, however, increasing the light intensity to 20 lux significantly enhanced stretching activity in Cobb broilers, but further increasing the light to 50 lux reduced this behavior. Excessive brightness may cause discomfort in Cobb broilers, resulting in a decrease in welfare-related behaviors. Cobb broilers exhibited a stable stretching pattern throughout the day, with little variation between morning and afternoon.

Table 6.2 The effect of lighting intensity (LI, lux), age on the activity index% (AI%) and the hourly AI% patterns of the Cobb 700 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on AI% of Cobb on day 28

LI	5	20	50	Std Error	*P*-value
AI %	4.45^{a}	4.21^{a}	3.51^{b}	0.09	<0.01

The hourly AI% patterns of Cobb on day 28

hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
AI %	4.95^{a}	4.31^{abc}	4.54^{ab}	4.02^{abc}	3.87^{bc}	4.12^{abc}	3.88^{bc}	4.14^{abc}		
hour	15	16	17	18	19	20	21	22	0.07	<0.01
AI %	3.64^{bc}	3.77^{bc}	3.97^{abc}	3.77^{bc}	4.05^{abc}	4.07^{abc}	3.35^{c}	4.42^{ab}		

Effect of LI on AI% of Cobb on day 56

LI	5	20	50	Std Error	*P*-value
AI %	2.87	2.72	2.67	0.06	0.05

The hourly AI% patterns of Cobb on day 56

hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
AI %	3.96^{a}	3.49^{ab}	2.96^{bc}	2.85^{bcd}	2.64^{cd}	2.38^{cd}	2.62^{cd}	2.44^{cd}		
hour	15	16	17	18	19	20	21	22	0.14	<0.01
AI %	2.44^{cd}	2.20^{d}	2.55^{cd}	2.34^{cd}	2.67^{cd}	2.70^{cd}	2.97^{bc}	2.84^{bcd}		

Effect of age on AI% of Cobb

Age	Day 28	Day 56	Std Error	*P*-value
AI %	4.05^{a}	2.75^{b}	0.04	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

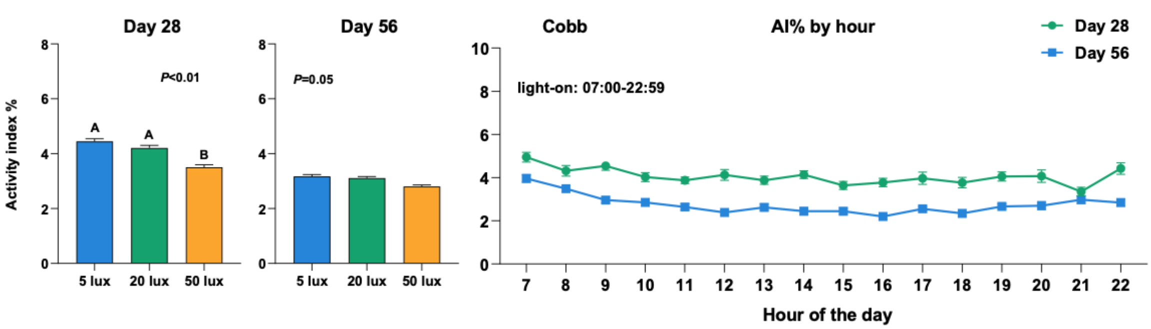


Figure 6.2 The effect of lighting intensity (LI, lux) on activity index% (AI%) of Cobb 700 broilers on days 28 and 56, and the hourly AI% patterns for Cobb on days 28 and 56.

Table 6.3 The effect of lighting intensity (LI, lux), age on the number of stretching behavior (times per bird per hour) and the hourly stretching behavior patterns of the Ross 708 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on the number of stretching of Ross on day 28										
LI		5			20			50	Std Error	*P*-value
Stretching		2.81^{b}			4.71^{a}			4.56^{a}	0.16	<0.01
The hourly stretching patterns of Ross on day 28										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Stretching	2.64^{e}	4.31^{abcde}	3.91^{abcde}	3.06^{de}	5.20^{abc}	3.59^{bcde}	5.35^{ab}	5.48^{a}		
Hour	15	16	17	18	19	20	21	22	0.36	<0.01
Stretching	5.12^{abc}	4.27^{abcde}	3.91^{abcde}	4.46^{abcd}	3.78^{abcde}	2.63^{e}	3.47^{cde}	3.23^{de}		
Effect of LI on the number of stretching of Ross on day 56										
LI		5			20			50	Std Error	*P*-value
Stretching		1.33^{c}			2.42^{a}			1.99^{b}	0.11	<0.01
The hourly stretching patterns of Ross on day 56										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Stretching	2.63	1.84	1.70	1.73	1.79	1.42	2.04	1.73		
Hour	15	16	17	18	19	20	21	22	0.25	0.17
Stretching	1.93	1.83	2.33	1.77	1.89	1.94	1.77	2.28		
Effect of age on the number of stretching of Ross										
Age			Day 28				Day 56		Std Error	*P*-value
Stretching			4.03^{a}				1.91^{b}		0.08	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

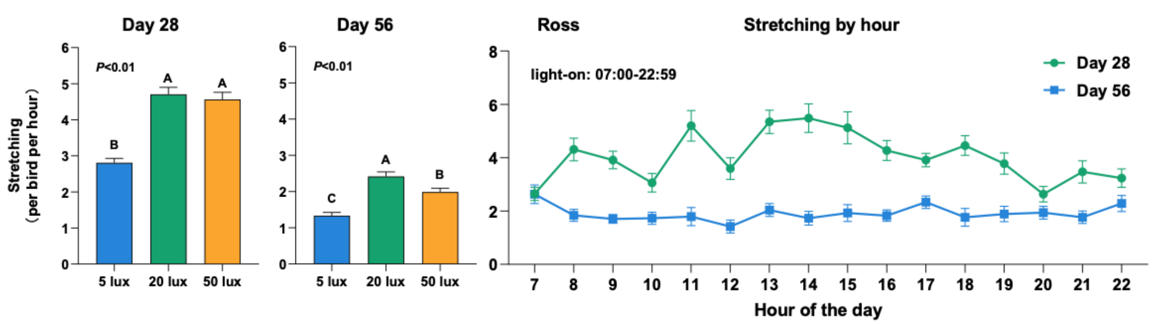


Figure 6.3 The effect of lighting intensity (LI, lux) on the number of stretching behavior (times per bird per hour) of Ross 708 broilers on days 28 and 56, and the hourly stretching behavior patterns for Ross on days 28 and 56.

Table 6.4 The effect of lighting intensity (LI, lux), age on the number of stretching behavior (times per bird per hour) and the hourly stretching behavior patterns of the Cobb 700 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on the number of stretching of Cobb on day 28										
LI	5		20			50			Std Error	*P*-value
Stretching	2.98		3.46			3.09			0.21	0.24
The hourly stretching patterns of Cobb on day 28										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Stretching	3.11	3.11	2.91	3.60	3.58	2.72	3.36	3.31		
Hour	15	16	17	18	19	20	21	22	0.49	0.63
Stretching	3.19	3.38	3.93	3.23	2.12	3.28	3.51	2.49		
Effect of LI on the number of stretching of Cobb on day 56										
LI	5		20			50			Std Error	*P*-value
Stretching	1.61^{B}		2.47^{A}			1.75^{B}			0.14	<0.01
The hourly stretching patterns of Cobb on day 56										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Stretching	2.89	2.32	1.80	2.00	2.20	1.80	2.17	2.54		
Hour	15	16	17	18	19	20	21	22	0.32	0.09
Stretching	1.78	1.73	1.28	1.68	2.05	1.48	1.53	1.80		
Effect of age on the number of stretching of Cobb										
Age	Day 28				Day 56				Std Error	*P*-value
Stretching	3.18^{a}				1.94^{b}				0.10	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

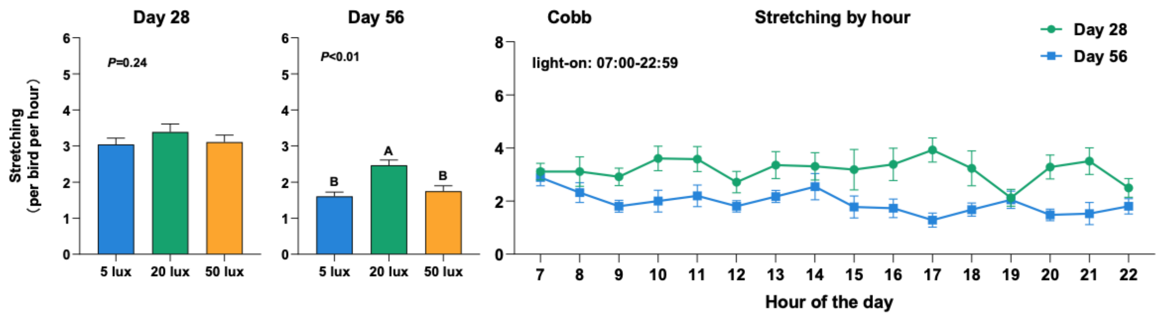


Figure 6.4 The effect of lighting intensity (LI, lux) on the number of stretching behavior (times per bird per hour) of Cobb 700 broilers on days 28 and 56, and the hourly stretching behavior patterns for Cobb on days 28 and 56.

Additionally, the change in activity level between 28 and 56 days was less pronounced for Cobb broilers compared to Ross broilers.

6.3.3 Effect of Lighting Intensity, Age on the Number of Preening Behavior and the Hourly Preening Patterns.

According to

Table 6.5 and **Figure 6.5**, increasing light intensity from 5 to 20 or 50 lux significantly enhanced preening behavior in Ross broilers at 28 days of age. However, by 56 days, a light intensity of 20 lux had a diminishing effect on preening, suggesting age-related sensitivity to light that warrants further investigation. The overall average preening frequency nearly halved, dropping from 8.40 events at 28 days to 4.34 at 56 days. The hourly preening pattern at 28 days showed increased preening in the early afternoon, while by 56 days, the hourly pattern stabilized at a consistently low level.

For Cobb 700 broilers (see **Table 6.6** and **Figure 6.6**), preening behavior was unaffected by changes in light intensity at both 28 and 56 days of age, highlighting the adaptability of Cobb broilers to low light (5 lux). The daytime preening pattern for Cobb broilers showed increased preening behavior between 10:00 and 18:00, with a notable fluctuation around 12:00 on day 28, possibly due to staff movements in the chicken house.

6.4 Discussion

6.4.1 Effect of Lighting Intensity, Age on the Activity Index% and the Hourly AI% Patterns.

The impact of LI on broiler activity and welfare varies significantly between strains and ages. In this study, Ross broilers exhibited significantly higher activity levels (Activity Index, AI%) under increased LI at 28 days, with the highest AI% observed at 50 lux. This supports prior findings that moderate to high LI promotes active behaviors like foraging, standing, and movement while enhancing circadian rhythms (Blatchford et al., 2009; Mahmood et al., 2014). By 56 days, AI% in Ross broilers decreased from 6.27% to 1.63%, aligning with age-related reductions in activity levels reported in earlier research (Rault et al., 2017). The hourly activity patterns at 28 days fluctuated due to external disturbances, such as staff presence, but became more stable by 56 days, suggesting a developmental adaptation to environmental stimuli.

Table 6.5 The effect of lighting intensity (LI, lux), age on the number of preening behavior (times per bird per hour) and the hourly preening behavior patterns of the Ross 708 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on the number of preening of Ross on day 28

LI	5	20	50	Std Error	*P*-value
Preening	6.26^{b}	9.46^{a}	9.47^{a}	0.32	<0.01

The hourly preening patterns of Ross on day 28

Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Preening	10.26^{abc}	8.99^{abcd}	6.74^{bcdef}	6.67^{cdef}	9.64^{abcd}	9.06^{abcd}	10.33^{ab}	11.64^{a}		
Hour	15	16	17	18	19	20	21	22	0.74	<0.01
Preening	10.19^{abcd}	10.31^{ab}	8.79^{abcd}	8.43^{abcde}	6.57^{def}	6.99^{bcdef}	4.65^{f}	5.06^{ef}		

Effect of LI on the number of preening of Ross on day 56

LI	5	20	50	Std Error	*P*-value
Preening	4.77^{A}	3.60^{B}	4.66^{A}	0.22	<0.01

The hourly preening patterns of Ross on day 56

Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Preening	2.86^{b}	3.72^{b}	5.17^{ab}	4.32^{ab}	4.78^{ab}	6.52^{a}	5.33^{ab}	5.30^{ab}		
Hour	15	16	17	18	19	20	21	22	0.52	<0.01
Preening	3.69^{b}	4.00^{ab}	3.83^{b}	4.38^{ab}	4.04^{ab}	3.60^{b}	3.70^{b}	4.26^{ab}		

Effect of age on the number of preening of Ross

Age	Day 28	Day 56	Std Error	*P*-value
Preening	8.40^{a}	4.34^{b}	0.16	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

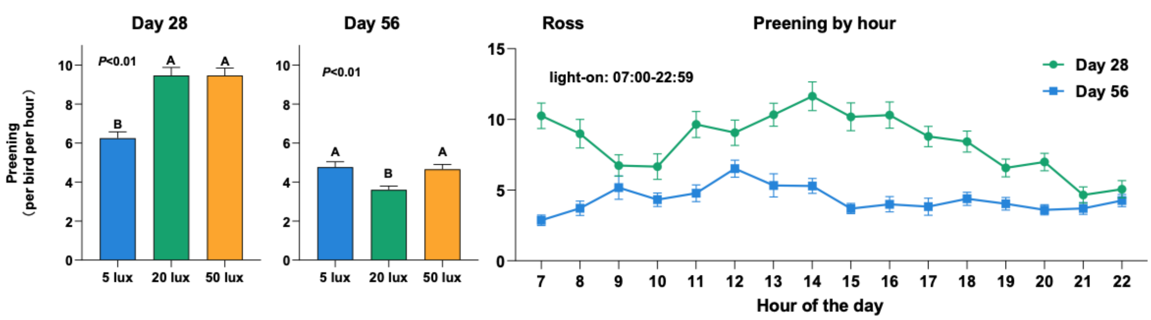


Figure 6.5 The effect of lighting intensity (LI, lux) on the number of preening behavior (times per bird per hour) of Ross 708 broilers on days 28 and 56, and the hourly preening behavior patterns for Ross on days 28 and 56.

Table 6.6 The effect of lighting intensity (LI, lux), age on the number of preening behavior (times per bird per hour) and the hourly preening behavior patterns of the Cobb 700 broilers. Lighting was provided for broilers from 7:00 to 22:59, followed by a dark period from 23:00 to 6:59.

Effect of LI on the number of preening of Cobb on day 28										
LI		5		20			50		Std Error	*P*-value
Preening		6.41		5.19			6.24		0.55	0.24
The hourly preening patterns of Cobb on day 28										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Preening	5.60^{abcd}	4.94^{bcd}	5.90^{abcd}	7.19^{abcd}	8.05^{ab}	4.79^{bcd}	9.06^{a}	7.38^{abc}		
Hour	15	16	17	18	19	20	21	22	1.27	0.05
Preening	6.17^{abcd}	7.70^{ab}	7.38^{abc}	5.56^{abcd}	3.78^{d}	3.80^{d}	3.85^{cd}	4.02^{cd}		
Effect of LI on the number of preening of Cobb on day 56										
LI		5		20			50		Std Error	*P*-value
Preening		3.88		3.28			3.91		0.26	0.17
The hourly preening patterns of Cobb on day 56										
Hour	7	8	9	10	11	12	13	14	Std Error	*P*-value
Preening	1.73^{d}	3.46^{abcd}	3.93^{abcd}	3.93^{abcd}	5.60^{a}	5.06^{abc}	5.33^{ab}	4.15^{abcd}		
Hour	15	16	17	18	19	20	21	22	0.62	<0.01
Preening	3.53^{abcd}	4.54^{abcd}	4.10^{abcd}	3.73^{abcd}	2.59^{abcd}	2.74^{abcd}	2.32^{bcd}	2.27^{cd}		
Effect of age on the number of preening of Cobb										
Age			Day 28				Day 56		Std Error	*P*-value
Preening			5.95^{a}				3.69^{b}		0.25	<0.01

Shared letters mean no significant difference, while distinct letters signify a significant difference (P<0.05).

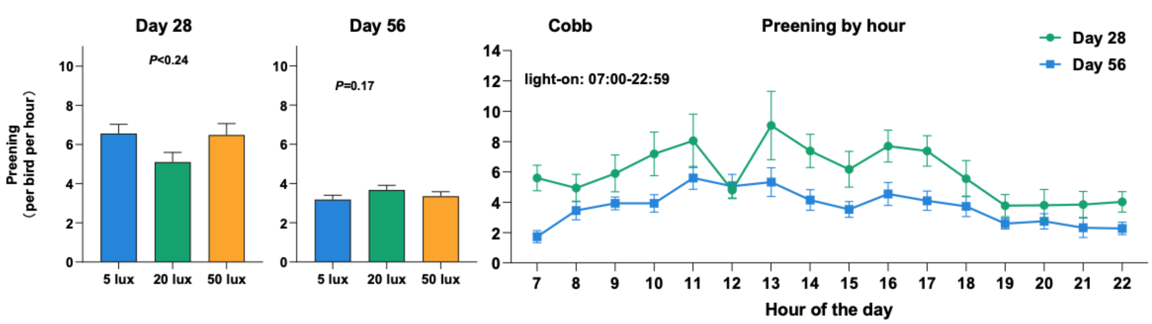


Figure 6.6 The effect of lighting intensity (LI, lux) on the number of preening behavior (times per bird per hour) of Cobb 700 broilers on days 28 and 56, and the hourly preening behavior patterns for Cobb on days 28 and 56.

In contrast, Cobb broilers showed a different response to LI. At 28 days, AI% was highest under 5 lux (4.45%) and lowest under 50 lux, indicating potential discomfort under higher light levels. Alvino et al. (2009b) similarly found that low LI (5 lux) better supported consistent activity patterns in Cobb 500 broilers, especially during the dark period, while higher LI disturbed their natural rhythm. By 56 days, LI had no significant effect on Cobb broilers, and their activity patterns remained consistently stable throughout the day, indicating reduced sensitivity to lighting changes as they aged. This strain-dependent variation highlights the need to tailor lighting conditions to specific broiler genetics, as suggested by (Blatchford et al., 2012).

Behavioral differences under various LIs align with earlier findings that higher light levels (e.g., 50–200 lux) encourage active behaviors but may also increase competition and aggression (Kristensen et al., 2007; Mahmood et al., 2014). Excessively high LI (200 lux) has been associated with hock bruising due to hyperactivity, although it can reduce footpad erosion (Blatchford et al., 2009). Conversely, dim lighting (e.g., 5 lux) supports consistent activity during the dark period but may impair welfare by disrupting circadian rhythms, as birds experience insufficient contrast between light and dark phases (Alvino et al., 2009b; Blatchford et al., 2012).

The findings in this study suggest that 50 lux may provide an optimal balance for Ross broilers, promoting natural behaviors and welfare without the adverse effects seen at higher intensities. For Cobb broilers, low LI may be more suitable during earlier stages, as higher intensities could cause discomfort. Similar observations by Škrbić et al. (2019) support that LIs above 50 lux can enhance activity without compromising production but may require careful management to avoid overstimulation.

From a welfare perspective, moderate LIs improve activity levels and natural behaviors while minimizing health risks like bruising or erosion. Rault et al. (2017) highlighted that light levels around 20 lux could stimulate natural movements without triggering adverse effects. Mahmood et al. (2014) further suggested that lower LIs (e.g., 5 lux) can reduce energy costs without harming growth or health, although long-term welfare impacts warrant further exploration.

6.4.2 Effect of Lighting Intensity, Age on the Number of Stretching Behavior and the Hourly Stretching Patterns.

The stretching behavior of broilers, an important welfare indicator, demonstrates variability influenced by light intensity, age, and strain. In this study, Ross broilers showed a significant increase in stretching frequency with higher light intensity at 28 days, peaking at 4.71 stretches per bird per hour under 20 lux. However, by 56 days, stretching declined to 1.91 stretches per hour, reflecting age-related decreases in activity, even as 20 lux continued to have a positive influence. The hourly pattern at 28 days indicated higher activity during the early afternoon, transitioning to a consistently low level throughout the day by 56 days. These findings highlight the role of light intensity in promoting stretching behavior in Ross broilers, particularly during earlier life stages. In contrast, Cobb 700 broilers exhibited no significant response to light intensity at 28 days, suggesting good adaptability to lower lighting conditions, such as 5 lux. By 56 days, however, increasing light intensity to 20 lux significantly enhanced stretching behavior, but further increases to 50 lux reduced it, likely due to discomfort under excessive brightness. The stable stretching patterns of Cobb broilers throughout the day and the smaller decline in activity between 28 and 56 days compared to Ross broilers underscore their distinct response to light management.

Previous research on the effect of light intensity on stretching behavior in broilers is limited, but related findings provide valuable context. Prayitno et al. (1997) demonstrated that light intensity significantly affects stretching behavior, with high-intensity red light (0.45 stretches per bird per hour) being more effective than blue light (0.26 stretches per bird per hour). They also found that red light intensity significantly enhanced stretching ($P < 0.01$), likely due to its stimulatory effects on muscle activity and bone health, which may reduce locomotion-related issues. In contrast, blue light showed limited effects in promoting stretching behaviors. Senaratna et al. (2016) studied the stretching behavior of broiler chickens but focused on the effects of light wavelengths on broiler chicken behavior.

These findings suggest that optimizing light intensity, particularly at early growth stages, can enhance welfare-related behaviors like stretching, which may improve muscle development and skeletal health. For Ross broilers, 20 lux appears to be an effective level for promoting stretching, while for Cobb broilers, a moderate intensity (20 lux) is beneficial at later stages, with caution needed to avoid discomfort at higher levels (50 lux). Future research should explore the combined effects of light intensity and spectrum to better understand their role in improving broiler welfare and health outcomes across different strains.

6.4.3 Effect of Lighting Intensity, Age on the Number of Preening Behavior and the Hourly Preening Patterns.

Ross broilers exhibited increased preening behavior with higher light intensities (20 and 50 lux) at 28 days of age, peaking at an average of 8.40 events per hour. However, by 56 days, preening frequency declined to 4.34 events per hour, and 20 lux had a diminishing effect, suggesting age-related sensitivity to light. Hourly preening patterns at 28 days showed peaks in the early afternoon, which stabilized to consistently low levels by 56 days. These findings align with prior research suggesting that brighter lighting (e.g., 20–50 lux) promotes comfort behaviors such as preening and foraging (Deep et al., 2012; Mahmood et al., 2014). In contrast, Cobb 700 broilers showed no significant response to changes in light intensity at either age, maintaining consistent preening behavior across conditions, even under low light (5 lux). The hourly preening pattern in Cobb broilers at 28 days showed higher activity between 10:00 and 18:00, with a midday dip likely due to staff disturbances, and remained stable at 56 days. This strain-specific adaptability to lower lighting conditions highlights the resilience of Cobb broilers to environments with minimal stimulation, consistent with findings by (Alvino et al., 2009b).

Previous studies have emphasized the role of light intensity in broiler welfare and behavior. Alvino et al. (2009b) and Mahmood et al. (2014) reported that preening behavior increases significantly under brighter lighting (50–200 lux), particularly during peak activity periods, as light serves as a temporal cue for synchronized behaviors. Lower light intensities, such as 5 lux, reduce preening and foraging behaviors, potentially compromising welfare by limiting the expression of comfort behaviors essential for feather maintenance and parasite removal (Deep et al., 2012). However, low light can also promote restful behaviors and reduce stress, as evidenced by decreased heterophil-to-lymphocyte ratios and corticosterone levels under low-intensity lighting (Tainika et al., 2023). Excessively bright lighting may induce stress or discomfort in broilers, as suggested by Adeleye et al. (2021) and Wu et al. (2022). For example, higher light levels can encourage activity but may also lead to stress-induced behaviors rather than exploratory or comfort-driven actions. Conversely, extremely dim lighting (e.g., 1 lux) reduces activity and disrupts natural behavior rhythms, leading to negative welfare outcomes (Deep et al., 2012).

This study highlights the importance of balancing light intensity to enhance welfare-related behaviors like preening without causing undue stress. Moderate light levels (e.g., 20 lux) appear optimal for promoting preening behavior in Ross broilers, especially during earlier growth stages, while Cobb broilers demonstrate greater adaptability to low light intensities.

6.5 Conclusions

This study demonstrates that the effects of light intensity on activity, stretching, and preening behaviors in broilers are influenced by age and strain. For Ross broilers, higher light intensities, particularly 20 lux, enhanced activity and welfare-related behaviors such as stretching and preening at 28 days of age, with peak levels observed under 50 lux for activity. However, by 56 days, the overall frequency of these behaviors declined significantly, reflecting age-related reductions in responsiveness to light. These findings suggest that maintaining 20 lux lighting before 28 days can maximize welfare benefits for Ross broilers by promoting natural behaviors and supporting activity patterns. In contrast, Cobb 700 broilers exhibited greater adaptability to low lighting conditions (5 lux), with higher activity levels at 28 days under dim light compared to higher intensities, indicating potential discomfort under excessive brightness. By 56 days, Cobb broilers' behavior stabilized across all lighting conditions, with no notable effects of light intensity on activity, stretching, or preening. These results confirm that a 5 lux environment is sufficient to support Cobb broilers' welfare without compromising their behavioral needs. The differences observed between strains emphasize the importance of tailoring light intensity to the specific requirements of broiler genetics. While moderate light levels (20 lux) are recommended for Ross broilers to enhance welfare-related behaviors, lower intensities (5 lux) are appropriate for Cobb broilers, particularly in the later stages of growth.

OVERALL CONCLUSIONS

This dissertation investigated the effects of growth rate (GR), stocking density (SD), and light intensity (LI) on production, welfare, and behavior in broiler chickens, with a focus on breed-specific and age-related responses. The results highlight the complex interplay between these factors and their significant implications for broiler production, welfare, and behaviors.

For growth rate, slower growth rates were found to enhance welfare indicators, such as improved feather coverage and better gait scores. However, these benefits came at the cost of a poorer feed conversion ratio and longer production cycles, which is not acceptable for producers. This means that while welfare improvements can align with consumer and regulatory demands, the economic trade-offs, including higher production costs and reduced overall profitability, must be carefully weighed.

For stocking density, reducing SD improved feather cleanliness and footpad health. High SD (44 kg/m^2) initially increased activity in younger birds (day 28) but later restricted natural behaviors as they aged (day 56). For producers, this suggests that optimal SD should be adjusted based on age and breed to strike a balance between maximizing space utilization, profitability, and maintaining welfare without significantly impacting production performance.

For light intensity, the results revealed that its effects are both age- and breed-dependent. Moderate LI (20 lux) supported natural behaviors in Ross broilers, while Cobb broilers performed better in lower LI environments (5 lux). This means producers must consider breed-specific lighting strategies, as inappropriate LI can either enhance or diminish welfare, affecting behavior, activity levels, and overall productivity.

Across all factors, broiler welfare declined with age, emphasizing the need for dynamic, adaptive management practices. To producers, this underscores the importance of tailoring strategies to broiler strain, age, and environmental conditions to optimize both ethical welfare practices and production efficiency.

This study acknowledges several limitations that provide important context for its findings and highlights areas for future research. Behavioral analysis was confined to the enclosure's open central area, excluding the pen's edges and regions near the feeders. This limitation arose from the constraints of current behavioral recognition technology, which lacks sufficient accuracy in occluded areas. Consequently, behaviors such as feeding and preening, which are commonly observed at the edge of the enclosure, were not considered. This narrow focus likely reduced the comprehensiveness of behavioral assessments, highlighting the need for future research to expand analyses to include the enclosure for a more complete understanding of broiler behavior.

Additionally, the dietary phase of the experiment (Chapters 3 to 6), a single diet containing 19% crude protein and 2851 kcal/kg metabolizable energy (Co-op Chick Starter/Grower Crumble - AMP BMD, Tennessee Farmers Cooperative, La Vergne, TN) was used throughout the study. Although this dietary consistency ensured controlled experimental conditions, it differed from standard commercial practices, where broilers are typically provided phase-specific feed formulations tailored to their evolving nutritional requirements. This deviation may have affected the comparability of production performance outcomes with commercial settings and potentially limited the applicability of the findings to commercial operations. This underscores the importance of incorporating growth-phase-adjusted diets in future research to enhance the relevance and practical utility of the results.

The choice of black topsoil and mulch as bedding materials also introduced a limitation. These materials, selected to provide a high-contrast background against the white broilers for video monitoring, facilitated more accurate image processing but deviated from industry-standard bedding materials such as shavings or rice hulls. This difference may limit the generalizability of the findings to commercial poultry systems where conventional bedding is used.

Seasonal variability introduced by the phased experimental design further complicates the interpretation of results. Trials involving different broiler breeds were conducted under varying seasonal conditions, with stocking density trials for Ross 708 broilers performed in September 2022 and for Cobb 700 broilers in January 2023, while light intensity trials were conducted in July 2023 and October 2023. The stark contrasts between hot summer and cold winter conditions significantly influenced broiler performance. Future studies should consider simultaneous trials to mitigate such seasonal effects.

Lastly, the method used to control growth rates relied on feed restriction, which successfully slowed broiler growth and improved some welfare parameters. However, prolonged hunger associated with feed restriction raises additional welfare concerns, highlighting the need to explore alternative methods that balance welfare considerations with production efficiency.

By acknowledging these limitations, this study provides a balanced perspective on its findings and offers a roadmap for future research to refine experimental methodologies and enhance their applicability to commercial broiler production systems.

To address these limitations, future research should focus on evaluating growth performance, stocking density, and light intensity requirements across a wider variety of broiler breeds to enhance the generalizability of findings. Simultaneous trials are recommended to reduce variability introduced by seasonal or environmental factors. Efforts should focus on optimizing behavior recognition methods to enable the expansion of analysis areas to include the entire pen. This advancement would enhance both the accuracy and comprehensiveness of behavioral assessments, providing a more complete understanding of broiler behavior. Additionally, research should incorporate phase-specific feed formulations tailored to align with commercial industry standards. Finally, alternative methods for controlling growth rates should be explored to address welfare concerns while maintaining production efficiency.

By refining methodologies and addressing these limitations, future studies can better support the development of strategies that optimize welfare and productivity in commercial broiler production systems.

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VITA

Shengyu Zhou was born in Fujian, China. He completed his Bachelor of Science in Animal Science at Fujian Agriculture and Forestry University (FAFU) in July 2018, graduating with a GPA of 3.70/5.00, ranking in the top 3% of his class. During his undergraduate studies, he actively participated in research and was awarded multiple scholarships, including the Da Bei Nong Scholarship.

In February 2018, Shengyu Zhou was selected as one of the four students for a CSC-sponsored exchange program at Charles Sturt University, New South Wales, Australia, where he achieved a perfect GPA of 5.00/5.00 in Animal Science. His international academic experience included hands-on work at local cattle and sheep farms, as well as research in Southern blotting techniques for virus detection.

Shengyu pursued his Master of Science in Animal Nutrition and Feed at China Agricultural University, Beijing, completing his degree in January 2021. His master's research focused on optimizing the protein-energy ratio in broiler diets to enhance growth performance and nutrient composition. During his time in Beijing, he received the title of Beijing Outstanding Graduate.

Shengyu began his PhD in Animal Science at The University of Tennessee, Knoxville, in August 2021, specializing in Precision Poultry Management. His doctoral research explores broiler welfare and behavior, assessing factors such as growth rate, stocking density, and light intensity using image processing and top-view vision systems. His work has led to multiple publications in peer-reviewed journals, including *Poultry Science* and *Foods*. He also served as a leader in numerous broiler experiments, overseeing management, welfare assessment, and sampling procedures. Shengyu Zhou has been recognized for his academic excellence through various awards, including the Oliver J. Hubbard Memorial Poultry Science Scholarship (2022, 2023) and the Dr. Ollia E. and Wilma B. Goff Graduate Student Award (2024).