WHY IMPROVED BROILER CHICKEN WELFARE IS ESSENTIAL

animal EQUALITY

COMPASSION in world farming

MERCY FOR ANIMALS

THE HUMANE LEAGUE

WORLD ANIMAL PROTECTION

INTRODUCTION

Over the past century, the broiler chicken industry has worked to increase chicken production through breeding and husbandry techniques, resulting in a bird who grows to 2.5 times the slaughter weight of a chicken in 1925 in 58% less time.[1] This focus on production has neglected a relatively new science: animal welfare. “Animal welfare” refers to the ability of animals to cope with their environment[2] and comprises three facets: health, affective states, and natural living.[3] When studying animal welfare, scientists examine both inputs and outcome-based measures. Inputs are what an animal is given (e.g., lighting conditions, feed, enrichment). Outcome-based measures assess an animal’s response to an input—that is, the outcome (e.g., rates of footpad lesions resulting from litter conditions). While outcome-based measures are essential to assessing animal welfare, when they indicate poor welfare, it is too late for the individual animals affected. In the broiler chicken industry, where animal suffering is a chronic issue[4–6] it is essential that animal welfare be protected through ensuring baseline levels of inputs that offer chickens the opportunity to experience “a life worth living”[7]. A list of relevant outcomes can then be used to ensure that these inputs, paired with good husbandry, elicit a positive welfare state[8].

Animal welfare scientists generally work to reduce animal suffering. We know that animals can suffer[9-10] and they do, in very large numbers. Of the ten billion animals raised and killed for food every year in the United States, 90% are chickens,[11-13] with poultry production expected to rise.[14] Broiler chickens suffer from a wide range of health and welfare problems; yet with changes to genetics and husbandry, suffering can be greatly alleviated in commercial production.[15] These changes include a shift to alternative breeds, lower stocking densities, better lighting conditions, enriched environments, cleaner litter, and a transition from live-shackle slaughter to controlled-atmosphere killing.

IMPACT OF BREED

A large body of research has examined the heritability of welfare outcomes as well as their association with different breeds of broiler chickens. By transitioning from the most commonly used commercial breeds, which we define as typically faster growing and intensively raised with enlarged breast muscle (e.g., Ross 308, Ross 708, and Cobb 500), common welfare problems, including reduced walking ability and activity, high mortality, and skin lesions, can be greatly improved.

WALKING ABILITY

Research suggests that current commercial broiler chicken breeds, growing quickly to a heavy weight, are predisposed to leg weakness and skeletal abnormalities. This is due to abnormally high weight gain on relatively immature bones and joints.[16] Angular bone deformity, tibial dyschondroplasia (lack of bone formation of the tibia), and osteochondrosis (abnormal bone growth that can lead to tissue death) are skeletal defects associated with rapid growth that result in reduced activity and feeding.[17–22] When compared with alternative breeds, commercial broiler chickens exhibit reduced walking ability 23 and much more lameness,24–26 with skeletal abnormalities being a common cause.[17,26] Such bone abnormalities restrict movement, increase risk of injury, reduce a bird's ability to eat and drink,[21] and cause pain.[27–29] There is also a clear link between first-week mortality on farms and lameness.30 Selection for fast growth and top-heavy conformation also affects general walking ability. While fast weight gain puts stress on the immature skeleton, the change in conformation due to a large breast muscle mass alters walking patterns.[23] A study comparing the walking patterns of alternative breeds and commercial breeds (Ross 308) found that the Ross birds walked more slowly, took shorter steps, and had decreased cadence as they grew heavier.[23] The slower walking speeds are believed to be a coping mechanism to minimize skeletal stress and reduce discomfort in fast-growing commercial broilers.[28]

ACTIVITY

In addition to causing bone abnormalities, rapid growth creates a high metabolic demand[31] that reduces energy available for activity[32] and negatively impacts the ability of broiler chickens to move.[33] Because standing and walking may cause discomfort and pain,[32,34] activity is significantly reduced (with 53–86% of the time spent resting)[32,35–41] when compared with that of the chicken's wild ancestor, the red junglefowl (who spends just 10% of the time resting)[42] and that of modern alternative breeds.[39] Alternative breed birds, who grow more slowly, can walk, run, and use perches more than those who grow more rapidly.33 The low activity levels and increased sitting and lying toward the end of the rearing period may also correlate with plumage dirtiness; clean plumage is also considered important for thermoregulation.[43] Despite the birds' lack of ability, the motivation, or internal biological drive, to move and perch still exists.[33,44,45]

PERCHING MOTIVATION AND ABILITY

Perching is a natural behavior of chickens—in the daytime it gives birds an elevated vantage point to monitor their surroundings, and at night it provides a sense of security from predators.[46] While the need for vigilance is decreased with domestication, the desire to perch has not been eliminated.[46] Commercial broilers perch less than laying hens, however, and this may be because rapid growth and body weight prevent expression of the behavior.[46] Leg weakness[47] and altered body proportions48 reduce broilers' ability to access perches and balance. In a study comparing the Ross 308 (common commercial breed) with the Rowan Ranger and Hubbard CY JA57 (intermediate-growth alternative breeds), the Ross 308 perched significantly less than the other breeds during the day and at night and used only the lowest perches.[49]

SKIN LESIONS

Broiler chickens are typically reared in indoor broiler houses atop a floor covered with litter (commonly wood shavings or a similar material), which is used for thermal insulation and cushioning from the cement flooring.[50,51] Birds resting on damp, dirty litter have a heightened risk of ammonia burns on the skin. These can get worse over time, developing mild to severe inflammation, and can then ulcerate.[52,53] Such lesions are likely painful.[53] Ammonia burns to the skin can cause breast blisters, hock burn, and footpad dermatitis. Hock burn and footpad dermatitis are correlated conditions caused by inflammation of the skin on the plantar surface of the hock (underside of the leg)[54] and the footpad. Footpad lesions have been reported in 25–70% of birds[55–58] in broiler flocks (translating to around 2.5–7.5 billion birds annually[59]). Genetic predisposition is also a factor.[53,60–64] Poor feathering may also predispose birds to skin lesions. With broilers reaching slaughter weight at an immature stage, down feathers may still be present around the head, neck, and possibly the abdomen.[65] Poor feathering leaves unprotected skin prone to skin damage and possible infection.[66] Environmental conditions, particularly poor litter quality, are the major risk factor for footpad dermatitis, hock burn, and breast blisters.

Broiler genotype is among the main factors impacting prevalence of footpad dermatitis, with the rapid-growth broiler genotype associated with deeper footpad lesions than slower-growth genotypes.[58] Underlying this relationship might be the differences in skin physiology and immune response. When compared with the skin of leghorns (a common breed used in egg production), the skin of fast-growing broiler breeds has been found to be more susceptible to injury and slower to heal, due to a combination of an inherent, structural skin weakness (including a thinner dermis layer, poorly defined connective tissue, and erratic collagen fibers); skin with a pH level favorable to E.coli colonization; and once infected, poor immune response to the infection site and lower-quality white blood cells unable to contain the spread of infection.[67] Significant differences have also been reported between the fast-growing breeds Ross 308 birds and Cobb 500 birds on footpad scores.68 Since genes predispose to broiler footpad lesions, using breeds with better skin integrity and healthier feet can help improve the welfare of broiler chickens.

MORTALITY

In recent years, average mortality on U.S. broiler farms has increased to 4.4% at 47 days of age.[69] A major cause of mortality is cardiovascular disorders,70 including ascites (otherwise known as "water belly" caused by fluid accumulation in the abdomen).[71] This is a multifactorial disorder that is chronic, causing discomfort and stress. It is estimated that up to 5% of broilers die from ascites.[72] The condition is linked to the high metabolic demands of rapid growth and is more common in heavier male chickens.[73–75]

Another common cardiovascular disorder suffered by broiler chickens is "sudden death syndrome" (SDS; also called "flip over" by producers). SDS is typically seen in heavy males when they are acutely affected by stress; birds suddenly begin violent wing flapping and die within minutes.[73–75] It is estimated to cause mortality rates of 0.5%–4% in broiler flocks equating to 50–400 million birds a year.[76]

Heavy, rapidly growing broiler chickens are also predisposed to bacterial bone infections.[30] The sheer force of the bird's heavy body weight on immature cartilage damages the growing tissue and can lead to infection.[77] Bacterial chondronecrosis and osteomyelitis are both significant causes of lameness and mortality in intensive systems.[30,70,77]

DEAD ON ARRIVAL

Modern broiler chickens are predisposed to thermal stress, altered heat exchange capacity, and muscular pathologies. Along with cardiovascular weakness, these abnormalities reduce their ability to withstand transport stress.[78] The genetic predisposition to thermal stress is also thought to contribute to seasonal effects of "Dead on Arrival" birds, and this is more pronounced in extreme thermal conditions and over longer periods (up to 28 hours).[79–83]

IMPACT OF ENVIRONMENT AND SPACE

LITTER

Friable (easily crumbled) litter is a good material for dustbathing, an instinctive behavior that birds perform to keep their feathers clean and in good condition. Birds are highly motivated to dustbathe, and as dustbathing is a communal activity, all birds should have adequate daily access to loose, dry litter to avoid competition and frustration.[84] Various substrates have been used for litter with some more suitable for dustbathing than others. As tens of thousands of birds eat, drink, and defecate in the same space, litter quality is key for moisture absorption.[85–90]

Poorly managed (wet) litter can create an environment conducive to production of ammonia,[91] which is an irritant to the birds' mucous membranes and respiratory tracts[91,92] and a contributing factor to the appearance of skin lesions, most notably footpad lesions.[50,57,58,85,93] Hock burn levels are associated with litter depth, with models predicting reduced severity for every 1 cm increase in depth.[94] Caked litter is wet litter that forms a manure cap, carrying similar risks and consequences as wet litter.[50,93] Despite being flagged as a problem nearly 100 years ago,[50,95] wet litter continues to be widespread[96] and along with it, the incidence of footpad dermatitis.

Scientific recommendations on litter address broilers' basic need for comfort and cleanliness. Provision of sufficient litter throughout the broiler house that is of appropriate quality (loose, friable, nontoxic) at the outset is required to ensure access for the entire flock. Litter depth of at least three inches is reported to accommodate moisture buildup,[97] with four inches recommended for colder conditions. If litter is reused for subsequent flocks, caked litter should be removed and replaced with fresh litter.[51,64,90] Assessment of litter friability should be performed throughout the production cycle. Since moisture may vary spatially within a broiler shed,[50,98] moisture levels should be checked by sampling litter in various locations.

LIGHT

Vision is a chicken's strongest sense and is impacted by light intensity and day length.[99,100] The light environment cues production of melatonin and plays a key role in creating physiological and behavioral rhythms.[101–103] Although inappropriate lighting leads to disruption of circadian rhythms and stress in captive animals, including chickens[38,104–107] chicken producers routinely utilize unnatural light environments to increase productivity.[108,109] The National Chicken Council (NCC) recommends that chickens be provided with four hours of darkness per day (which need not be continuous) with no recommendation on intensity.[110] While the NCC states that there is "no conclusive research on the optimum light intensity for broiler chicken health and welfare," a large body of research reveals that intensity, day-night contrast, and length of the dark period all affect welfare.

Research demonstrates that low light intensity is detrimental to welfare with impacts on activity,[41,105,106] performance of comfort behaviors,[38,111] flock synchronicity and resting ability,[38,104–106] ability to communicate socially,[112] and leg,[105,113,114] eye,[105,106,113,114] and immune system health.[106] When compared with industry-standard light intensities of 1–6 lux, higher light intensities were associated with greater activity,[115] preening,[116] and foraging,[117,118] with 50 lux being the lowest intensity demonstrated to increase all three behavior patterns. Research shows that the contrast between day and night light intensity provides important environmental cues allowing the entire flock to rest simultaneously;[119] flocks are more synchronous with contrasts of 1 lux at night to 50 lux during the day.[38,104–106] increases.[106] The current research shows that light intensity must be kept above 50 lux to avoid negative impacts on behavior, rest, and health.

Despite this knowledge, chicken producers often raise chickens at 5 lux intensity to limit activity but maintain high feeding motivation.[113,114,121] For comparison, office buildings are lit to 500–750 lux.100

The duration of the dark period also impacts health and welfare. Dark periods of fewer than seven hours result in decreased activity and comfort behavior,[122] inability to form sleep cycles,[115,119,122] reduced leg health[120,123] and eye health,[99] and increased mortality.[109,120,124] Research showed that giving broilers 7–10 hours of nightly darkness resulted in the lowest mortality, including reduced rates of sudden death syndrome and ascites, and fewer pathological skeletal issues. It also resulted in distinct behavioral rhythms[119,120,122] and simultaneously increased leg and foot health, activity, feeding, drinking, preening, dustbathing, leg and wing stretching, and litter pecking. This is corroborated by research finding walking ability improved with increased dark periods.[125] Given these clear impacts on health and welfare, current dark periods should be increased from the standard four hours to a minimum of six hours and must be continuous.

STOCKING DENSITY

A major contributor to poor broiler welfare is high stocking density (SD).[126] High SD reduces freedom of movement, including the ability to adequately perform natural, highly motivated behavior.[127–131] Under experimental conditions, broiler chickens preferred less crowded spaces.[132] Higher SD in broilers impedes preening behavior, probably due to disturbance by other birds.[130] Densely stocked broilers show increased fearfulness in response to humans, probably as a consequence of the aversive conditions.[127,133] Birds at high SD have been shown to prefer lying next to walls, a behavior thought to avoid disturbance due to overcrowding and enable birds to rest.[131] High SD also increases manure buildup, reducing litter and air quality.[134–137] It can increase susceptibility to disease, including experimentally induced Salmonella enteritidis infection[138] and necrotic enteritis.[139] High SD can decrease plumage cleanliness, increase skin and leg lesions, increase mortality, and impact carcass quality.[129,130,137,140–147] High SD can also increase stress[128,143,145,148,149] and reduce productivity and growth.[128,134,136,137,143,150] Leg weakness is significantly reduced at lower stocking densities,[146,147] and in one study at around 34 kg/m2, the lowest SD in the study, over 3% of birds suffered severe lameness compromising their ability to access feed and water.[146]

High SD can indirectly impact the welfare of broilers through poor litter and air quality and high temperature and humidity.[151,152] Due to restricted space, locomotor and litter-directed behavioral activity are likely to be increasingly constrained by stocking densities above 6 lbs./ft2. Higher SD also leads to skin problems from reduced litter quality, and dirty litter can cause infections through lesions on the feet that increase leg disorders,[153] which can reduce growth rates and depress feed intake.[115] Although several studies show greater health, welfare, and productivity benefits and bird preference for a lower SD, combined research results indicate a steep reduction in welfare beyond a maximum of 6 lbs./ft2 (30 kg/m2).[147,153] While lowering stocking density improves broiler welfare, it should be done in combination with other housing, management, and genetic improvements.[135] In other words, in well-controlled environmental conditions, a maximum of 6 lbs./ft2 is suggested, and in less well-controlled conditions,[154] lower stocking densities should be considered.

ENVIRONMENTAL ENRICHMENT

Environmental enrichment is defined as “an improvement of the environment of captive animals, which increases the behavioral opportunities of the animal and leads to improvements in biological function.”[155] Increasing motivation and exercise opportunities through enrichment positively affects broiler welfare. Addition of enrichment items, such as perches, platforms, panels, straw bales, and pecking objects, has been shown in research trials to improve leg health and increase activity levels.[156] Exercise in turn improves leg health by strengthening muscle and bones.[157 158]

For alternative breeds with outdoor access, providing access to perches inside the house increased the percentage of time the birds spent standing.[142,159142,159–161] In indoor environments, provision of horizontal perches can improve leg health, as perch provision reduces tibial dyschondroplasia.[162] Provision of perches has been positively correlated with increased activity levels, and broilers have been observed to use perches as early as six days of age and on average at nine days of age.[163,164] Platforms have been found to positively affect leg health; birds with access to platforms have improved gait scores and lower prevalence and severity of tibial dyschondroplasia.[163] Visual barriers may also positively affect broiler behavior and welfare, as they serve as shelter areas.[165] Provision of barriers has been observed to reduce disturbances during rest.[166]

Provision of straw bales has also been observed to positively impact activity levels.[156] When provided in environments with natural light, straw bale enrichments positively affect walking ability and decrease time spent lying down.[156] Pecking objects, such as bundles of string, have also been found to improve walking ability in conjunction with other environmental factors, such as natural light.[167] Provision of multiple enrichments results in higher overall activity levels and a higher likelihood of birds engaging with the enrichment items.[167]

SLAUGHTER

WATER-BATH STUNNING

Chickens in the U.S. are typically slaughtered in an electrical water-bath system.[168] Birds are first hung upside down by their legs in metal shackles on a moving processing line while fully conscious. Then their heads pass through the electrical water bath designed to stun them before their throats are cut by an automated blade.[168] Water-bath stunning was originally designed for speed of slaughter,[169] however, and the system poses a number of serious welfare implications for chickens. The inversion of the birds into shackles is stressful and likely to cause pain.[170–173] Birds sometimes exhibit wing flapping at inversion and this can lead to dislocations and bone breakages.[168] The metal shackles used to hang birds often do not account for leg diameter variation and this leads operators to force larger birds with thick legs into narrow shackles.[174] Chickens may also experience painful pre-stun electric shocks if their wing tips enter the bath before their heads.[175] Birds may be stunned incorrectly or miss the stun bath altogether by raising their heads and missing the water.[168] Even when their heads do enter the water bath, if the current and frequency do not meet the required parameters to ensure unconsciousness, the stun may be ineffective and leave the birds conscious, having suffered a painful electrical shock, to experience their necks being cut.[168] In 2016 over half a million birds[176] were registered as cadavers post-mortem at the slaughterhouse, meaning they died for reasons other than slaughter. These birds were possibly alive and conscious when entering the scald tank.[168]

Slaughter conditions are improved by the use of controlled-atmosphere killing (CAK), which involves irreversible stunning of birds before slaughter using gas instead of electricity. This may be an inert gas, such as argon or nitrogen, or a mixture of carbon dioxide and other gases.[168] Birds are stunned and then killed by exposure to the gas or gases. CAK eliminates the need for live handling, shackling, and inversion of conscious chickens and should ensure chickens are fully unconscious at neck cutting and dead by the time they reach the scald tank.[168,177]

SUMMARY

The narrow focus of the modern broiler industry on productivity and efficiency has resulted in major welfare concerns and suffering for billions of broiler chickens every year. Current standards and policy fall short of the basic welfare requirements for broiler chickens as determined by extensive research in the field of animal welfare science and related disciplines. The science has also made clear that animal welfare is a complex concept, and that its adequate assessment requires a comprehensive approach that addresses the importance of each facet of animal welfare: health, affective states, and natural living. The interaction and interdependence of these three aspects of welfare cannot be overstated. Walking ability, for instance, which is significantly impaired in common commercial breeds, is affected by genetic selection favoring fast growth, but other factors also contribute, such as poor litter quality, high stocking densities, and dim lighting.

The complexity of assessing whether birds are provided with what they need to experience “a life worth living” requires attention to both inputs and outcomes.[7] While a focus on outcomes, such as measuring levels of hock burn or assessing feather cover, can give us more accurate information about the actual welfare state of an animal, the role of inputs in determining these outcomes cannot be ignored. The extensive research on the correlations among genetics, environmental inputs, and welfare outcomes underlines the need to implement adequate thresholds for environmental provisions, especially those that severely affect aspects of broiler welfare, such as litter, light, stocking density, and environmental enrichment. Alongside these crucial improvements to the environment, a shift to alternative breeds with greater potential to thrive in better environments is essential. After decades of genetic selection for commercially valuable traits, common commercial broiler breeds are no longer physically able to meet the basic requirement of a life worth living, even in the best of environments.

SUPPORTING LITERATURE

1. **U.S. Broiler Performance - The National Chicken Council.** The National Chicken Council Available at: http://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance/. (Accessed: 28th December 2017)
2. **Broom, D. M. Animal welfare: concepts and measurement.** J. Anim. Sci. 69, 4167 (1991).
3. **Fraser, D. Understanding animal welfare.** Acta Vet. Scand. 50, S1 (2008).
4. **Moyer, J. W. Seven sentenced after animal rights activists film abuse at chicken farms.** The Washington Post (2017).
5. **Moyer, J. W. 'You need to kill him?': Tyson Food contractors caught on video mistreating chickens.** The Washington Post (2017).
6. **Greenwald, G. & Woodhouse, L. A. Consumers Are Revolting Against Animal Cruelty — So the Poultry Industry Is Lobbying for Laws to Force Stores to Sell Their Eggs.** The Intercept (2018). Available at: https://theintercept.com/2018/03/02/consumers-are-revolting-against-animal-cruelty-so-the-poultry-industry-is-lobbying-for-laws-to-force-stores-to-sell-their-eggs/. (Accessed: 5th March 2018)
7. **Mellor, D. J. Updating Animal Welfare Thinking: Moving beyond the 'Five Freedoms' towards 'A Life Worth Living'.** Animals (Basel) 6, (2016).
8. **Yeates, J. W. & Main, D. C. J. Assessment of positive welfare: a review.** Vet. J. 175, 293–300 (2008).
9. **Dawkins, M. S. The Science of Animal Suffering.** Ethology 114, 937–945 (2008).
10. **Duncan, I. J. H. Science-based assessment of animal welfare: farm animals.** Rev. Sci. Tech. 24, 483–492 (2005).
11. **National Agricultural Statistics Service, Agricultural Statistics Board, United States Department of Agriculture.** Poultry Slaughter. (USDA, 2018).
12. **National Agricultural Statistics Service, Agricultural Statistics Board, United States Department of Agriculture.** Chickens and Eggs. (USDA, 2018).
13. **National Agricultural Statistics Service, Agricultural Statistics Board, United States Department of Agriculture.** Livestock Slaughter. (USDA, 2018).
14. **Conway, A. Global poultry and egg market projections.** WATTAgNet (2012). Available at: https://www.wattagnet.com/articles/14110-global-poultry-and-egg-market-projections. (Accessed: 5th March 2018)
15. **Animal Equality Compassion in World Farming USA Compassion Over Killing Mercy For Animals The American Society for the Prevention of Cruelty to Animals (ASPCA) The Humane League The Humane Society of the United States (HSUS) World Animal Protection.** Joint Animal Protection Organization Statement on Broiler Chicken Welfare Issues. (2017). Available at: http://poultryprogress.com/docs/Statement.pdf. (Accessed: 5th March 2018)
16. **Lilburn, M. S. Skeletal growth of commercial poultry species.** Poult. Sci. 73, 897–903 (1994).
17. **Julian, R. J. Rapid growth problems: ascites and skeletal deformities in broilers.** Poult. Sci. 77, 1773–1780 (1998).
18. **Shim, M. Y., Karnuah, A. B., Anthony, N. B., Pesti, G. M. & Aggrey, S. E. The effects of broiler chicken growth rate on valgus, varus, and tibial dyschondroplasia.** Poult. Sci. 91, 62–65 (2012).
19. **Julian, R. J. Valgus-varus deformity of the intertarsal joint in broiler chickens.** Can. Vet. J. 25, 254–258 (1984).
20. **Lynch, M., Thorp, B. H. & Whitehead, C. C. Avian tibial dyschondroplasia as a cause of bone deformity.** Avian Pathol. 21, 275–285 (1992).
21. **Kestin, S. C., Knowles, T. G., Tinch, A. E. & Gregory, N. G. Prevalence of leg weakness in broiler chickens and its relationship with genotype.** Vet. Rec. 131, 190–194 (1992).
22. **Mercer, J. T. & Hill, W. G. Estimation of genetic parameters for skeletal defects in broiler chickens.** Heredity 53, 193 (1984).

SUPPORTING LITERATURE

23. **Corr, S. A., Gentle, M. J., McCorquodale, C. C. & Bennett, D. The effect of morphology on walking ability in the modern broiler: a gait analysis study.** (2003).

24. **Van Middlekoop, K., van Dam, J., Jan Wiers, W. & van Horne, P. Slower growing broilers pose lower welfare risks.** World Poultry 18, 20–21 (2002).

25. **Wilhelmsson, S. Comparison of behaviour and health of two broiler hybrids with different growth rates.** (2016).

26. **Kestin, S. C., Gordon, S., Su, G. & Sorensen, P. Relationships in broiler chickens between lameness, liveweight, growth rate and age.** Vet. Rec. 148, 196–197 (2001).

27. **McGeown, D., Danbury, T. C., Waterman-Pearson, A. E. & Kestin, S. C. Effect of carprofen on lameness in broiler chickens**. Vet. Rec. 144, 668–671 (1999).

28. **Caplen, G. et al. Kinematic analysis quantifies gait abnormalities associated with lameness in broiler chickens and identifies evolutionary gait differences.** PLoS One 7, e40800 (2012).

29. **Hothersall, B. et al. Effects of carprofen, meloxicam and butorphanol on broiler chickens' performance in mobility tests.** Anim. Welf. 25, 55–67 (2016).

30. **Kittelsen, K. E. et al. Associations among gait score, production data, abattoir registrations, and postmortem tibia measurements in broiler chickens.** Poult. Sci. (2017). doi:10.3382/ps/pew433

31. **Decuypere, E., Buyse, J. & Buys, N. Ascites in broiler chickens: exogenous and endogenous structural and functional causal factors*.** Worlds. Poult. Sci. J. 56, 367–377 (2000).

32. **Weeks, C. A., Danbury, T. D., Davies, H. C., Hunt, P. & Kestin, S. C. The behaviour of broiler chickens and its modification by lameness.** Appl. Anim. Behav. Sci. 67, 111–125 (2000).

33. **Bokkers, E. Behavioural motivations and abilities in broilers.** (Wageningen University, 2004).

34. **Nääs, I. A. et al. Impact of lameness on broiler well-being.** J. Appl. Poult. Res. 18, 432–439 (2009).

35. **Riber, A. B. Effects of color of light on preferences, performance, and welfare in broilers.** Poult. Sci. 94, 1767–1775 (2015).

36. **Taylor, P., Hemsworth, P., Dawkins, M., Groves, P. & Rault, J. Free-range broiler chicken behavioural time budgets: Inside and outside of the shed. in 26th Annual Australian Poultry Science Symposium 227** (researchgate.net, 2015).

37. **Murphy, L. B. & Preston, A. P. Time budgeting in meat chickens grown commercially.** Br. Poult. Sci. 29, 571–580 (1988).

38. **Alvino, G. M., Archer, G. S. & Mench, J. A. Behavioural time budgets of broiler chickens reared in varying light intensities.** Appl. Anim. Behav. Sci. 118, 54–61 (2009).

39. **Bizeray, D., Leterrier, C., Constantin, P., Picard, M. & Faure, J. M. Early locomotor behaviour in genetic stocks of chickens with different growth rates.** Appl. Anim. Behav. Sci. 68, 231–242 (2000).

40. **Preston, A. P., Pamment, P., McBride, G. & Foenander, F. Some activity patterns of meat chickens.** Proc. Fifth Australasian Poultry and Stock Feed Conversion, Adelaïde 203–207 (1983).

41. **Newberry, R. C., Hunt, J. R. & Gardiner, E. E. Influence of light intensity on behavior and performance of broiler chickens.** Poult. Sci. 67, 1020–1025 (1988).

42. **Dawkins, M. S. Time budgets in red junglefowl as a baseline for the assessment of welfare in domestic fowl.** Appl. Anim. Behav. Sci. 24, 77–80 (1989).

43. **Forkman, B. & Keeling, L., eds. Assessment of Animal Welfare Measures for Layers and Broilers.** Welfare Quality Reports No. 9. (2009).

44. **Weeks, C. A., Nicol, C. J., Sherwin, C. M. & Kestin, S. C. Comparison of the Behaviour of Broiler Chickens in Indoor and Free-Range Environments.** Anim. Welf. 3, 179–192 (1994).

SUPPORTING LITERATURE

45. **Haye, U. & Simons, P. C. Twisted legs in broilers.** Br. Poult. Sci. 19, 549–557 (1978).

46. **Nicol, C. Behavioral Needs, Priorities, and Preferences. in The Behavioural Biology of Chickens 5** (CABI, 2015).

47. **Kestin, S. C., Su, G. & Sørensen, P. Different commercial broiler crosses have different susceptibilities to leg weakness.** Poult. Sci. 78, 1085–1090 (1999).

48. **Paxton, H., Daley, M. A., Corr, S. A. & Hutchinson, J. R. The gait dynamics of the modern broiler chicken: a cautionary tale of selective breeding.** J. Exp. Biol. 216, 3237–3248 (2013).

49. **Wedin, M. Perching behaviour and disturbance during sleep in three hybrids of broiler chicken (Gallus gallus domesticus).** 664, 27 (2016).

50. **Dunlop, M. W. et al. The multidimensional causal factors of 'wet litter' in chicken-meat production.** Sci. Total Environ. 562, 766–776 (2016).

51. **Cobb Broiler Management Guide.** (2012). Available at: http://www.cobb-vantress.com/docs/default-source/management-guides/broiler-management-guide.pdf. (Accessed: 24th February 2018)

52. **Haslam, S. M. et al. Factors affecting the prevalence of foot pad dermatitis, hock burn and breast burn in broiler chicken.** Br. Poult. Sci. 48, 264–275 (2007).

53. **de Jong, I., Berg, C., Butterworth, A. & Estevéz, I. Scientific report updating the EFSA opinions on the welfare of broilers and broiler breeders.** EFSA Supporting Publications 9, (2012).

54. **Hepworth, P. J., Nefedov, A. V., Muchnik, I. B. & Morgan, K. L. Early warning indicators for hock burn in broiler flocks.** Avian Pathol. 39, 405–409 (2010).

55. **Kjaer, J. B., Su, G., Nielsen, B. L. & Sørensen, P. Foot pad dermatitis and hock burn in broiler chickens and degree of inheritance.** Poult. Sci. 85, 1342–1348 (2006).

56. **Dawkins, M. S., Roberts, S. J., Cain, R. J., Nickson, T. & Donnelly, C. A. Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption.** Vet. Rec. 180, 499–499 (2017).

57. **Saraiva, S., Saraiva, C. & Stilwell, G. Feather conditions and clinical scores as indicators of broilers welfare at the slaughterhouse.** Res. Vet. Sci. 107, 75–79 (2016).

58. **Allain, V. et al. Skin lesions in broiler chickens measured at the slaughterhouse: relationships between lesions and between their prevalence and rearing factors.** Br. Poult. Sci. 50, 407–417 (2009).

59. **Butterworth, A. & Weeks, C. The Impact of Disease on Welfare. in The Welfare of Domestic Fowl and Other Captive Birds** (eds. Duncan, I. & Hawkins, P.) 9, 189–218 (Springer, 2010).

60. **Dawkins, M. S., Roberts, S. J., Cain, R. J., Nickson, T. & Donnelly, C. A. Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption.** Vet. Rec. 180, 499 (2017).

61. **Ask, B. Genetic variation of contact dermatitis in broilers.** Poult. Sci. 89, 866–875 (2010).

62. **Bessei, W. Welfare of broilers: a review.** Worlds. Poult. Sci. J. 62, 455–466 (2006).

63. **Kjaer, J. B., Su, G., Nielsen, B. L. & Sørensen, P. Foot pad dermatitis and hock burn in broiler chickens and degree of inheritance.** Poult. Sci. 85, 1342–1348 (2006).

64. **Shepherd, E. M. & Fairchild, B. D. Footpad dermatitis in poultry.** Poult. Sci. 89, 2043–2051 (2010).

65. **Leeson, S. & Walsh, T. Feathering in commercial poultry I. Feather growth and composition.** Worlds. Poult. Sci. J. 60, 42–51 (2004).

66. **Elfadil, A. A., Vaillancourt, J. P. & Meek, A. H. Impact of stocking density, breed, and feathering on the prevalence of abdominal skin scratches in broiler chickens.** Avian Dis. 40, 546–552 (1996).

SUPPORTING LITERATURE

67. **Olkowski, A. A., Wojnarowicz, C., Chirino-Trejo, M., Wurtz, B. M. & Kumor, L. The Role of First Line of Defence Mechanisms in the Pathogenesis of Cellulitis in Broiler Chickens: Skin Structural, Physiological and Cellular Response Factors.** J. Vet. Med. A Physiol. Pathol. Clin. Med. 52, 517–524 (2005).

68. **Martins, B. B., Martins, M., Mendes, A. A., Fernandes, B. & Aguiar, E. F. Footpad Dermatitis in Broilers: Differences between Strains and Gender.** Rev. Bras. Cienc. Avic. 18, 461–466 (2016).

69. **The National Chicken Council. U.S. Broiler Performance - The National Chicken Council** (2017). Available at: http://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance. (Accessed: 24th February 2017)

70. **Kittelsen, K. E., Granquist, E. G., Kolbjørnsen, Ø., Nafstad, O. & Moe, R. O. A comparison of post-mortem findings in broilers dead-on-farm and broilers dead-on-arrival at the abattoir.** Poult. Sci. 94, 2622–2629 (2015).

71. **Balog, J. M. et al. Effect of Cold Stress on Broilers Selected for Resistance or Susceptibility to Ascites Syndrome1.** Poultry Science 1383–1387 (2003).

72. **Urbaityte, R. Feeding to reduce ascites in poultry.** (JUNE 25, 2009). Available at: http://www.wattagnet.com/articles/416-feeding-to-reduce-ascites-in-poultry. (Accessed: 24th February 2017)

73. **Awachat, V. & Majumdar, S. Sudden death syndrome in poultry.** North-East Veterinarian 14, 31 (2014).

74. **Siddiqui F., M. F., Patil, M. S., Khan, K. M. & Khan, L. A. Sudden Death Syndrome – An Overview.** Veterinary World 2, 444–447 (2009).

75. **Olkowski, A. A. et al. A study on pathogenesis of sudden death syndrome in broiler chickens.** Res. Vet. Sci. 85, 131–140 (2008).

76. **Merck Veterinary Manual. Overview of Sudden Death Syndrome of Broiler Chickens - Poultry** (2016). Available at: http://www.merckvetmanual.com/poultry/sudden-death-syndrome-of-broiler-chickens/overview-of-sudden-death-syndrome-of-broiler-chickens. (Accessed: 24th February 2017)

77. **Wideman, R. F., Jr. Bacterial chondronecrosis with osteomyelitis and lameness in broilers: a review.** Poult. Sci. 95, 325–344 (2016).

78. **Mitchell, M. A. & Kettlewell, P. J. Welfare of poultry during transport – a review.**

79. **Chauvin, C. et al. Factors associated with mortality of broilers during transport to slaughterhouse.** Animal 5, 287–293 (2011).

80. **Haslam, S. M. et al. Prevalence and factors associated with it, of birds dead on arrival at the slaughterhouse and other rejection conditions in broiler chickens.** Br. Poult. Sci. 49, 685–696 (2008).

81. **Nijdam, E., Arens, P., Lambooij, E., Decuypere, E. & Stegeman, J. A. Factors influencing bruises and mortality of broilers during catching, transport, and lairage.** Poult. Sci. 83, 1610–1615 (2004).

82. **Petracci, M., Bianchi, M., Cavani, C., Gaspari, P. & Lavazza, A. Preslaughter mortality in broiler chickens, turkeys, and spent hens under commercial slaughtering.** Poult. Sci. 85, 1660–1664 (2006).

83. **United States of America. Twenty-Eight Hour Law** (49 USC, Section 80502). (1994).

84. **Hawkins, P. The Welfare Implications of Housing Captive Wild and Domesticated Birds. in The Welfare of Domestic Fowl and Other Captive Birds** (eds. Duncan, I. & Hawkins, P.) 9789048136490, 53–102 (Springer, 2010).

85. **SCAHAW. The Welfare of Chickens Kept for Meat Production (Broilers).** https://ec.europa.eu (2000). Available at: https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out39_en.pdf. (Accessed: 19th February 2018)

86. **de Gussem, M., van Middlekoop, K., van Mullem, K. & van 't Veer, E. Broiler Signals: A Practical Guide to Broiler Focussed Management.** (Roodbont Publishers B.V., 2015).

87. **Baxter, M., Bailie, C. L. & O'Connell, N. E. An evaluation of potential dustbathing substrates for commercial broiler chickens.** Animal 1–9 (2017).

SUPPORTING LITERATURE

88. **Shields, S. J., Garner, J. P. & Mench, J. A. Effect of sand and wood-shavings bedding on the behavior of broiler chickens.** Poult. Sci. 84, 1816–1824 (2005).
89. **Bilgili, S. F. et al. Influence of bedding material on footpad dermatitis in broiler chickens.** J. Appl. Poult. Res. 18, 583–589 (2009).
90. **Ritz, C. W., Fairchild, B. D. & Lacy Extension Poultry, M. Litter Quality and Broiler Performance.** (2009).
91. **Meluzzi, A. & Sirri, F. Welfare of broiler chickens.** Ital. J. Anim. Sci. 8, 161–173 (2009).
92. **Kristensen, H. H. & Wathes, C. M. Ammonia and poultry welfare: a review.** Worlds. Poult. Sci. J. 56, 235–245 (2000).
93. **Ross Broiler Management Handbook**. http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-Broiler-Handbook-2014i-EN.pdf (2014). Available at: http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-Broiler-Handbook-2014i-EN.pdf. (Accessed: 24th February 2018)
94. **Haslam, S. M. et al. Factors affecting the prevalence of foot pad dermatitis, hock burn and breast burn in broiler chicken.** Br. Poult. Sci. 48, 264–275 (2007).
95. **Dann, A. B. Wet Litter in the Poultry House.** Poult. Sci. 3, 15–19 (1923).
96. **Hermans, P. G., Fradkin, D., Muchnik, I. B. & Organ, K. L. Prevalence of wet litter and the associated risk factors in broiler flocks in the United Kingdom.** Vet. Rec. 158, 615–622 (2006).
97. **Shepherd, E. M., Fairchild, B. D. & Ritz, C. W. Alternative bedding materials and litter depth impact litter moisture and footpad dermatitis.** J. Appl. Poult. Res. 26, 518–528 (2017).
98. **Miles, D. M., Brooks, J. P., McLaughlin, M. R. & Rowe, D. E. Broiler litter ammonia emissions near sidewalls, feeders, and waterers.** Poult. Sci. 92, 1693–1698 (2013).
99. **Prescott, N. B., Wathes, C. M. & Jarvis, J. R. Light, vision and the welfare of poultry.** Anim. Welf. 12, 269–288 (2003).
100. **Manser, C. E. Effects of Lighting on the Welfare of Domestic Poultry: A Review.** Anim. Welf. 5, 341–360 (1996).
101. **Fleissner, G. Perception of Natural Zeitgeber Signals. in Biological Rhythms 83–93** (Springer, Berlin, Heidelberg, 2002).
102. **Brandstätter, R. The Circadian Pacemaking System of Birds. in Biological Rhythms 144–163** (Springer, Berlin, Heidelberg, 2002).
103. **Olanrewaju, H. A. et al. A review of lighting programs for broiler production.** Int. J. Poult. Sci. 5, 301–308 (2006).
104. **Alvino, G. M., Blatchford, R. A., Archer, G. S. & Mench, J. A. Light intensity during rearing affects the behavioural synchrony and resting patterns of broiler chickens.** Br. Poult. Sci. 50, 275–283 (2009).
105. **Blatchford, R. A., Archer, G. S. & Mench, J. A. Contrast in light intensity, rather than day length, influences the behavior and health of broiler chickens.** Poult. Sci. 91, 1768–1774 (2012).
106. **Blatchford, R. A. et al. The effect of light intensity on the behavior, eye and leg health, and immune function of broiler chickens.** Poult. Sci. 88, 20–28 (2009).
107. **Morgan, K. N. & Tromborg, C. T. Sources of stress in captivity.** Appl. Anim. Behav. Sci. 102, 262–302 (2007).
108. **Yang, Y., Pan, C., Zhong, R. & Pan, J. Artificial light and biological responses of broiler chickens: dose-response.** J. Anim. Sci. (2018). doi:10.1093/jas/skx044
109. **Schwean-Lardner, K., Fancher, B. I. & Classen, H. L. Impact of daylength on the productivity of two commercial broiler strains.** Br. Poult. Sci. 53, 7–18 (2012).
110. **National Chicken Council. National Chicken Council Animal Welfare Guidelines and Audit Checklist.** (2017).

SUPPORTING LITERATURE

111. **Deep, A., Schwean-Lardner, K., Crowe, T. G., Fancher, B. I. & Classen, H. L. Effect of light intensity on broiler behaviour and diurnal rhythms.** Appl. Anim. Behav. Sci. 136, 50–56 (2012).

112. **Kristensen, H. H., White, R. P. & Wathes, C. M. Light intensity and social communication between hens.** Br. Poult. Sci. 50, 649–656 (2009).

113. **Deep, A., Schwean-Lardner, K., Crowe, T. G., Fancher, B. I. & Classen, H. L. Effect of light intensity on broiler production, processing characteristics, and welfare.** Poult. Sci. 89, 2326–2333 (2010).

114. **Deep, A., Raginski, C., Schwean-Lardner, K., Fancher, B. I. & Classen, H. L. Minimum light intensity threshold to prevent negative effects on broiler production and welfare.** Br. Poult. Sci. 54, 686–694 (2013).

115. **Bessei, W. Welfare of broilers: a review.** Worlds. Poult. Sci. J. 62, 455 (2006).

116. **Delius, J. D. Preening and associated comfort behavior in birds.** Ann. N. Y. Acad. Sci. 525, 40–55 (1988).

117. **Mason, G. & Mendl, M. Do the stereotypies of pigs, chickens and mink reflect adaptive species differences in the control of foraging?** Appl. Anim. Behav. Sci. 53, 45–58 (1997).

118. **Rodenburg, T. B. et al. Feather pecking in laying hens: new insights and directions for research?** Appl. Anim. Behav. Sci. 86, 291–298 (2004).

119. **Schwean-Lardner, K., Fancher, B. I., Laarveld, B. & Classen, H. L. Effect of day length on flock behavioural patterns and melatonin rhythms in broilers.** Br. Poult. Sci. 55, 21–30 (2014).

120. **Schwean-Lardner, K. et al. Effect of day length on cause of mortality, leg health, and ocular health in broilers.** Poult. Sci. 92, 1–11 (2013).

121. **Controlling Light in Broiler Production. The Alabama Poultry Engineering and Economics Newsletter, Auburn University** (2000).

122. **Schwean-Lardner, K., Fancher, B. I. & Classen, H. L. Impact of daylength on behavioural output in commercial broilers.** Appl. Anim. Behav. Sci. 137, 43–52 (2012).

123. **Danbury, T. C., Weeks, C. A., Chambers, J. P., Waterman-Pearson, A. E. & Kestin, S. C. Self-selection of the analgesic drug carprofen by lame broiler chickens.** Vet. Rec. 146, 307–311 (2000).

124. **Rozenboim, I., Robinzon, B. & Rosenstrauch, A. Effect of light source and regimen on growing broilers.** Br. Poult. Sci. 40, 452–457 (1999).

125. **Knowles, T. G. et al. Leg disorders in broiler chickens: prevalence, risk factors and prevention.** PLoS One 3, e1545 (2008).

126. **Gocsik, É., Brooshooft, S. D., de Jong, I. C. & Saatkamp, H. W. Cost-efficiency of animal welfare in broiler production systems: A pilot study using the Welfare Quality® assessment protocol.** Agric. Syst. 146, 55–69 (2016).

127. **Andrews, S. M., Omed, H. M. & Phillips, C. J. The effect of a single or repeated period of high stocking density on the behavior and response to stimuli in broiler chickens.** Poult. Sci. 76, 1655–1660 (1997).

128. **Simitzis, P. E. et al. Impact of stocking density on broiler growth performance, meat characteristics, behavioural components and indicators of physiological and oxidative stress.** Br. Poult. Sci. 53, 721–730 (2012).

129. **Martrenchar, A., Morisse, J. P., Huonnic, D. & Cotte, J. P. Influence of stocking density on some behavioural, physiological and productivity traits of broilers.** Vet. Res. 28, 473–480 (1997).

130. **Hall, A. L. The effect of stocking density on the welfare and behaviour of broiler chickens reared commercially.** Anim. Welf. 10, 23–40 (2001).

131. **Buijs, S. et al. Resting or hiding? Why broiler chickens stay near walls and how density affects this.** Appl. Anim. Behav. Sci. 124, 97–103 (2010).

SUPPORTING LITERATURE

132. **Buijs, S., Keeling, L. J. & Tuyttens, F. A. Using motivation to feed as a way to assess the importance of space for broiler chickens.** Anim. Behav. 81, 145–151 (2011).

133. **Sanotra, G. S., Lawson, L. G., Vestergaard, K. S. & Thomsen, M. G. Influence of Stocking Density on Tonic Immobility, Lameness, and Tibial Dyschondroplasia in Broilers.** J. Appl. Anim. Welf. Sci. 4, 71–87 (2001).

134. **Meluzzi, A., Fabbri, C., Folegatti, E. & Sirri, F. Effect of less intensive rearing conditions on litter characteristics, growth performance, carcase injuries and meat quality of broilers.** Br. Poult. Sci. 49, 509–515 (2008).

135. **Estevez, I. Density allowances for broilers: where to set the limits?** Poult. Sci. 86, 1265–1272 (2007).

136. **Guardia, S. et al. Effects of stocking density on the growth performance and digestive microbiota of broiler chickens.** Poult. Sci. 90, 1878–1889 (2011).

137. **Farhadi, D., Hosseini, S. M. & Dezfuli, B. T. Effect of house type on growth performance, litter quality and incidence of foot lesions in broiler chickens reared in varying stocking density.** Journal of BioScience & Biotechnology 5, 69–78 (2016).

138. **Gomes, A. V. et al. Overcrowding stress decreases macrophage activity and increases Salmonella Enteritidis invasion in broiler chickens.** Avian Pathol. 43, 82–90 (2014).

139. **Tsiouris, V. et al. High stocking density as a predisposing factor for necrotic enteritis in broiler chicks.** Avian Pathol. 44, 59–66 (2015).

140. **Bradshaw, R. H., Kirkden, R. D. & Broom, D. M. A Review of the Aetiology and Pathology of Leg Weakness in Broilers in Relation to Welfare.** Avian and Poultry Biology Reviews 13, 45–103 (2002).

141. **Buijs, S. et al. The influence of stocking density on broiler chicken bone quality and fluctuating asymmetry.** Poult. Sci. 91, 1759–1767 (2012).

142. **Ventura, B. A., Siewerdt, F. & Estevez, I. Effects of barrier perches and density on broiler leg health, fear, and performance.** Poult. Sci. 89, 1574–1583 (2010).

143. **Villagrá, A. et al. Stocking density and stress induction affect production and stress parameters in broiler chickens.** Anim. Welf. 18, 189–197 (2009).

144. **Tullo, E. et al. Association between environmental predisposing risk factors and leg disorders in broiler chickens.** Journal of Animal Science 95, 1512–1520 (2017).

145. **Imaeda, N. Influence of the stocking density and rearing season on incidence of sudden death syndrome in broiler chickens.** Poult. Sci. 79, 201–204 (2000).

146. **Sørensen, P., Su, G. & Kestin, S. C. Effects of Age and Stocking Density on Leg Weakness in Broiler Chickens.** Poult. Sci. 79, 864–870 (2000).

147. **Buijs, S., Keeling, L., Rettenbacher, S., Van Poucke, E. & Tuyttens, F. A. Stocking density effects on broiler welfare: identifying sensitive ranges for different indicators.** Poult. Sci. 88, 1536–1543 (2009).

148. **Beloor, J. et al. The Effect of Stocking Density on Stress Related Genes and Telomeric Length in Broiler Chickens.** Asian-australas. J. Anim. Sci. 23, 437–443 (2010).

149. **Uzum, M. H. & Oral Toplu, H. D. Effects of stocking density and feed restriction on performance, carcass, meat quality characteristics and some stress parameters in broilers under heat stress.** Revue Méd. Vét. 164, 546–554 (2013).

150. **Velo, R. & Ceular, A. Effects of stocking density, light and perches on broiler growth.** Anim. Sci. J. 88, 386–393 (2017).

151. **Dawkins, M. S., Donnelly, C. A. & Jones, T. A. Chicken welfare is influenced more by housing conditions than by stocking density.** Nature 427, 342–344 (2004).

SUPPORTING LITERATURE

152. **Jones, T. A., Donnelly, C. A. & Stamp Dawkins, M. Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities.** Poult. Sci. 84, 1155–1165 (2005).

153. **Scientific Committee on Animal Health and Animal Welfare. The Welfare of Chickens Kept for Meat Production (Broilers).** (2000).

154. **Broom, D. M. Chicken Production in Relation to Animal Welfare and Disease. in The Importance of Farm Animal Welfare Science to Sustainable Agriculture, 29–30 March 2008, Beijing 256–265** (Office for Official Publications of the European Communities, 2010).

155. **Riber, A. B. et al. Review of environmental enrichment for broiler chickens.** Poult. Sci. (2017). doi:10.3382/ps/pex344

156. **Bailie, C. L., Ball, M. E. & O'Connell, N. E. Influence of the provision of natural light and straw bales on activity levels and leg health in commercial broiler chickens.** Animal 7, 618–626 (2013).

157. **Reiter, K. & Bessei, W. Gait analysis in laying hens and broilers with and without leg disorders.** Equine Vet. J. 23, 110–112 (1997).

158. **Bizeray, D., Estevez, I., Leterrier, C. & Faure, J. M. Effects of increasing environmental complexity on the physical activity of broiler chickens.** Appl. Anim. Behav. Sci. 79, 27–41 (2002).

159. **Ventura, B. A., Siewerdt, F. & Estevez, I. Access to barrier perches improves behavior repertoire in broilers.** PLoS One 7, e29826 (2012).

160. **Rodriguez-Aurrekoetxea, A., Leone, E. H. & Estevez, I. Effects of panels and perches on the behaviour of commercial slow-growing free-range meat chickens.** Appl. Anim. Behav. Sci. 165, 103–111 (2015).

161. **Rodriguez-Aurrekoetxea, A., Leone, E. H. & Estevez, I. Environmental complexity and use of space in slow growing free range chickens.** Appl. Anim. Behav. Sci. 161, 86–94 (2014).

162. **Tablante, N. L., Estevez, I. & Russek-Cohen, E. Effect of Perches and Stocking Density on Tibial Dyschondroplasia and Bone Mineralization as Measured by Bone Ash in Broiler Chickens.** J. Appl. Poult. Res. 12, 53–59 (2003).

163. **Kaukonen, E., Norring, M. & Valros, A. Perches and elevated platforms in commercial broiler farms: use and effect on walking ability, incidence of tibial dyschondroplasia and bone mineral content.** (2017).

164. **Bergmann, S. et al. Field trial on animal-based measures for animal welfare in slow growing broilers reared under an alternative concept suitable for the German market.** Berl. Munch. Tierarztl. Wochenschr. 129, 453–461 (2016).

165. **Cornetto, T. & Estevez, I. Behavior of the Domestic Fowl in the Presence of Vertical Panels.** Poult. Sci. 80, 1455–1462 (2001).

166. **Cornetto, T., Estevez, I. & Douglass, L. W. Using artificial cover to reduce aggression and disturbances in domestic fowl.** Appl. Anim. Behav. Sci. 75, 325–336 (2002).

167. **Bailie, C. L. & O'Connell, N. E. The influence of providing perches and string on activity levels, fearfulness and leg health in commercial broiler chickens.** Animal 9, 660–668 (2015).

168. **Shields, S. J. & Raj, A. B. M. A critical review of electrical water-bath stun systems for poultry slaughter and recent developments in alternative technologies.** J. Appl. Anim. Welf. Sci. 13, 281–299 (2010).

169. **Boyd, F. Humane Slaughter of Poultry: The Case Against the Use of Electrical Stunning Devices. Journal of Agricultural and Environmental Ethics 7, 221–236** (1994).

170. **Sparrey, J. M. & Kettlewell, P. J. Shackling of poultry: is it a welfare problem?** Worlds. Poult. Sci. J. 50, 167–176 (1994).

SUPPORTING LITERATURE

171. **Berri, C. et al. Variations in chicken breast meat quality: implications of struggle and muscle glycogen content at death.** Br. Poult. Sci. 46, 572–579 (2005).

172. **Kannan, G. & Mench, J. A. Influence of different handling methods and crating periods on plasma corticosterone concentrations in broilers.** British Poultry Science 37, 21–31 ((1996).

173. **Kannan, G., Heath, J. L., Wabeck, C. J. & Mench, J. A. Shackling of broilers: effects on stress responses and breast meat quality.** Br. Poult. Sci. 38, 323–332 (1997).

174. **Gregory, N. G. & Bell, J. C. Duration of wing flapping in chickens shackled before slaughter.** Vet. Rec. 121, 567–569 (1987).

175. **EFSA. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals.** EFSA Journal 2, (2004).

176. **USDA. Poultry Slaughter 2016 Summary (February 2017). USDA, National Agricultural Statistics Service (2017).** Available at: https://www.nass.usda.gov/Publications/Todays_Reports/reports/pslaan17.pdf. (Accessed: 1st March 2017).

177. **McKeegan, D. E., Sandercock, D. A. & Gerritzen, M. A. Physiological responses to low atmospheric pressure stunning and the implications for welfare.** Poult. Sci. 92, 858–868 (2013).