Improvement of welfare in BROILERS and TURKEYS

W. Bessei, D. Flock and D. Cavero

Contact: ***bessei@uni-hohenheim.de***

SUMMARY

Concern about the welfare of broilers kept under intensive management systems is raised mainly in industrialized countries. Most welfare problems are related to early growth.

Fast growing broilers were susceptible to sudden death syndrome (SDS), Ascites and leg problems. Using slow growing breeds or reducing early growth would reduce these problems considerably. This strategy, however, would have a negative economic and environmental impact.

Genetic studies have shown that the mentioned problems can be solved when welfare aspects are considered in multi-trait breeding programs.

Progress in this respect has been demonstrated in commercial lines where the incidence of SDS, Ascites and leg problems was significantly reduced while growth rate was still improved.

Legislation of broiler welfare is focused on environmental factors, such as stocking density, enrichment and light. It has been shown that stocking density as such is not the primary cause of welfare problems.

However, high stocking density can lead to wet litter and increased heat and ammonia production. This results in decreased growth rate through heat stress and increased susceptibility to respiratory diseases, hock burns, and foot pad dermatitis. Stress parameters have not been found to be significantly influenced by increasing stocking density. Environmental enrichment is considered a useful tool to stimulate natural behaviour and to improve welfare in chickens.

Attempts to stimulate behavioural activities through enrichment showed only limited effects.

Perches as enrichment structure are used by a low percentage of the birds and may produce breast blisters.

Therefore, ramps and raised platform may be used instead of perches. The traditional lighting system with continuous light has negative effects on behavioural activity and leads to enlargement of the eyeballs.

Even growth rate is compromised under continuous light. Dark periods of 4 to 6 hours not only improve performance but also welfare criteria.

Light intensity has only a marginal influence on both, welfare and performance. Blue and green light stimulate growth rate.

The effect of light color on welfare criteria is not consistent throughout the experiments and needs further research.

Keywords: Broilers, welfare, performance, stocking density, litter, enrichment, light

INTRODUCTION

With the growth of the worldwide population, the demand for poultry meat as a valuable and cheap source of protein for human nutrition increases continuously. The expansion of poultry production is mainly based on intensive production systems, which include broiler breeds with high performance, compound feed and large populations kept under high stocking density. Intensive production of farm animals, and in particularly poultry, has been subject to criticism in industrial countries (Bessei, 2018). Only 3% of the population in industrial countries is living in rural areas while the share of the rural population in developing countries is 40 to 50% (Ribbekk, 2005). Urban societies are lacking knowledge on the present husbandry systems and the major part of the population has some idealistic views of animal production, which is far from reality. With increasing wealth of the population, especially in Northern European countries, animal welfare has gained momentum among consumers, government authorities as well as retailers. There exists a large number and variety of legal acts and directives concerning animal welfare. These regulations are mainly aiming at improving the environmental conditions. Nevertheless, welfare criteria are also considered in commercial animal breeding (FAIP, 1999; Neeteson et al., 2020). At a fixed point in time, the higher level of animal welfare leads to higher production costs, which are seldom balanced by higher productivity or price for the products (Schrader, 2013) -but over time welfare has improved simultaneously with production(Avendaño et al, 2017).

It is well documented, that most consumers, who express a positive attitude towards animal welfare, are not prepared to pay a higher price when buying poultry products.

Welfare problems on meat producing poultry were mainly related to rapid early growth. Broilers of the 1960ies needed about 56 days to reach 1 kg of live weight. At the same age, modern broilers grow to 4.2 kg (Zuidhof et al., 2014). Though intensive feeding and management contribute to the actual rapid growth, the largest effect can be attributed to genetic selection. The main welfare problems in broilers and turkeys were leg problems, failure of the cardiovascular system and reduced locomotor activity.

These problems are often intensified through intensive feeding and management procedures. It is the aim of the present study to review the present state of knowledge of the most important welfare related issues and the achievements to solve the problems.

LOHMANN INFORMATION

ANIMAL - ORIENTED PROBLEMS

Skeleton

Damages of the leg skeleton and lameness represent a considerable part of mortality in broiler flocks. Tibial Dyschondroplasia (TD), deformation of tibial and femoral bones as well as degeneration of the femoral head are the generally known skeleton damages. TD can be identified in living birds using X-ray technology (Lixiscope). Using this technique, Ducro and Sørensen (1992) estimated the heritability of TD to be 0.33. The incidence of TD could be reduced by 50 percent within one selection generation. The Lixiscope technique has been efficiently used in commercial broiler breeding (McKay, 1997) and TD occurs only rarely in modern broiler strains.

Similarly, it was possible to significantly reduce the deformation of femur and tibia bones by genetic selection (Sørensen, 1992) and the leg conditions are now considered in commercial broiler and turkey breeding. There is generally a low negative correlation between leg bone conditions and growth rate (Rekaya et al., 2013). Using multi-trait selection programmes including TD, bone criteria and gait scores allows improvement in leg conditions with marginal effects on the selection progress in growth rate. This confirms the report of Kapell et al. (2012). Long term simultaneous selection against various leg abnormalities resulted in significant reduction of welfare –related criteria, such as leg bone deformities, crooked toes, hock burns and TD.

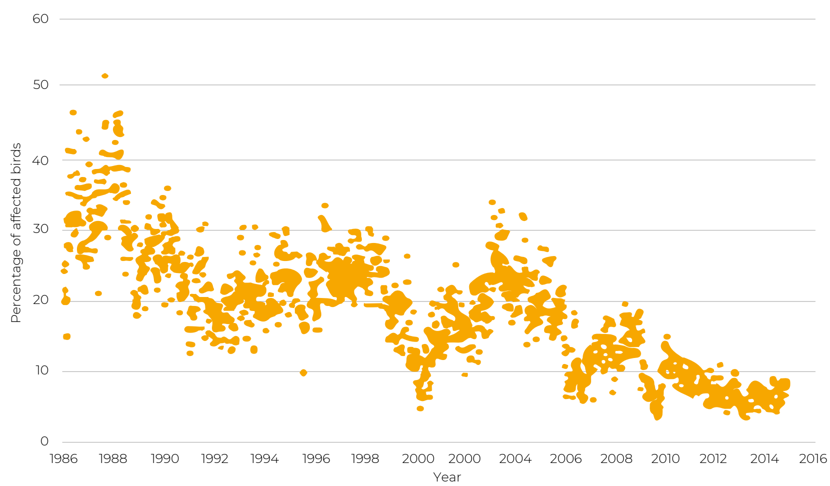

***Figure 1.** Response of leg defects in a commercial fast growing broiler strain after 26 years of selection (Neeteson et al, 2016).*

Figure 1 shows the decrease in leg defects in a fast growing broiler strain from about 30 to less than 10 percent.

Independent records of condemnation rates due to leg problems in Canadian poultry slaughter plants reflect the successful transfer of the selection response to commercial broiler production.

According to the Canadian Food Inspection Agency, leg condemnation rates per 10 000 birds have decreased significantly from 1995 onwards (Canadian Food Inspection Agency, 2020; figure 2). Varus valgus deformation was the criterion for condemnation from 1995 to 2007. From 2008 onwards, the statistics show all leg condemnations. This explains the small increase of the condemnations in the following years.

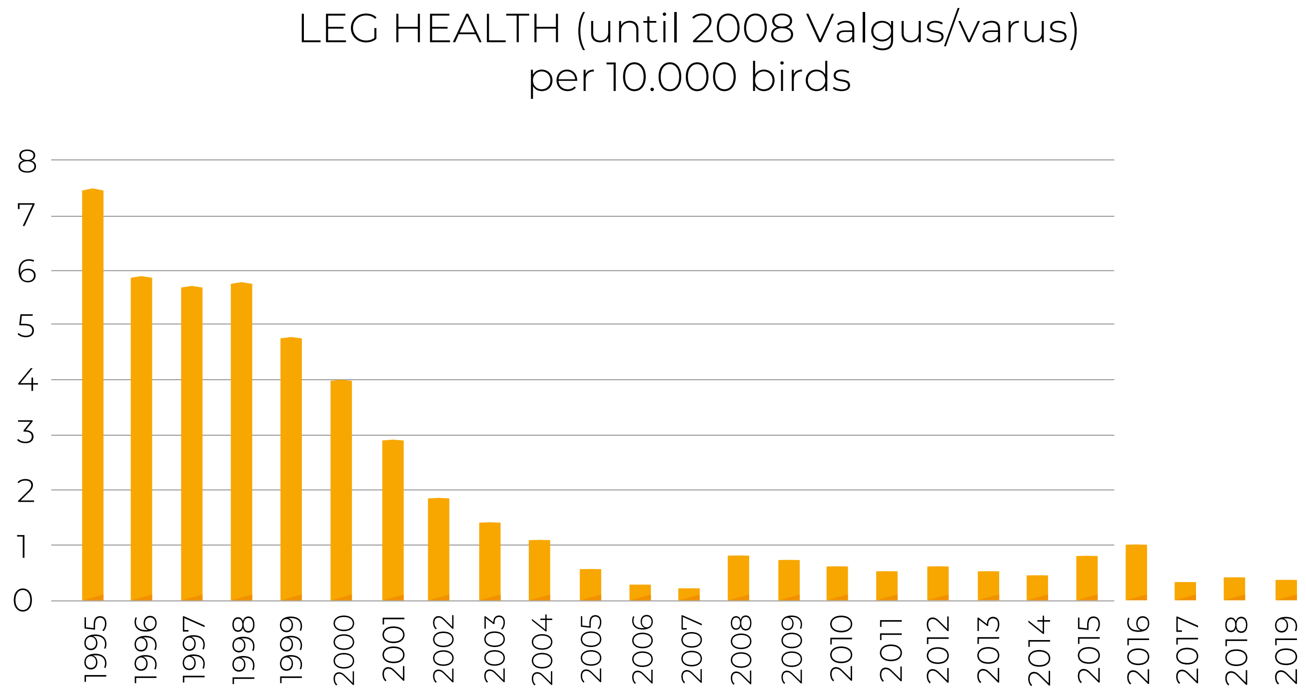

***Figure 2.** The reduction of leg condemnation rates in broilers was particularly important in the 1990ies and reflect the improvement welfare conditions (Canadian Food Inspection Agency 2020).*

Dermatitis

Lesions at the footpads (footpad dermatitis; FPD) and hock burns can occur frequently in growing broilers and turkeys. They are the result of skin inflammation, which is spreading on the surface, and extend to deeper areas of the tissue.

There exist different scoring systems, which rank the size and severity of dermatitis. Hocking et al. (2008) proposed a scoring system for FPD in turkeys from 0 (no lesions) to 4 (large and deep lesions) **(table 1).**

Table 1. *Definitions of different scores of FPD in turkeys (Hocking, et al., 2008)*

Score	Description of foot pad
0	No external signs of FPD. The skin of the foot pad feels soft to the touch and no sweeling or necrosis is evident.
1	The pad feels harder and denser than a non affected foot. The central part of the pad is raised, reticulate scales are separated and small black necrotic areas may be present.
2	Marked sweelling of the food pad. Reticulate scales are black, forming scale shaped necrotic areas. The scales around the outside of the black areas my have turned white. The area of necrosis is less than one quarter of the total area of the foot pad
3	Swelling is evident and the total foot pad size is enlarged. Reticulate scales are pronounced, increased in number and separated from each other. The amount of necrosis extends to one half of the foot pad.
4	As score 3, but with more than half the foot pad covered by necrotic cells.

Lesion scores of >2 are considered to compromise the bird`s welfare seriously.

A special scoring system exists in Scandinavian countries. A total of 100 footpads of a flock is scored using three categories:

Score 0 : No or very small superficial lesions, slight discoloration on limited area of the foot pad, mild hyperkeratosis or healed skin

Score 1 : substantial discoloration of the foot pad, superficial lesions, dark papillae.

Score 2: ulcers or scrabs of significant size, signs of haemorrhages or severely swollen foot pads. The scores are adjusted to their severity by multiplying score 1 by 0.5, and score 2 by 2. The resulting sum represents the adjusted score. In Sweden score 40 is set as pass. Higher scores are being tolerated in other European countries.

The percentage of birds showing FPD varied between 0 and 100 (Kjaer et al., 2006). Wet litter is the most important causal factor for the development of FPD (Mayne et al., 2007; Youssef et al., 2011). Nevertheless, variation exists of the incidence of Dermatitis among genetic strains kept under similar environmental conditions, which indicate a genetic basis of the problem (Allain et al., 2009; Haslam et al., 2007).

Kjaer et al. (2006) estimated the heritability of FPD of 0.31 and for hock burns of 0.08. The genetic correlations between body weight and the different types of dermatitis were small and not significant.

The genetic correlations between FPD and body weight was low and showed positive as well as negative values. Low positive phenotypic correlations between both criteria have been reported in various studies (Bessei et al., 2012; da Costa et al., 2014).

Data suggest that genetic selection against FPD would not seriously impair progress in growth rate. It has been suggested that pain caused by FPD would compromise locomotor activity (Martland, 1984) and prevent the birds from accessing feeders and drinkers. Since FPD is mainly caused by wet litter, reduced body weight and high incidence of FPD may be the result of co-occurrence rather than of a causal relationship (Mayne et al., 2007).

Since breeding programs select against footpad dermatitis (Kapell et al, 2012b; Ralph, 2017), and producers implement footpad reduction strategies, footpad dermatitis has been much reduced in both broilers and turkeys.

From 2003 to 2013 the incidence of the adjusted score < 40 (Scandinavian system) in commercial broilers increased from 30 to 75 % and the worst category (score > 120) decreased from 15 to 3 % (Steenberg 2014).

Similar improvement in food pad scores in broilers have been reported in Finland from 2012 to 2019 (Animal Health ETT 2020; figure 3).

Each batch of broilers is scored by official meat inspection using the Scandinavian scoring system. Data shown in figure 3 represent > 90 % of total broilers slaughtered in Finland.

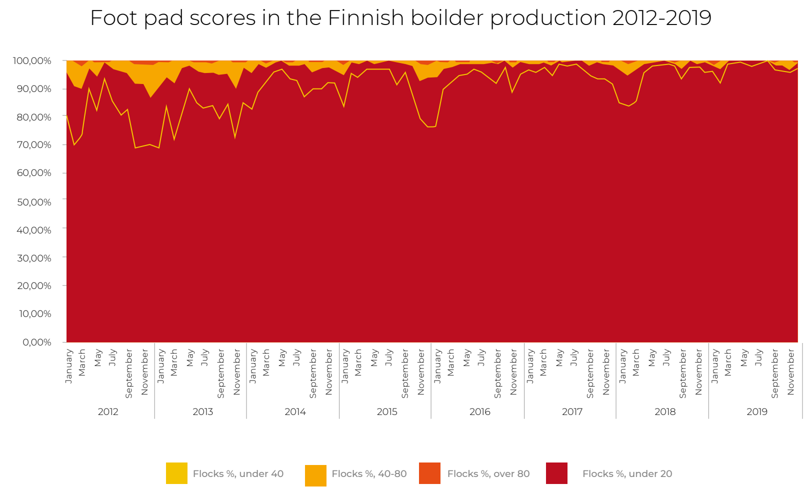

Figure 3. *Change in foot pad scores in commercial broilers in Finland from 2012 to 2019 (by courtosy Dr. Hannele Nauholz, Veterinary Advisor, Animal Health ETT)*

Behaviour

The behaviour of fast growing broilers is characterized by reduced locomotor activity, increased resting (sitting and lying) and alteration of the gait. Chicks of broiler strains show lower activity than those of layer strains from the first week of age (Savory, 1975).

There is a sharp drop from the second week onwards (Reiter and Bessei, 1998). Besides the low level of general locomotor activity, an increasing number of birds were showing irregular gait pattern and lameness.

Under practical rearing conditions gait quality is usually scored using subjective criteria as described for broilers by Kestin et al. (1992) and Webster et al. (2008) **(table 2).**

Table 2. *Five-point-gait scoring system (Kestin et al. 1992; Webster et al., 2008, slightly modified)*

Score	Description
0	No visible abnormality
1	Slight defect in walking ability; irregular gait
2	Clearly identifiable gait problems with no or little hindrance of movement
3	Obvious gait defect, with hindrance to move (limp, jerky and unsteady stride)
4	Sever gait defect. Capable of walking when driven or motivated by feed; sits down after a few steps
5	Unable to walk; shuffling on shanks or hocks with assistance of wings

Body weight, and in particular rapid growth rate during the first weeks of age, was assumed to be the most important reason for poor gait quality (Kestin et al. 2001; Djukic et al., 2004). The incidence of intermediate and severe gait problems was about 25 percent (Kittelsen et al., 2017) even though the broilers were kept under moderate stocking density and were slaughtered at the early age of 31 days. Kestin et al. (1992) reported similar percentage of broilers with gait problems.

Su und Sørensen (unpublished; loc. cit. Muir und Aggrey, 2003) estimated the heritability of gait scores of 0.20. Despite the obvious negative phenotypic effect of growth rate on gait score, the genetic correlation between these traits was small. Improvement of gait scores in broilers has been reported in Denmark. A compilation of data from 2001, 2005 and 2012 shows that gait scores 3 and 4 have disappeared and gait score 3 represents only 3 % **(Figure 4)**.

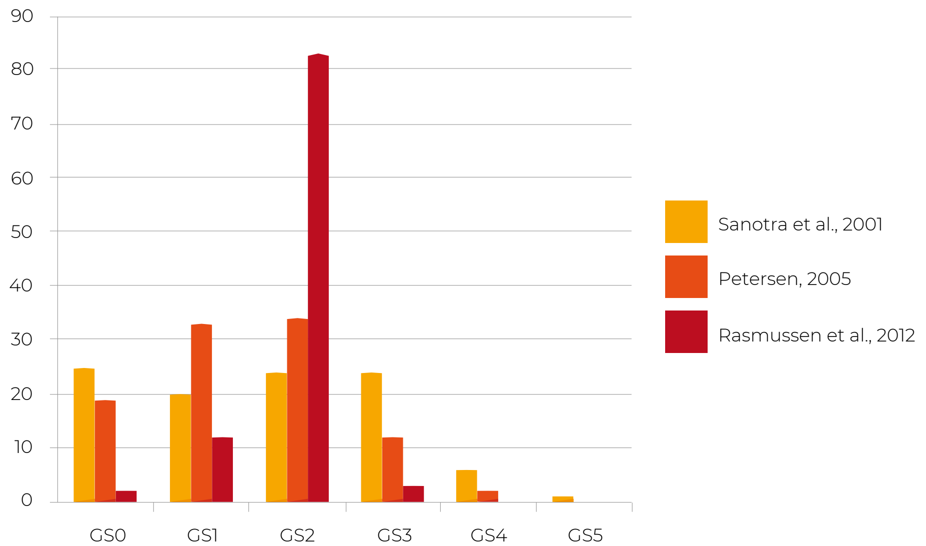

Figure 4. *Gait scores in Denmark reported in three papers: Sanotra et al., 2001; Petersen , 2005 and Rasmussen et al., 2012)*

In commercial turkey strains Swalander (2012) found genetic correlations between body weight (at 14 and 18 weeks of age) and gait score of 0.47 and 0.43, and between body weight and leg deformities of 0.47 and 0.45. The genetic correlation between gait score and leg deformities was much higher (0.85) than between gait score and TD (0.34).

This led to the conclusion, that TD does not necessarily produce leg deformities and impair gait in turkeys. TD should, however, be considered as risk factor, which may have an impact on gait and leg deformities in the presence of diseases.

SUDDEN DEATH SYNDROME (SDS) AND ASCITES

SDS and Ascites are the result of insufficient performance of the cardiovascular system (SDS: Gardiner et al., 1988; Grashorn, 1993; Maxwell and Robertson, 1997). Sudden death typically occurs in broilers, which do not show obvious symptoms of disease. The time span from the first signs of excitement and flip-over is from about half a minute to one minute (Newberry et al., 1987). Hence, the duration of suffering is short. Birds affected by Ascites, in contrast, suffer for several days and weeks before being culled or dying. Ascites is characterized by increase of the heart, change in liver function, insufficient performance of the lung (lack of oxygen) and accumulation of liquid in the abdominal cavern (Grashorn, 1993; Riddell, 1991). The common cause of both, SDS and Ascites is insufficient supply of oxygen of the fast growing muscles. Oxygen satiation of the blood is an indicator for the susceptibility of broilers for the diseases. In fact, genetic selection for high oxygen satiation in the blood has successfully reduced the incidence in modern broiler breeds (Avendaño et al., 2017; **(figure 5)**.

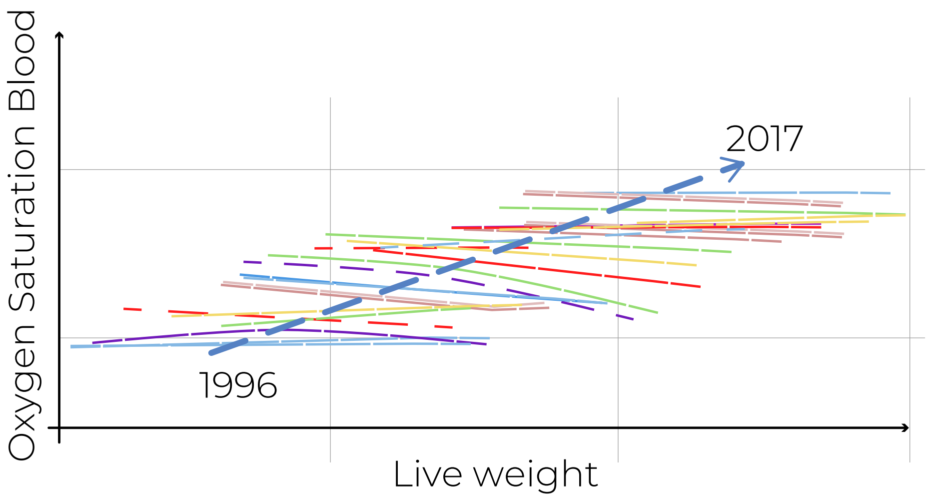

Figure 5. *Long-term relationship between body weight and oxygen saturation (Avendaño et al., 2017 2017). Each coloured line represents the relationship between breeding values within one year. The broken arrow represents the direction of the average breeding value.*

The response of selection for oxygen saturation is reflected in the report of the Canadian Food Inspection Agency on Ascites related condemnation rates (Neeteson et al, 2016; **(Figure 6)**.

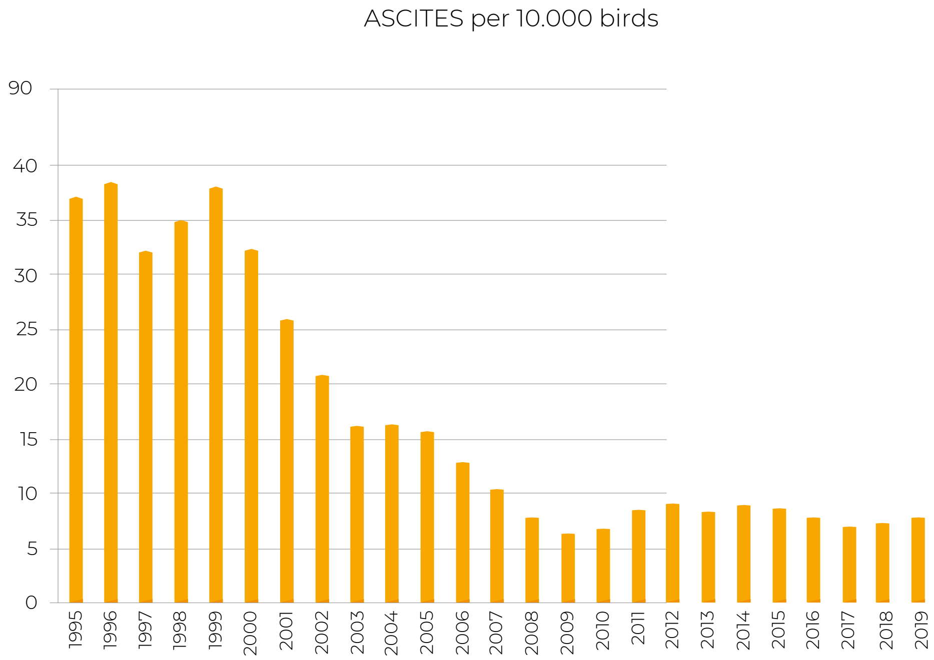

***Figure 6.** Condemnation rates due to Ascites/Oedema recorded by the Canadian Food Inspection Agency from 1995 to 2019*

(http://www.agr.gc.ca/eng/industry-markets-and-trade/market-information-by-sector/poultry-and-eggs/poultry-and-egg-market-information/condemnations/?id=1384971854399#chicken)

ENVIRONMENTAL CRITERIA

Environmental criteria of broiler welfare are considered in EU directives and national laws in Europe and other industrialized countries. The scientific background of the most important welfare aspects, stocking density, litter, light and enrichment will be dealt with in the following.

STOCKING DENSITY AND LITTER CONDITION

Stocking density is the most prominent welfare criterion of broiler welfare. Since stocking density has an important influence on litter quality, both factors are closely related. According to the EU-directive on broiler welfare (EU, 2007) the basic stocking is 33 kg/m². This limit can be extended to 39 kg/m² when certain climatic factors, such as ammonia, CO2, temperature and humidity are kept within an optimum range. A further extension of stocking density to 42 kg/m² is permitted when in addition to the above mentioned criteria further improvement of the management is granted. Some European countries have introduced stricter rules on stocking density. In Germany, for example, stocking density should not exceed 39 kg/m² at any time. For broilers up to 1600 g live weight an average stocking density of 35 kg/m² should not be exceeded in three consecutive crops. Welfare is also controlled at the slaughter plant. The cumulative daily mortality of each flock has to be reported, and if these data together with other criteria, such as Dead on Arrival (DoA), bruises, FPD, indicate poor welfare, the competent authority can impose lower stocking density for the next flocks.

Physical restriction of space has been considered as indicator of poor welfare in broilers under practical conditions. At the end of the growing period, the animals cover a major part of floor space. It has been assumed, that stocking density restricts locomotor behaviour and impairs access to feeders and drinkers.

Figure 7. *Low (20kg/m², top) and high stocking density (40 kg/m², down) of broilers at 5 weeks of age*

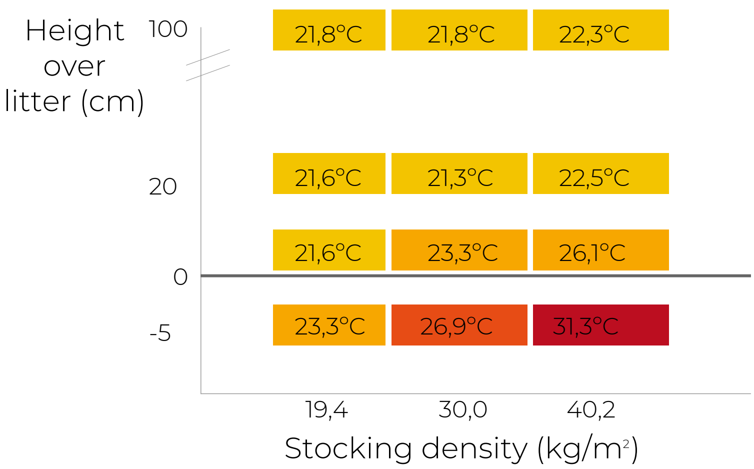

Figure 8. Temperature at different height above the litter and underneath the litter surface in response to stocking density (Reiter and Bessei, 2000)

This assumption was supported by results showing that feed intake and weight gain decrease when stocking density exceeds 30 kg/m² (Shanawany, 1988; Grashorn and Kutritz, 1991; Wiedmer and Hadorn, 1998). Behavioural observations revealed that locomotor activity did not decrease when stocking density was increased from 30 to 40 kg/m² (Bessei, 1992).

Similarly, the increase of stocking density from 30 to 36 kg/m² did not significantly change lying behaviour (Bailie et al., 2018). However, there was a significant decrease of locomotor activity of stocking density in the range between 10 and 30 kg/m² (Blokhuis and van der Haar, 1990; Lewis and Hurnik, 1990; Reiter and Bessei, 2000). Body weight development is usually not impaired at this low level of stocking density. We can therefore not conclude, that impeded access to feed and water is the cause of reduced feed intake and growth rate under high stocking density. Reiter and Bessei (2000) found an increase in temperature at the litter surface higher than 30 centigrade, when stocking density increased to 40 kg/m². Since floor space is entirely covered by the animals at high density **(figure 7)**, ventilation amongst the birds is impaired and the heat produced by the animals and the microbial activity inside the litter cannot escape. Consequently litter temperature increased up to 31 °C **(figure 8).**

It is well documented, that high temperature depresses the appetite and consequently the growth rate of birds. McLean et al. (2001) and Lolli et al. (2010) reported a rapid increase of panting with increased stocking density and litter temperature. Keeping broilers on perforated floor can attenuate the adverse effect of high temperature caused by high stocking density. The depression of growth rate occurred at higher stocking density when the birds are kept in cages (Andrews, 1972; Scholtyssek, 1973), on elastic perforated plastic floor (Scholtyssek and Grashorn, 1989), or on permeable tissue (Arkenau et al., 1997). However, keeping broilers and turkeys without litter is prohibited in European countries and deep litter systems prevail in commercial broiler production worldwide.

Buijs et al. (2009) recorded different criteria of broiler welfare in response to increasing stocking densities from 6 to 56 kg/m². There was no significant effect of stocking density on stress parameters such as the weight of bursa fabricii, corticosterone in the blood and mortality. Leg conditions were clearly affected by stocking density from 6 to 23 kg/m². Hock Burns increased when stocking density increased from 35 to 56 kg/m². Foot pad dermatitis at 56 kg/m² was significantly higher than at lower stocking densities.

Foot pad dermatitis is mainly caused by wet litter. Under practical conditions, many other factors influence the water content of the litter, such as ambient temperature, technique of water supply, diets, diseases and ventilation (Manning et al., 2007). The authors reported the correlation of 0.91 of water consumption per square meter and the incidence of food pad dermatitis and of 0.88 for water consumption per square meter and the incidence of condemnation rates of carcasses.

Wet litter is also an important source of ammonia in broiler houses. 10 ppm of ammonia caused damage of the lung of broilers and increased the susceptibility to respiratory diseases (Olanrejawu, 2008). Growth rate is affected by ammonia when the concentration exceeds 50 ppm. High ammonia contents of the litter aggravates the destructive effect of wet litter on footpad dermatitis. Algers and Svedberg (1989) found a direct relationship between the water and ammonia contents of the litter and footpad dermatitis. Stocking density from 10 to 35 kg/m² showed no influence on footpad dermatitis in this study.

The characteristics of the litter material, e.g. the capacity of water absorption and retention, and litter thickness play a vital role in this regard. The results of a meta-analysis on the effect of different types of litter on the incidence of FPD in turkeys are shown in table 3 (Bessei et al., 2012).

Cardboard and straw, whether dry or wet, produced the highest rates of FPD. Wet paper and wet wood shavings showed also high percentages of FPD. Wood shaving ranked better than straw under dry and wet conditions. The best results (3.7 %) were obtained with dry and clean wood shavings (table 3). This study did not include results of straw pellets, which are increasingly used in broiler and turkey production. Straw pellets have a high water absorption capacity and, when applied in small quantities, the litter remains dry and friable. This results in rates of FPD lower than 10% (own unpublished observations).

The incidence of FPD in turkeys and broilers is usually higher in winter than in summer (Ekstrand and Carpenter, 1998; Rudolf, 2008). This effect can attributed to poor litter conditions in the cold season. In order to reduce heat loss and to save energy, farmers tend to keep the ventilation rate on a low level. Suboptimal ventilation often results in wet litter and high incidence of FPD.

***Table 3** Percentage of Foot pad dermatitis in growing turkeys in response to litter substrate and dry matter (results of a meta-analysis) (Bessei et al., 2012)*

Sustrate	Humidity		Difference
	dry	wet	
Paper	33,9	88,8	54,9
Cardboard	83,7	87,2	3,5
Straw	81,9	85,9	4,0
Wood shav (clean)	3,7	52,3	48,6
Wood shav (conv.)	73,2	81,9	8,7

These results confirm the conclusion of Dawkins et al. (2004) that stocking density as such has no direct influence on welfare related criteria in broilers. It is the interaction of stocking density with other management factors, which influence performance and the well-being of the animals.

In this regard, litter condition is of utmost importance. The excretion of nitrogen, water and heat increase proportional with increasing stocking density. This leads to intensive microbial activity and increased temperature in the litter and increased ammonia in the litter and the air of broiler houses.

ENRICHMENT AND OCCUPATION

Conventional broiler growing is characterized by a barren environment. This is generally considered as cause of low variability of behaviour and low level of welfare. Enrichment devices should stimulate natural behaviours, such as scratching, dust bathing, exploration, and perching (Riber et al., 2018). Litter is usually accepted as occupation material. In many cases, however, litter is wet and caked and does not provide appropriate opportunity for pecking and dust bathing. Special welfare programs request additional materials of environmental enrichment. These materials should be attractive in order to stimulate desirable behaviours and to avoid undesirable behaviours (Jones, 2004). The material should also be workable in commercial farms, accepted by the birds and bear no health risks.

Supply of strings and special areas with dry sand has shown to increase the activity of broilers during the first weeks of life (Leterrier et al., 2001; Bailie et al., 2018). This effect however was numerically small and disappeared at the end of the growing period. Bailie and O`Connell (2015) reported even a negative effect of strings on the activity of broilers at the end of the fattening period. There was no clear effect of strings as occupation material on welfare related traits. Other materials, such as wood shavings, peat, oat shells and straw pellets are considered to increase behavioural activities. Peat and oat shells in particular have been found to be extremely attractive to stimulate dust-bathing behaviour (Baxter et al. 2018).

There was no effect of enrichment on leg conditions in this experiment. Mench et al. (2001) in contrast, found a significant improvement on the leg bones and on the behaviour of broilers when given the opportunity of scratching, climbing and perching.

Similarly, Kaukonen et al. (2017) could show that the gait quality was improved, when broilers were given the opportunity to use elevated platforms. In several other studies there were no or marginal effects of perches or ramps between feeders and drinkers on leg health and gait quality (Balog et al, 1997; Bizeray et al., 2001).Bench et al. (2017) found no effect of perches on performance, bone density and carcass quality of broilers. Theoretically, the use of perches could reduce the stocking density on the litter surface and relieve the birds from heat stress.

However, the use of perches decreases with increasing age and body weight. Hence, stocking density in the litter area is not significantly reduced at the end of the growing period when stocking density reaches its maximum.

Kaukonen et al. (2017) reported, that only a few birds perched under practical conditions. Rare use of perches have also been reported by other authors. Only 1% of the birds used perches when the birds were kept under low stocking density of 11 birds per square meter (Matrenchar et al., 2000).

The use of perches increased up to 10% when stocking density was increased to 20 birds per square meter. When the height of the perches was continuously adapted to the size of the birds, up to 22% of the birds used the perches (Davies and Weeks, 1995). The use of perches increased the incidence of breast blisters and breastbone deformation (Bokkers and Koene, 2003). To avoid breast blisters and breastbone deformation, it has been proposed to use ramps or raised platforms instead of perches.

Newberry and Shackleton (1997) tested the influence of vertical panels as structural elements in broiler pens. This form of enrichment is based on the observation that broilers prefer areas near walls for resting. Rodriguez-Aurrekoetxea et al. (2014; 2015) enriched large broiler pens with vertical panels and perches.

Panels lead to better use of the centre of the pens and thus, to a better dispersion of the birds over the total space. The panels had no influence on weight gain, behaviour, footpad dermatitis and fluctuating asymmetry as a stress parameter. Buijs et al. (2010) installed panels as separation elements in small broiler pens. The use of the area nearby the panels increased with increasing age and stocking density.

Birds resting in this area were less disturbed by pen mates than birds resting elsewhere. The use of vertical panels attached on the ceiling of commercial broiler houses is reported on **page 86** of this issue.

Variation in feeding programs has been considered as an opportunity for environmental enrichment in broilers. Ad libitum feeding of uniform pelleted feed is one of the causes of low behavioural activity. Attempts were made to increase the locomotor activity (walking, scratching and litter pecking) through variation of feed structure and feeding schedules. Scattering grain in the litter was not successful as long as pelleted feed was available in the feeder (Jordan et al., 2011).

Increase of activity could only be shown when the whole diet was distributed in the litter. Difficulty to increase the activity through feeding programs has also been reported by Pichova et al. (2016). There was no effect on the activity of broilers when feed was scattered in the litter. Only the distribution of highly preferred mealworms led to a short time increase of activity.

Another possibility to stimulate behaviour through feeding technique is sequential feeding. Two diets that differed in their contents of lysine have been presented in an alternating pattern (Bizeray et al., 2001). This feeding technique significantly increased litter pecking (foraging) and locomotor activity, but reduced growth rate. Reiter and Bessei (2009) increased the distance between feeders and drinkers from 2 to 12 m. This measure led to a more coordinated resting and activity behaviour among the birds, increase of locomotor activity and improved leg conditions. Growth rate was not significantly affected.

Riber et al. (2017) called attention to a general deficit of information on implementation and economical aspects of environmental enrichment in broilers under commercial conditions. To overcome this problem, a program to improve the welfare of broilers has been established in Germany since 2015 (Initiative Tierwohl, 2018). The program comprises reduced stocking density and enrichment devices. Progress of welfare is communicated to the consumer and the costs of enrichment are compensated through a special fund. At present about 400 000 broilers are produced under this scheme.

LIGHT

According to the EU directive as well as the German legislation on the welfare of broilers, houses have to be sufficiently illuminated. In windowless houses light intensity should be 20 lux in at least 80 % of the surface. A dark period of 6 hours minimum has to be provided.

Light programs

Broilers have traditionally been kept under a 23 hours light and 1 hour dark program. This represents quasi-continuous light conditions, which have shown optimum growth and feed conversion rates in former broiler lines (Morris, 1967). Extended dark periods showed positive effects on leg condition and mortality, but reduced weight gain, particularly in short growing periods (Zubair and Leeson, 1996).

Extended dark periods of 12 hours from 3 to 21 days of age, and continuous light thereafter, showed reduced body weight development compared to broilers kept under continuous light from day-old. Extending the growing period to 49 days compensated the shortfall (Thomsen, 1989). Bayram and Özkan (2010) found full compensation of reduced body weight development in response to an 8 hours dark period at 35 days of age.

Dark periods of 16 hours could not be compensated at 56 days of age (Olanrewayu et al., 2018). Sørensen et al. (1999) reported reduced Tibial Dyschondroplasia in broilers kept under extended dark periods from 3 to 21 days of age. The positive effect of darkness has been attributed to the increase of locomotor activity during the light phase. Reiter and Bessei (2002) confirmed this effect: The intensity of locomotor activity during the light phase increased with increasing duration of the dark period. The phases of high locomotor activity during the light periods improved leg bone characteristics even though the total activity was not increased.

Continuous light not only reduces the locomotor activity but also prevents the development of circadian rhythm.

The expression of a circadian rhythm is considered as important indicator of animal wellbeing. Intermittent lighting programs with short light – dark phases, such as 2h light : 2h darkness, showed similar growth rate as continuous light (Onbasilar et al., 2007; Olanrewaju et al., 2018).

There is no circadian rhythm developed under these conditions.

Schwean-Lardner et al. (2012) found that a continuous dark period of at least 4 hours is required to enable the development of a circadian rhythm in modern broiler strains. In contrast to traditional broiler lines today's strains do not require continuous light or 23 hours light to show optimum weight gain and feed conversion rate.

According to their results the optimum dark period is between 4 and 8 hours **(Figure 9)**

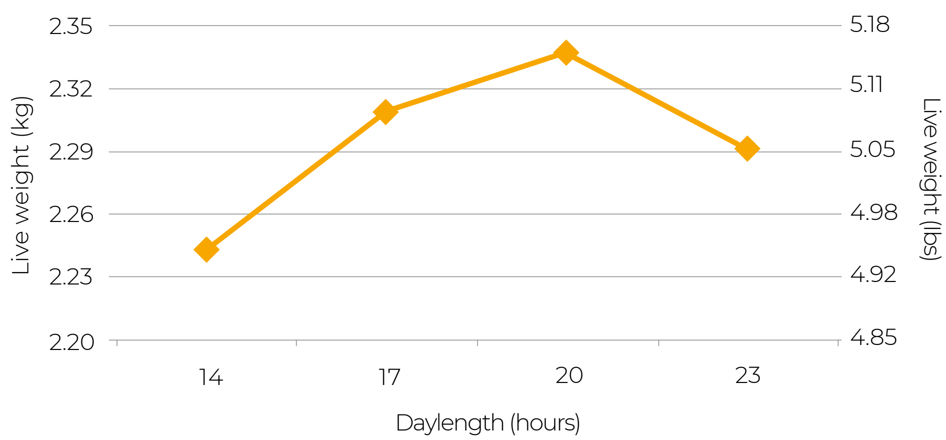

Figure 9. *Effect of daylength on live weight in broilers at 38/39 days of age (Graph produced on the basis of data of Schwean-Lardner et al., 2012)*

Continuous light leads also to an enlargement of the eyeballs of broilers (Lauber and McKinnear, 1979). The effect of this phenomenon on the bird`s welfare has not been studied so far. However, enlargement of eyeballs are considered as anatomical abnormality. Extension of the dark period to 4 hours prevented the increase of the eyeball in layer and broiler strains (Li et al., 2000; Schwean-Lardner et al., 2012).

Broilers experience hunger during extended dark periods. This leads to crowding and excitement in front of the feeders at the beginning of the light period. Stepping on the back of pen mates results in high incidence of deep scratches on the back skin. These injuries not only compromise the bird`s welfare but also lead to downgrading of carcasses at the processing plant. Under practical production conditions it is advised to limit continuous dark periods to 4 hours and provide a further dark period after a 1 to 2 hours light period, to match the legal requirement.

High activity of broilers kept under extended dark periods hampers catching procedures. In this regard continuous light should be introduced 2 to 3 days before slaughter. This procedure reduces excitement of the birds and is legally permitted.

Light intensity

According to the EU directive on broiler welfare light intensity at the height of the birds head should not be lower than 20 lux. Less than 10 lux is provided at the end of the growing period in many countries in windowless houses. There exists controversial information on the effect of light intensity on performance and leg conditions. Newberry et al. (1988) found positive effects of high light intensity (180 vs. 6 lux) on locomotor activity and leg health. In contrast, Gordon and Thorp (1994) reported higher deformation of the tibial bone under high versus low light intensity. Blatchford et al. (2009) compared body weight, behaviour, leg conditions and immune function of broilers kept under 5, 50 and 200 lux. Light intensity showed no influence on body weight, gait quality and immune criteria. The weight of the eyeball was higher at 5 lux than at higher light intensities. In all above-mentioned experiments, light intensity showed no effect on performance criteria. The incidence of discoloration of footpads and hock joints were highest at 200 lux, but more footpad erosion was found at 5 and 50 lux. Deep et al. (2013) reported a curvilinear response to increasing light intensity (0.1 to 10 lux) for feed intake, growth rate and mortality with optimum values at 5 lux. The incidence of footpad dermatitis decreased linearly with increasing light intensity. Gait quality was not affected.

Light quality

Studies on light intensity in chickens are problematic in so far as in most experiments light intensity is measured in lux, which is based on the sensitivity of the human eye for different wavelengths. In order to determine the perception of light intensity of chickens the conventional lux needs to be translated in chicken lux (clx) (Lewis and Morris, 1998). Using such translated values Kristensen et al. (2007) observed the behaviour of broilers kept under light intensities from 5 to 100 clx. There was no effect of light intensity on a wide range of behaviours. Only foraging was higher at lower light intensity.

Since the availability of LED lamps, which image defined spectra of light, information on the effect of light quality on chickens is gaining momentum. Rozenboim et al. (1999a;b) and Cao et al. (2008) found improved growth rates, when broilers where exposed to monochromatic blue and green light. The combination of blue and green light improved weight gain and carcass quality compared with incandescent white light (Rozenboim et al., 2004).

Information on the influence of light quality on welfare criteria is rare. Olanrevajo et al. (2015) raised broiler chicks under three different types of LED lamps and incandescent and fluorescent light as control. One LED type, which was quoted to be especially adapted to the sensitivity of the chicken ("cool poultry specific filtered LED") improved body weight gain compared to conventional incandescent lamps.

No significant differences were found among other light sources on other performance traits, weight of the eyeballs and plasma corticosterone. In a later study of Olanrevajo et al. (2018) the LED light adapted to the chicken eye improved body weight and carcass yield when compared with incandescent light. There was no significant response to the light sources on feed intake, feed conversion rate, mortality and immune response.

Rogers et al. (2015a,b) tested two different LED lamps with cold cathode fluorescent and conventional incandescent light as control. LED light showed similar results to the control concerning live weight, feed conversion rate and mortality.

Performance under cold cathode fluorescent light was lower than under incandescent and LED lights. There was no consistent trend of the Heterophile : Lymphocyte ratio as stress criterion in response to the light sources. The authors concluded that LED light had no negative effect on broiler welfare. Riber (2015) compared neutral-white LED (4100 K) and cold-white LED (6065 K) with regard to performance and behaviour. Birds raised on cold-white (6065 K) showed higher body weight at the end of the growing period (35 days).

There was a slight preference for this light source in choice tests. Behavioural observations revealed a tendency of more resting under 6065 K illumination. Both the increase of live weight and the preference for this light source was attributed to the higher proportion of blue light.

Positive influence of cold LED light (5000 K) with a higher proportion of blue/green colour versus warm LED light (2700 K) on weight gain and feed conversion rate have also been found by Archer (2017). In addition broilers kept under cold LED light showed less fear and less stress responses than those kept under warm light.

Blue light is generally considered to have a calming and fear reducing effect on chickens (Xie et al., 2008; Sultana et al., 2013). Reduced activity and increased growth rate may have detrimental effects on the leg conditions. Riber (2015), however, did not find such a negative effect on leg conditions (lameness and dermatitis) of 6065 K versus 4100 K.

This could have been due to the small effect of the light source on growth and activity. But it should also be considered that blue light exhibits its effect on growth during the later phase of the growing period, while leg problems develop in the first two weeks of age. Red and yellow light have been reported to increase the activity, aggression (Prayitno et al., 1997) and fear (Sultana et al., 2013) in chickens.

This may compromise welfare. However, these results need further investigations. Kaemmerling et al. (2018) compared the light spectra of the natural habitat of turkeys and chickens with commonly used artificial light sources including LED lamps.

The spectra of all artificial light sources deviated extremely from the light in the natural habitats.

In summary, blue and green light provided through monochromatic light or through white LED light with a higher proportion of green and blue, improve growth and feed conversion rate.

The effects of different types of LED light on behaviour and welfare criteria are lower and not consistent throughout the different studies. Further investigations are required in this respect.

References. *Algers, B., and J. Svedberg. 1989. Effects of atmospheric ammonia and litter status on broiler health, Proc. 3rd. Europ. Symp. on Poultry Welfare, Tours, France:237–241.*

Allain, V., L. Mirabito, C. Arnould, M. Colas, S. Le Bouquin, C. Lupo, and V. Michel. 2009. 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. doi: 10.1080/00071660903110901.

Andrews, L. D. 1972. Cage rearing of broilers, Poult. Sci. 51:1194–1197.

Animal Health ETT. 2020. Foot pad dermatitis, broiler – A suitable indicator for broiler flock welfare. https://www.ett.fi/wp-content/uploads/2020/03/Footpad-scores-Finland-2012-2019.pdf. Accessed April 2020.

Archer, G. S. 2017. Color temperature of light-emitting diode lighting matters for optimum growth and welfare of broiler chickens, Animal:1–7. doi: 10.1017/S1751731117002361.

Arkenau von, E. F., Macke, H. and Van den Weghe, H. (1997) Einfluss der Bodenbelüftung in Broilermastställen auf Tierleistung und Tierverluste. Züchtungskunde 69 :307-313.

Avendaño, S., Neeteson, A. and B. Fancher. 2017. Broiler Breeding for Sustainability and Welfare – are there Trade Offs? In: Proceedings Poultry Beyond 2023 Conference, New Zealand. 17pp. 2017. Broiler Breeding for Sustainability and Welfare – are there Trade Offs? In: Proceedings Poultry Beyond 2023 Conference, QUEENSTOWN, New Zealand,16 - 20 OC TOBER 2017New Zealand,:17pp.

Bailie, C. L. and N. E. O'Connell. 2015. The influence of providing perches and string on activity levels, fearfulness and leg health in commercial broiler chickens, Animal: an international journal of animal bioscience. 9:660–668. doi: 10.1017/S1751731114002821

Bailie, C. L., C. Ijichi, and N. E. O'Connell. 2018. Effects of stocking density and string provision on welfare-related measures in commercial broiler chickens in windowed houses, Poultry Science. 97:1503–1510. doi: 10.3382/ps/pey026.

Balog, J. M., G. R. Bayyari, N. C. rath, W. E. Huff, and N. B. Anthony. 1997. Effect of intermittent activity on broiler production parameters, Poult. Sci. 76:6.

Baxter, M., C. L. Bailie, and N. E. O'Connell. 2018. Evaluation of a dustbathing substrate and straw bales as environmental enrichments in commercial broiler housing, Appl. Anim. Behav. Sci. 20:78–85. doi: 10.1016/j.applanim.2017.11.010.

Bayram, A., and S. Ozkan. 2010. Effects of a 16-hour light, 8-hour dark lighting schedule on behavioral traits and performance in male broiler chickens, The Journal of Applied Poultry Research. 19:263–273. doi: 10.3382/japr.2009-00026.

Bench, C. J., M. A. Oryschak, D. R. Korver, and E. Beltranena. 2017. Behaviour, growth performance, foot pad quality, bone density, and carcass traits of broiler chickens reared with barrier perches and fed different dietary crude protein levels, Canadian Journal of Animal Science. 97:268–280. doi: 10.1139/cjas-2015-0202.

Bessei, W. 1992. Das Verhalten von Broilern unter intensiven Haltungsbedingungen, Arch. Gefluegelkde. 56:1–7.

Bessei, W. (2018): Impact of animal welfare on worldwide poultry production. In: World's Poult. Sci. J., S. 1–14. DOI: 10.1017/S0043933918000028.

Bessei, W., M. Rudolph and H.M. Hafez. 2012. The Incidence of Footpad Dermatitis in Experimental and Commercial Flocks from 1969 – 2011 A Historical Review, Proc. 9th International Turkey Symposium. Berlin, 21st – 23 June 2012.

Bizeray, D., C. Leterrier, P. Constantin, and J. M. Faure. 2001. Sequential feeding with low lysine diet induces higher level of activity in meat-type chickens, Proc. 6th Europ. Symp. Poultry Welfare, Zollikofen, Switzerland:173–176.

Blatchford, R. A., K. C. Klasing, H. L. Shivaprasad, P. S. Wakenell, G. S. Archer, and J. A. Mench. 2009. The effect of light intensity on the behavior, eye and leg health, and immune 7unction of broiler chickens, Pou. 88:20–28. doi: 10.3382/ps.2008-00177.

Blokhuis, H. J., van der Haar, J. W. 1990. The effect of the stocking density on the behaviour of broilers, Arch. f. Geflkde. 54:74–77.

Bokkers, E.A.M., and P. Koene. 2003. Behaviour of fast- and slow growing broilers to 12 weeks of age and *the physical consequences, App. An. Behav. Sci. 81:59–72. doi: 10.1016/S0168-1591(02)00251-4.*

Buijs, S., L. Keeling, S. Rettenbacher, E. van Poucke, and F. A. M. Tuyttens. 2009. Stocking density effects on broiler welfare. Identifying sensitive ranges for different indicators, Poult. Sci. 88:1536–1543. doi: 10.3382/ps.2009-00007.

Buijs, S., L. J. Keeling, C. Vangestel, J. Baert, J. Vangeyte, and F.A.M. Tuyttens. 2010. Resting or hiding? Why broiler chickens stay near walls and how density affects this, App. An. Behav. Sci. 124:97–103. doi: 10.1016/j.applanim.2010.02.007.

Canadian Food Inspection Agency. 2020. Condemnation Report 2019. http://www.agr.gc.ca/eng/industry-markets-and-trade/market-information-by-sector/poultry-and-eggs/poultry-and-egg-market-information/condemnations/?id=1384971854399#chicken

Cao, J., W. Liu, Z. Wang, D. Xie, L. Jia, and Y. Chen. 2008. Green and Blue Monochromatic Lights Promote Growth and Development of Broilers Via Stimulating Testosterone Secretion and Myofiber Growth, The Journal of Applied Poultry Research. 17:211–218. doi: 10.3382/japr.2007-00043.

Da Costa, M. J., J. L. Grimes, E. O. Oviedo-Rondón, I. Barasch, C. Evans, M. Dalmagro, and J. Nixon. 2014. Footpad dermatitis severity on turkey flocks and correlations with locomotion, litter conditions, and body weight at market age1, The Journal of Applied Poultry Research. 23:268–279. doi: 10.3382/japr.2013-00848.

Davies, H. C. and Weeks, C. A. (1995) Effects of age and leg weakness on perching behaviour of broilers. Brit. Poult. Sci. 36 :838

Dawkins, M. S., S. Donelly, and T. A. Jones. 2004. Chicken welfare is influenced more by housing conditions than by stocking density, Nature. 427:342.

Deep, A., C. Raginski, K. Schwean-Lardner, B. I. Fancher, and H. L. Classen. 2013. Minimum light intensity threshold to prevent negative effects on broiler production and welfare, Br.Poult.Sci. 54:686–694. doi: 10.1080/00071668.2013.847526.

Djukic, M., A. Harlander-Matauschek, and W. Bessei. 2004. The effect of weight load on the legs on locomotor activity and resting behaviour of fast and slow growing chickens, Proc. : 38th International Congress of the ISAE, Helsinki, Finland:183.

Ducro, B.J. and P. Soerensen. 1992. Evaluation of a selection experiment on tibial dyschondroplasia in broierl chickens. Proc. XIX World`s Poultry Congress, Amsterdam, 386 – 389.

Ekstrand, C. and T.E. Carpenter. 1998. Temporal aspects of of foot pad dermatitis in Swedish broilers. Acta Vet. Scand. 39: 273-280.

EU 2007. Council Directive 2007/43/EC Minimum rules for the protection of chickens kept for meat production.

Gardiner, E. E., Hunt, J. R. and Newberry, R. C. (1988) Relationship between age, body weight and season of the year and the incidence of sudden death syndrome in male broiler chickens. Poult. Sci. 67:1243-1249.

Gordon, S. H., and B. H. Thorp. 1994. Effect of light intensity on broiler liveweight and tibia plateau angle, Proc. 9th Europ. Poultry Conference, Glasgow, UK:286–287.

Grashorn, M. 1993. Untersuchungen zur Ätiologie und Pathogenese des plötzlichen Herztods bei Masthühnern, Hohenheimer Arbeiten, Verlag Eugen Ulmer, Stuttgart:123 S.

Grashorn, M., and B. Kutritz. 1991. Der Einfluß der Besatzdichte auf die Leistung moderner Broilerherkünfte, Arch. Geflügelk. 55:84–90.

Haslam, S. M., T. G. Knowles, S. N. Brown, L. J. Wilkins, S. C. Kestin, P. D. Warriss, and C. J. Nicol. 2007. Factors affecting the prevalence of foot pad dermatitis, hock burn and breast burn in broiler chicken, British Poultry Science. 48:264–275. doi: 10.1080/00071660701371341.

Hocking, P. M., R. K. Mayne, R. W. Else, N. A. FRENCH, and J. GATCLIFFE. 2008. Standard European footpad dermatitis scoring system for use in turkey processing plants, World's Poult.Sci.J. 64:323–328. doi: 10.1017/S0043933908000068.

Jones, R.B. 2004. Environmental enrichment: the need for practical strategies to improve poultry welfare. In: Welfare of the Laying Hen, pp. 215-225. G. Perry CAB International Wallingford, UK.

Initiative Tierwohl. 2018. https://initiative-tierwohl.de/impressum/

Jordan, D., I. Štuhec, and W. Bessei. 2011. Effect of whole wheat and feed pellets distribution in the litter on broilers' activity and performance, Arch.Gefluegelkunde. 75:98–103.

Kaemmerling, D., S. Döhring, A. Uhlenkamp and R. Andersson 2018. Lighting of Poultry Houses to Meet the Needs of Bird Eyes. Lohmann Information 51 (2), 24 – 34.

Kapell, D.N.R.G., W. G. Hill, A.-M. Neeteson, J. McAdam, A.N.M. Koerhuis, and S. Avendaño. 2012. Twenty-five years of selection for improved leg health in purebred broiler lines and underlying genetic parameters, Poult. Sci. 91:3032–3043. doi: 10.3382/ps.2012-02460.

Kapell D.N.R.G., Hill W.G., Neeteson A.M., McAdam J., Koerhuis A.N.M. and Avendaño S. 2012. Genetic parameters of foot-pad dermatitis and body weight in purebred broiler lines in 2 contrasting environments. Poultry Science 91:565–574.

Kaukonen, E., M. Norring, and A. Valros. 2017. Perches and elevated platforms in commercial broiler farms: use and effect on walking ability, incidence of tibial dyschondroplasia and bone mineral content, Animal. 11:864–871. doi: 10.1017/S1751731116002160.

Kestin, S. C., S. Gordon, G. Su, and P. Sørensen. 2001. Relationships in broiler chickens between lameness, liveweight, growth rate and age, Vet. Rec. 148:195–197. doi: 10.1136/vr.148.7.195.

Kestin, S., T. Knowles, A. Tinch, and N. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype, Vet. Rec. 131:190–194. doi: 10.1136/vr.131.9.190.

Kittelsen, K. E., B. David, R. O. Moe, H. D. Poulsen, J. F. Young, and E. G. Granquist. 2017. Associations among gait score, production data, abattoir registrations, and postmortem tibia measurements in broiler chickens, Poultry Science. 96:1033–1040. doi: 10.3382/ps/pew433.

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

Kristensen, H. H., N. B. Prescott, G. C. Perry, J. Ladewig, A. K. Ersbøll, K. C. Overvad, and C. M. Wathes. 2007. The behaviour of broiler chickens in different light sources and illuminances, Appl. Anim. Behav. Sci. 103:75–89. doi: 10.1016/j.applanim.2006.04.017.

Lauber, J. K., and A. Kinnear. 1979. Eye enlargement in birds induced by dim light, Can. J. Ophthalm. 14:265–269.

Leterrier, C., C. Arnould, D. Bizeray, P. Constantin, and J. M. Faure. 2001. Environmental enrichment and leg problems in broiler chickens, Br.Poult.Sci. 42:S13-S14.

Leterrier, C., C. Arnould, D. Bizeray, P. Constantin, and J. M. Faure. 2001. Environmental enrichment and leg problems in broiler chickens, Br.Poult.Sci. 42:S13-S14.

Lewis, N. J., and J. F. Hurnik. 1990. Lokomotion of Broiler Chickens in Floor Pens, Pou. 69:1087–1093.

Lewis, P. D., and T. R. Morris. 1998. Responses of domestic poultry to various light sources, World's Poult.Sci.J. 54:21–25.

Li, T., H. C. Howland, and D. Troilo. 2000. Diurnal illumination patterns affect the development of the chicks eye, Vision Res. 40:2387–2393.

Lolli, S., W. Bessei, A. Cahaner, L. Yadgari, and V. Ferrante. 2010. The influence of stocking density on the behaviour of featherless and normally-feathered broilers under hot ambient temperature, Arch. Geflugelkunde. 74:73–80.

Manning, L., S. A. Chadd, and R. N. Baines. 2007. Water consumption in broiler chicken. A welfare indicator. World's Poult. Sci. J. 63:63–71. doi: 10.1079/WPS2006127.

Martland, M. F. 1984. Wet litter as a cause of plantar pododermatitis leading to foot ulceration and ameness in fattening turkeys, Avian Pathol. 14:241–252.

Martrenchar, A., D. Huonnic, J. P. Cotte, E. Boilletot, and J. P. Morisse. 2000. Influence of stocking density, artificial *dusk and group size on the perching behaviour of broilers. Br. Poult. Sci. 41:125–130. doi: 10.1080/713654921.*

Maxwell, M. H., and G. W. Robertson. 1997. World Broiler Ascietes survey 1996, Poultry International. 36:16–30.

Mayne, R. K., R. W. Else, and P. M. Hocking. 2007. High litter moisture alone is sufficient to cause footpad dermatitis in growing turkeys, British Poultry Science. 48:538–545. doi: 10.1080/00071660701573045.

McKay, J. 1997. The next decade - a breeders perspective, International Poultry Production. 5:9–11.

McLean JA, Savory CJ and Sparks NHC. 2001. Welfare of male and female broiler chickens in relation to stocking density, as indicated by performance, health and behaviour, Animal Welfare. 11:55–73.

Mench, J.A., J. P. Garner, and C. Falcone. 2001. Behavioral activity and its effects on leg problems in broiler chickens, Proc. 6th Eur. Symp. Poult. Welf. H. Oester and C. Wyss, ed. World's Poultry Science Association, Zollikofen, Switzerland:152–156.

Morris, T. R. 1967. Light requirement of the fowl, In: Carter, T. C. Environmental control in poultry production, Edinburgh-London.

Neeteson A.-M., Swalander, M., Ralph, J. and A. Koerhuis. 2016. Decades of Welfare and Sustainability Selection at Aviagen Chickens and Turkeys. AviagenBrief, July 2016.

Neeteson, A.-M., Avendaño, S. and Koerhuis, A. 2020. Chapter 6 in: The Economics of Farm Animal Welfare: Theory, Evidence and Policy (eds B. Vosough Ahmadi et al.) CABI Publishing, Walllingford (in press).

Newberry, R. C., and D. M. Shackleton. 1997. Use of visual cover by domestic fowl. A venetian blind effect?, Animal Behaviour. 54:387–395. doi: 10.1006/anbe.1996.0421.

Newberry, R. C., E. E. Gardiner, and J. R. Hunt. 1987. Behavior of chickens prior to death from sudden death syndrome, Poult. Sci. 66:1446–1450. doi: 10.3382/ps.0661446.

Newberry, R. C., J. R. Hunt, and E. E. Gardiner. 1988. Influence of light intensity on behavior and performance of broiler chickens, Pou. 67:1020–1025. doi: 10.3382/ps.0671020.

Olanrewaju, H. A., W. W. Miller, W. R. Maslin, S. D. Collier, J. L. Purswell, and S. L. Branton. 2018. Influence of light sources and photoperiod on growth performance, carcass characteristics, and health indices of broilers grown to heavy weights, Poult. Sci. 97:1109–1116. doi: 10.3382/ps/pex426.

Olanrewaju, H. A., J. L. Purswell, W. R. Maslin, S. D. Collier, and S. L. Branton. 2015. Effects of color temperatures (kelvin) of LED bulbs on growth performance, carcass characteristics, and ocular development indices of broilers grown to heavy weights, Poult. Sci. 94:338–344. doi: 10.3382/ps/peu082.

Olanrewaju, H. A., J. P. Thaxton, W. A. Dozier III, J. Purswell, S. D. Collier, and S. L. Branton. 2008. Interactive effects of ammonia and light intensity on hematochemical variables in broiler chickens, Poult. Sci. 87:1407–1414. doi: 10.3382/ps.2007-00486.

Onbaşilar, E. E., H. Erol, Z. Cantekin, and Ü. Kaya. 2007. Influence of intermittent lighting on broiler performance, incidence of tibial dyschondroplasia, tonic immobility, some blood parameters and antibody production, Asian-Aus. J.Anim.Sci. 20:550–555. doi: 10.5713/ajas.2007.550.

Petersen, J. Dansk Slagtefjerkræ (2005). Færre slagtekyllinger med benproblemer. Nyhedsbrevet danskkyling.dk. September. 13653. 4pp.

Pichova, K., J. Nordgreen, C. Leterrier, L. Kostal, and R. O. Moe. 2016. The effects of food-related environmental complexity on litter directed behaviour, fear and exploration of novel stimuli in young broiler chickens, Appl.Anim.Behav.Sci. 174:83–89. doi: 10.1016/j.applanim.2015.11.007.

Prayitno, D. S., C. J. Phillips, and D. K. Stokes. 1997. The effects of color and intensity of light on behavior and leg disorders in broiler chickens, Poult. Sci. 76:1674–1681. doi: 10.1093/ps/76.12.1674.

Ralph, J. 2017. Reducing Footpad Dermatitis in Turkeys. International Turkey Disease Symposium. Berlin. https://www.dropbox.com/s/b47kdiihfzua1ul/Ralph17Reducing%20Footpad%20Dermatitis%20

John%20Ralph%20Abstract%20Int%20Turkey%20Diseases%20Symp%20Berlin.pdf?dl=0

Rasmussen, I.K., Spangberg, A. and Kristensen, H.H. (2012) Screening af slagtekyllingers gangegenskaber anno 2011. Videncentret for Landbrug. Fjerkrae. Arhus Denmark. 11pp.

Reiter, K., and W. Bessei. 1998. Effect of locomotor activity on bone development and leg disorders in broilers, Arch. Geflügelk. 62:247–253.

Reiter, K., and W. Bessei. 2000. Einfluß der Besatzdichte bei Broilern auf die Temperatur in der Einstreu und zwischen den Tieren, Arch. f. Geflügelk. 64:1–3.

Reiter, K., and W. Bessei. 2009. Effect of locomotor activity on leg disorder in fattening chicken, Berl.Münch.Tierärztl.Wochenschr. 122:264–270. doi: 10.2376/0005-9366-122-264.

Reiter, K., and Bessei W. 2002. Biological rhythms of behaviour, 11th Europ. Poultry Conference, Bremen, Germany: 40.

Rekaya, R., R. L. Sapp, T. Wing, and S. E. Aggrey. 2013. Genetic evaluation for growth, body composition, feed efficiency, and leg soundness, Poult. Sci. 92:923–929. doi: 10.3382/ps.2012-02649.

Ribbekk, E. 2005. World Urbanization Prospects: The 2005 Revision United Nations Department of Economic and Social Affairs / Population Division, »www.un.org/esa/«.

Riber, A. B. 2015. Effects of color of light on preferences, performance, and welfare in broilers, Poult. Sci. 94:1767–1775. doi: 10.3382/ps/pev174.

Riber, A. B., H. A. van de Weerd, I. C. de Jong, and S. Steenfeldt. 2018. Review of environmental enrichment for broiler chickens, Poult. Sci. 97:378–396. doi: 10.3382/ps/pex344.

Riddel, C. 1991. Ascites and right ventricular failure in broiler chickens and ducks. In: Diseases of Poultry, 9th Edition Iowa State University Press: 839

Rodriguez-Aurrekoetxea, A., E. H. Leone, and I. Estevez. 2014. Environmental complexity and use of space in slow growing free range chickens, App. An. Behav. Sci. 161:86–94. doi: 10.1016/j.applanim.2014.09.014.

Rodriguez-Aurrekoetxea, A., E. H. Leone, and I. Estevez. 2015. Effects of panels and perches on the behaviour of commercial slow-growing free-range meat chickens, App. An. Behav. Sci. 165:103–111. doi: 10.1016/j.applanim.2015.02.004.

Rogers, A. G., E. M. Pritchett, R. L. Alphin, E. M. Brannick, and E. R. Benson. 2015a. I. Evaluation of the impact of alternative light technology on male broiler chicken growth, feed conversion, and allometric characteristics, Poult. Sci. 94:408–414. doi: 10.3382/ps/peu045.

Rogers, A. G., E. M. Pritchett, R. L. Alphin, E. M. Brannick, and E. R. Benson. 2015b. II. Evaluation of the impact of alternative light technology on male broiler chicken stress, Poult. Sci. 94:331–337. doi: 10.3382/ps/peu046.

Rozenboim, I., I. Biran, Z. Uni, B. Robinzon, and O. Halevy. 1999a. The effect of monochromatic light on broiler growth and development, Poult. Sci. 78:135–138. doi: 10.1093/ps/78.1.135.

Rozenboim, I., B. Robinzon, and A. Rosenstrauch. 1999b. Effect of light source and regimen on growing broilers, British Poultry Science. 40:452–457. doi: 10.1080/00071669987197

Rozenboim, I., I. Biran, Y. Chaiseha, S. Yahav, A. Rosenstrauch, D. Sklan, and O. Halevy. 2004. The effect of a green and blue monochromatic light combination on broiler growth and development, Poult. Sci. 83:842–845. doi: 10.1093/ps/83.5.842.

Rudolf, Miriam. 2008. Einfluss von Besatzdichte und Einstreumaterial auf die Pododermatitis bei Mastputen. Inaug. Diss. FU Berlin.

Sanotra, G.S., Lund, J.S., Ersøll, A.K., Petersen, J.S. and Vestergaard, K.S. (2001) Monitoring leg problems in broilers: a survey of commercial broiler production in Denmark. World's Poultry Science Journal, 57:1, 55-69, DOI: 10.1079/WPS20010006

Savory, C. J. 1975. A growth study of broiler and layer chicks reared in single-strain and mixed-strain groups, Brit. Poultry Science. 16:315–318.

Scholtyssek, S. 1973. Zur Frage der Besatzdichte in Broilerherden, Archiv. Geflügelk. 35:235–239.

Scholtyssek, S. and G. M.Grashorn. 1989. Laufböden in der Broilermast, Züchtungskunde. 61:152–163.

Schrader, L. (2013): Tierschutz in der Nutztierhaltung – wo liegen Chancen und Grenzen? In: Züchtungskunde 85, S. 34–39.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2012. Impact of daylength on the productivity of two commercial broiler strains, Br.Poult.Sci. 53:7–18. doi: 10.1080/00071668.2012.659652.

Shanawany, M. M. 1988. Broiler Performance under high stocking densities, Br.Poult.Sci. 29:43–52.

Sørensen, P. 1992. The genetics of leg disorders. In: Whitehead, C.C. (ed.) Bone biology an Skeletal Disorders in Poultry. Carfax Publishing Co., Abingdon, UK,:213–229.

Sørensen, P., G. Su, and S. C. Kestin. 1999. The effect of photoperiod:Scotoperiod on leg weakness in Broiler chickens, Pou. 78:336–342. doi: 10.1093/ps/78.3.336.

Steenberg, B. 2012. Introduction to the Danish broiler sector. Facts about the production of poultry meat in Denmark. p14. Landbrug og Foedevarer.

Su and Sørensen loc. cit. Muir, W. M., and S. E. Aggrey. 2003. Poultry genetics, breeding and biotechnology. CABI Publishing, Wallingford.

Sultana, S., M. R. Hassan, H. S. Choe, and K. S. Ryu. 2013. The effect of monochromatic and mixed LED light colour on the behaviour and fear responses of broiler chicken, Avian Biol Res. 6:207–214. doi: 10.3184/175815513X13739879772128.

Swalander, M. 2012. Balanced breeding of turkeys for health and welfare. Lohmann Information 47(1), 43-48.

Thomsen, M. G. 1989. Lysprogammet og foderstructurens inflydelse pa slagtekyllingers adfaersmonster., Statens Husdyrbrugsforsog. Meddelse Nr. 736, Kopenhagen, Dänemark.

Webster, A. B., B. D. Fairchild, T. S. Cummings, and P. A. Stayer. 2008. Validation of a Three-Point Gait-Scoring System for Field Assessment of Walking Ability of Commercial Broilers, The Journal of Applied Poultry Research. 17:529–539. doi: 10.3382/japr.2008-00013.

Wiedmer, H., and R. Hadorn. 1998. Revision Tierschutzverordnung. Kurzmast-Besatzdichten lassen, Schweizerische Geflügelzeitung. 2/98:10–15.

Xie, D., Z. X. Wang, Y. L. Dong, J. Cao, J. F. Wang, J. L. Chen, and Y. X. Chen. 2008. Effects of monochromatic light on immune response of broilers, Poult. Sci. 87:1535–1539. doi: 10.3382/ps.2007-00317.

Youssef, I. M. I., A. Beineke, K. Rohn, and J. Kamphues. 2011. Effects of litter quality (moisture, ammonia, uric acid) on development and severity of foot pad dermatitis in growing turkeys, Avian Diseases. 55:51–58.

Zubair, A. K., and S. Leeson. 1996. Compensatory growth in the broiler chicken. A review, World's Poult.Sci.J. 52:197–201.

Zuidhof, M. J., B. L. Schneider, V. L. Carney, D. R. Korver, and F. E. Robinson. 2014. Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 20051, Poult. Sci. 93:2970–2982. doi: 10.3382/ps.2014-04291.