UNIVERSITY OF HELSINKI
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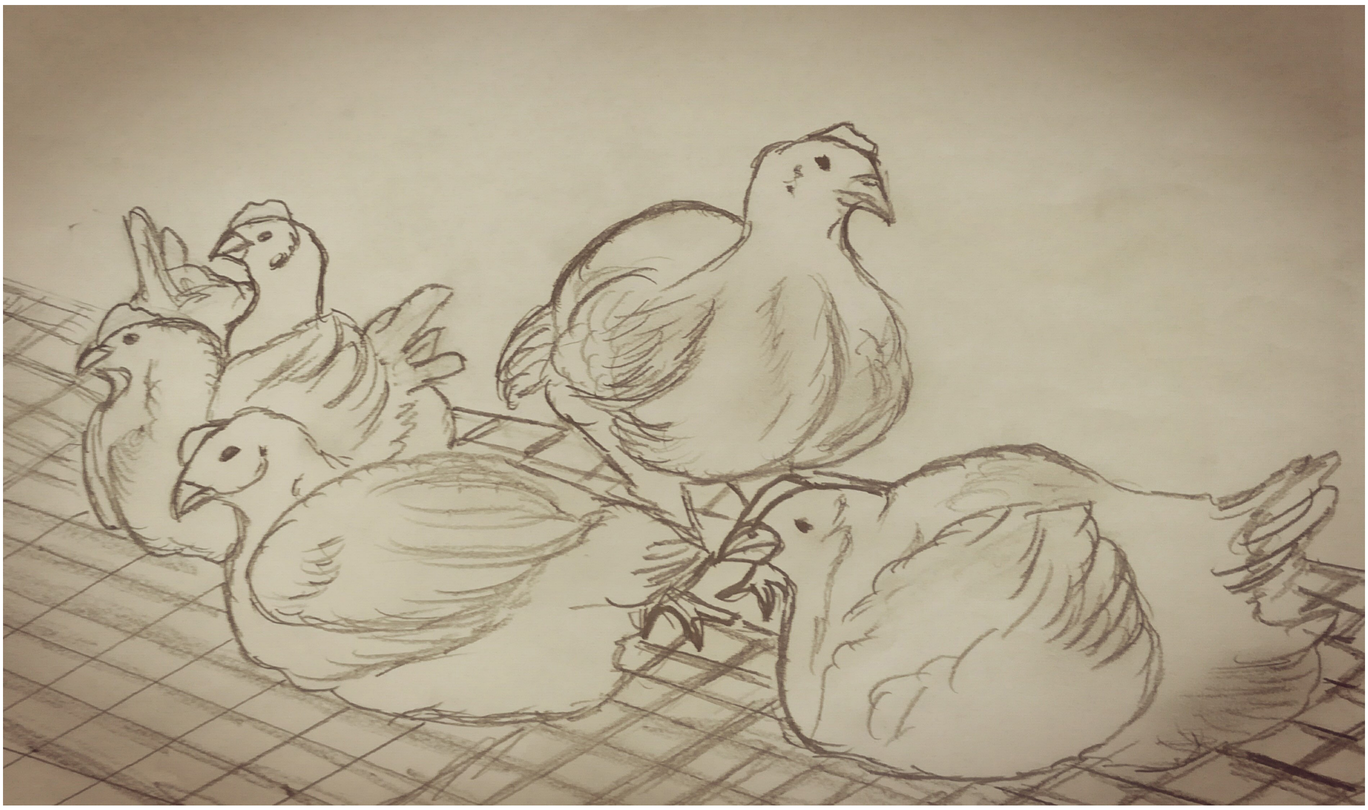
HOUSING CONDITIONS AND BROILER AND BROILER BREEDER WELFARE

THE EFFECT OF LITTER CONDITION ON CONTACT DERMATITIS IN BROILERS AND BREEDERS, AND THE EFFECT OF ELEVATED STRUCTURES ON BROILER LEG HEALTH

EIJA KAUKONEN



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Housing conditions and broiler and broiler breeder welfare

the effect of litter condition on contact dermatitis in broilers and breeders, and the effect of elevated structures on broiler leg health

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Cover: ”Viewing the surroundings”

I dedicate this thesis to all the animals that have touched my life

Alku aina hankala –

Abstract

Contact dermatitis in broilers is a multifactorial condition that is most commonly caused by poor litter quality or otherwise unsuitable material affecting the footpad or hock skin. Footpad health is mainly maintained by keeping litter in a dry and friable condition. Hence, footpad lesions reflect litter quality that, more widely, describes the housing conditions and bird health. The evaluation of the prevalence of contact dermatitis denotes a commonly accepted approach to assess the welfare of broiler flocks. However, there is lack of knowledge about footpad lesions in broiler breeders. Although numerous studies on the effect of litter materials on footpad condition have been conducted, experiments with peat are scarce. Also, knowledge of the influence of peat on hock burns and litter quality is lacking.

Modern fast-growing broilers spend excessive time resting and this inactivity has been suggested to increase the incidence of impaired gait and leg disorders. Tibial dyschondroplasia (TD) is one of the most common leg pathologies in broilers. Perches or elevated platforms add complexity to the broilers' environment and may stimulate locomotion. However, research on the use of elevated structures under commercial rearing conditions and possible benefits for broiler leg health is limited.

This thesis provides descriptive information about contact dermatitis and breast blisters in broiler breeders throughout the production period with respect to litter condition. Secondly, the study compared the influence of peat bedding with wood shavings and ground straw (fine crushed straw) on contact dermatitis and plumage cleanliness in fast-growing broilers and litter condition in commercial broiler houses. Furthermore, the study examined the use of perches and elevated platforms by broilers, and the impact of the additional equipment on contact dermatitis, plumage cleanliness, walking ability, the occurrence of TD and litter conditions under intensive rearing circumstances.

Litter condition in broiler and breeder houses was evaluated according to the Welfare Quality® (WQ) protocol for broiler chicken. Additionally, litter height was measured, and litter quality determined according to moisture, pH and ammonia content. Footpad condition was visually inspected with the WQ-scoring method (broilers), the official Finnish system (broilers) or employing a method modified from the official system (breeders). Hock skin lesions and plumage cleanliness were assessed according to the WQ-protocol. Broiler gait was scored before slaughter following the WQ-protocol. The severity of TD was determined. The use of perches and platforms was monitored by video recording. Additionally, farmers estimated the platform and perch usage twice a week throughout the growing period.

The condition of breeder footpads deteriorated towards the end of the production period, with the occurrence of severe lesions reaching a maximum of 64% on average at slaughter. However, hock burns and breast blisters were rarely recorded. The litter layer became drier over time. Although dry and friable litter in breeder houses was associated with healthier footpads, other factors were of greater importance, as footpad lesions, particularly severe lesions, appeared more often towards slaughter age.

Broiler footpads were generally in good condition at slaughter age, 80% of the birds having healthy footpads. In broilers, hock burns were more frequently detected than

footpad lesions. Inferior footpad and hock skin health was scored on wood shavings rather than on peat, without differences in litter condition and moisture. Moreover, the lack of difference in moisture between ground straw and peat still resulted in poorer litter, footpad and hock skin condition on ground straw. Farms differed for footpad and hock burn condition, and litter quality. In risk analysis, the impact of farmer on contact dermatitis severity exceeded the effect of litter quality.

The platforms were used frequently while only single birds used perches. The study indicated no effects of platform treatment on footpad and hock skin health, and litter condition. The birds with access to platforms, however, had enhanced leg health: mean gait score, the percentage of birds scored 3, and TD percentage and severity were lower for birds in platform-equipped houses. Access to platforms most likely enables more versatile movement, such as walking forward, up and down, grasping by feet, and jumping, which may promote leg health and gait.

This was the first study to follow footpad health in broiler breeders through the whole production period. The results indicate the need for further investigation because good litter condition alone appears insufficient to keep breeder footpads healthy for their entire life. Further, this thesis provides new knowledge about the applicability of peat as broiler bedding. According to our results, regarding footpad health, peat seems to be the optimal litter material for Finnish conditions. Furthermore, the study underlines the importance of farmer ability to manage litter conditions, regardless of the chosen litter material. Hock burn monitoring could represent a more sensitive indicator of litter condition and possibly also signal leg health status, therefore monitoring hock burns at slaughter should be considered. The advantages of traditional perches for broilers should be re-evaluated as they remained largely unused. However, the extensive use of platforms suggests that broilers are motivated to perch on elevated structures. Hence, platform availability could enhance their emotional wellbeing. Elevated platforms offering additional possibilities for locomotion seem promising because they show apparent potential to enhance leg health without compromising litter condition or footpad health. Based on all these findings, elevated platforms with ramps can be recommended as a way forward to enhance broiler welfare in commercial environments.

Contents

List of original publications

This thesis is based on the following publications:

I Eija Kaukonen, Marianna Norring & Anna Valros (2016). Effect of litter quality on foot pad dermatitis, hock burns and breast blisters in broiler breeders during the production period. Avian Pathology, 45, 667–673.
DOI: 10.1080/03079457.2016.1197377

II Eija Kaukonen, Marianna Norring & Anna Valros. Evaluating the effects of bedding materials and elevated platforms on contact dermatitis and plumage cleanliness of commercial broilers, and litter condition in broiler houses. Accepted to British Poultry Science 28.4.2017.

III Marianna Norring, Eija Kaukonen & Anna Valros (2016). The use of perches and platforms by broiler chickens. Applied Animal Behaviour Science, 184, 91–96.
doi.org/10.1016/j.applanim.2016.07.012

IV Eija Kaukonen, Marianna Norring & Anna 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.
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The publications are referred to in the text by their Roman numerals.
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1 Introduction

Broiler meat consumption is increasing worldwide (Bruinsma 2003, European Commission 2015), requiring increasingly more commercial broilers and broiler breeders. At the same time consumers demand improved welfare for broilers (Pouta *et al.* 2010, European Commission 2016). Problems related to fast growth of broilers, such as poor leg health, trigger concerns over compromised welfare (Julian 1998, SCAHAW 2000, Bradshaw *et al.* 2002, Butterworth and Haslam 2009, de Jong *et al.* 2012a). In addition, poor leg health may have negative financial consequences for farmers, including reduced growth and poorer feed efficacy (McIlroy *et al.* 1987, Bruce *et al.* 1990, Menzies *et al.* 1998, Cook 2000, Bradshaw *et al.* 2002, Butterworth and Haslam 2009, de Jong *et al.* 2014). Furthermore, broilers are normally kept in very featureless environments, which provide minimal stimulation. The European Commission regards such a lack of environmental enrichment as a concern for broiler welfare (SCAHAW 2000).

A good level of animal welfare is assured by combining good health, positive emotions and possibilities to perform natural behaviours. One definition for animal welfare is proposed by the World Animal Health Organisation (OIE 2016),

> ”Animal welfare means how an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling and humane slaughter/killing.”

Footpad and hock skin lesions are forms of contact dermatitis (Greene *et al.* 1985), which is a common problem impairing broiler welfare (Ekstrand *et al.* 1998, Haslam *et al.* 2007, Meluzzi *et al.* 2008b, Allain *et al.* 2009, de Jong *et al.* 2012b, Kyvsgaard *et al.* 2013) and probably also affects breeders. However, research on contact dermatitis in breeders is scarce. Contact dermatitis is a condition with a multifactorial background (Shepherd and Fairchild 2010), but in broilers these pathologies have most commonly been associated with poor litter conditions (Bruce *et al.* 1990, Haslam *et al.* 2007, Mayne *et al.* 2007, Cengiz *et al.* 2012, de Jong *et al.* 2014). The existence and severity of contact dermatitis is thought to reflect housing conditions, management and broiler health in a broad sense (Haslam *et al.* 2006). Thus, evaluating the prevalence of contact dermatitis provides a well-established approach to assess the welfare of broiler flocks (Ekstrand *et al.* 1998, Council Directive 2007/43/CE). There is also need to develop animal-based indicators to monitor broiler breeder welfare (EFSA 2010). Nevertheless, research on breeder welfare has mainly been focused on attempts to diminish negative consequences of feed restriction (Hocking *et al.* 1993, de Jong *et al.* 2005, Sandilands *et al.* 2006, D'Eath *et al.* 2009), while other aspects of breeder welfare are, for the most part, overlooked.

The bedding material of choice has been shown to impact footpad health (Su *et al.* 2000, Bilgili *et al.* 2009, Kyvsgaard *et al.* 2013). In Europe, wood shavings and straw appear to be the most popular litter materials for broilers (Jones *et al.* 2005, Meluzzi *et al.* 2008b, Kyvsgaard *et al.* 2013). In Finland peat is the standard bedding material used in broiler production. Numerous studies have explored the effect of different litter materials on footpad condition (Su *et al.* 2000, Sirri *et al.* 2007, Meluzzi *et al.* 2008a, Bilgili *et al.* 2009, Cengiz *et al.* 2012). However, the existing knowledge about the effects of different litter materials does not address peat, which needs to be assessed for its effects on litter quality and contact dermatitis.

Perching is considered to be an integral chicken behaviour (Olsson and Keeling 2000), and is suggested to encourage increased physical activity among birds, potentially leading to better leg health and welfare (Bizeray *et al.* 2002a, Ventura *et al.* 2012, Bailie *et al.* 2013, Ohara *et al.* 2015, Bailie and O'Connell 2015) because it stimulates diversification of locomotion (Sandusky and Heath 1988a,b). A number of studies have focused on the effects of perches on broiler behaviour in experimental settings (Ventura *et al.* 2012, Rodriguez-Aurrekoetxea *et al.* 2015, Ohara *et al.* 2015). However, there is lack of research on the suitability of perches for improving broiler welfare under commercial conditions. Moreover, published reports on other kinds of elevated structures are rare (Oester *et al.* 2005) and research is insufficient on the influence of perches on contact dermatitis in broilers and litter condition in commercial broiler houses.

Even though animal welfare, when defined as above, covers multible aspects of health, emotions and natural behaviours, this study measured welfare using only a few specific aspects of welfare, namely as the severity of contact dermatitis in broilers and breeders, and as leg health and perching behaviour in broilers. This thesis presents new knowledge about footpad health in broiler breeders in relation to litter condition through the entire production period. Furthermore, the study provides novel information about the applicability of peat as broiler bedding in comparison with wood shavings and ground straw, and the perching behaviour of broilers in large commercial flocks. The effects of elevated platforms on broiler leg health are also determined.

2 Review of the literature

2.1 Contact dermatitis

Footpad, hock and breast skin lesions all represent a form of contact dermatitis, a condition affecting skin areas in contact with poor quality litter or otherwise unsuitable and irritating material (Greene *et al.* 1985). Contact dermatitis is a common problem that impairs the welfare of broilers (Ekstrand *et al.* 1998, Haslam *et al.* 2007, Kyvsgaard *et al.* 2013), turkeys (Ekstrand and Algers 1997, Martrenchar *et al.* 2002) and laying hens (Weitzenbürger *et al.* 2006). In broilers, the prevalence of footpad lesions appears to vary depending on the reporting country, 65% in the Netherlands (de Jong *et al.* 2012b) versus 50% in Portugal (Saraiva *et al.* 2016) and 13% in Norway (Kittelsen *et al.* 2017). Control programmes, which include consultation that assists farmers in preventing footpad dermatitis, have improved the situation over time (Algers and Berg 2001, Kyvsgaard *et al.* 2013).

Healthy footpad skin has neither macroscopic nor histologic changes (Michel *et al.* 2012). The first signs of footpad dermatitis are characterized by brownish-coloured skin (Martland 1985), enlarged scales and mild hyperkeratosis (Martland 1984, Michel *et al.* 2012). These contusions may deteriorate into moderate, superficial lesions with more hypertrophic scales and yellow or brownish exudate on the top (Michel *et al.* 2012). As lesions become more severe, the affected skin covers large areas of the foot- and toepads (Martland 1985). The total loss of normal skin, replaced by deep ulcers, covered with a dark, thick crust, is evident for the most severe lesions (Michel *et al.* 2012). At this stage histology reveals necrosis in the epidermis and the inflammation of the sub cutis (Greene *et al.* 1985, Martland 1985, Michel *et al.* 2012).

Aetiology of contact dermatitis

Footpad lesions can develop quickly, in less than a week under wet litter conditions (Greene *et al.* 1985). The healing process may start within two weeks if causative factors are removed (Greene *et al.* 1985, Martland 1985, Mayne *et al.* 2007, Cengiz *et al.* 2012). Lesions with smooth skin lacking a papilla structure are considered to be recovered lesions with scar tissue (Martland 1985, Michel *et al.* 2012).

In broilers, contact dermatitis typically appears first on the footpads, and is followed by hock burns and breast skin lesions. The development of hock and breast burns seems to be the same as for footpad dermatitis, lesions starting as hyperaemic abrasions of the skin developing into deep ulcers (Greene *et al.* 1985). Also these skin lesions can appear and deteriorate within a week and recovery seems possible, though slower than with foot lesions (Martland 1985).

Breast blisters are thought to be caused by long-lasting pressure on the keel bone bursa, which subsequently enlargs and fills with fluid (McCune and Delmann 1968, Miner and Smart 1975). Breast blisters have been diagnosed together with severe footpad lesions affecting male turkeys grown on damp litter (Martland 1984). Some evidence also exists on the connection between footpad lesions and breast blisters in broilers (Harms and Simpson 1975). Moreover, broilers reared on wet litter can suffer from breast blisters, and improved litter conditions have enabled the lesions to heal (Martland 1985).

Bacteria are commonly found on the superficial footpad skin layers but seldom in deeper layers (Martland 1984), and no specific pathogens have been associated with contact dermatitis (Greene *et al.* 1985). Alterations in skin structure due to hyperkeratosis may benefit bacterial colonization, possibly increasing the risk for secondary infections (Weitzenbürger *et al.* 2006). In laying hens, the severe type of footpad dermatitis, bumble foot, manifests as a severely swollen and inflamed metatarsal footpad (Tauson and Abrahamsson 1996). The aetiology of bumble foot is similar to footpad dermatitis in broilers, but bumble foot also often involves bacterial infection leading to abscesses, and occasionally even to systemic infections (Wang *et al.* 1998, Olsen *et al.* 2013).

Consequences of contact dermatitis

Severe footpad dermatitis may cause lameness (Martland 1984, Greene *et al.* 1985, da Costa *et al.* 2014) and reduced growth (Martland 1984, Martland 1985, de Jong *et al.* 2014). Furthermore, several studies have shown a correlation between impaired walking ability and hock burns (Kestin *et al.* 1999, Su *et al.* 1999, Sørensen *et al.* 1999, Sørensen *et al.* 2000, Kristensen *et al.* 2006, Haslam *et al.* 2007, de Jong *et al.* 2014). Hock burns may be triggered by walking difficulties, which induce more resting, thus more time for skin in contact with litter. The link might also be the reversed, as lameness could be caused by painful hock lesions (Sørensen *et al.* 2000, Kristensen *et al.* 2006). Some evidence also exists on the relationship between increasing footpad dermatitis severity and reduced performance in mobility tests (Caplen *et al.* 2014, Hothersall *et al.* 2016).

There are nociceptors in the scaly footpad skin (Gentle *et al.* 2001) and pain-medicated broilers with footpad lesions have shown improved mobility (Caplen *et al.* 2014, Hothersall *et al.* 2016). Turkeys with footpad lesions can walk better (Weber Wyneken *et al.* 2015), and have more varying behavioural patterns and increased times standing after pain medication (Sinclair *et al.* 2015). All these findings indicate that contact dermatitis can be painful.

2.1.1 Factors influencing footpad and hock lesions

Contact dermatitis is a condition with a multifactorial background (Shepherd and Fairchild 2010), but good litter quality is considered to be the most important factor preventing it (Bruce *et al.* 1990, Haslam *et al.* 2007, Mayne *et al.* 2007, Meluzzi *et al.* 2008b). In addition, a number of other risk factors have been recognised, such as housing conditions, nutrition, bird age, sex, weight and genetics (Mayne 2005, Shepherd and Fairchild 2010; Figure 1). Footpad dermatitis and hock burns exhibit, to a great degree, similar backgrounds. However, these forms of contact dermatitis have been suggested to display, at least partly, different aetiologies because they do not appear to share all the same risk factors (Haslam *et al.* 2007).

2.1.1.1 Litter material and litter conditions

The characteristics of bedding material markedly influence litter condition (Bilgili *et al.* 2009, Cengiz *et al.* 2012). The damaging effect of wet litter on footpad (Mayne *et al.* 2007, Cengiz *et al.* 2012, de Jong *et al.* 2014) and hock skin health (Bruce *et al.* 1990, Haslam *et al.* 2007, de Jong *et al.* 2014) is well documented. In addition, several other factors, such as ventilation, stocking density, perches, nutrition and bird health, affect via litter condition.

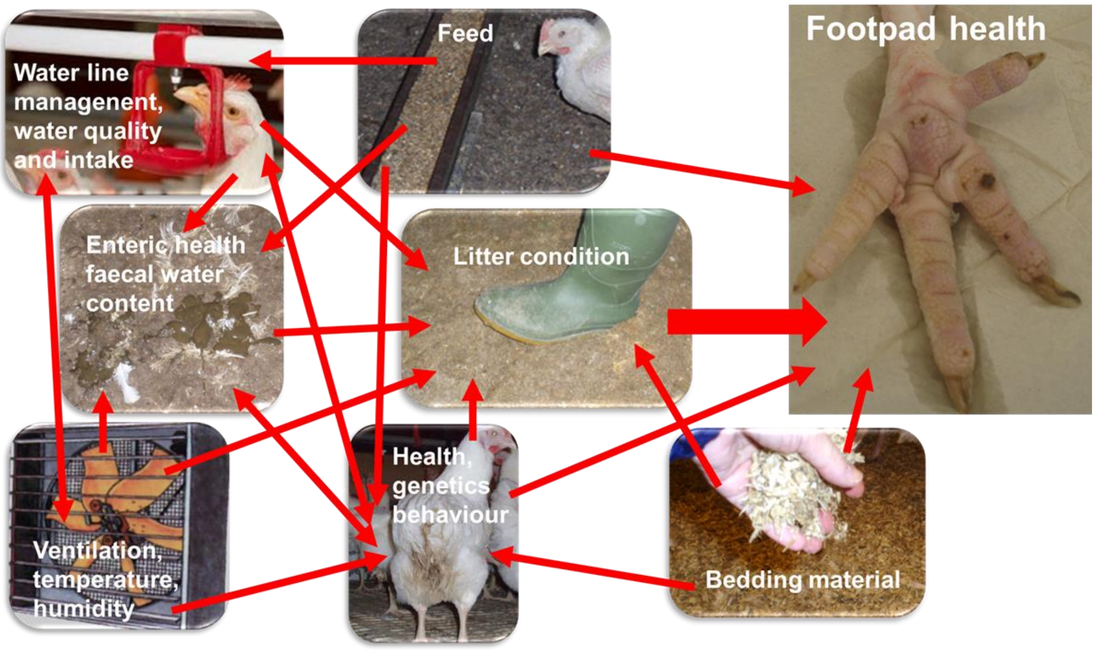

Figure 1 *Illustration of connections between factors affecting footpad health in broilers.*

Litter material

The suitability of various materials, such as wood shavings, sawdust, straw, sand, rice hulls and peat as broiler litter have been tested (Su *et al.* 2000, Meluzzi *et al.* 2008a, Bilgili *et al.* 2009, Garcia *et al.* 2012, Farhadi 2014). A number of studies have demonstrated that straw bedding, compared with wood shavings, appears less advantageous for footpad health (Su *et al.* 2000, Sirri *et al.* 2007, Meluzzi *et al.* 2008a, Kyvsgaard *et al.* 2013). The properties of the material, such as the roughness of the particles or water absorbing capacity, might explain the differences between the materials. Bedding material containing smooth and fine particles has been connected with enhanced footpad health, compared with materials of coarse particles (Cengiz *et al.* 2012). In one of the rare studies comparing peat with wood shavings, peat litter was healthier for footpads in broilers (de Baere *et al.* 2009), whereas a large Danish investigation found no marked differences in footpad condition resulting from the use of wood shavings and peat, but footpad health was inferior on straw litter (Kyvsgaard *et al.* 2013). American studies exploring the suitability of reed-sedge peat as turkey bedding material concluded that even though peat worked acceptably and was easier to maintain in a friable condition than wood shavings, birds on peat had impaired footpad health (Enueme and Waibel 1987, Enueme *et al.* 1987).

Moisture content

Litter condition, particularly moisture content, is considered the most important factor influencing footpad health under experimental conditions (Harms *et al*. 1977, Martland 1985, Mayne *et al.* 2007, de Jong *et al.* 2014) and in commercial situations (Greene *et al.* 1985, Meluzzi *et al.* 2008b, Bassler *et al.* 2013). Litter wetness exceeding 30% radically increased lesions in turkeys (Wu and Hocking 2011), but a more recent study demonstrated a higher threshold moisture of 49% in relation to greater risk for footpad dermatitis (Weber Wyneken *et al.* 2015). Moreover, wet litter conditions result in dirty plumage (Martland 1985, de Jong *et al.* 2014) and may decrease broiler growth and feed efficacy (McIlroy *et al.* 1987, Bruce *et al.* 1990, de Jong *et al.* 2014).

In addition to litter moisture, also the ability of bedding material to absorb, retain and release moisture was demonstrated to be essential for good footpad health (Bilgili *et al.* 2009) and litter condition (Dunlop *et al.* 2015). Wood shavings litter appears to increase its water retaining capacity during the rearing period (Dunlop *et al.* 2015). Nonetheless, reusing litter for several successive flocks increased the severity of footpad dermatitis in broilers (Bilgili *et al.* 2009, Almeida *et al.* 2010). *Sphagnum* peat exhibits high water absorbing, retaining and releasing capability (Feustel and Byers 1936), which could add to its value as broiler bedding. Peat acts like a sponge, absorbing moisture that stimulates marked swelling, and its porous character allows easy movement for water, assisting in evaporation (Feustel and Byers 1936).

Ammonia content and pH

Occasionally, footpad dermatitis is referred to as ‘ammonia burns’ (Cravener *et al.* 1992, Sanotra *et al.* 2001b, Venäläinen *et al.* 2006, Kyvsgaard *et al.* 2013) due to the assumed adverse effect of ammonia on skin. Ammonia is produced by bacteria decomposing uric acid in litter faeces (Schefferle 1965), where its formation is affected by temperature, pH and moisture. Bacterial growth requires a suitable temperature. Low pH and extremely dry or wet litter appear to prohibit ammonia production, whereas an alkaline pH, together with moderate moisture, increases ammonia levels (Elliot and Collins 1982). Ammonia production seems to be minimal in litter with pH lower than 7.5 (Carr *et al.* 1990). Higher aerial ammonia levels were connected with the increased incidence of footpad lesions (Dawkins *et al.* 2004, Haslam *et al.* 2006). On the other hand, several studies showed that wet litter alone, without ammonia or faecal contamination, can induce footpad lesions (Wang *et al.* 1998, Mayne *et al.* 2007, Martins *et al.* 2013).

Fresh wood shavings are slightly acid, approximately pH 5, whereas exhausted litter has an increased pH (Miles *et al.* 2011). Furthermore, litter pH may be linked with its moisture content. Dry wood shavings had a higher pH, about 8 (Martland 1985, Miles *et al.* 2011), than moist litter, which has a pH of about 7 (Martland 1985, Miles *et al.* 2011). If ammonia plays as important a role as previously supposed, a higher pH would be expected to be associated with wetter litter. Research has also revealed negligible impacts of wood shavings (Wang *et al.* 1998, Meluzzi *et al.* 2008a, Wu and Hocking 2011) and straw (Meluzzi *et al.* 2008a) litter pH on footpad health.

The natural acidity of *Sphagnum* peat, pH 4 (Feustel and Byers 1936, Cocozza *et al.* 2003), possibly presents some buffering capacity against the harmful effects of ammonia. Moreover, topping wood shavings litter with peat during the broiler rearing period decreased the coliform bacteria, yeast and mould contamination of litter (Everett *et al.* 2013).

Litter layer thickness

Some researchers reported fewer footpad lesions on a thinner litter layer, as compared with a thicker layer. A thin litter layer probably requires less effort to heat and ventilate and could also be easier for broilers to scratch from top to bottom (Ekstrand *et al.* 1997, Martrenchar *et al.* 2002). However, not all studies have demonstrated the effect of litter thickness on footpads, whereas, a thicker litter layer has been linked with lower incidence of hock burns, possibly indicating the different aetiology of footpad and hock dermatitis (Haslam *et al.* 2007).

2.1.1.2 Housing conditions affecting litter quality

Litter condition in broiler houses is mainly maintained by controlling the temperature and relative humidity through adequate ventilation and heating (McIlroy *et al.* 1987, Jones *et al.* 2005), and management routines consequently substantially influence the housing conditions (Jones *et al.* 2005). The association between inferior litter condition, poorer feed efficacy and higher mortality rate, and increased risk for hock burns, has been suggested to indicate inferior overall management skills of the farmer (Menzies *et al.* 1998). This suggestion is supported by several large field studies that highlighted a marked impact of the farmer on litter quality and the incidence of contact dermatitis (McIlroy *et al.* 1987, Ekstrand *et al.* 1997, Jones *et al.* 2005, Meluzzi *et al.* 2008b, de Jong *et al.* 2012b).

Temperature and ventilation

Maintaining house temperature and ventilation at optimal levels through the whole rearing phase is important in preventing damp litter conditions and contact dermatitis, and generally ensuring good broiler welfare (Dawkins *et al.* 2004, Jones *et al.* 2005). High relative humidity increases litter moisture and leads to impaired footpad health (Weaver and Meijerhof 1991, Jones *et al.* 2005), and by accelerating airflow near the floor, litter and footpad condition can be enhanced (Weaver and Meijerhof 1991). Broiler houses equipped with misting systems, to regulate air humidity, temperature and dustiness, seem to be connected with a higher risk for footpad lesions (Jones *et al.* 2005), most probably because mismanagement of misting systems easily results in wet litter with an adverse effect on footpad skin. Regardless of the original cause, the wetter the litter, the more intensified ventilation rate is required to dry it (Dunlop *et al.* 2015). However, maintaining the correct balance in litter moisture must be underlined because extremely dry litter may result in dusty air, leading to other types of welfare concern, such as increased risk for respiratory problems.

Numerous studies have revealed a seasonal influence on the incidence of contact dermatitis, footpad lesions (Ekstrand and Carpenter 1998, Dawkins *et al.* 2004, Haslam *et al.* 2007, de Jong *et al.* 2012b, Kyvsgaard *et al.* 2013) and hock burns (McIlroy *et al.* 1987, Bruce *et al.* 1990, Hepworth *et al.* 2010) more commonly emerging during the cold season. In-house humidity reflects outside humidity (Reece *et al.* 1985), and the higher relative humidity in the air in winter (McIlroy *et al.* 1987, Bruce *et al.* 1990, Ekstrand and Carpenter 1998) most likely represents a greater challenge for in-house humidity control during cold weather. Even though outside air humidity can be low under extremely cold weather conditions in the winter, the substantial temperature gradient between outside and inside air easily generates condensation on the warm litter surface, consequently leading to wet litter.

Drinkers

The number of drinkers, drinker type and the management of drinkers influence litter condition. A greater number of drinkers per unit floor area was connected with wetter litter (Dawkins *et al.* 2004, Jones *et al.* 2005). Nipple drinkers, compared with cup drinkers, are associated with enhanced footpad condition (Ekstrand *et al.* 1997), and nipple drinkers with drip cups help keep litter dry and friable (Bray and Lynn 1986, Jones *et al.* 2005). Automated water consumption meters that enable precise monitoring and control of water consumption have been suggested to lower the risk for hock burns (Hepworth *et al.* 2010). Furthermore, adjusting the water pressure in drinker lines and height according to birds' size contribute to drier litter (Carey *et al.* 2004).

Stocking density

Increasing stocking densities affects litter condition adversely (Thomas *et al.* 2004, Dozier *et al.* 2006), and higher density stocking has also frequently been associated with impaired footpad health (Craventer *et al.* 1992, Martrenchar *et al.* 1997, Hall 2001, Arnould and Faure 2004, Thomas *et al.* 2004, Dozier *et al.* 2006, Buijs *et al.* 2009) and hock skin condition (McIlroy *et al*. 1987, Martrenchar *et al.* 1997, Arnould and Faure 2004, Thomas *et al.* 2004, Hepworth *et al.* 2010). A Danish study detected a seasonal effect of stocking density. In the summer higher stocking density was associated with more severe footpad lesions, but in winter the effect was reversed (Kyvsgaard *et al.* 2013). However, some studies show a negligible effect of stocking density on footpads (Martrenchar *et al.* 2002, Haslam *et al.* 2006, Haslam *et al.* 2007, Sirri *et al.* 2007, Allain *et al.* 2009) and hock skin health (Bruce *et al.* 1990, Dawkins *et al.* 2004, Haslam *et al.* 2006).

The discrepancies among results may indicate that various types of contact dermatitis display different density thresholds as was presented in a study comparing effects of increasing (from 6 to 56 kg/m²) stocking densities on footpad and hock dermatitis. Hock lesions seemed to increase significantly after 41 kg/m², while footpad condition was negatively affected only at the highest tested density (Buijs *et al.* 2009). Furthermore, housing conditions impacted broiler welfare to a greater degree than bird density *per se* (Dawkins *et al.* 2004, Jones *et al.* 2005). Yet, bird density at an older age may considerably affect relative humidity in the broiler house, implying that at higher densities optimal housing conditions are more challenging to achieve and maintain, thus emphasizing the negative consequence of high bird density (Jones *et al.* 2005).

Lighting

A longer dark period, possibly associated with diminished bird activity, negatively affected litter quality, but, was associated with enhanced footpad health (Bassler *et al.* 2013). An earlier study presented contradictory results, a longer day being related with lower occurrence of contact dermatitis (Sørensen *et al.* 1999). Brighter light reduced the incidence of footpad lesions (Blatchford *et al.* 2009, Deep *et al.* 2010, Deep *et al.* 2013). The intensity of natural light is higher than that of artificial light. Lower litter moisture has been associated with natural light, possibly because of improved airflow from increased bird activity under natural light conditions (Bailie *et al.* 2013). However, again, the effect of lighting is not straightforward, some studies having demonstrated no significant influence of light intensity (Kristensen *et al.* 2006, Sherlock *et al.* 2010) and day length (Sirri *et al.* 2007) on contact dermatitis. Such inconsistent results may indicate that lighting alone plays a less important role, but probably affects litter condition and the incidence of contact dermatitis via other factors.

Outside range

The production systems using slow-growing broiler breeds, with markedly lower stocking density and outside range, are expected to deliver healthier footpads and fewer hock burns than intensive production systems. Some studies confirm this (Broom and Reefman 2005, Gouveia *et al.* 2009, Lund *et al.* 2017). However, research comparing these two production systems does not always support this assumption. Some studies showed more footpad lesions for broilers with outside access (Pagazaurtundua and Warris 2006a). Those researchers suggested that the difference was due to older slaughter age, or possibly unsuitable pasture ground with sharp stones wounding footpad skin. However, differentiating the effect of breed and age from outside access is difficult because the factors typically act together.

Elevated structures
Furnishing broiler houses with perches may have effects on footpad and hock skin. Firstly, birds can escape wet litter by perching, hence perch availability might decrease the prevalence of contact dermatitis (Oester *et al.* 2005, Ventura *et al.* 2010, Ohara *et al.* 2015, Kiyma *et al.* 2016). Secondly, extra equipment on the broiler house floor might interfere with airflow at floor level, compromising litter condition and adversely affecting footpad and hock skin. Furthermore, any added equipment, if not used by broilers, unnecessarily occupies floor space, increasing stocking density, and thus contributing to diminished welfare (Heckert *et al.* 2002, Tablante *et al.* 2003, Ventura *et al.* 2010). Wet wooden perches negatively affected the footpads of laying hens (Wang *et al.* 1998). Perching was also demonstrated to be associated with increased risk of breast blisters in slow-growing broilers (Nielsen 2004). In laying hens, the use of perches may induce the development of hyperkeratotic lesions on footpads (Weitzenbürger *et al.* 2006), and in broiler breeders pressure-treated wooden slat material caused serious damage to footpads (Sander *et al.* 1994). Evidently, perch design (shape, width, softness) influences pressure distribution on a laying hen's footpad, and a soft rubber-covered perch may reduce peak force on footpads, leading to better balance in pressure distribution (Pickel *et al.* 2011).

2.1.1.3 Other factors influencing contact dermatitis

Age, size and gender of birds
Contact dermatitis becomes more common and prominent as broilers age (McIlroy *et al.* 1987, Bruce *et al*. 1990, Haslam *et al.* 2007, Gouveia *et al.* 2009) and grow heavier (Kjaer *et al.* 2006, Hepworth *et al.* 2010, Saraiva *et al.* 2016). Wolanski *et al*. (2004) studied male broiler breeders, and concluded that body weight, rather than age, might have a greater impact on footpad condition. However, differentiating the effect of weight and age is difficult, if not impossible, since birds get heavier throughout the production period.

Males appear to exhibit contact dermatitis more commonly than females (Greene *et al.* 1985, McIlroy *et al.* 1987, Bruce *et al*. 1990, Menzies *et al.* 1998, Bilgili *et al.* 2006), which could be explained by heavier body weight and faster growth of males (Shepherd and Fairchild 2010). However, not all studies confirm this finding, because, on occasion, more skin lesions have been detected in females (Kjaer *et al.* 2006, Hepworth *et al.* 2010, Kapell *et al.* 2012a). Other studies found no sex-related effects on footpad health (Martland 1985, Gouveia *et al.* 2009). These contrasting results indicate that gender represents a minor risk factor for contracting contact dermatitis.

Breed
Some broiler breeds seem to be more prone to contact dermatitis (Kestin *et al.* 1999, Bilgili *et al.* 2006, Haslam *et al.* 2007, Allain *et al.* 2009). Fast-growing breeds often show greater sensitivity for footpad lesions than slow-growing breeds (Nielsen *et al.* 2003, Kjaer *et al.* 2006, Allain *et al.* 2009). However, different breeding lines seem

to display varying susceptibility for skin lesions depending on the housing environment (Kapell *et al.* 2012a). Genetic selection to improve footpad (Kestin *et al.* 1999, Kjaer *et al.* 2006, Ask 2010, Kapell *et al.* 2012a), and hock skin health (Kestin *et al.* 1999, Ask 2010, Kapell *et al.* 2012b) is possible without negatively influencing growth potential. Ask (2010) emphasized the importance of selection against both footpad lesions and hock burns in breeding programmes.

Nutrition

Feeding and nutrition can affect footpad health in several ways. Firstly, several studies reported differences in footpad condition according to feed manufacturers. Varying feed quality among feed mills may account for this finding (McIlroy *et al.* 1987, Bruce *et al.* 1990, Ekstrand and Carpenter 1998, Haslam *et al.* 2007, de Jong *et al.* 2012b). Secondly, deficiencies in certain essential vitamins, amino acids and micro-nutrients for skin development and condition, such as biotin, pantothenic acid, methionine, lysine and zinc, may predispose birds to footpad lesions (reviewed by Mayne 2005). The negative effect of extremely wet litter can be moderated by feeding high levels of zinc and biotin (El-Wahab *et al.* 2013). Thirdly, excessive amounts of salt (Harms and Simpson 1982, Garland and Pritchard 2008) or sodium (Garland and Pritchard 2008, Cengiz *et al.* 2012) increase water intake, causing watery faeces that compromise litter and footpad condition. Fourthly, the protein source of feed affects faecal water content and thus litter condition. Especially high levels of soya protein were linked with inferior litter and footpad quality (Jensen *et al.* 1970, Eichner *et al.* 2007). Also, a barley-containing broiler diet leads to sticky faeces (Hofshagen and Kaldhusdal 1992). Furthermore, poor feed digestibility may, by increasing the stickiness of faeces, negatively impact litter quality (Jensen *et al.* 1970, Bray and Lynn 1986). The dietary nutrient density and energy and protein levels can also impact the incidence of contact dermatitis. Feed of reduced energy and high protein level affected litter and hock skin condition negatively (Bray and Lynn 1986), and low-nutrient-density feeding has appeared more beneficial for footpads than high-density diets (Bilgili *et al.* 2006).

Biosecurity and health

Appropriate biosecurity routines on-farm impact litter condition positively (Hermans *et al.* 2006). This is understandable, because diseases causing thirst and reduced bird activity, like infectious bronchitis (Cook 2008) and infectious bursal disease (van den Berg 2008), and especially compromised enteric health and loose droppings, directly influence litter condition (Kaldhusdal and Hofshagen 1992, Hermans *et al.* 2006, Alcorn 2008, Bailey 2010). A Dutch field study reported enhanced footpad health in flocks with no history of antibiotic treatment, compared with flocks that had been medicated (de Jong *et al.* 2012b).

2.1.2 Applications of measuring systems

Due to the multifactorial background of contact dermatitis (Shepherd and Fairchild 2010), the presence and severity of footpad and hock skin lesions in broilers is taken to reflect housing conditions, management and bird health in a broad sense (Haslam *et al.* 2006). Hence, evaluating the prevalence of contact dermatitis provides a well-established approach to assessing the welfare of broiler flocks (Ekstrand *et al.* 1998, Butterworth *et al.* 2016).

Measuring contact dermatitis

Research has employed a wide variety of scoring scales, from a simple lesion-no-lesion scale (Kumari *et al.* 2015) to a 10-point scale (Allain *et al.* 2009), making comparison between different studies difficult. Visual inspection, as a subjective assessment method, may represent a source of inaccuracy in results among observers and studies (Haslam *et al.* 2007, Kyvsgaard *et al.* 2013). Flocks showing a high or low prevalence of footpad dermatitis appear to reflect enhanced scoring accuracy, compared with flocks with intermediate symptoms (de Jong *et al.* 2012c). Furthermore, objectivity can, to a great extent, be improved using a precise description of the system, and education of inspectors (Ekstrand *et al.* 1998, Haslam *et al.* 2007, Butterworth *et al.* 2016). The accuracy of evaluation, particularly differentiating mild and severe lesions, could be enhanced with confirmatory post-mortem incision of footpads to assess lesion depth (Lund *et al.* 2017). In addition, the reliability of scoring can be further improved with histology (Michel *et al.* 2012). Within a flock, footpad health of individual birds varies depending on the local litter condition (de Jong *et al.* 2012c). Therefore, when footpad lesion scoring describes the situation at flock level, the evaluated birds should accurately represent varying litter areas. This being ensured, a reduced number of birds needs to be assessed (de Jong *et al.* 2012c).

Most commonly, visual inspection of lesions is employed in laboratory settings (Meluzzi *et al.* 2008a, Bilgili *et al.* 2009, de Jong *et al.* 2014), in commercial situations (Ekstrand *et al.* 1998, Butterworth *et al.* 2016), and as an instrument of inspection (Government Decree 375/2011). The assessment of footpad and hock lesions is adopted in the Welfare Quality® Assessment (WQ) protocol for poultry, applied to broilers as one of the animal-based indicators determining the absence of injuries (Welfare Quality® 2009). In Finland, the Government Decree (375/2011) on the protection of broiler chickens prescribes footpad lesion scoring as one of the welfare indicators. This monitoring system is based on the 3-point scoring method described by Ekstrand *et al.* (1998), which is currently employed in Sweden and a number of other European countries (Meluzzi *et al.* 2008b, de Jong *et al.* 2012b, Kyvsgaard *et al.* 2013, Kittelsen *et al.* 2017). The Finnish Decree (375/2011) regulates the evaluation of footpad lesions for each slaughter batch, and in the case of repeatedly poor scores, the authorities may further restrict the maximum stocking density of the house.

In the future, with modern technology, automated tools for lesion scoring can provide a more accurate and objective approach to monitoring contact dermatitis. An automated scoring system utilizing camera recording and computerized assessment has been developed. Despite some weaknesses, such as identifying incorrect footpad areas or totally failing to assess footpads, at flock level the system delivers reasonably comparable results with visual scoring (Vanderhasselt *et al.* 2013). Also the suitability of a dielectric constant, technology that measures alterations in skin water content, has been explored to determine footpad lesion severity, with a promising outcome (Hoffmann *et al.* 2013). Currently, commercial tools for evaluating footpad dermatitis are available, enabling inspection of all individuals in a flock at the slaughter line (Meyn 2013).

Evaluating litter condition
Welfare indicators measured at slaughter, such as contact dermatitis and plumage cleanliness, furnish valuable information on the flock status and housing conditions. However, these retrospectively collected data only enable improvement of the welfare in the future and cannot benefit the birds from which they were measured (Manning *et al.* 2007). Litter friability, on the other hand, accurately reflects footpad health and widely the contributing factors for litter condition (Ekstrand *et al.* 1998, Haslam *et al.* 2006, Shepherd and Fairchild 2010; Figure 1). Therefore, continuous monitoring of litter condition, together with prompt corrective procedures, through the rearing phase, may be employed to assess an on-going situation and prevent contact dermatitis. The evaluation of litter condition is included in the broiler WQ-protocol as one of the resource- and management-based measures (Welfare Quality® 2009).

2.2 Broiler leg health

As a consequence of selection for fast growth, the modern broiler has become prone to several health problems (Julian 1998, SCAHAW 2000, de Jong *et al.* 2012a), such as deterioration in walking ability and leg health (Paxton *et al.* 2013, de Jong *et al.* 2012a). In addition to economic losses (Butterworth 1999, Cook 2000, Bradshaw *et al.* 2002, Butterworth and Haslam 2009), poor leg health raises concerns of compromised broiler welfare (Julian 1998, SCAHAW 2000, Bradshaw *et al.* 2002, Butterworth and Haslam 2009). Fast growth rate has been connected with abnormal gait (Kestin *et al*. 1999, Nääs *et al.* 2009) and a variety of leg pathologies, like tibial dyschondroplasia (TD), angular bone deformity, kinky back, and femoral head necrosis (Julian 1998, Butterworth and Haslam 2009). Leg disorders can be divided into developmental, metabolic and infectious diseases of the musculoskeletal system (Butterworth and Haslam 2009), and also spine, nerves and skin can be involved (Thorp 2008, Butterworth and Haslam 2009).

2.2.1 Gait and walking ability

A walking broiler tends to sway laterally with each step and pause between steps, while a laying hen moves in more of a straight line with continuous steps (Reiter and Bessei 1997). Laying hens also walk faster, taking narrower steps than broilers (Duggan *et al.* 2016). Compared with broilers with restricted growth, fast-growing broilers take shorter steps, walk more slowly (Corr *et al.* 2003b), and they rarely walk a straight line (Paxton *et al.* 2013). With age, a broiler's walking speed slows and step length shortens even more (Duggan *et al.* 2016).

The most prominent clinical sign of leg problems is lameness, which can begin from minor changes in gait and end in total inability to walk (Bradshaw *et al.* 2002, Thorp 2008). A number of studies have shown that only a minority of broilers near slaughter age display normal gait, whereas most of the birds face difficulties in walking (Kestin *et al.* 1992, Sanotra *et al.* 2001b, Knowles *et al.* 2008).

Not only pathological conditions, but also physiological and anatomical qualities, may influence the way broilers walk. Presumably, the mass and shape of breast muscles affect a broiler's gait (Skinner-Noble and Teeter 2009, Paxton *et al.* 2013): a broiler has to adapt its gait to meet challenges of heavy weight, and large girth and breast muscles (Caplen *et al.* 2012). Enlarged pectoral muscles (Corr *et al.* 2003a) force a fast-growing broiler to keep its legs in an abnormal outward position to maintain balance better, and for the same reason, the broiler's centre of gravity is more anteriorly inclined (Corr *et al.* 2003b, Paxton *et al.* 2013, Duggan *et al.* 2016) as compared with that of a laying hen. The altered centre of gravity causes the broiler's uneven waddling gait (Reiter and Bessei 1997, Nääs *et al.* 2010) and leads to prolonged phases of support from both legs being on the ground (Corr *et al.* 2003b, Caplen *et al.* 2012, Duggan *et al.* 2016).

2.2.1.1 Factors influencing broiler walking ability

Leg disorders

Leg disorders affect the way broilers walk. The length of pauses and steps, extent of lateral swinging, and evenness of steps differ between sound and lame birds (Reiter and Bessei 1997). Lameness also decreases the time broilers spend walking (Dawkins *et al.* 2009, Weeks *et al.* 2000, Sørensen *et al.* 2000), slows down the walking speed (Mc Geown *et al.* 1999, Nääs *et al.* 2009, Nääs *et al.* 2010) and reduces the number of steps (Dawkins *et al.* 2009). Yet, the association between leg pathologies and gait difficulties is not straightforward (Sandilands *et al.* 2011, Fernandes *et al.* 2012, Paxton *et al.* 2013). A recent study concluded that birds exhibiting moderate gait abnormality form an uneven group facing different degrees of pain, probably depending on underlying pathological conditions (Caplen *et al.* 2014). Valgus deformity appears to be most frequently associated with deteriorated gait (Sanotra *et al.* 2001b, Fernandes *et al.* 2012). Also, the other more severe, and thus probably more painful, pathologies, such as femoral head necrosis, bacterial arthritis, kinky back (McNamee *et al.* 1998) and tendon ruptures (Julian 1998) have been connected with walking difficulties.

Pain

The birds showing impaired gait have been stated to suffer pain because after receiving pain medication they walk faster with improved gait (Mc Geown *et al.* 1999, Nääs *et al.* 2010). Birds with walking difficulties also tend to choose feed with pain medicine (Danbury *et al.* 2000). Pain medication (Caplen *et al.* 2013) and broiler mobility experiments (Caplen *et al.* 2014) have also confirmed that, in addition to body conformation, other factors, such as pain, are involved in broiler lameness. Inflammatory leg pathologies are considered most likely to inflict pain, but the relationship between other causes of lameness and pain requires further investigation (Gentle 2011). Antibiotic medication may positively influence broiler walking ability (Knowles *et al.* 2008), most probably due to a decrease in infectious leg pathologies (Bradshaw *et al.* 2002, Butterworth and Haslam 2009).

Age and size of birds

Walking ability deteriorates as broilers age (Vestergaard and Sanotra 1999, Sørensen *et al.* 2000, Kestin *et al*. 2001, Brickett *et al.* 2007, Bassler *et al.* 2013), higher body weight is correlated with impaired gait (Kestin *et al.* 1992, Kestin *et al*. 2001, Sanotra *et al*. 2001a, Venäläinen *et al*. 2006, Nääs *et al.* 2010), and males tend to walk worse than females (Sørensen *et al.* 2000, Venäläinen *et al.* 2006, Brickett *et al.* 2007). Still, as with contact dermatitis, because age and weight, and often also weight and sex, are confounded, it is difficult to attribute effects separately.

Genetics

Genotype greatly affects a broiler's gait (Kestin *et al.* 1992, Kestin *et al.* 1999, Knowles *et al.* 2008). Some aspects of leg health, such as long bone deformities, TD and crooked toes, have been addressed in broiler breeding programmes for over two decades with a positive outcome. Weight gain and leg health traits are not necessarily always negatively correlated, and thus genetic selection to improve leg health seems possible without losses in weight gain. However, because components of gait abnormalities are a consequence of large breast muscles, such walking difficulties will inevitably become more common, simultaneously with continuous genetic progress in muscle yield and growth. Production traits (growth rate, muscle yield, feed efficacy) seem to be more strongly heritable than leg health traits (Kapell *et al.* 2012b, Rekaya *et al.* 2013), thus leading to faster progress in production traits and slower development in leg health. Indeed, Kestin *et al.* (1999) calculated around twenty years ago that, without greater emphasis on leg health in breeding programmes, broiler walking ability could not be expected to improve but would only remain constant or rather continue to deteriorate.

Growth rate

Walking ability differs among broiler breeds, with slow-growing breeds typically demonstrating a better gait than fast-growing birds (Kestin *et al*. 1999, Nielsen *et al.*

2003, Sanotra *et al*. 2003, Fanatico *et al.* 2008, Nääs *et al.* 2009, Stojcic and Bessei 2009). This can be explained by higher breast muscle yield in fast-growing broilers and, in contrast, higher wing and leg muscle yields in slow-growing breeds (Fanatico *et al.* 2008). The fast growth rate of broilers impacts bone mineralization, leading to a less mineralized and more porous bone structure in fast-growing birds (Williams *et al.* 2000, Williams *et al.* 2004). However, bone mineral content seems to have a minor influence on broiler walking ability (Bizeray *et al.* 2002c, Venäläinen *et al.* 2006, Talaty *et al.* 2010).

A case report concluded that fast-growing broilers cannot bear rapid growth rate to extensively greater age and heavier weight (over 80 days and 4 kg) than is commonly the case (42 days and 2.2 kg) without facing severe gait difficulties (Butterworth *et al.* 2002). In other words, long-term effects of modifications in leg posture due to large breast muscles and heavy weight bearing at a young age can result in devastating consequences for leg health later in a broiler's life.

Also other negative consequences of fast growth, such as heart-related conditions and metabolic disorders, are likely to increase walking difficulties (Paxton *et al.* 2013). At least these fast-growth-associated problems may provoke immobility, reluctance to move and taking only few required steps, thus ultimately leading to unfavourable results in gait analysis.

Measures lowering growth rate are frequently associated with enhanced walking ability. Gait difficulties can be reduced by feed restriction (Lynch *et al.* 1992), meal feeding (Su *et al.* 1999), low-nutrient diet (Fanatico *et al.* 2008), or a whole-wheat diet (Knowles *et al.* 2008). The same outcome was recorded with feed containing poor quality pellets, leading to mash feeding instead of effective pellet feeding (Brickett *et al.* 2007, Knowles *et al.* 2008). Also, swapping diets during the day may improve walking ability, probably due to decreased weight gain accompanied by increased activity (Bizeray *et al.* 2002d).

Exercise

Lack of exercise increases the incidence of leg disorders (Haye and Simons 1978, Simmons 1982, Wilson *et al.* 1984, Kestin *et al.* 1992). Consequently, walking ability can be improved by encouraging broiler mobility. Increasing walking distances (Reiter and Bessei 2009, Ruiz-Feria *et al.* 2014), lowering stocking density (Knowles *et al.* 2008, Aydin *et al.* 2010), and offering broilers attractive possibilities for locomotion (Bizeray *et al.* 2002b, Groves and Muir 2013), including outside access (Fanatico *et al.* 2008), are possible means to ameliorate broiler leg health. Nevertheless, it should be noted that if a broiler suffers from painful leg pathology any locomotion might ultimately increase pain and lead to diminished welfare.

Housing conditions

Bird management and housing conditions impact broiler walking. Air quality and temperature directly affect leg health. Poor control of broiler house temperature has been associated with impaired walking ability (Jones *et al.* 2005), while wet litter (Su *et al.* 2000, Dawkins *et al.* 2004) and higher ammonia levels have been linked to valgus deformity (Jones *et al.* 2005, Dawkins *et al.* 2004). Moreover, wet litter induced footpad dermatitis (Martland 1984, Greene *et al.* 1985, da Costa *et al.* 2014, de Jong *et al.* 2014) and hock burns are associated with lameness (Kestin *et al.* 1999, Su *et al.* 1999, Sørensen *et al.* 1999, Sørensen *et al.* 2000, Kristensen *et al.* 2006, Haslam *et al.* 2007).

Lighting

Providing natural light for broilers positively affects walking ability (Bailie *et al.* 2013). Lengthening the dark period improves gait (Sanotra *et al.* 2002, Brickett *et al.* 2007, Knowles *et al.* 2008, Bassler *et al.* 2013), possibly by allowing longer resting period and provoking activity during the daytime. Blatchford *et al.* (2012) noted a slightly better walking ability in birds kept in bright daylight. However, in most studies, higher light intensity has not directly improved broiler gait (Kristensen *et al.* 2006, Blatchford *et al.* 2009, Deep *et al.* 2010, Sherlock *et al.* 2010, Deep *et al.* 2013). Nevertheless, it has been suggested that brighter light may motivate activity (Charles *et al.* 1992, Alvino et al. 2009, Blatchford *et al.* 2009, Blatchford *et al.* 2012) that, in turn, could result in altered body appearances (Deep *et al.* 2010), and reduced carcass fat, together with greater protein quantities (Charles *et al.* 1992).

Stocking density

High stocking densities increase lameness (Sørensen *et al.* 2000, Hall 2001, Sanotra *et al.* 2001a, Sanotra *et al.* 2001b, Dawkins *et al.* 2004, Knowles *et al.* 2008), which could be caused by reduced overall activity (Sørensen *et al.* 2000, Knowles *et al.* 2008, Simitzis *et al.* 2012, Ventura *et al.* 2012). Field studies have shown that unfavourable effects of high stocking densities on welfare can, to a certain degree, be overcome by suitable and careful control of housing conditions (Dawkins *et al.* 2004, Jones *et al.* 2005). However, different welfare indicators seem to display varying risky densities, implying a complex relationship between welfare and stocking density. A study testing effects of different stocking densities on a number of welfare indicators, demonstrated deteriorated leg health at lower densities than expected, even from 6 kg/m² on (Bujis *et al.* 2009).

2.2.1.2 Measuring walking ability

Gait scoring is the most commonly employed method to assess broiler walking ability at flock level. In addition, there are several other methods, both subjective and objective, used to evaluate walking ability and leg health. Basically, methods involving human assessment or scoring are considered subjective, whereas the objective approach is typically based on precisely defined findings, computerized analysis, or quantifiable measurement, including timing or number of steps taken.

Gait scoring

Kestin *et al.* (1992) first introduced a gait scoring method in 1992 to evaluate broiler walking ability. Originally gait scoring was performed with a 6-point scale, categorizing gait from normal to incapable of walking. Typically, in commercial situations, gait scoring results in low numbers of the lowest scores, 0-1, and approximately 15-30% of the assessed birds are scored ≥ 3, depending on age and breed of the birds (Kestin *et al.* 1992, Sanotra *et al.* 2001a, Knowles *et al.* 2008, Bassler *et al.* 2013, Kittelsen *et al.* 2017). Generally, the birds scored 4 and 5 most likely suffer from serious leg pathologies (Kestin *et al.* 1992, Aydin *et al*. 2010), and are usually culled (Kestin *et al.* 1992, Bradshaw *et al.* 2002, Knowles *et al.* 2008).

In this scoring system, the difference between scores 2 and 3 is partly based on the birds' manoeuvrability; birds scored 2 do not face difficulties in moving around, while movement is compromised in birds with a score of 3 (Kestin *et al.* 1992, Welfare Quality® 2009). This definition has led to the suggestion that the threshold between acceptable gait abnormality and walking difficulties indicating reduced welfare lies between scores 2 and 3 (Kestin *et al.* 1992). Broilers scored 3 rest more than birds scored 2 (Skinner-Noble and Teeter 2009). Furthermore, pain medication improved the walking ability of birds scored 3 (Mc Geown *et al.* 1999, Danbury *et al*. 2000). All of these findings support the previous conclusion that gait abnormalities ≥ 3 reduce broiler welfare. However, an investigation measuring the activity of broilers with different gait scores demonstrated no differences in activity between scores 0 to 2, whereas birds with score 3 were heavier and most active, probably due to feeding-related activity, and birds scored 4 and 5 were lighter and most immobile. The authors concluded that the deterioration of walking ability from 0 to 3 was due to increased body weight but scores 4 and 5 represented clinically lame birds (Aydin *et al*. 2010). Another study claimed that the difference between gait scores 2 and 3 was attributable to physical challenges due to enlarged breast muscles. Further, the paper suggested that birds with scores 2 and 3, despite increased resting time of birds with score 3, faced the same level of welfare, because no evidence was found of higher stress levels in birds scored 3 compared with those scored 2 (Skinner-Noble and Teeter 2009).

Gait scoring is a subjective measurement of walking ability showing varying within- and between-observer consistency (Kestin *et al.* 1992, Garner *et al.* 2002, Butterworth *et al.* 2007). The original assessment system has been improved in objectivity with added principles for each score and a more accurately described scoring protocol. The modified method achieves improved within- and between-observer reliability (Garner *et al.* 2002). Furthermore, with adequate training and experience, gait scoring reaches reasonably good within-observer consistency to reflect the situation at flock level (Garner *et al.* 2002, Butterworth *et al.* 2007, Webster *et al.* 2008). Thus using only one assessor could improve the reliability of the method within a study. Even though between-observer accuracy can also be enhanced with education, the subjectivity of the method cannot totally be eliminated (Butterworth *et al.* 2007). Therefore, comparing results among different studies may still be imprecise.

In addition to subjectivity, gait scoring is characterized by some other weaknesses. First, it appears to poorly correlate with leg pathologies (Sandilands *et al.* 2011, Fernandes *et al.* 2012, Paxton *et al.* 2013). Serious leg disorders tend to better correlate with higher scores (Sandilands *et al.* 2011), but lower scores (1-3) often fail to relate to pathological conditions. On the other hand, even birds with gait score 0 and 1 can have dyschondroplastic lesions (McNamee *et al.* 1998) or varus/valgus deformity (Sandilands *et al.* 2011). Secondly, there are implications that gait scoring provides inconsistent results depending on whether the birds are encouraged to move or if they are allowed to walk freely; impaired walking ability is more likely judged for freely moving birds (Cordeiro *et al.* 2009).

A simpler scoring system, based on a 3-point scale (0 = normal gait, 1 = obvious and 2 = severe gait abnormality), has been developed. Despite obvious differences between methods, both systems seem to present the same outcome on walking ability at flock level in commercial circumstances, but with enhanced between-observer agreement for the 3-point scale method (Webster *et al.* 2008). Gait scores for the 3-point scale have been accurately associated with optical flow patterns, an objective method for assessing broiler locomotion behaviour, suggesting an objective background for gait scoring (Dawkins *et al.* 2009). Furthermore, the use of a 2-point scale ("no impairment" and "severe impairment"), was explored to establish the leg health status of broiler flocks (Kumari *et al.* 2015). Even with the obvious simplicity of this method, the definition leaves a gap between "no" and "severe", easily leading to inaccuracies in evaluation.

Transect walks

A fairly simple method, transect walks throughout the broiler house while observing lame and immobile birds, was tested to evaluate leg health at flock level. The principle for this method is the same as that which broiler farmers employ as an everyday tool in observing the condition of a flock and which veterinarians use when estimating the health status of the flock. Even though the method is faster than individual gait scoring (Marchewka *et al.* 2013) and does not involve stressful handling of the birds, possibly affecting the results (Cordeiro *et al.* 2009), it remains subjective and does not produce as detailed information on walking ability as the original gait assessment (Marchewka *et al.* 2013). Furthermore, immobility could be caused by conditions other than leg problems, thus misrepresenting leg health status, and failing to recognise less obvious gait abnormalities as accurately and efficiently as is possible during gait scoring.

Leg culls

Some studies have assessed leg health by calculating the number of birds culled due to leg problems (Hall 2001, Dawkins *et al.* 2004, Bailie and O'Connell 2015). However, because not all leg pathologies lead to culling, milder forms of lameness are excluded (Hall 2001). Furthermore, a large field study found no correlation between mean gait scores and the number of culled birds with leg problems (Knowles *et al.* 2008). Without proper diagnosis, this number does not accurately inform the leg health status of the flock because other diseases can also cause immobility or unwillingness to walk.

Latency-to-lie

An objective latency-to-lie test measures time that a broiler is willing or able to stand in shallow water before lying down. This test is based on a broiler's dislike of sitting in water: birds with healthy legs continue to stand for longer, but birds with leg problems sit sooner and the more severe the disorder the more rapidly the bird sits (Weeks *et al.* 2002). Further modification has provided a less time-consuming latency-to-lie test to measure individual birds in farm conditions (Berg and Sanotra 2003). Gait scores and the results of latency-to-lie tests seem to correlate positively (Weeks *et al.* 2001, Weeks *et al.* 2002**,** Berg and Sanotra 2003).

Group Obstacle test
A recently developed objective "Group Obstacle test" evaluates broiler walking ability by determining the number of crossings over of an obstacle between feeder and drinker. The results of this test correlated positively with gait scores (Caplen *et al.* 2014).

Pathology
Post-mortem investigation of dead or culled birds reveals underlying pathological conditions for impaired gait, particularly, when accompanied by histology and microbiological examination (Thorp 1994, McNamee *et al.* 1998, Thorp 2008). Unfortunately, pathology does not automatically expose fast-growth or body-conformation-related gait abnormalities (Paxton *et al.* 2013). This shortcoming, however, can be diminished with clinical evaluation before post-mortem examination (McNamee *et al.* 1998, Butterworth and Haslam 2009). Pathological examination remains too inefficient, one-sided and expensive in assessing walking ability for it to be used in practice.

Behavioural observations
Behavioural observations based on video recording have been used for decades in behaviour and gait analyses for individual birds and small groups in experimental settings (Reiter and Bessei 1992, Weeks *et al.* 2000, Sinclair *et al.* 2015). In recent years, modern technology has been successfully applied to investigate broiler walking ability. Kinematic gait analysis with video recording and computer technology has been employed to determine the detailed gait description of individual broilers (Caplen *et al.* 2012). An image monitoring system, based on digital video camera and computer technology, was used to explore the relationship between broiler activity levels and gait scores (Aydin *et al.* 2010). Furthermore, video-recording technology, optical flow patterns of a broiler flock, offers an objective assessment method to investigate walking ability and behaviour at flock level (Dawkins *et al.* 2009). Modern poultry houses are often equipped with video cameras for surveillance purposes, and this technology could be modified for optical flow analysis to assess broiler lameness and welfare on farms (Dawkins 2012). Camera technology, eYeNamic™, is one example of a commercialized solution to monitor broiler movement and activity in broiler houses (Fancom 2012).

Force plate technology
Force plate technology represents another objective approach for estimating broiler gait. A bird is lured to walk across a surface that records footprints and allows

several measures to be calculated, such as weight, walking speed, number of steps and step length, width and angle (Nääs *et al.* 2010, Sandilands *et al.* 2011, Corr *et al.* 2003b). The results of a force plate study and gait scoring showed good correlation (Sandilands *et al.* 2011), but the method is expensive, time consuming and enables only single bird testing.

There is no single best method to test broiler walking ability and leg health at flock level, but combining several tests would be optimal. Nevertheless, over the years, gait scoring has become a well-accepted approach to assess broiler walking ability. The method was included in the WQ-protocol for poultry as one of the animal-based indicators to measure freedom from injuries (Welfare Quality® 2009). Despite subjectivity, gait scoring has benefits: it is easily useable in commercial farms for large flocks (Kestin *et al.* 1992, Butterworth and Haslam 2009) and does not rely only on pathological leg disorders, but covers all causes of altered gait (Kestin *et al.* 1992).

2.2.2 Tibial dyschondroplasia

In fast-growing broilers, TD is one of the most common pathological conditions (Thorp and Waddington 1997, McNamee *et al.* 1998, Sanotra *et al.* 2003, Dinev 2012). The condition appears also in turkeys (Poulos 1978, Walser *et al.* 1982) and ducks (Wise and Nott 1975). However, attempts to induce TD lesions in laying hens have failed (Reiland *et al.* 1978, Edwards 1984), indicating that the pathology is distinctly connected with meat poultry.

Aetiopathogenesis
In a TD lesion, the maturation of chondrocytes, and the growth of the tibia in the growth plate are disturbed, leading to abnormally large cartilaginous mass accumulating in the metaphysis of the tibia (Leach and Nesheim 1965, Riddel 1975b, Orth and Cook 1994). It has been suggested that varying mechanisms may lead to similar dyschondroplastic lesions (Thorp *et al.* 1991, Farquharson and Jefferies 2000). Even though knowledge of the exact course of the pathogenesis of TD is still lacking (Farquharson and Jefferies 2000), it has been generally accepted that the lesions are caused by unsuccessful chondrocyte differentiation in the growth plate (Thorp *et al.* 1993, Farquharson and Jefferies 2000, Pines *et al.* 2005).

Dyschondroplastic lesions are described as being whitish, opaque cartilage, typically of varying sizes and shapes (Leach and Nesheim 1965), replacing a normal thin (approximately 1 mm) growth plate (Thorp *et al.* 1997). Most commonly, TD lesions appear in the proximal growth plate of the tibia, probably due to the fastest growth rate at this location (Riddell 1975a). Macroscopically, a TD lesion resembles the lesion of rickets caused by vitamin D or calcium deficiency, but microscopically these conditions differ from each other (Leach and Nesheim 1965). In TD lesions, the accumulation of prehypertrophic chondrocytes lacking vascularization are evident (Thorp *et al.* 1993, Farquharson and Jefferies 2000), whereas hypocalcaemic rickets exhibits proliferating chondrocytes (Lacey and Huffer 1982, Farquharson and Jefferies 2000) with increased vascular appearance (Lacey and Huffer 1982, Long *et al.* 1984).

An experiment comparing bone development and growth plate lesions between broilers and laying hens detected histological differences in growth plates already at one week of age (Reiland *et al.* 1978). The first signs of TD lesions may show as early as 2 weeks of age (Leach and Nesheim 1965, Riddell 1975b, Lynch *et al.* 1992), and continue developing until 8 weeks of age according to an early study (Riddell 1975b). However, later research concluded that TD lesions develop from 2 to 5 weeks of age and the lesions detected beyond this age should be considered previously developed lesions (Lynch *et al.* 1992). TD lesions may heal and disappear or, in some cases, the abnormal cartilage could be disconnected from the original growth plate as the birds reach 12-14 weeks of age (Riddell 1975b). The healing process, or alternatively the appearance of small loose bone sections, takes too long to be significant for broilers in conventional intensive production.

2.2.2.1 Diagnosing TD

The condition of the tibia growth plate is most commonly determined post-mortem by scoring the extent of abnormal cartilage formation (Timms *et al.* 1986, Thorp *et al.* 1997, Pines *et al.* 2005). A longitudinal ventral cut on the ends of the tibia reveals the growth plate for detailed observation (Riddell 1975a, Timms *et al.* 1986). However, because the growth plate may occasionally be abnormally thickened without the typical cellular changes of TD (Thorp *et al.* 1991), visual gross pathology alone may result in inaccurate diagnosis. The reliability of diagnosis can be improved by combining macroscopical and histological examination (Thorp *et al.* 1991, Rennie *et al.* 1993), particularly in young birds (Thorp *et al.* 1991).

Radiology offers a possibility to investigate the status of the growth plate in live animals (Riddell 1975a, Riddell 1976). Lixiscope, a transportable X-ray fluoroscope, has been used in broiler breeding when selecting breeders with low susceptibility to TD (Bartels *et al.* 1989, Thorp *et al.* 1997). Unfortunately, the accuracy of TD diagnosis with Lixiscope, compared with gross pathology and histology, has been poor, especially in detecting mild lesions (Thorp *et al.* 1997). Lixiscope has failed to diagnose TD lesions in 30% to 40% of cases (Thorp *et al.* 1997, Almeida *et al.* 2005).

2.2.2.2 Factors affecting the occurrence of TD

Genetics

Early studies on TD revealed the genetic background of the condition (Leach and Nesheim 1965, Riddell 1976, Sheridan *et al.* 1978, Wong-Walle *et al.* 1993). Genetic selection for over two decades against TD included in breeding programmes has reduced the incidence of TD (Kapell *et al.* 2012b). TD heritability may be linked with faster growth rate (Sheridan *et al.* 1978).

Fast-growing broiler breeds are more prone to TD (Fanatico *et al.* 2008, Shim *et al.* 2012a), but also faster growth rate, as such, increases the incidence of TD (Riddell 1975a, Lynch *et al.* 1992, Shim *et al.* 2012a). Possibly due to faster growth, male broilers seem more prone to TD lesions (Leach and Nesheim 1965, Edwards 1984). However, at individual level, fast growth is not necessarily associated with TD, suggesting that fast growth alone is not enough to cause the pathological condition (Riddell 1975a). TD incidence can be reduced with a restricted diet (Huff 1980, Lynch *et al.* 1992, Su *et al.* 1999), and lowering the growth rate with dietary alterations is one of the most efficient ways to prevent TD (Huff 1980).

Nutrition

Nutritional deficiencies or imbalances can induce TD (Edwards and Veltman 1983, Riddell 1976). High calcium and low phosphorus contents, and particularly, a high Ca-P ratio in the diet can lower the incidence of TD (Edwards 1984, Riddell and Pass 1987), whereas a high chloride level tends to increase the incidence (Riddell 1975b, Riddell 1976, Edwards 1984). TD appears to be more likely caused by excessive dietary P than the insufficient Ca (Riddell and Pass 1987). By four weeks of age TD incidence can be reduced by correcting the Ca- and P-content of the diet (Edwards 1985).

Vitamin D and its metabolites, such as 1,25$(OH)_2$cholecalciferol, play an important role in the metabolism of Ca and P. Research has provided evidence of the reduced numbers and affinity of vitamin-D-receptors in growth plates with TD lesions (Berry *et al.* 1996). Although TD is not a consequence of dietary deficiency of 1,25$(OH)_2$cholecalciferol, the negative effect of an imbalanced nutritional Ca-P ratio on TD occurrence can be diminished, even prevented, with high enough levels of additional cholecalciferol in the diet (Rennie *et al.* 1993, Thorp *et al.* 1993).

Feed containing trichothecenes mycotoxin has been confirmed as causing TD in broilers (Lee *et al.* 1985, Wu *et al.* 1993). Ascorbic acid, vitamin C, may have a role in collagen synthesis in growth plates and vitamin D metabolism, thus assist in preventing TD lesion formation (Farquharson and Jefferies 2000).

Bone quality

Bone ash and mineral content may reflect bone strength (Williams *et al.* 2000, Shim *el al.* 2012b) and be associated with bone pathologies (Thorp and Waddington 1997). Although lower bone ash contents have been measured in birds with TD compared with healthy birds (Tablante *et al.* 2003), the relationship between bone ash and TD severity is largely inconsistent among different studies. Birds affected by TD have been shown to exhibit well-calcified bones while birds with no TD lesions on a low-P diet have poorly calcified bones and low bone ash values (Edwards and Veltman 1983).

Nutritional Ca-deficiency, leading to rickets at young age, may underlie dyschondroplastic lesions (Long *et al.* 1984, Thorp *et al.* 1997). Also Riddell and

Pass (1987) reported an even, or slightly U-shaped, thickening of the growth plate prior to typical TD lesions.

Housing conditions

Higher stocking density was reported to be associated with higher TD incidence (Sanotra *et al.* 2001a, Sanotra *et al.* 2001b, Sanotra *et al.* 2002), though, not in all studies (Tablante *et al.* 2003, Sørensen *et al.* 2000). Longer daylight period was positively associated with the incidence of TD (Sørensen *et al.* 1999). One paper reported a lower presence and severity of TD in broilers provided with hanging mobiles compared with birds without (Balog *et al.* 1997). There is no proof that increased exercise, stimulated by added perches or barriers to broilers' environment, improves bone mineralization (Tablante *et al*. 2003, Bizeray *et al.* 2002b), or reduces TD incidence in broilers (Tablante *et al*. 2003).

2.2.2.3 Consequences of TD

The relationship between TD and lameness appears contradictory: some studies demonstrate an association between impaired gait and TD (Sørensen *et al.* 1999, Vestergaard and Sanotra 1999, Sanotra *et al.* 2002) while others show no correlation (Garner *et al.* 2002, Lynch *et al.* 1992, Venäläinen *et al.* 2006). Severe TD lesions seem to cause lameness, but the effect is less evident in milder forms of TD (Riddell 1975b, Riddell 1976, Lynch *et al.* 1992, McNamee *et al.* 1998).

The existence of TD lesions restricts the normal longitudinal growth of the tibia (Thorp 1988). TD may also be linked to some other leg disorders. In an early study, broilers with severe TD lesions exhibited lateral bending of knee and tibiotarsus with progressive lameness. Additionally, osteomyelitis and bacterial arthritis were diagnosed in some of the birds (Riddell 1975b). Dyschondroplastic lesions were also connected with osteomyelitis in male turkey breeders (Wyers *et al.* 1990). In broilers, TD was reported to be associated with the abnormal bowing of tibia (Timms *et al.* 1986, Lynch *et al.* 1992), more severe TD lesions correlating with greater bone deformity together with increasing lameness (Lynch *et al.* 1992).

2.3 Broiler behaviour

The possibility to perform natural behaviours has been recognised as an essential part of animal welfare (Webster 2001, Appleby *et al.* 2004, OIE 2016). In modern intensive broiler production birds are kept in a very barren environment that offers minimal stimulation. Maintaining large flocks in high densities and a barren environment with easy access to feed and water does not inspire broilers to be active and perform a wide variety of natural behaviours (Newberry 1999). This lack of environmental complexity has been identified as a concern for animal welfare in broiler production in the report on the welfare of broilers by the European Commission (SCAHAW 2000).

2.3.1 Litter-directed behaviour

Chickens display natural litter-directed behaviours already at young age, and thus this behaviour is probably relevant also during a broiler's life. Bedding material and condition affects the litter-related behaviours of poultry. Friable litter allows birds to express natural behaviours, like foraging, scratching (Hall 2001) and dustbathing more easily (Bokkers and Koene 2003, Appleby *et al.* 2004). Moist litter seems to restrict the behavioural variety of turkeys (Sinclair *et al.* 2015) and damp litter also reduces the dustbathing frequency of broilers (Moesta *et al.* 2008). Access to sand has been associated with increased locomotion, scratching and foraging behaviours (Arnould *et al.* 2004). Additional access to bedding material that differs from everyday material has stimulated explorative behaviour and scratching by broilers (Newberry 1999). Furthermore, broilers present more variable behavioural patterns on sand bedding when able to choose between sand and wood shavings (Shields *et al.* 2005), or sand, wood shavings, rice hulls and paper rolls (Toghyani *et al.* 2010). However, without the offered choice, no differences among litter materials were recorded (Shields *et al.* 2005).

Feeding behaviour

Chicken feeding behaviour includes two phases: foraging, i.e. searching for food by scratching and pecking at litter, and a consumatory phase of feeding behaviour that includes eating (Duncan 1998, Appleby *et al.* 2004). Basically, the broiler house environment enables both behaviours, but easily reachable *ad libitum* feeding reduces the need to forage. Despite easy access to feed, foraging remains important for laying hens, and they try to express the behaviour even in thwarting access to suitable pecking material (Appleby *et al.* 2004). In broiler breeders, it has been shown that during the rearing phase, feeding with spin feeders that scatter feed on the litter encouraged more foraging behaviour compared with feeding in a trough (de Jong *et al.* 2005). However, fast-growing broilers rarely forage (Bizeray *et al.* 2000, Bokkers and Koene 2003, Svihus *et al.* 2013), although most of their active time is spent in eating and drinking behaviours (Weeks *et al.* 2000, Bokkers and Koene 2003). Even wheat seeds spread across the litter have failed to provoke more foraging (Bizeray *et al.* 2002a). For broilers, foraging bouts include most active behaviours and movements (Bizeray *et al.* 2002c). Aging considerably reduces broilers' feed searching behaviours and activity during foraging bouts (Bizeray *et al.* 2002c). Meal-fed broilers, compared with *ad libitum* fed birds, have been reported to display more foraging behaviour near feeding time (Svihus *et al.* 2013). Slow-growing broilers eat less (Bokkers and Koene 2003) and exhibit more food searching behaviour than fast-growers (Bizeray *et al.* 2000).

Dustbathing

Dustbathing, one part of a chicken's maintenance behaviour, is done to maintain feathers in good condition (Duncan 1998, Appleby *et al.* 2004). It consists of a particular cascade of movements (Vestergaard *et al.* 1990). Access to suitable material is required to complete an entire dustbathing episode (Duncan 1998, Appleby *et al.* 2004), but the absence of the substrate does not hinder the behaviour (Vestergaard *et al.* 1990). Adult chickens perform dustbathing approximately every other day (Vestergaard 1982).

In commercial conditions, broilers appear to perform dustbathing extremely seldom (Murphy and Preston 1988, Hall 2001). Nevertheless, broilers denied access to a dustbathing area have dustbathed more when offered an opportunity than birds with continuous dustbathing possibilities (Vestergaard and Sanotra 1999). Also, additional access to peat litter encourages broiler dustbathing (Newberry 1999) and sand is associated with more frequent dustbathing bouts compared with straw (Vestergaard and Sanotra 1999). It has been speculated that this behaviour could have been reduced simultaneously with the selection for fast growth and improved feed efficacy (Murphy and Preston 1988). However, impaired leg health also may lower the broiler's motivation to dustbathe as lameness and the presence of TD in broilers have been connected with reduced dustbathing frequency and fewer complete dustbaths, more profoundly at older age (Vestergaard and Sanotra 1999).

2.3.2 Resting and activity

To fulfil fundamental behaviours, sleeping and resting, a suitable resting place (Blokhuis 1983, Blokhuis, 1984) and appropriate diurnal light rhythm are required. Blokhuis (1984) described resting "as a prolonged period of inactivity that can clearly be distinguished from other maintenance behaviours". Night sleeping and short resting periods during the day typically occur as a synchronized behaviour for a group of birds to seek shelter and protection against predators (Appleby *et al.* 2004). The same reason may drive broilers to rest near wall or, if offered, close to additional equipment providing cover (Cornetto and Estévez 2001a). Adult chickens use perches for night roosting (Blokhuis 1984, Newberry *et al.* 2001, Appleby *et al.* 2004), and in the absence of perches, broiler breeders use the elevated slatted surface for the same purpose (Gebhardt-Henrich *et al.* 2016). In adult birds, short resting phases during daylight often occur on the floor, most commonly in a sitting position, but also while standing (Blokhuis 1984). However, broilers tend to rest while lying down, and for them comfortable resting demands dry and friable litter (Weeks *et al.* 2000).

Time-budgets

A number of studies have shown that broilers spend most of their time resting (Murphy and Preston 1988, Weeks *et al.* 2000, Cornetto and Estévez 2001a,b, Hall 2001, Bokkers and Koene 2003, Arnould and Faure 2004, Febrer *et al.* 2006, Svihus *et al.* 2013). Yet, determining precise resting times remains difficult due to varying definitions for resting behaviour. Broilers may perform several behaviours in a lying position, like pecking, preening and stretching (Weeks *et al.* 2000, Bokkers and Koene 2003, Febrer *et al.* 2006). Resting, in some studies, may cover all these behaviours, while other studies report them separately. Broiler resting bouts seem to endure for a short period of time that may, at least in high densities, be caused by other birds disrupting lying (Febrer *et al.* 2006). According to several studies performed in experimental settings, time spent lying down by fast-growing broilers ranges from about 60% to 90%. All these studies, however, agree that resting time increases with age (Weeks *et al.* 2000, Bokkers and Koene 2003, Arnould and Faure 2004, Cornetto and Estévez 2001a, Svihus *et al.* 2013). Broilers have been shown to most actively display locomotive behaviours around 4 weeks of age (Ventura *et al.* 2012, Pettit-Riley and Estévez 2001). Even when broilers are offered a possibility to move freely in low bird densities they seem to move voluntarily as little as necessary (Sherlock *et al.* 2010).

Studies observing broiler behaviour in commercial environments have discovered that on average the birds spent over 60% of their time lying down (Murphy and Preston 1988, Hall 2001). A field study found that at young age broilers exhibited more locomotion than access to feed and water would have required. This movement, however, was depressed with age, either owing to age or increased density (Preston and Murphy 1989). Instead of pure resting, broiler lying sessions were frequently interrupted by disturbances of other birds, or alternatively, restlessness could have been birds' attempts to cool themselves in hot weather (Murphy and Preston 1988). Increased resting times observed in the presence of vertical panels are most likely due to peaceful areas for undisturbed resting provided by supplementary environmental complexity (Cornetto and Estévez 2001a).

Breed

Slow-growing broilers have been shown to express more activity already at 2-3 days of age than fast-growing birds despite their heavier weight at that age. Later, at 20-21 days of age, slow-growing broilers still exhibited more activity compared with much heavier fast-growing broilers. Also, fast-growing chicks have shown less explorative behaviour during the first 2-3 days. These results possibly indicate a genetic effect on locomotor activity. If this proves to be an accurate assumption, genetic selection for chicks exhibiting more activity could positively affect broiler activity at older age, and thus also improve leg health (Bizeray *et al.* 2000). The behavioural repertoire of broilers seems to remain unaffected by growth rate, but time-budgets are greatly affected: fast-growing birds sit, eat and drink more, whereas slower growth has been associated with more perching, walking and scratching (Bokkers and Koene 2003). Even locally bred meat chicken breeds have varying behavioural time-budgets according to their growth rate. Heavier breeds feed and rest more, seem less active, and walk and perch less compared with lighter breeds (Lee and Chen 2007).

Resting and lameness

The reduced locomotion of fast-growing broilers is associated with the incidence of leg pathologies (Haye and Simons 1978, Simmons 1982, Wilson *et al.* 1984, Stojcic and Bessei 2009). Shorter distances walked by heavy broilers, compared with lighter birds, indicate differences in physical condition to move (Rutten *et al.* 2002, Bokkers *et al.* 2007). Decreasing weight load of heavy broilers enhances their mobility, and *vice versa,* increasing weight load of lighter birds increases resting (Stojcic and Bessei 2009). Broiler inactivity can, at least partly, be induced by the energy-consuming walking style that easily tires them (Corr *et al.* 2003b). On the other hand, walking ability modifies activity and behaviour: lame birds rest more, walk less, groom and explore less and eat more while lying compared with healthy birds. Lameness also reduces eating and drinking bouts, but without affecting eating time and consumed feed amount (Weeks *et al.* 2000).

Lighting

Light intensity (Alvino *et al.* 2009, Blatchford *et al.* 2009) and dark-light schedule affect broiler activity and behavioural repertoires (Sanotra *et al.* 2002). Blatchford *et al.* (2012) concluded that light intensity more strongly affected broiler activity than day length. Additionally, light source (wave length) modified behaviour (Kristensen *et al.* 2007). Continuous light seems to increase broiler inactivity and distinguishing day and night periods encourages birds to express a wider variety of natural behaviours, such as pecking and scratching litter during daytime (Sanotra *et al.* 2002). The development of a proper diurnal rhythm demands also a clear enough difference in light intensity between day and night. Broilers kept in dim daylight spent less time in active behaviours during daytime but exhibited more activity during night-time compared with birds reared in brighter daylight (Alvino *et al.* 2009, Blatchford *et al.* 2009). Thus, broilers in low daylight intensity are prone to intermittent resting bouts in the night (Alvino *et al.* 2009).

Stocking density

An investigation conducted in commercial conditions suggested that farmer's ability to maintain uniform housing conditions, namely temperature, humidity, light, feed and water, around the house greatly influences how evenly broilers use the offered space. At a younger age, and at lower stocking density (kg/m^2), broilers moved over a larger area than at older age, and thus higher density (Preston and Murphy 1989). At lower density, broilers demonstrated more standing and less lying than at higher densities (Martrenchar *et al.* 1997). Other studies indicated less walking at higher densities (Lewis and Hurnik 1990, Febrer *et al.* 2006, Buijs *et al.* 2010), but no effect on visits to feeders and drinkers (Lewis and Hurnik 1990). High density generally tends to inhibit broiler activity (Ventura *et al.* 2012). However, regardless of the density, fast-growing broilers seem to limit their physical movement, and more space offered at lower densities and free access to feed and water do not appear to stimulate more activity (Arnould and Faure 2004, Sherlock *et al.* 2010).

Preferred resting place
Broilers prefer to occupy the peripheral area near walls and avoid open spaces in the middle of the house (Cornetto and Estévez 2001a). Aggressive behaviour most commonly appears in open areas (Cornetto *et al.* 2002, Petit-Riley *et al.* 2002), whereas disturbances are most likely to occur at the periphery (Cornetto *et al.* 2002). In spite of density, broilers seem voluntarily to choose to lie down near flock mates (Febrer *et al.* 2006). However, different densities apparently influence the desired resting place of the birds because at lower densities broilers willingly lie down near feeders and drinkers but at higher densities birds more likely rest in free areas (Arnould and Faure 2004). Besides density, group size may affect desired resting locations; central areas appear more popular for small groups but larger group sizes drive broilers to occupy more peripheral areas (Buijs *et al.* 2010). However, this may be irrelevant in commercial situations with flocks of thousands. Furthermore, at high densities, rest seems to be frequently disturbed by other birds (Murphy and Preston 1988, Lewis and Hurnik, 1990, Martrenchar *et al.* 1997, Buijs *et al.* 2010). Thus at higher densities the reduced motivation to walk might partly be attributable to other birds obstructing free movement (Hall 2001).

2.3.3 Perching by broilers

Perches, defined as elevated structures that birds can grasp with their feet and use to survey their environment from (EFSA 2015), are important recourses for chicken (Olsson and Keeling 2000). Night roosting is part of the natural anti-predator behaviour in chickens (Newberry *et al.* 2001). The use of perches by layer pullets promoted their skeletal development (Yan *et al.* 2014) and might also develop their spatial skills (Gunnarsson *et al.* 2000). Furthermore, access to perches at young age, before 4 weeks, lowered the number of floor eggs and reduced the risk of cloacal cannibalism in laying hens (Gunnarsson *et al.* 1999). Offering broiler breeders a perching possibility during the rearing phase reduced the number of floor eggs (Brake 1987) and alleviated fearfulness (Brake *et al.* 1994).

Equipping broiler houses with perches is one way of adding variety to the environment. Providing greater environmental complexity, with a possibility to perch, has been suggested to encourage increased physical activity of birds, which potentially leads to better leg health and welfare (Bizeray *et al.* 2002a, Ventura *et al.* 2012, Ohara *et al.* 2015). Furthermore, a change in exercise patterns brought about by barrier perches affected the development of musculature in broilers (Sandusky and Heath 1988a,b).

Environmental complexity could support more uniform use of the available space (Leone *et al.* 2007, Ventura *et al.* 2012, Cornetto and Estévez 2001a, Rodriguez-Aurrekoetxea *et al.* 2015), including the vertical dimension. An experiment conducted in commercial broiler breeder houses showed better spatial distribution of males, together with improvements in egg production, fertility and hatchability in houses furnished with cover panels. The researchers suggested that the presence of panels decreased stress levels and positively modified male-female contacts (Leone and Estévez 2008). The presence of vertical panels (Cornetto and Estévez 2001a, Cornetto *et al.* 2002) and barrier perches (Ventura *et al.* 2012) reduced disturbances between broilers and perching may also diminish aggressiveness among birds (Pettit-Riley *et al*. 2002, Ventura *et al.* 2012), depending on the perch design (Petit-Riley *et al*. 2002). A further potential benefit of promoting perching in broilers in commercial farming environments is that it can decrease contact between footpads and litter (Ventura *et al.* 2012). Under high temperatures, access to cool perches, compared with no perches, reduced the incidence of contact dermatitis and panting, and improved growth and feed efficacy despite less time spent eating and drinking (Zhao *et al.* 2013). An experiment providing broilers with a possibility to choose between cool and warm perches showed a preference for cooler perches, possibly due to enhanced thermoregulation (Estévez *et al.* 2002).

Comparing among perching studies is complex due to the various ways to assess it. However, most experimental studies on broiler perching indicate that perches are used only to a modest degree (LeVan *et al.* 2000, Su *et al.* 2000, Pettit-Riley and Estévez 2001, Tablante *et al.* 2003, Groves and Muir 2013, Kiyma *et al.* 2016), typically 1-3% of birds have been observed perching (LeVan *et al.* 2000, Su *et al.* 2000, Pettit-Riley and Estévez 2001, Tablante *et al.* 2003). Slow-growing broilers perched more frequently than fast-growing birds (Bokkers and Koene 2003). However, even in slow-growers, perching was highly inconsistent and depended on bird age and breed (Nielsen 2004, Lee and Chen 2007, Rodriguez-Aurrekoetxea *et al.* 2015).

Age

In layer chicks, the daytime use of perches begins at about 2 weeks of age, while perching at night starts to develop at about 3 weeks (Heikkilä *et al.* 2006). Also broiler breeders prefer night roosting on perches when given a possibility (Gebhardt-Henrich *et al.* 2016). Probably due to young age, diurnal rhythm does not seem to affect broiler perching (Hughes and Elson 1977, Martrenchar *et al.* 2000).

Age influences broiler perching rate (Hughes and Elson 1977, LeVan *et al.* 2000, Pettit-Riley and Estévez 2001). An early study showed increasing perching by broilers up to 8 weeks of age (Hughes and Elson 1977). However, because broiler growth performance has markedly increased over decades, those results hardly apply to modern fast-growing birds. According to more recent studies, broiler perching seems to reflect general activity since perch usage peaked at 4-5 weeks of age, declining thereafter (Bizeray *et al.* 2002a, Ventura *et al.* 2012, Bailie and O´Connell 2015).

Perch design and location

Several studies concluded that broilers are motivated to perch when offered an attractive opportunity to do so (Hughes and Elson 1977, Davies and Weeks 1995, Ventura *et al.* 2012). Perch design affects broiler perching (LeVan *et al.* 2000, Pettit-Riley and Estévez 2001, Oester *et al.* 2005). Modern broilers at older age might not be agile enough to use perches (Pettit-Riley and Estévez 2001), and easy accessibility could increase perching. An angled perch leading from floor to horizontal perches was shown to encourage perching (LeVan *et al.* 2000), however, not consistently (Pettit-Riley and Estévez 2001). A Swiss study demonstrated that instead of traditional perches, broilers more frequently used elevated platforms with ramp access (Oester *et al.* 2005). Also some laying hen strains demonstrated a preference for platforms over traditional wooden perches (Faure and Jones 1982).

Perch usage has been more commonly observed at higher densities (Hughes and Elson 1977, Martrenchar *et al.* 2000, Pettit-Riley and Estévez 2001), indicating that perching may be motivated by an attempt to avoid crowding. Not all existing data support this suggestion because higher density was reported to decrease all activity, including perching (Ventura *et al.* 2012). On the other hand, highest perching frequency was recorded at medium stocking density compared with lower and higher densities, depending on age and perch design (Hongchao *et al.* 2014). It was suggested that, at high densities, perching frequency could also be influenced by social factors (Pettit-Riley and Estévez 2001). The increased use of a central open area in a broiler house at higher densities (Leone *et al.* 2007, Ventura *et al.* 2012, Cornetto and Estévez 2001a) seems also to apply to perching: at lower densities broilers appear to favour perches located at peripheries, but at increasing densities perching is enhanced in the central area (Pettit-Riley and Estévez 2001).

3 Aims of the thesis

The overall aim of the thesis was to examine the influence of particular characteristics of housing conditions, namely litter quality and elevated perching structures, on the welfare of broilers and broiler breeders. Welfare was estimated by measuring a few specific aspects, namely the severity of contact dermatitis in broilers and breeders, and leg health and perching behaviour in broilers.

The study aimed to

1. Deliver descriptive information about contact dermatitis and breast blisters in broiler breeders throughout the production period (Study I).

   Hypothesis: contact dermatitis and breast blisters become more common and severe with age

2. Monitor the changes in litter over time, and evaluate the impact of litter on footpads of breeders and broilers (Study I & II).

   Hypothesis: litter condition deteriorates over time, and inferior litter condition and higher moisture are associated with impaired footpad health

3. Compare the effects of peat with wood shavings and ground straw litter on contact dermatitis and plumage cleanliness in broilers, and litter condition and quality in broiler houses (Study II).

   Hypothesis: peat was expected to provide the best litter condition and promote the most favourable footpad and hock skin health, due to its low pH

4. Assess the effect of elevated platforms on contact dermatitis and the plumage cleanliness of broilers, and litter condition and quality in broiler houses (Study II).

   Hypothesis: extra equipment obstructs the airflow, and thus negatively affects litter condition, and possibly also footpad and hock skin health

5. Compare the use of platforms and traditional perches by broilers in commercial conditions (Study III & IV).

   Hypothesis: platforms appear more popular among broilers than perches

6. Evaluate the effect of a more complex environment furnished with perches or elevated platforms on the walking ability and TD of fast-growing broilers on commercial farms (Study IV).

   Hypothesis: perches and platforms could increase versatile locomotion sufficiently to improve broiler walking ability and leg health

4 Materials and methods

4.1 Birds and housing

The University of Helsinki Viikki Campus Research Ethics Committee approved the entire study. The data were collected on broiler and broiler breeder farms in Southwest Finland. All farms used a single fast-growing broiler breed, Ross 508. All farms applied the all-in all-out production system. Houses and all equipment were carefully cleaned and disinfected between flocks. Detailed information about the houses and flocks is provided in Table 1.

Broiler breeders
All breeder flocks were kept in environmentally controlled houses where the litter quality was maintained by adjusting heating and ventilation. The birds, feeding and housing were managed according to the normal practice of each farmer. The average initial male percentage was 10% (9-11%) decreasing to 8% (6-10%) by the end of the investigations. Spiking, i.e. the addition of younger males, was not practised. The decrease in bird number and density in breeder flocks was due to mortality and selection of birds. Commercially available plastic slats of different types were used in all houses in front of nests. The slatted area represented, on average, 38% (29-48%) of the total floor area. *Sphagnum* peat was used as bedding material on most farms. In one house wood shavings were used.

Broilers
The broilers, obtained from commercial hatcheries, were kept in environmentally controlled houses equipped with ventilation, heating and misting systems. The birds, housing conditions, and feeding were managed according to the company management practices and farmer's normal routine. The houses had no windows. Artificial light was provided in all houses for 18 hours. The dark period was either 6 hours or 4 + 2 hours, and the light intensity followed the requirements of EU and Finnish legislation. The light intensity was aimed to be the same in all houses on the same farm. Stocking density in the beginning was the same in all houses and mortality was anticipated to be similar. The initial chick number was calculated so that the final density at slaughter age would be near the maximum allowed density (42 kg/m^2), but not exceeding it. In broiler farms, no thinning, that is slaughtering some of the birds once or multiple times before final depopulation, was practised. In several broiler flocks, the mortality rate was higher than normal due to vertically transmitted diseases (*Escherichia coli* infection and inclusion body hepatitis). The mortality level, and thus the final density, was not affected by treatments (perches, platforms, bedding materials), but mortality rates influenced the final stocking density. Drinking water and three or four phase commercial feed were available *ad libitum*. Feeding included whole wheat from the first week until slaughter. More detailed information about the housing in one of the farms is available in paper III.

Table 1 *Summary of broiler breeder and broiler farms and flocks.*

Farm and flock parameters	*Study I* †	*Study II* *Litter comparison* ††	*Study II* *Elevated structures* ‡	*Study III* ‡	*Study IV* ‡
Farms	10	7	3	1	4
Houses/farm	1-2	2-4	2	4	2-4
Consecutive replicates	1	2	6	4	4-6
Flocks, total	18	32	36	16	62
Time	2013-2014	2014-2015	2013-2014	2013-2014	2013-2014
Flock size, beginning	2714-9456 hens 10% (9-11%) males	11772-27704	5147-13947	12038-13947	5016-13947
Total mortality, %, slaughter age (SD)	7.9 (2.9)	5.3 (2.7)	5.4 (2.3)	4.8 (1.2)	5.4 (2.7)
Floor area, m^2	514-1646	750-1681	337-797	797	337-797
Mean bird density, slaughter age, /m^2 (min-max)	5.4 (4.8-6.0) hens	39 kg (35-44)	39 kg (36-43)	40 kg (36-43)	40 kg (36-43)
Wheat % in feed (min-max)	na	14 (12-15)	20 (14-28)	17 (13-20)	19 (13-28)
Slaughter age	55-64 weeks	37-39 days	37-39 days	37-38 days	37-39 days
Target/actual weight at slaughter, kg (SD)	na	2.3-2.5 / 2.4 (0.1)	2.3-2.5 / 2.4 (0.1)	2.3-2.5 / 2.5 (0.1)	2.3-2.5 / 2.4 (0.1)

na No applicable

† Broiler breeder farms

†† Comparing wood shavings and peat, and ground straw and peat in broiler farms

‡ Perches and elevated platforms in broiler farms

4.2 Study design

Broiler breeders
The study was designed to follow the occurrence and severity of footpad lesions in breeders and changes in litter condition in breeder houses throughout the production period without any additional experimental design.

Broilers
The comparison of effects of three bedding materials (Photo 1) on litter condition in broiler houses and the frequency and severity of contact dermatitis and level of plumage cleanliness in broilers was examined between November and April, each year. On six farms two houses and in one farm four houses were included. In one house test bedding material, wood shavings or ground straw, was used and in the other house standard bedding material, *Sphagnum* peat, was used as a control. On the second round the role of the house was switched. Ground straw was very fine wheat or rye straw crushed from pellets, finished with heat treatment. Altogether 8 flocks on wood shavings, 8 flocks on ground straw, and 16 control flocks (8 per comparison) were monitored.

Photo 1 *Bedding materials tested in broiler houses: peat, wood shavings and ground straw.*

The use of elevated platforms (Figure 2, Photo 2) was followed throughout 6 successive flocks, but due to unexpectedly low use of perches (Figure 3, Photo 2), we decided not to follow perches after 4 or 5 successive flocks. Each farm had at least two separate houses, enabling the comparison of furnished flocks (with platforms or perches) to control flocks during each batch. Two farms supplied four houses, making it possible to test both perches and platforms. Comparison between the use of perches and platforms by video recording was conducted through 4 consecutive flocks on one of the farms offering four similar houses. The effect of elevated platforms on contact dermatitis and plumage cleanliness of broilers, as well as litter condition in the house, was assessed in platform-equipped houses and their controls across 6 replicates. Peat was used as bedding material. Either elevated plastic platforms covering 10% of the floor area or wooden perches 15 cm/ bird calculated for 10% of the birds were provided in one house. The amount of perch and platform space chosen was based on practical considerations. The control and furnished houses were alternated between the flocks. Chicks had access to the perches from the first day, and access to the platforms was offered during the first week, between days 3 and 7. The equipment was removed one day before slaughter. At each end a ramp allowed easy access to the platform, the entire structure of which is referred to as a platform in this text onwards. Platforms were made of plastic slats commonly used in laying hen and breeder houses. The holes in the slats measured 20 x 25 mm, while the surrounding plastic grid was 8 mm wide. A perch structure included horizontal perches of two heights and two widths. The platform and perch structures were high enough (30 cm) to enable the birds also to use the floor space underneath and were evenly distributed between drinker and feeder lines in the house in order to provide the same opportunity for all the birds to use them.

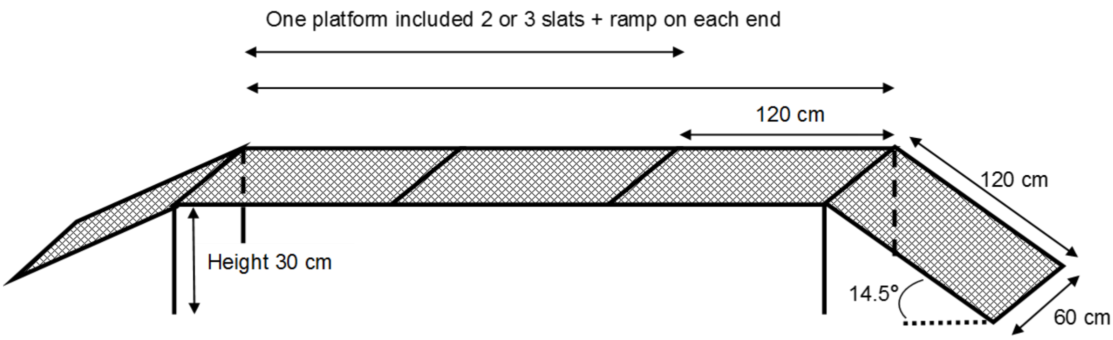

Figure 2 *Illustration of the elevated platform structure.*

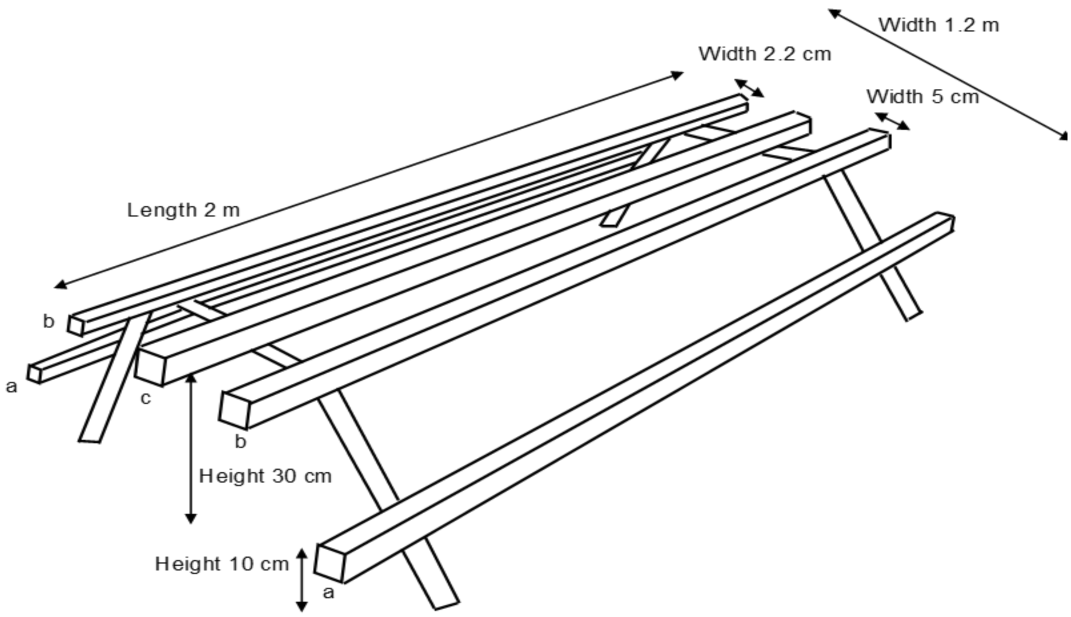

Figure 3 *Illustration of the perch structure showing* ***a****: low perches,* ***b****: high perches and* ***c****: high middle perch.*

Photo 2 *Left: perch structure in a broiler house (Photo courtesy of Hanna Hamina). Right: platform structures in a broiler house (Photo courtesy of Eeva Korimäki).*

4.3 Data collection

4.3.1 Scoring

Contact dermatitis and breast blisters in breeders
Broiler breeder footpads were first examined on the rearing farm as the birds were being loaded for transport to the laying farm (age 18-19 weeks). Thereafter scoring was performed at 24, 36 and 48 weeks of age, and at slaughter (age 55-64 weeks). Both footpads were lesion scored in 100 hens per flock by visual inspection and palpation. During loading, the researcher assessed footpads from about every tenth hen during the first and the second half of loading. During the production period, the farmer and researchers chose the nearest manually catchable hens at 4-5 locations for inspection. At slaughter, evaluation was conducted of every fifth carcass during two separate monitoring periods of 50 birds. Scoring was performed with a 5-point system (Table 2) modified from the official Finnish system used for broilers (Evira 2011; Table 3). This modification of scoring system assured that possible presence of scar tissue on footpads was considered in observation.

The presence and severity of hock burns were assessed at slaughter from the same birds as footpads. Lesion scoring was performed using the photographic system described in the WQ-protocol (Welfare Quality® 2009). The example photos from the WQ-system were turned into a practical system based on the hock area (Table 2). A single researcher performed all scoring. However, whole carcass and partial condemnation percentages due to breast blisters at flock level were obtained from the official meat inspection data.

Contact dermatitis and plumage cleanliness in broilers
Footpad lesions were visually inspected at slaughter using two methods, the official programme and WQ-assessment, independently of each other from different birds of the same flock. The researcher, an experienced poultry veterinarian that was blinded

regarding the official results, assessed footpads based on the example photos of WQ-assessment applied for broiler chicken (Welfare Quality® 2009). Hock lesions and plumage cleanliness were visually assessed at slaughter according to the example photos of WQ-assessment. The scoring scale was based on the presence, size and severity of lesions on footpads and hocks: score 0 = healthy skin, scores 1 and 2 = slight lesion on footpads or hocks, scores 3 and 4 = clear indication of footpad dermatitis or hock burn. Plumage cleanliness was assessed from the ventral side of the bird with scores: 0 = completely clean feathers, 1 = slight dirtiness and 2= moderate dirtiness on the central part of abdomen, and 3 = extensive dirt on abdomen and wings. The skin lesions and plumage cleanliness were assessed at the slaughter line during the first and second half of the slaughter batch over two separate 5-minute monitoring periods for each (based on slaughter line speed the total number of assessed birds was 1550). Plumage cleanliness was estimated after stunning and hanging, and footpads and hocks of both legs were evaluated after scalding and plucking at the meat inspection station. We compared the results of the WQ footpad assessment with the data obtained from the official programme. According to official programme, official veterinarians of the slaughterhouse are bound to evaluate footpad condition from every slaughter batch by assessing one footpad per bird from 100 birds per batch following the guidelines of the Finnish Food Safety Authority, Evira (Table 2; Evira 2011). Official veterinarians were blinded to treatment.

Table 2 *Description of scoring systems used for assessing footpad and hock lesions in broiler breeders and litter condition in breeder houses.*

Score	*Footpad lesions* ‡	*Hock lesions* ‡‡	*Litter condition* ‡‡
0	Healthy footpad	Healthy skin	Completely dry and flaky
1	Small (⦰ ≤ 1 cm) superficial lesion scaring included	Minimal signs of superficial hock burn on less than half area of hock	Dry but not easy to move with boot
2	Large (⦰ > 1 cm) superficial lesion scaring included	Minimal signs of superficial hock burn on over half area of hock	Leaves imprint of foot and can be shaped in a ball that easily falls apart
3	Small (⦰ ≤ 1 cm) severe lesion	Clear sign of hock burn as dark scabby skin on less than half area of hock	Sticks to boots and can be formed in a firm ball
4	Large (⦰ > 1 cm) severe lesion	Dark scabby skin covering whole area of hock	Wet and sticky under hard crust

‡ Footpad lesion scoring is based on modified Finnish system

‡‡ Hock lesion and litter condition scoring scale is based on the Welfare Quality® Assessment protocol for poultry

Litter condition

In breeder houses, litter condition was assessed and litter height measured when the birds were 24, 36, 48 weeks of age and during the last week before slaughter. Assessment was performed in 4-5 different locations per house, depending on the layout (Figure 4). In broiler houses, litter condition evaluation and height measurements were conducted before chick delivery and 1-3 days before slaughter in 6 different locations per house (Figure 5). Litter condition was scored by a single researcher using the method described in the WQ-protocol (Table 2). Adding fresh bedding material, changing and turning over litter was noted during the farm visits.

Table 3 *Description of footpad lesion scoring performed by the official veterinarian of the slaughterhouse following the guidelines of the Finnish Food Safety Authority Evira.*

Score	*Description*
0 healthy footpad	• smooth skin, no lesion • small superficial lesion, slight hyperkeratosis • discoloration on limited area • lesion size max 5 mm x 5 mm area
1 mild, superficial lesion	• superficial lesion of marked size covering several papillae • papilla structure still existing, discoloured or dark papillae • crust or ulceration on maximum 5 mm x 5 mm area • ulceration at the bottom of toe < 1 cm long
2 severe, deep lesion	• ulceration or crust of significant size, over 5 mm x 5 mm, without existing papilla structure • ulceration on the bottom of toes > 1 cm long

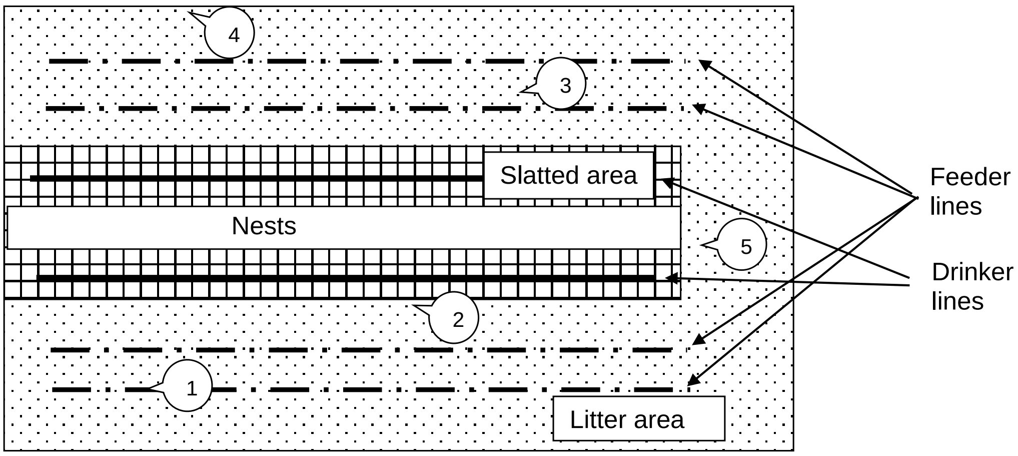

Figure 4 *Typical layout of a broiler breeder house with litter assessment and sampling locations. 1 = below the feeder line, 2 = at the edge of slatted area, 3 = free space between feeder lines, 4 = near the wall, 5 = at rear end of the house; not taken from every house because in some houses nests and slatted area continued to the rear wall.*

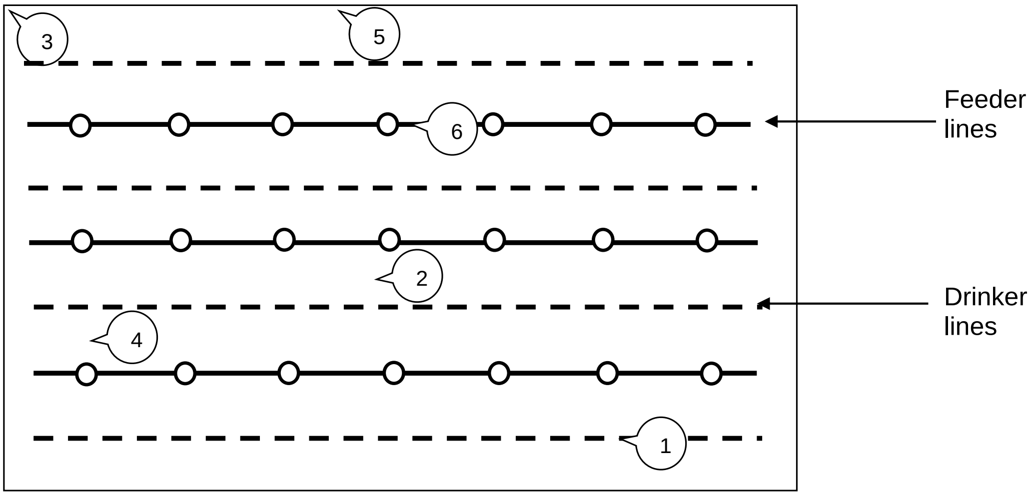

Figure 5 *Schematic layout of a broiler house showing the approximate litter assessment and sampling locations. 1 = under the drinker line, 2 = middle of the house between feeder and drinker lines or under the platform in equipped houses, 3 = rear corner, 4 = between feeder and drinker lines near the rear end of the house, 5 = wall side, 6 = under the feeder line.*

Gait scoring

All test and control flocks were gait scored 1-3 days before slaughter (age 34-36 days) in the winter (4-5 production cycles on each farm) and at around 30 days of age (29-31 days) in the summer (2 production cycles per farm in platform-equipped houses and their controls) to prevent possible problems caused by hot weather conditions near slaughter age, such as the risk of increased mortality due to the additional handling. Gait scoring was based on the WQ-protocol by scoring at least 150 birds per flock (Welfare Quality® 2009). The scoring scale was from 0 = normal gait to 5 = unable to walk (Table 4). Birds were confined in a catching pen at 5-7 different locations in dimmed light. The assessment locations always represented at least a central part of the house, the wall side and the front and rear end of the house. During the scoring light intensity was returned to normal. As all the caught birds were scored, the final number of assessed birds was 150-172. All birds scored as 3 were killed by neck dislocation for TD examination. These are of special interest because there is no agreement on the impact of moderate gait abnormality on broiler welfare. Additionally, all birds with severe walking difficulties (scores 4 and 5) were assumed to be suffering and therefore culled for ethical reasons.

Tibial dyschondroplasia scoring

On the farms, the severity of TD was determined in all birds gait scored as 3 (18-71 birds per flock), and at the slaughterhouse a convenient sample of 200 birds per flock was collected for the severity assessment. The condition of the proximal growth plate of both tibias was assessed on a 4-point scale (Table 5, Photo 3). Slight uniform thickening of the growth plate was scored as normal.

Table 4 *Description of the scoring system for broiler gait using a 6-point scale (following the Welfare quality® protocol applied for broiler chicken).*

Score	*Description*
0	Normal gait: even steps, toes furled while foot is in the air
1	Uneven gait at times, slight defect not easily defined, toes may furl in the air
2	Uneven gait, mild but definite defect, foot flat in the air, gait abnormality does not compromise bird's manoeuvrability
3	Obvious, moderate gait abnormality, impaired ability to move around, chooses to sit when not forced to walk
4	Severe walking difficulties, takes only few steps if forced and sits readily at every opportunity, bird's manoeuvrability severely compromised
5	Unable to walk, uses wings or crawls when forced to move, growth often seriously reduced

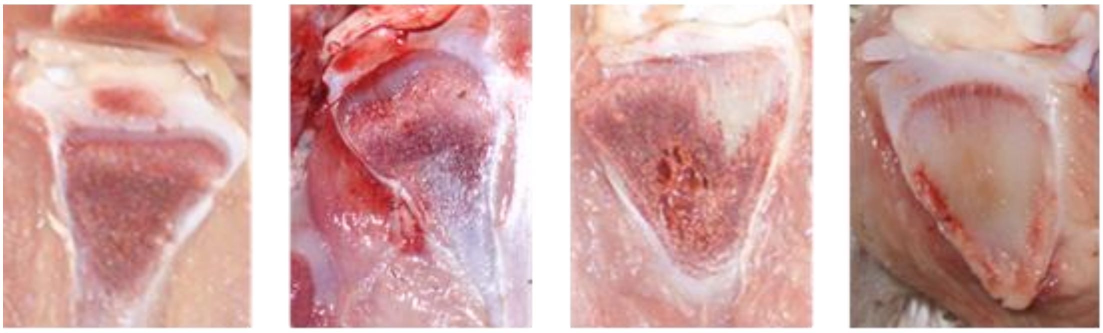

Photo 3 *Example photos of tibial dyschondroplasia (TD) scores 0-3.*

Table 5 *Description of the scoring system for tibial dyschondroplasia (TD) in broilers.*

TD score	*Description*
0	Normal growth plate
1	Mild lesion with cartilage development to ≤ 0.5 cm
2	Moderate lesion with abnormal cartilage developed in > 0.5-0.75 cm
3	Severe lesion with cartilage extended > 0.75 cm

Perch and platform usage

Farmers were asked to note the day they saw the first birds on perches or platforms and estimate the overall usage of platforms and perches twice a week (Table 6). They were instructed to assess the use in the morning from the middle of the house, after allowing birds to familiarize with the presence of the observer for 2 minutes. Two out of four farmers followed the use of both types of equipment, adding reliability of the estimation. All houses on the same farm were scored on the same day.

Table 6 *Scoring scale farmers used to estimate the use of perches and elevated platforms by broilers.*

Score	*Description*
Empty	Only single birds using the structures
Minor use	≈ 25% of the structures used
Moderate use	> 25-50% of the structures used
Good use	> 50%-75% of the structures used
Full	100% of the structures used

4.3.2 Video recordings and observations of platform and perch use

Infrared cameras were attached to the ceiling in the middle of the houses. One perch and half of a platform structure were filmed with one camera in each treatment house. Treatment and control flocks were observed simultaneously. During each day a light and a dark period observation were included. Daytime observations started at 9am (5 h after lights on) and night-time observations at 1am (1 h after lights off). Observations were performed on approximately days 11 (10-14), 19 (17-21), and 32 (31-34) after the birds arrived at the farm.

To quantify the use of platforms and perches, the number of birds on them was counted on 6 occasions, 10 minutes apart during each observation period. The number of birds sitting on one perch structure was counted and half of a platform structure was recorded in a similar manner. For analysis, the number of birds on half of the platform was doubled to get an estimate of the number of birds on the entire platform structure.

4.3.3 Litter quality

Litter quality was evaluated using moisture, pH and ammonia levels at the same locations as where litter condition was assessed. Litter samples of 1 litre each were taken from the full depth of the litter layer in moisture-proof plastic bags from breeder houses at 24 and 48 weeks, and during the last week before slaughter. In broiler houses sampling was performed before chick delivery and 1-3 days before slaughter. All samples collected before chick delivery were pooled, mixed manually and a sample of 1 litre was taken. Before slaughter all 6 samples were taken separately.

All samples were stored frozen. Before analysis thawed samples were thoroughly mixed manually. For ammonia and pH analysis, 30 g of litter was mixed with 270 ml water and homogenized with a mixer (Seward, Stomacher® 400 Circulator, Seward Ltd, United Kingdom) for 2 min. The homogenate was kept in 8 °C for 30 min and homogenized again. An aliquot of homogenate was transferred to a test tube and centrifuged for 15 min at 4750 x g. Litter pH was measured from clear supernatant. The supernatant was diluted 1:100 with water and ammonia was determined using a colorimetric method (McCullough 1967). Litter moisture was determined in duplicate using an automatic moisture analyser (Ohaus MB23, New Jersey, USA) by drying 3 g of previously mixed sample at 115 °C to constant weight. The intra assay coefficient of variance (CV) of duplicate samples was 1.5%.

4.4 Statistical analysis

All statistical analyses were carried out with SPSS vs 22–23 (Petrie and Watson 2006, Metsämuuronen 2009).

4.4.1 Study I

The factors affecting footpad lesions were analysed with linear mixed models for repeated measurements. Due to different numbers of observation points for different variables, two models were employed. In both models mean footpad lesion scores and the percentage of severe lesions (scores 3 and 4) were outcome variables. The first model included age and mean litter score. The second, aiming to explain further the specific effect of all factors, included the measures of litter quality, as well as bird density and slat percentage as independent variables. As litter score is expected to be an outcome of these more detailed factors, it was not included in the model.

The effect of bird age at sampling and sampling location on litter quality was analysed using separate linear mixed models for each litter quality measure. The litter quality measures, i.e. litter height, pH, moisture, and ammonia content were used as outcome variables. Age and sampling location were used as independent variables and the models included house as a random effect.

4.4.2 Study II

Litter material and platform treatment

The effects of farm and treatment (litter materials or platform) on mean footpad scores and the severity of footpad dermatitis assessed with both scoring systems, mean hock burn and mean cleanliness scores, and the distribution of hock burn and cleanliness scores were analysed with general linear univariate models for each of the dependent variables separately. Wood shavings and ground straw were compared with their controls (peat) in separate models. The models included farm and litter material, and farm and platform treatment as fixed factors. The interaction between farm and litter material was included in the initial model, but omitted from the final model when the interaction was not significant. Only significant interactions are reported.

Because the data for litter condition and quality did not meet the assumptions of normality effects for litter material, platform treatment, farm, sampling time and sampling location, litter condition and quality were analysed using nonparametric tests. Effects of litter material and platform treatment, as well as of farm, on litter condition and quality were analysed with the independent samples Mann-Whitney U-test and Kruskal-Wallis test, respectively. The changes in litter height, moisture and pH over time were analysed with the Wilcoxon signed rank test. The analyses of sampling location effects on litter condition and quality were carried out using the related samples Friedman's test and further adjusted with Bonferroni-corrections. All 16 control batches with peat were analysed together for analyses of sampling location.

Risk factors for lesions

Separate mixed models were used to identify risk factors for footpad lesions and hock burns. Mean flock footpad and hock skin lesion scores were outcome variables. The models included farm, flock, litter material, sampling location and the measures of litter quality at the end of production period (i.e. litter height, pH and moisture), as well as bird density and house size as independent variables. Factors having correlation coefficients greater than 0.6 were not introduced into the model. Thus ammonia and body weight were not included in the initial model. No correlations between other continuous independent variables were over 0.6 when detected using a Pearson correlation test. Non-significant variables were stepwise removed. Model fit was monitored by using Akaike information criteria. The normality of residuals was graphically assessed to ensure model suitability. Results of the final model are reported.

4.4.3 Study III

The use of platforms and perches was analysed using non-parametric tests as the sample size was rather limited, and the data on the use of platforms and perches were not normally distributed. The mean number of birds on perches and platforms across the 6 observations was used as the outcome variable. The development in the use of elevated structures (data pooled across day and night) by age was analysed with related samples Friedman tests separately for platform and perch use. The difference in the use of platforms and use of perches, separately, during day and night was analysed individually for each observation ages with Friedman tests.

The difference in the use of low and high perches, and thinner and thicker perches was analysed with related samples Friedman tests. The mean number of birds on perches of different height and thickness, and at different age, was analysed with separate tests. The mean number of birds per single perch was used in the analyses.

4.4.4 Study IV

Due to the low use of perches, the houses with perches were excluded when analysing the difference from control houses on walking ability and TD. Effects of scoring age, treatment (platform or control) and farm on mean gait score and the percentage of birds scored 3 and 4-5 were analysed using separate general linear univariate models. For analysis, scoring age was categorized as younger (29-31 days of age) and older (34-36 days of age). The models included scoring age, treatment and farm as fixed factors.

Effects of house size, mean bird density, mean live weight at slaughter, and mean wheat percentage in feed on mean gait score and the percentage of birds scored as 3 and 4-5 were analysed using general linear multivariate model. For analysis, house size was categorized as smaller ≤ 500 m^2 and larger > 500 m^2, mean bird density as lower ≤ 39 kg/m^2 and higher > 39 kg/m^2, mean live weight at slaughter as lower ≤ 2.41 kg and higher > 2.41 kg, and mean wheat percentage in feed as lower ≤ 19% and higher > 19%. The model included house size, mean bird density, mean live weight at slaughter age and mean wheat percentage as fixed factors.

Since the data for TD did not meet the assumptions of normality they were analysed with nonparametric tests. TD percentage, the number of birds with each TD score assessed at slaughter, TD percentage and the number of birds with each TD score in birds with gait score 3 were used as outcome variables. The effect of platforms on TD was analysed separately using the independent samples Mann-Whitney U-test. The effect of gait scoring age on TD percentage in birds with gait score 3 was analysed with the Mann-Whitney U-test. The effect of farm on the same outcomes was analysed separately with the independent samples Kruskal-Wallis test. Data for each bird were included into the analysis according to the highest TD score. Furthermore, the effects of house size, bird density, mean live weight at slaughter, and mean wheat percentage in feed on TD were analysed separately with Mann-Whitney U-tests.

5 Results

Results are expressed as means and standard errors (SE) unless otherwise indicated. Statistically significant differences are reported. A *P*-value < 0.05 was considered statistically significant. For exact *P*-values, refer to papers and manuscripts at the end of the thesis.

5.1 Contact dermatitis, breast blisters in breeders and litter quality in breeder houses (Study I)

Breeder footpad and litter condition

The condition of breeder footpads deteriorated as the birds aged: mean footpad score increased after 24 weeks of age and severe lesions became more common towards slaughter age (Figure 6). Mean litter condition score over the entire testing period was 0.2 ±0.04. Litter condition had an effect on footpad scores – when litter condition score increased by 0.16 (95% confidence interval (CI) 0.006 to 0.31) footpad lesion score increased by 1. At slaughter, the percentage of severe lesions ranged between 51 and 85% (mean 64% ±2.1). There were 4 houses with a mean litter condition score of 0 through the whole production period. In those houses 53% (range 51-55%) of the birds had severe lesions at slaughter. However, litter condition had no effect on the percentage of severe lesions in the house.

Litter height increased and moisture decreased towards the end of the production period (Table 7). Sampling location affected litter height, moisture, ammonia content and litter condition (Table 8).

Risk factors for footpad lesions

Higher litter moisture (slope 0.02 mean footpad condition score/ %; 95% CI 0.01 to 0.04), lower ammonia content (slope -0.0002 mean footpad condition score/ µg/g; 95% CI -0.00 to -6.15) and higher pH (slope 0.1 mean footpad condition score/pH; 95% CI 0.03 to 0.21) were associated with inferior footpad condition. Larger slat area was linked with poorer footpad condition (slope 0.02 mean footpad condition score/ slat percentage; 95% CI 0.01 to 0.02). There was a tendency for bird density at the end to correlate negatively with footpad lesion scores (slope -0.09 mean footpad condition score/ bird density at the end; 95% CI -0.17 to -3.87; *P* = 0.05). However, litter height was not associated with footpad condition.

Hock burns and breast blisters

Mean prevalence of hock lesions at slaughter was 0.005% ±0.001. In 8 flocks, no hock lesions were observed and in 10 flocks small superficial (score 1) hock lesions were present in 1 or 2 birds. No whole carcass condemnations due to breast blisters occurred. Mean partial condemnation percentage due to breast blisters was 0.1% ±0.05. In 13 flocks no partial condemnations were reported and in 5 flocks the condemnation percentage varied between 0.05-0.63. Due to the low incidence of hock burns and breast blisters no statistical analysis was performed.

Litter management

Only one farm reported adding fresh bedding occasionally in the middle of the production period. None of the other farmers changed litter, turned litter over or added fresh bedding material.

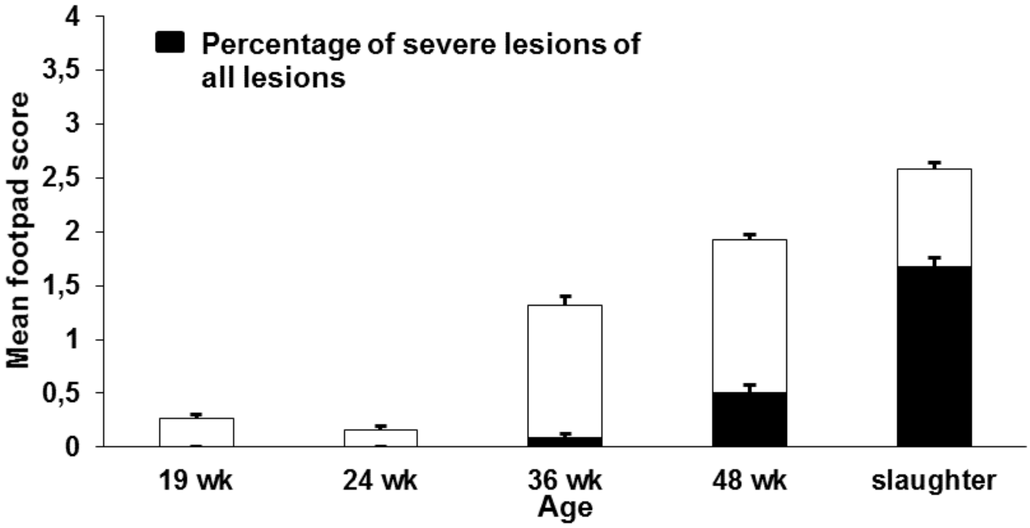

Figure 6 *Mean lesion scores and percentages of severe lesions on the footpads of broiler breeders during the production period. Scoring scale was from 0 = healthy to 4 = large severe lesion.* P-*value < 0.05 was considered statistically significant. Mean lesion score increased after 24 weeks of age. The proportion of birds with severe lesions among the assessed birds was higher at 48 weeks of age and at slaughter age compared to all earlier observation times. Error bars stand for SE.*

Table 7 *Changes in mean litter condition score and litter quality in 18 broiler breeder houses during the production period.*

Age	*24 wk*	*36 wk*	*48 wk*	*Slaughter (55-63 wk)*	*SE*
Litter condition	0.1^{a}	0.2	0.4^{b}	0.3	0.07
Height cm	7^{a}	7^{a}	10^{b}	12^{c}	0.4
Moisture %	33^{a}	nt	28^{b}	24^{c}	0.7
pH	8.2^{a}	nt	8.7^{b}	8.7^{b}	0.054
Ammonia µg/g	1987	nt	2210^{a}	1771^{b}	77.5

[abc] Different letter within each row shows post hoc statistics difference at the 0.05 level
nt Not tested

Table 8 *Differences in mean litter condition score, height, moisture, pH and ammonia content in litter samples from five different locations in broiler breeder houses.*

Litter sampling location	*under feeder line*	*at the edge of slat*	*between feeder lines*	*wall side*	*rear end of the house*
Litter condition	0.1 ±0.07	0.4 ±0.07	0.2 ±0.07	0.2 ±0.07	0.4 ±0.08
Height cm	7 ±0.4[a]	12 ±0.4[b]	9 ±0.4[c]	9 ±0.4[c]	7 ±0.5[a]
Moisture %	27 ±0.9[a]	31 ±0.9[b]	28 ±0.9	27 ±0.9[a]	29 ±1.1
pH	8.4 ±0.1	8.6 ±0.1	8.5 ±0.1	8.5 ±0.1	8.5 ±0.1
Ammonia µg/g	1785 ±98[a]	2350 ±98[b]	1992 ±98	2009 ±98	1809 ±111[a]

[abc] Different letter within each row shows post hoc statistics difference at the 0.05 level

5.2 Contact dermatitis and plumage cleanliness in broilers and litter quality in broiler houses (Study II)

5.2.1 Contact dermatitis and plumage cleanliness – comparison between bedding materials

Overall 87% ±2.6 of the birds assessed according to the official protocol, and 82% ±3.0 of the birds assessed according to the WQ-assessment had healthy footpads (score 0 and WQ0). The severest footpad and hock skin lesions identifiable using the WQ-assessment (score WQ4) were absent.

Wood shavings vs peat

Mean official footpad score (Table 9) and the severity of footpad dermatitis were influenced by litter material for scores 0 and 1 (Figure 7a), but severe lesions (score 2) were found only in 1 out of 4 farms. Mean footpad scores and the distribution of scores 0 and 1 differed among farms. There was an interaction between farm and litter material for mean official footpad score and for scores 0 and 1.

Litter material affected mean WQ footpad score (Table 9). Fewer healthy footpads (score WQ0) were recorded on wood shavings than on peat (Figure 7b). Mean footpad score and the distribution of footpad scores WQ0, WQ1 and WQ2 differed among farms. An interaction between farm and litter material was established for mean WQ footpad score and scores WQ0, WQ1 and WQ2.

Mean hock burn score appeared inferior on wood shavings compared with peat (Table 9). Litter material had no influence on the distribution of scores 1 and 2. However, there was a tendency of litter material affecting the percentage of hock burn score 0 (P = 0.052). On wood shavings 64.7% ±2.2 of the birds exhibited healthy hock skin and on peat 71.6% ±2.2 of the birds. Although score 3 was detected only seldom, litter material impacted the percentage of score 3 (0.1% ±0.002 of the birds on wood shavings and 0.01% ±0.002 on peat). Mean hock burn score and the occurrence of scores 0, 1 and 3 differed among farms.

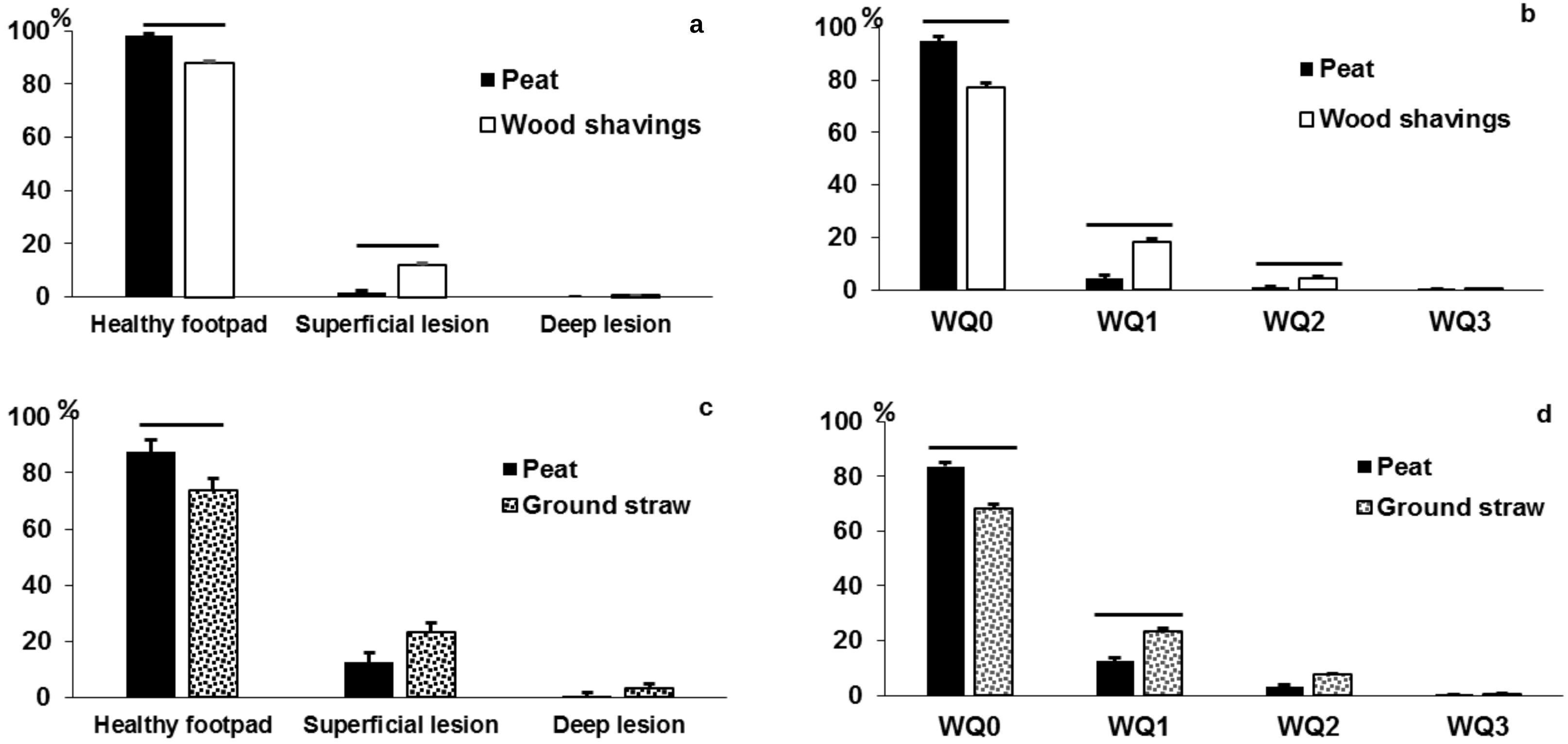

Figure 7 *Distribution of footpad lesion scores in broilers on wood shavings compared with peat assessed according to Finnish official programme (a) and Welfare Quality® Assessment protocol for poultry (WQ) (b), and on ground straw compared with peat assessed with official programme (c) and WQ-assessment (d). The official scoring scale varied from 0 = healthy footpad to 3 = deep lesion. WQ-assessment was performed with scale from WQ0 = healthy footpad to WQ5 = clear indication of footpad dermatitis. Error bars indicate SE and line over bar significant difference (P < 0.05).*

Ground straw vs peat
Litter material had no effect on mean official footpad score (Table 9), but affected the percentage of healthy footpads (Figure 7c). There was a tendency for litter material to affect score 1 percentage (P = 0.051). Severe lesions were detected on three out of four farms. Mean official footpad score, and the occurrence of healthy footpads and superficial lesions differed among farms.

Litter material impacted mean WQ footpad score (Table 9) and the distribution of scores WQ0 and WQ1 (Figure 7d), but scores 2 and 3 remained unaffected. Mean WQ footpad score and the distribution of scores WQ0, and WQ1 differed among farms.

Mean hock burn score was higher on ground straw than on peat (Table 9), but litter material had no effect on the severity of hock lesions. The hock skin was healthy in 66.9 % ±1.7 of the birds on ground straw and in 70.4% ±1.7 of the birds on peat. Mean hock burn score and the distribution of scores 0, 1 and 2 differed among farms.

Plumage cleanliness
Overall 99% ±0.1 of the assessed birds appeared at least slightly dirty (cleanliness score $\geq$ 1). Mean cleanliness score was 1.1 ±0.01. Mean cleanliness score and the level of cleanliness were not affected by litter material and farm.

Table 9 *Mean footpad and hock skin lesion scores for broilers on different litter materials (comparing wood shavings with peat and ground straw with peat) and on peat litter in platform-equipped houses and their controls.*

	Mean official ‡ footpad score	*Mean WQ ‡‡ footpad score*	*Mean WQ ‡‡ hock burn score*
Wood shavings vs peat	P < 0.05	P < 0.05	P < 0.05
Wood shavings	0.13 ±0.01	0.28 ±0.02	0.4 ±0.03
Peat	0.02 ±0.01	0.06 ±0.02	0.3 ±0.03
Ground straw vs peat	n.s.	P < 0.05	P < 0.05
Ground straw	0.3 ±0.06	0.4 ±0.06	0.4 ±0.02
Peat	0.1 ±0.06	0.2 ±0.06	0.3 ±0.01
Platform treatment †	0.2 ±0.04	0.3 ±0.05	0.3 ±0.02

‡ Scoring is based on official Finnish system
‡‡ Scoring follows the Welfare Quality® Assessment protocol for poultry
† Results are shown as overall as the treatments did not differ

5.2.2 Litter assessment in bedding material comparison

Wood shavings vs peat
None of the farmers reported any additional procedures to manage litter condition. Litter condition and moisture at the end of production period did not differ between wood shavings and peat (Table 10). The wood shavings layer became lower, and pH

and moisture increased with time. Peat moisture remained unchanged over time, and height and pH rose during the production phase. Height, pH and moisture at the beginning and ammonia content differed among farms.

Ground straw vs peat

All farmers reported at least once adding fresh ground straw bedding during the rearing phase, but no extra procedures with peat litter. At the end of the production period, peat litter was more friable than ground straw, whereas in moisture content no differences were detected (Table 10). The height and moisture of the ground straw layer increased during the growing period, while pH decreased. Peat height remained unchanged over time, moisture and pH rose during the production period. Initial pH, moisture content at both sampling times, and ammonia content differed among farms.

Risk analysis

None of the litter quality measurements were associated with mean footpad lesion or hock burn scores. Farm and litter material impacted the footpad and hock skin condition ($P < 0.05$, each). Higher bird density was associated with lower mean footpad lesions scores (slope -0.03 mean footpad condition score / bird density kg/m^2; 95% CI -0.04 to -0.02, $P < 0.05$).

5.2.3 Effect of platform treatment on contact dermatitis, plumage cleanliness and litter quality

In platform-equipped houses and their controls on average 83% ±3.4 of the birds assessed according to official protocol and 74% ±3.2 of the birds assessed according to the WQ-method exhibited healthy footpads (score WQ0).The severest footpad lesions from the WQ-assessment (score WQ4) were detected at two farms (mean 0.02% ±0.02). Furthermore, the most severe hock burns (score 4) were found on one farm (mean 0.02% ±0.02).

Footpad lesions and hock burns were not affected by platform treatment (Table 9). Mean official footpad score, the distribution of scores 0 and 1 differed among farms. Also mean WQ footpad score and scores WQ0, WQ1 and WQ2 differed among farms.

Mean cleanliness score was 1.1 ±0.01. Overall 99% ±0.1 of the assessed birds appeared at least slightly dirty (cleanliness score ≥ 1). Mean cleanliness score and the level of cleanliness were not affected by platform treatment and farm.

Litter condition and quality remained unaffected by platform treatment. Litter moisture increased and pH rose over time but height remained unchanged. Litter height, moisture and pH in the beginning and at the end, and ammonia content and litter condition differed among farms. Also, litter height and moisture at location 2 (under the platform in equipped houses) differed among farms.

Table 10 *Median (min-max) litter condition scores (according to Welfare Quality® Assessment protocol for poultry) and litter quality measurements in broiler houses comparing wood shavings with peat and ground straw with peat, and peat litter in houses equipped with elevated platforms and their controls.*

	Wood shavings and peat comparison			*Ground straw and peat comparison*			
Litter measurement	*Wood shavings*	*Peat*	P-*value*	*Ground straw*	*Peat*	P-*value*	*Platform treatment* ‡
Litter condition score	0.8 (0.3-1.2)	0.5 (0.2-0.8)	n.s.	1.0 (0.5-1.7)	0.7 (0.2-0.8)	< 0.05	0.7 (0.2-1.7)
Height beginning, cm	6.4 (3.5-7.8)	3.7 (2.5-4.7)	< 0.05	1.3 (0.9-1.5)	4.7 (2.5-6.2)	< 0.05	4.8 (2.3-10.8)
Height end, cm	4.9 (4.7-5.8)	4.8 (4.2-6.0)	n.s.	3.9 (3.2-5.0)	4.5 (4.2-6.7)	< 0.05	5.1 (3.1-9.8)
pH beginning	5.4 (5.1-5.9)	4.0 (3.4-4.5)	< 0.05	8.1 (7.6-8.5)	4.1 (2.3-4.4)	< 0.05	4.0 (3.5-4.5)
pH end	8.1 (7.8-8.5)	8.1 (7.7-8.4)	n.s.	7.4 (6.6-8.0)	8.0 (7.6-8.4)	< 0.05	7.8 (7.1-8.6)
Moisture beginning, %	10.4 (6.1-21.2)	33.1 (18.5-61.1)	< 0.05	7.3 (4.6-10.9)	23.9 (13.1-64.5)	< 0.05	24.8 (14.2-47.2)
Moisture end, %	32.3 (27.8-34.4)	31.2 (27.2-39.1)	n.s.	53.8 (42.1-63.1)	50.8 (31.6-59.3)	n.s.	33.8 (25.8-44.7)
Ammonia end, µg/g	2130 (1810-2760)	2270 (1810-2760)	n.s.	2200 (1560-2330)	2270 (1810-2760)	n.s.	2370 (1630-3220)

n.s. Non-significant
‡ Houses equipped with elevated platforms and their controls, results are shown as overall as the treatments did not differ

5.2.4 Effects of sampling location

Overall, litter under drinker lines appeared the stickiest. Litter quality under the feeder lines differed most from litter at other sampling locations (Table 11).

5.3 Perch and platform use by broilers (Study III & IV)

Video recordings

The number of birds using platforms massively exceeded the number of birds seen perching. There was a mean of 0.4 (SD 0.5) birds sitting on a perch structure with a perch length of 10 m in total versus a mean of 48 birds (SD 18) observed on a platform structure of a total of 3.6 m^2.

The use of platforms was lower on the last observation day than during the earlier observation days (Table 12). The birds used the platforms more during daytime than nights during the observation days 11 and 19 (Table 13). Time of day had no effect on perch use.

Broilers used the low perches more frequently than high perches at 32 days of age, but no difference on the other observation days was recorded. The median numbers of birds observed per single perch at the age of 32 days are: low 0.2, high 0.0 and high in the middle 0.0 (range 0.3, 0.0 and 0.0; respectively) birds/perch. The thickness of the perches had no effect on perch use.

Farmers' estimation

According to the farmers' bookkeeping, the first broilers were detected on perches on average at 9 days of age (6-19 days of age). The chicks started to use the platforms immediately when access was allowed, i.e. between 3 and 7 days of age. Farmers estimated platform use between 50 and 100% in all flocks through the entire growing period. Only single birds used the perches, and perch structures were evaluated as being empty throughout all the batches (Photo 4).

Photo 4 *Usage of elevated platforms (left) and perches (right) by broilers at 5 weeks of age.*

Table 11 *Median (min-max) litter condition scores at the end of growing period assessed according to the Welfare Quality® Assessment protocol for poultry, and litter quality in samples from different locations in broiler houses with tested litter materials (peat, wood shavings and ground straw) and peat litter in houses equipped with elevated platforms and their controls.*

Litter sampling location	*under drinker line*	*middle house between feeder and drinker lines ‡*	*rear corner*	*rear end of the house between feeder and drinker lines*	*wall side*	*under feeder line*
Litter condition	1.5 (0-4)[a]	1.0 (0-3)[b]	0 (0-3)[bc]	0 (0-4)[bc]	0 (0-3)[b]	0 (0-1)[c]
Height cm	5 (3-12)[ab]	5 (1.5-12)[ab]	6 (2-14)[a]	4.5 (1-12)[bc]	4 (1.5-9)[c]	4 (2-10)[c]
Moisture %	41 (24-63)[a]	35 (19-59)[b]	35 (20-55)[b]	33 (18-58)[b]	36 (20-52)[b]	20 (13-37)[c]
pH	8.1 (4.9-8.9)[a]	8.5 (5.5-8.9)[b]	8.3 (5.5-9.0)[ab]	8.5 (5.5-9.0)[b]	8.4 (5.4-8.8)[ab]	7.6 (6.2-8.7)[c]
Ammonia µg/g	2580 (1310-4460)[a]	2320 (1200-3570)[a]	2360 (920-3680)[a]	2320 (810-9350)[a]	2330 (1140-3840)[a]	1710 (1040-3150)[b]

[abc] Different letter within each row shows post hoc statistics difference at the 0.05 level
‡ Under the elevated platform in equipped houses
N = 68

Table 12 *Median (interquartile range) number of birds on perch structure or on platform by age of broiler.*

	N	*Day 11*	*Day 19*	*Day 32*	P-*value*
Perch	4	0 (0.4)	1.0 (1.4)	0.3 (0.6)	n.s.
Platform	4	54 (22)	56 (18)[a]	30 (8)[b]	< 0.05

[ab] Different letter within each row shows post hoc statistics difference at the 0.05 level
n.s. Non-significant

Table 13 *Median (interquartile range) number of birds on platform by time of day (N=4).*

	Day	*Night*	P-*value*
Day 11	62 (22)	20 (22)	< 0.05
Day 19	66 (20)	56 (18)	< 0.05
Day 32	34 (18)	30 (8)	n.s.

n.s. Non-significant

5.4 Effect of platforms on broiler leg health (Study IV)

Walking ability

Overall 30% of the tested birds (18-71 birds per flock) had gait score ≥ 3 (Figure 8). Scoring age influenced walking ability, with younger age resulting in lower mean gait scores (2.2 ±0.02 at younger and 2.3 ±0.01 at older age), percentages of birds scored 3 (21% ±1.6 at younger and 31% ±1.0 at older age) and 4-5 (0.2% ±0.3 at younger and 0.9% ±0.2 at older age). Walking ability was enhanced in flocks with access to platforms: mean gait score was lower in birds with platforms (2.2 ±0.02) compared with no platforms (2.3 ±0.01). The percentage of birds scored 3 was lower for those with platforms (Figure 9). However, no effect on the percentage of birds scored 4-5 was detected. Farm affected mean gait score, but had no effect on the percentage of birds scored 3 and 4-5. No interaction was established between any of the above variables. House size, mean bird density, mean live weight at slaughter age or mean wheat percentage did not influence mean gait scores or the percentage of birds scored as 3 and 4-5.

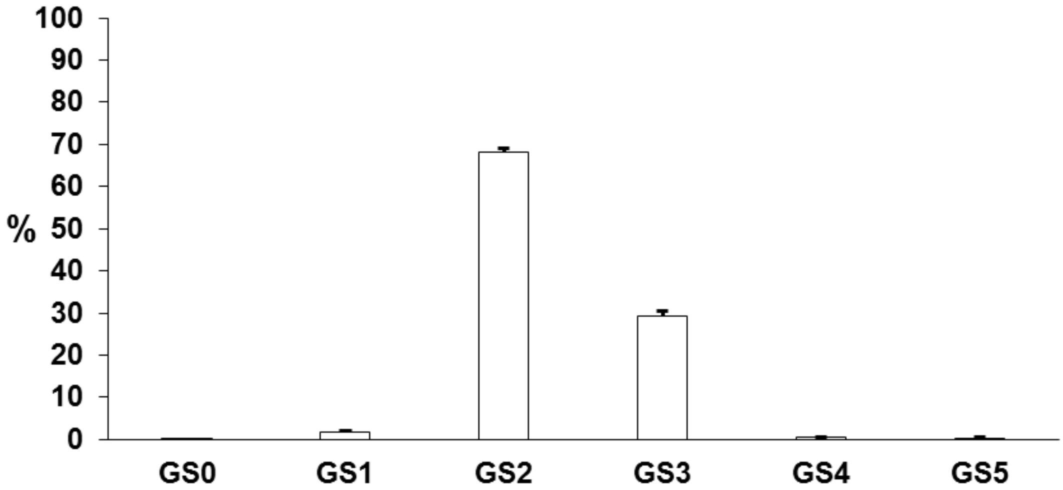

Figure 8 *Overall distribution of gait scores in broiler flocks (N = 49). Scoring followed the assessment scale of Welfare Quality® from 0 = normal gait to score 5 = incapable to walk. Error bars indicate SE.*

TD assessment

On average 2.3%, ranging between 0 and 12%, of the birds examined at slaughter were affected by TD and 43% of the affected birds had lesions in both legs. In birds with gait score 3 the overall mean occurrence of TD was 3.5%, ranging between 0 and 14%. Access to platforms resulted in lower percentage of TD but did not influence TD occurrence in birds with gait score 3 (Figure 10). The severity of TD in birds evaluated at slaughter was reduced by access to platforms (Table 14). The severity of TD in birds with gait score 3 remained unaffected by platform access and scoring age. Farm influenced the occurrence of TD and TD scores 0 and 1, but not scores 2 and 3. Furthermore, the occurrence of TD as well as TD scores of 0, and 1 in birds with gait score 3 differed among farms. The larger house size was linked with higher TD percentage, lower proportion of TD score 0, and higher proportion of TD score 1 in birds evaluated at slaughter. Likewise, TD percentage was higher in larger houses in birds with gait score 3. Lower mean live weight at slaughter age was associated with lower TD percentage in birds with gait score 3, but had no effect on TD examined at slaughter. Neither bird density nor mean wheat percentage in feed affected TD.

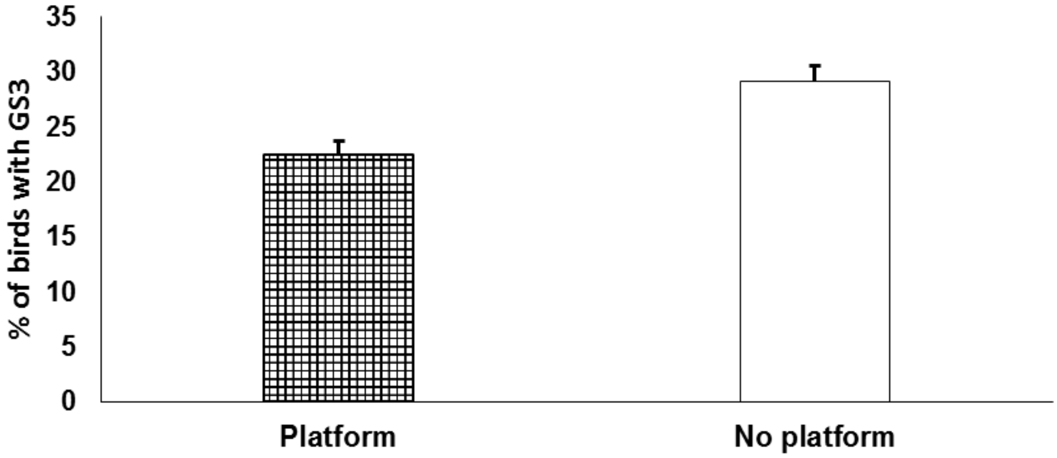

Figure 9 *Mean percentage of broilers with gait score 3 (GS3) with and without access to elevated platforms. Gait scoring followed the assessment scale of Welfare Quality®; score 3 = moderate gait abnormality. Access to platforms resulted in lower percentage of birds scored 3 (*P *< 0.05). Error bars indicate SE.*

Table 14 *Median number of tibial dyschondroplasia (TD) affected (scores 1-3) and unaffected broilers in control and platform groups examined at slaughter from 200 birds per flock.*

TD score	*No platforms (min-max) N = 31*	*Platforms (min-max) N = 18*	P-*value*
0	196 (177-200)	198 (194-200)	< 0.05
1	2.0 (0-9)	1.0 (0-4)	n.s.
2	1.0 (0-6)	0 (0-3)	n.s.
3	2.0 (0-11)	0.5 (0-3)	< 0.05

n.s. Non-significant
N Flock

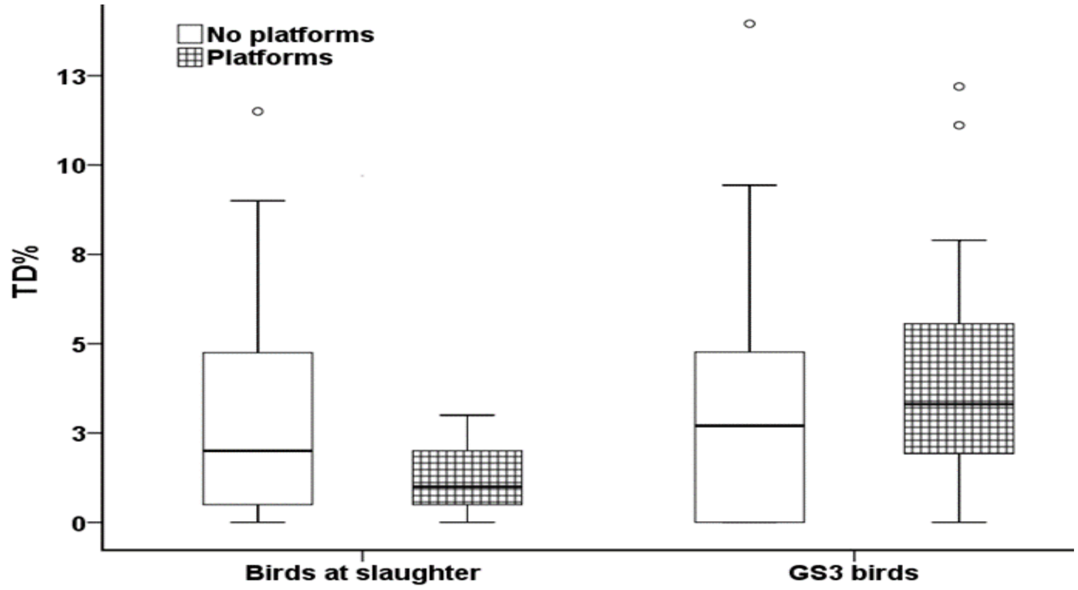

Figure 10 *Median percentage and interquartile range of broilers with tibial dyschondroplasia (TD) lesions in 200 birds assessed at slaughter and of TD in birds with gait score 3 (GS3). Gait was scored at the age of 34-36 days in the winter or at 29-31 days of age in the summer following the assessment scale of Welfare Quality®; score 3 = moderate gait abnormality. Line over boxes indicates statistical difference (*P *< 0.05).*

6 Discussion

6.1 Contact dermatitis and breast blisters in broiler breeders (Study I)

As was expected, the occurrence of footpad lesions increased and they became more severe as broiler breeders aged, with severe lesion occurrence reaching a maximum of 64% at slaughter age. Observations of these lesions at gross and histopathological levels revealed no suggestion of bacteriological involvement.

Footpad lesions may start to heal if litter conditions improve (Greene *et al.* 1985, Martland 1985, Mayne *et al.* 2007, Cengiz *et al.* 2012). Smooth footpad skin without scales is considered to be scar tissue from recovered lesions (Michel *et al.* 2012). These kinds of lesions were included in the scoring system within small and large superficial lesions (scores 1 and 2), and were not recorded separately. The increasing number of severe lesions towards slaughter age probably obscured any minor effect of healing in the current study.

Hock lesions and breast blisters were rarely detected in this study. Compared with footpad lesions these pathologies appeared to represent minor problems in the investigated breeder hens. Our study might, however, underestimate the occurrence of these lesions as they are commonly reported in males (McIlroy *et al.* 1987, Bruce *et al.* 1990, Gouveia *et al.* 2009). Males were not included in our study, and as far as we know, there is no information about the prevalence of hock lesions or breast blisters in broiler breeders.

The manual catching of birds for inspection during the production period could have affected the selection of evaluated birds. We changed the catching locations throughout the whole house during scoring. Often birds in poor condition are easier to catch, which could lead to over-representation of weak birds. On the other hand, sick and weak birds often tend to hide in the nests and thus are out of catchers' reach. The results over the entire production period, including the sampling points at transport and slaughter, which were not influenced by the catching method, are, however, in line. Therefore, we could assume that a possible effect of catching was minimal.

6.2 Effects of housing conditions on breeder footpads (Study I)

Litter condition

Mean litter condition score was poorest when birds were 48 weeks of age. Overall, the litter was in good condition with the mean score never exceeding 1, on a scale from 0 to 4. Although higher litter condition score was associated with higher footpad lesion scores, litter condition score had no effect on the percentage of severe lesions. Also, it is worth noting that completely dry and friable litter over the whole production period did not guarantee healthy footpads. In regard to severe footpad lesions in broilers, litter condition is usually much worse than observed in this study (Martland 1985, de Jong *et al.* 2014).

The litter condition in breeder houses does thus not fully explain the deterioration of footpads. Nevertheless, friable litter has other advantages: it allows birds to express normal behaviour like foraging, scratching (Hall 2001) and dustbathing more easily (Bokkers and Koene 2003, Appleby *et al.* 2004). This litter-directed behaviour may, in contrast, help keep litter in a friable condition. Dry litter could also help keep floor eggs cleaner (Sander *et al.* 2003) and contribute to plumage cleanliness (Martland 1985, Haslam *et al.* 2006).

Reusing litter over several successive batches increases the severity of footpad dermatitis in broilers (Bilgili *et al.* 2009, Almeida *et al.* 2010). One could hypothesise that the effect of reused litter and litter used for a long period is the same. Over a long production period faecal material, which accumulates in the bedding, might increase the irritant level of the litter even when litter is not wet or sticky. Some species of fungi growing in poultry litter may potentially produce mycotoxins (Dennis and Gee 1973, Brown *et al.* 2008) that could cause skin damage and act as an irritant (Brown *et al.* 2008). Adding fresh bedding material regularly has a positive impact on footpad health of turkeys, as compared with birds kept on unchanged litter (Charles and Fortune 1977). Added fresh litter material might dilute irritants to a level less harmful for footpads. In our study none of the producers added fresh bedding material regularly. Martins *et al.* (2013) suggested that impaired footpad condition of more active birds was due to more intense contact of footpads with litter. Broiler breeders are more active than broilers, which might increase the negative effect of irritants of litter on footpad health. The influence of irritants in litter and regular addition and turnover of litter on the footpad health of broiler breeders would merit detailed investigation.

Litter quality

During the production period the litter layer became drier. Litter moisture is affected by management practices, especially by the control of temperature and relative humidity through adequate ventilation (McIlroy *et al.* 1987, Jones *et al*. 2005). Also the water-releasing capacity of the litter material could influence the result (Bilgili *et al*. 2009). Although drier litter was associated with better footpad condition, other factors were of greater importance, as footpad lesions, particularly severe lesions, became more frequent towards slaughter age. In several studies litter wetness was considered to be the most important factor leading to footpad lesions in broilers, turkeys and laying hens (Wang *et al.* 1998, Mayne *et al.* 2007, de Jong *et al.* 2014). In Martland's (1985) study, wet litter (71% moisture) caused more contact dermatitis than dry litter (58% moisture). Wu and Hocking (2011) concluded that litter moisture exceeding 30% leads to impaired footpad condition. In our study litter moisture was slightly over 30% only at 24 weeks. Nevertheless, it is unlikely that this would have resulted in the increase of severe lesions after 48 weeks because footpad lesions deteriorate quickly on wet litter (Greene *et al.* 1985, Martland 1985). Litter wetness might be a less important factor for older birds than for younger birds, while other causes might become more important at an older age (Mayne *et al.* 2007). This could be the case with broiler breeders. Maybe the structure of footpad skin changes over time, thus increasing the susceptibility of the skin. However, in none of the houses of this study was litter extremely wet, therefore we were not able to establish the long-term effects of overly wet litter conditions on breeder footpads.

We observed better footpad condition in flocks from houses with higher litter ammonia content and lower pH. A contrary connection with ammonia was reported previously (Haslam *et al.* 2006). On the other hand, in several studies, ammonia did not have an impact on footpad lesions (Wang *et al.* 1998, Mayne *et al.* 2007, Martins *et al.* 2013). It is, however, important to note that we measured litter ammonia, while atmospheric ammonia was measured in most previous studies (Wang *et al.* 1998, Haslam *et al.* 2006, Mayne *et al.* 2007, Martins *et al.* 2013), thus making the role of ammonia difficult to determine. Maybe atmospheric ammonia does not influence footpad skin in the same way as ammonia absorbed into litter particles.

Slats

In addition to litter, the footpads of broiler breeders are in contact with slat material. We observed increasing slat area to be associated with poorer footpad condition. Several characteristics of the slats might be important. Unsuitable slat material, such as wood containing irritant compounds, was reported to cause serious damage to footpads in broiler breeders (Sander *et al.* 1994). In addition, wet perches (Wang *et al.* 1998) and unsuitable perch design had a negative effect on footpads of laying hens (Tauson and Abrahamsson 1994, Pickel *et al.* 2011). A high prevalence of footpad lesions and increased culling rate due to footpad damage were detected in an experiment exploring the effect of a wire cage floor on footpad health in broiler breeders (Pearson 1983). Adult chickens use perches for night-time roosting (Appleby *et al.* 2004) and broiler breeders use the elevated slat surface for the same purpose (Gebhardt-Henrich *et al.* 2016). Since they are heavier than laying hens, slat design and material, combined with a long time spent on the slats, might have even greater impact on pressure distribution on footpads, enhancing the negative effect of slats on footpads. Our setup did not, however, allow for the comparison of different slat materials. Furthermore, conclusions related to slat area are difficult to reach due to the confounding effect on litter area: the larger the slat area the smaller the litter area, and *vice versa*. The impact of slats on footpads of breeders should thus be studied further.

Other causes

This study focused on litter condition and quality on contact dermatitis in breeder hens. Also other factors, such as nutrition (reviewed by Mayne 2005), genetics (Kjaer *et al.* 2006) and sex (McIlroy *et al.* 1987, Bruce *et al.* 1990) affect footpad health of broilers. Our results do indicate that the effect of litter quality on the condition of footpads in breeders is not as straightforward as it is in broilers, therefore the impact of other risk factors should be studied.

6.3 Contact dermatitis in broilers (Study II)

In general, footpad health in tested broiler flocks appeared good in comparison with earlier studies; over 70% of the birds had healthy footpads and, more importantly, in both assessment methods the most severe lesions (score 2 in official and score 4 in the WQ-assessment) were detected only occasionally. This finding differs from several earlier observations made on commercial broilers where the majority (from about 50% to nearly 100%) of birds had footpad lesions (Ekstrand *et al.* 1997, Meluzzi *et al.* 2008b, Allain *et al.* 2009, de Jong *et al.* 2012b, Kyvsgaard *et al.* 2013, Saraiva *et al.* 2016). Because this investigation was performed during winter, which is the season with highest risk for footpad dermatitis (Haslam *et al.* 2007, Meluzzi *et al.* 2008b, de Jong *et al.* 2012b), the difference between our and the international situation is probably not a consequence of seasonal effect. A lower prevalence of footpad lesions was linked with a lower incidence of severe footpad lesions (Pagazaurtundua and Warris 2006b) and our observation supports this conclusion. The farms voluntarily participated in this study and it is possible that there is bias towards better performing farms in our sample. Also, farmers may, due to ongoing investigations, pay more careful attention to controlling housing conditions, leading to a favourable outcome. However, the same concerns probably apply to most comparable field studies.

The presence and severity of footpad lesions varies depending on local litter condition in the house. To display accurately footpad health at flock level varying litter condition areas should be thoroughly represented (de Jong *et al.* 2012c). The importance of severe contact dermatitis for individual broilers should not be ignored, even if the results indicate a good situation at flock level.

We observed lesions on hock skin more frequently than on footpads, yet most of the hock lesions were mild (score 1 and 2) and severe lesions were as scarce as for footpads. The data from previous studies showed contrary results, more footpad lesions than hock burns (Haslam *et al.* 2007, Allain *et al.* 2009, Saraiva *et al.* 2016). The hock burn prevalence in the UK and Portugal surveys was low, 1.3% and 9.7%, respectively (Haslam *et al.* 2007, Saraiva *et al.* 2016), compared with our results. However, a French study detected a considerably higher number of affected birds, 60% (Allain *et al.* 2009), than observed in the present study. Various scoring scales make the comparison among different studies difficult.

Because hock burns appear more frequently in Finnish circumstances than footpad lesions, hock burn monitoring could represent a more sensitive indicator for litter condition, at least in Finland. However, these forms of contact dermatitis have been suggested to display, at least partly, different aetiologies because they do not appear to share all the same risk factors (Haslam *et al.* 2007). The impact of bird weight and/or age could exceed the effect of litter condition for hock burns (Haslam *et al.* 2007, Hepworth *et al.* 2010). Also stocking density (kg/m^2) at slughter age, or even at 2 weeks of age are reported as possible risk factors for hock burns (Hepworth *et al.* 2010). Hock lesions seemed to increase significantly after 41 kg/m^2 (Buijs *et al.* 2009), so it is possible that densities in this study may have negatively affected hock skin health. Hock burn occurrence may reflect simply different skin structure on hock area and footpads. The function of footpads is to be in constant contact with the ground or perch, while hock skin is not. Therefore, hock skin structure and strength likely differ from footpad skin. Modern heavy broilers rest most of their time, resting more with increasing age (Weeks *et al.* 2000) and while lying down hock skin is placed on the litter, not just the footpads (Kjaer *et al.* 2006, de Jong *et al.* 2012b), increasing the risk of hock skin lesions. Impaired bird health have been suggested to predispose to hock burns (Haslam *et al.* 2007). The compromised health status, due to *E. coli* infections, in several flocks in this study could have induced more resting, and thus caused impaired hock skin health.

6.4 Effects of litter materials on broiler contact dermatitis (Study II)

Peat was more beneficial for footpad health than either of the other bedding materials, although the difference between peat and ground straw was not as obvious as between peat and wood shavings. Surprisingly, regardless of superior footpad condition on peat, the difference in litter condition between peat and wood shavings was not substantial, whereas houses with ground straw had poorer litter condition compared with their peat-controls. This conflicting observation could arise from the overall inferior footpad health and slightly worse general litter condition in houses with ground straw and respective peat-controls compared with wood shavings and their controls. Supposedly, the farms for ground straw comparison struggled also to maintain peat in an acceptable condition, resulting in nearly similar footpad health on peat and ground straw.

Friable and dry litter is recognised as the most important factor promoting footpad health (Greene *et al.* 1985, Meluzzi *et al.* 2008b, Bassler *et al.* 2013), but the litter material of choice also impacts footpad health (Su *et al.* 2000, Bilgili *et al.* 2009, Kyvsgaard *et al.* 2013). Previous research has frequently demonstrated better footpad condition on wood shavings than on straw (Su *et al.* 2000, Meluzzi *et al.* 2008a, Kyvsgaard *et al.* 2013). This difference could be explained by the particle size of the material. Bedding material containing smooth and fine particles has been connected with enhanced footpad health, compared with materials consisting of coarse particles (Cengiz *et al.* 2012). However, it should be noted that straw in earlier studies has typically been cut straw while we tested ground straw containing fine particles that, we assume, improved the water absorbing capacity of the product. Peat is not a globally common bedding material for poultry, thus it has been tested in few studies only, with contradictory results. Compared with wood shavings, more friable peat litter results in healthier footpads in broilers (de Baere *et al.* 2009). In contrast, a large Danish investigation demonstrated no significant differences in litter condition on wood shavings, straw and peat despite inferior footpad health on straw litter (Kyvsgaard *et al.* 2013). Furthermore, turkeys on reed-sedge peat exhibited reduced footpad health even though peat bedding was found to be easier to sustain in a friable condition than wood shavings (Enueme *et al.* 1987). However, comparing the results of that and our study is questionable because we tested *Sphagnum* peat.

Peat litter resulted in healthier hock skin than either of test materials. Previous research verified that litter condition affects the incidence of hock burns (Bruce *et al.* 1990, Haslam *et al.* 2007, Allain *et al.* 2009, de Jong *et al.* 2014), which probably explains the observed differences among litter materials.

Litter moisture

Wet litter conditions compromise footpad health (Martland 1985, Mayne *et al.* 2007, de Jong *et al.* 2014). Litter moisture over 30% has been shown to substantially increase lesions in turkeys (Wu and Hocking 2011), but a more recent study demonstrated a higher threshold moisture of 49% in relation to greater risk for footpad dermatitis in turkeys (Weber Wyneken *et al.* 2015). Our observation of the moisture of peat and wood shavings exceeding 30% at the end of production period, with still acceptable litter condition and footpad health, is more in line with the latter conclusion. We also measured fairly high initial moisture in peat, with mean moisture over 30% in half of the houses. Interestingly, in the beginning, fresh peat was moister than either of the test bedding materials, but the moisture of exhausted litter did not differ from that of the other bedding materials. However, footpad health was scored inferior on wood shavings compared with peat, without observed differences in litter condition and moisture at the end of the production period. Moreover, the lack of difference in end moisture between ground straw and peat still resulted in poorer litter and footpad condition on ground straw. In an earlier study, comparing reed-sedge peat and wood shavings, in spite of similar moisture contents, peat litter maintained its friability better than wood shavings (Enueme *et al.* 1987). Based on our results, we hypothesize that the relationship between litter condition, moisture and footpad lesions is more complex than previously stated.

In addition to litter wetness *per se*, also the ability of bedding material to absorb and release moisture has been demonstrated to be essential for footpad health (Bilgili *et al.* 2009) and litter condition (Dunlop *et al.* 2015); better absorbing and releasing capacities have been connected with enhanced footpad and litter condition. During the production period the water holding capacity of wood shavings litter has been shown to increase, compared with that of fresh wood shavings. However, while the litter moisture content is maintained, the porosity of the litter layer decreases, leading to a more compact litter layer. Furthermore, the water releasing capacity of wood shavings bedding seems to improve along with increasing litter moisture (Dunlop *et al.* 2015). *Sphagnum* peat has high water absorbing capacity (Feustel and Byers 1936). A study, performed with peat as broiler litter, demonstrated that the high initial moisture of 40-50% rapidly evaporated from the litter (de Baere *et al.* 2009). We measured increased average moisture content in wood shavings and ground straw during the production phase. However, peat had constant average moisture in half of the houses, probably due to high initial moisture of peat in the houses. Our finding suggests that, with regard to footpad lesions and litter condition, peat may have a higher level threshold for when moisture content becomes a risk factor for contact dermatitis. Furthermore, it is possible that the threshold moisture to induce hock burns is lower than that for footpad lesions. Peat may be able to maintain more successfully its friability and an acceptable moisture content through the production period. However, further investigation, preferably under more challenging conditions, is required to confirm this conclusion.

Litter pH

As expected, peat had the lowest initial pH. However, in the end we recorded no difference in pH between peat and wood shavings, while ground straw litter had even lower end pH than peat. Also, litter pH did not influence footpad health. Earlier research, using other bedding materials, also revealed negligible impacts of litter pH on footpad health (Wang *et al.* 1998, Meluzzi *et al.* 2008a, Wu and Hocking 2011). Since pH was measured only twice, we are unable to conclude how quickly pH rose with time, but obviously, in opposition to our hypothesis, low pH alone cannot explain the superior footpad condition on peat. Litter pH influences the bacterial composition in litter (Elliot and Collins 1982, Everett *et al.* 2013). The lower pH of peat at the outset might favour bacterial growth that provides better circumstances for footpad health. This suggestion, however, requires more research.

Farm effect

The observed profound variation between farms in litter quality and the prevalence of contact dermatitis agrees with previous conclusions on the impact of farmers (McIlroy *et al.* 1987, Jones *et al.* 2005, Meluzzi *et al.* 2008b, de Jong *et al.* 2012b). Farmers in this study had long experience with managing peat bedding and handling a new material would probably have required some time to adapt, which may partly explain the differences detected among litter materials, offering an advantage for peat. Despite the detected interaction between farm and litter material, peat was numerically superior in all farms (results not shown). However, although farmers were familiar with peat, variation in peat bedding quality seems large, suggesting a marked effect of management skills, houses or equipment on the outcome. To improve moisture release from moist litter an accelerated ventilation rate is required (Weaver and Meijerhof 1991, Dunlop *et al.* 2015), thus the farmer's capability to manage house ventilation, temperature and humidity is key to control litter moisture and sustain skin health (McIlroy *et al.* 1987, Dawkins *et al.* 2004, Jones *et al.* 2005). A recent study concluded that when moisture generation is highest during the production period, it might be challenging to keep litter in a dry and friable condition (Dunlop *et al.* 2015). In this study, litter condition and moisture were unable to explain fully the lower prevalence of contact dermatitis on peat litter compared with wood shavings and ground straw. Therefore, we can speculate that, regarding footpad health, peat proved to be more forgiving a bedding material in challenging circumstances, and for a less experienced farmer. Furthermore, misting systems in broiler houses have been connected with higher risk of contact dermatitis (Jones *et al.* 2005). All houses in this study, were equipped with misting systems. Thus the higher litter wetness in some houses could have been caused by suboptimal management of misting systems.

Despite the overall satisfactory litter condition in all houses, we detected a large variation in litter condition in different locations within a house. Logically, litter under the drinker lines was wettest, as reflected by a worse condition score. The number of drinkers (Jones *et al.* 2005), drinker type (Bray and Lynn 1986, Ekstrand *et al.* 1997, Jones *et al.* 2005) and the adjustment of the water pressure and height of drinker lines affect litter quality (Carey *et al.* 2004). The incidence and severity of footpad dermatitis in birds at a certain location in a broiler house depend on local litter condition (de Jong *et. al.* 2012c). This effect is probably stocking-density related: at lower densities birds can more easily avoid wet areas, but the higher the density the greater the negative influence of wet locations in the house. At flock level, the size of the compromised litter area may also impact the situation, a larger area leading to a worse outcome. It is possible that differences in footpad health among farms could indicate variation in wet area under drinker lines among farms.

6.5 Differences in contact dermatitis and litter condition between breeder and broiler production (Study I & II)

Contact dermatitis

At slaughter age (around 60 weeks for breeders and 38 days for broilers), the footpad health of breeders and broilers appeared almost opposite. In breeder flocks the majority of hens had severe lesions and healthy footpads were detected only in few birds, whereas in broiler flocks the vast majority of the birds had healthy footpads and severe lesions were scarce. The age or weight of the birds may partly explain this difference. Contact dermatitis becomes more common and prominent as broilers age (McIlroy *et al.* 1987, Bruce *et al*. 1989, Haslam *et al.* 2007, Gouveia *et al.* 2009) and grow heavier (Kjaer *et al.* 2006, Hepworth *et al.* 2010, Saraiva *et al.* 2016). However, when breeder footpads were evaluated for the first and second time, at 19 and 24 weeks of age, almost all the birds had healthy footpads. Thus, age alone does not account for the difference. As the growth rate of breeders is not as fast as that of broilers it is apparent that the role of weight might be of less importance in the aetiology of footpad dermatitis in breeders. However, Wang *et al.* (1998) considered the enhanced risk for footpad lesions in laying hens over time to be partly due to weight increase. In addition, Wolanski *et al.* (2004) studied male broiler breeder males, and concluded that body weight, rather than age as such, might have a greater impact on footpad condition. Thus, increasing body weight might explain part of the deterioration of footpad scores of broiler breeders towards slaughter age because the body weight of breeders does increase throughout the production period, from on average 2.0 kg at 19 to 3.9 kg at 60 weeks of age (Aviagen 2013).

Furthermore, the presence of hock burns in broilers and parents appeared very different. This pathology was rarely detected in all breeder flocks, but in broilers hock skin lesions were more common than footpad dermatitis. The difference may reflect better leg health in breeders than broilers, or it could result from varying activity and sitting position of these birds. Fewer hock skin lesions were found in organic broilers, which may imply their greater activity and better walking ability (Broom and Reefman 2005). In modern heavy broilers, while lying down, hock skin is placed on the litter rather than only the footpads (Kjaer *et al.* 2006, de Jong *et al.* 2012b), increasing the risk for hock skin lesions to develop. Breeders, on the other hand, spend more time standing and walking, and even when sitting weight is set on the feet, leaving hock skin in the air. Furthermore, breeders use the elevated slat surface for night-time roosting (Gebhardt-Henrich *et al.* 2016), thus avoiding contact with litter. Several studies reported a correlation between impaired walking ability and hock burns (Kestin *et al.* 1999, Su *et al.* 1999, Sørensen *et al.* 1999, Sørensen *et al.* 2000, Kristensen *et al.* 2006, Haslam *et al.* 2007). Hock burns may be triggered by walking difficulties, inducing more resting and thus allowing more time for skin to be in contact with litter. Convercely, lameness could be caused by painful hock lesions (Sørensen *et al.* 2000, Kristensen *et al.* 2006). In this study, impaired hock skin health in broilers could possibly also be explained by increased resting periods due to *E. coli* infections in several flocks.

Litter condition

Litter condition evaluation did not reveal substantial differences between breeder and broiler houses. However, due to different layouts of the houses, the locations of higher risk for litter deterioration did differ. In broiler houses, the moistest litter was located under the drinker lines, whereas in breeder houses drinker lines are typically placed over the slatted area, which reduces the risk represented by leaking nipples. In breeder houses, the litter at the edge of slats was highest, most moist and the ammonia content was also highest there. The result possibly reflects active bird traffic at the edge of slats as well as accumulation of moisture from faeces at such locations. Also, air movement could be different in that area compared with other parts of the house, making local litter management more challenging.

According to our broiler study, peat was confirmed to be more advantageous for footpad health than other tested bedding materials. Nevertheless, breeders had compromised footpad health despite most breeder flocks being kept on peat bedding.

Litter quality

At the end of the production period litter moisture in breeder houses was lower than in boiler houses with peat bedding. The majority of breeders had severe footpad lesions in spite of an average litter moisture of 24% at slaughter age. In contrast, the average moisture in half of broiler houses with peat litter was over 50% at the end, yet even in those houses severe footpad lesions were scarce. This strengthens our earlier conclusion that, with regard to breeder footpad health, litter moisture is not the sole key contributing factor. Even though environmental control successfully managed litter moisture in breeder houses, faecal load over 40 weeks of production compared with broilers' 5-6 weeks may create the critical difference, leading to contrasting outcomes between breeder and broiler footpad health.

Lower pH in breeder house litter was connected with healthier footpads while pH in broiler house litter was not associated with footpad condition. Already at first sampling litter pH in breeder houses was at the same level as in broiler houses at the end of the production period. Thus a possible advantage of low initial pH of peat bedding vanished by the end of the broiler rearing period, and during the breeder production period already at an early stage. These results further support our previous conclusion that the initial acidity of peat bedding plays a minor role in prevention of footpad lesions.

A thinner layer of litter had a positive impact on footpad condition of broilers (Ekstrand *et al.* 1997, Martrenchar *et al.* 2002). Our results disagree with this. During the production period the litter layer in breeder houses continuously became higher, but height did not impact footpad condition. Neither in broiler houses did litter thickness correlate with footpad health.

Stocking density

The effect of stocking density on footpad condition seems complex. We recorded a tendency for higher breeder density at the end to be linked to better footpad condition. Furthermore, higher broiler density was associated with healthier footpads. However, the number of observed flocks was low, thus limiting to the generalization of the results. Higher stocking density in broiler houses has previously been found to affect footpad health negatively (Craventer *et al.* 1992, Martrenchar *et al.* 1997, Hall 2001, Arnould and Faure 2004, Thomas *et al.* 2004, Dozier *et al.* 2006, Buijs *et al.* 2009), while other authors reported no association (Martrenchar *et al.* 2002, Haslam *et al.* 2006, Haslam *et al.* 2007, Sirri *et al.* 2007, Allain *et al.* 2009). Some studies measured stocking density as kg/floor space, while others calculated it as birds/floor space. Also, effects of stocking density can differ according to experimental settings and field conditions. These factors may impede comparisons among results of different studies.

In this study, it is however possible that a lower bird density in the end actually reflects poorer health, and thus increased mortality during the production period. This suggestion particularly applies to the situation in broiler flocks, as the lowest bird densities were registered for flocks with the highest mortality levels due to *E. coli* infections.

Stocking densities in breeder houses are much lower than commonly found densities in broiler houses, making comparison of the effect of density on footpad condition in breeders and broilers difficult. A previous study described a possible threshold for risky stocking density adversely affecting broiler footpad health (Buijs *et al.* 2009). The hazardous level of bird density may be different for broilers and breeders.

6.6 Litter condition and contact dermatitis in platform-equipped houses (Study II)

The study indicated no effects of platform treatment on footpad health and litter condition, implying that this additional equipment did not interfere with the airflow. However, it should be noted that this outcome applied to peat bedding, and thus does not necessarily apply to other litter materials. Yet, the familiar bedding material, peat, in the houses of the present study, better assured impartial circumstances to test platform effect on litter condition and contact dermatitis.

Limited and contradictory data are available on the influence of perching possibility on footpad health. One previous study found no effect of perches on broiler footpads (Su *et al.* 2000), but others showed a tendency for improved footpad health in birds with perches (Hongchao *et al.* 2014, Ventura *et al.* 2010, Kiyma *et al.* 2016). Ohara *et al.* (2015) suggested that more active use of perches or higher activity of females resulted in enhanced footpad health in female broilers with access to perches. However, none of the earlier studies offered information about perch presence on litter condition. Further research is required to ensure the effects of equipment introduced into broiler houses on litter and footpad condition.

The study established no effect of platforms on hock skin condition, possibly due to undetected differences in litter condition between equipped and control houses. Existing literature provides inconsistent information about the effect of perches on hock skin health. Swiss research detected fewer hock burns in birds with access to elevated platforms (Oester *et al.* 2005), but other studies found no influence of perches on hock skin condition (Ventura *et al.* 2010, Hongchao *et al.* 2014).

6.7 Use of perches and platforms by broilers (Study III & IV)

We observed almost no use of perches, whereas platforms were used frequently. The difference was consistent throughout the entire study, during the whole growing period in all flocks. Furthermore, farmers' observations agreed with the actual numbers of birds observed by video recording occupying the same perches and platforms in one farm. Our results support those of earlier studies showing a low use of conventional perches by broilers. Most experimental studies on broiler perching indicate that perches are used only to a modest degree, typically, 1-3% of the birds have been observed perching (LeVan *et al.* 2000, Su *et al.* 2000, Pettit-Riley and Estévez 2001, Tablante *et al.* 2003, Groves and Muir 2013). A recent study reported an average 7% of broilers using perches (Kiyma *et al.* 2016) and broilers have also been reported to perch as much as 10-25% of their time (Bizeray *et al.* 2002a, Ventura *et al.* 2012). However, even in slow-growing broilers, perching behaviour is highly variable, depending on bird age and breed (Nielsen 2004, Lee and Chen 2007, Rodriguez-Aurrekoetxea *et al.* 2015).

In the current study, observations made on broilers under commercial conditions may have contributed to the low use of perches. Due to prominent differences between field conditions and experimental settings it is difficult to compare the results of our field survey with those of earlier studies conducted as small-scale pen trials (Pettit-Riley and Estévez 2001, Ventura *et al.* 2012, Hongchao *et al.* 2013, Kiyma *et al.* 2016). Nevertheless, the marked difference in the use of perches compared with platforms observed in the present study indicates that offering traditional perches to broilers in commercial farms might be suboptimal use of a farmer's resources. Although it is important to increase the environmental complexity for broilers, the value of traditional perches, at least of the type used in this study, for broiler welfare, might need critical evaluation.

Age

Our results show that fewer birds used the platforms near slaughter age than at the younger observation age. This might be mainly due to the fact that the broilers were larger and there was not enough room for as many birds to use the platforms as at the beginning. Another possible factor contributing lower use of platforms of older broilers is their dwindling locomotor activity. Most commonly, a peak in perching behaviour was observed at 4-5 weeks of age (Rind *et al.* 2003, Ventura *et al.* 2012, Bailie and O´Connell 2015, Kiyma *et al.* 2016). However, Ohara *et al.* (2015) recorded highest perching rate already at the age of 3 weeks.

Diurnal use

Platforms were used more during the day than during the night. This implies that platforms were not primarily used for nocturnal perching, which, in adult chickens is a highly motivated behavioural pattern (Olsson and Keeling 2000). Diurnal rhythm does not seem to affect broiler perching (Hughes and Elson 1977, Martrenchar *et al.* 2000, Kiyma *et al.* 2016). Though, easy access increases perching in the night (Sandilands *et al.* 2016). Nielsen (2004) reported a clear diurnal rhythm of more perching at night with one slow-growing broiler strain at 5 weeks of age while no perching at all with another slow-growing strain. However, also layer chicks started using perches during the day at a much earlier age than during the night. Still, at the age of 6 weeks, layer chicks mostly rested under the heating lamps during the nights rather than perching (Heikkilä *et al.* 2006). This suggests that also broilers may be too young for regular nocturnal roosting.

Perch accessibility

Compared with layer chickens, broilers are much heavier and are bred for muscle size (Duggan *et al.* 2016). One possible reason for restricted perch use is the breed. In the present study, we used a fast-growing meat chicken (Ross 508) with a high breast muscle yield. Enlarged breast muscles that have shifted the broiler's centre of gravity forward (Corr *et al.* 2003b, Paxton *et al.* 2013, Duggan *et al.* 2016), and impaired gait are associated with selection for fast growth (Kestin *et al.* 1999) and may cause difficulties for broilers to jump and balance on traditional perches. Hence, we suggest that ramp access increased the acceptance of platforms, as was reported by Oester *et al.* (2005). It is possible that if we had used ramps with the perches, this could have increased perch usage. However, in a previous study, an angled perch, offering easy access from the floor to the perch, did not significantly increase perching (Pettit-Riley and Estévez 2001). In the present study, platforms may have provided a more pleasant place to lie down instead of balancing on a conventional perch.

Broiler chickens seem to have difficulties reaching higher perches as they mostly used the lowest ones, only requiring a leap of 10 cm. In addition to being the lowest, the 10 cm perches were also at the outside of the structure, allowing birds to jump on them directly from the ground, whereas the higher perches were probably reachable from another perch. Some earlier studies with comparable perch height (15 cm) reported more frequent perching (Bizeray *et al.* 2002a, Ventura *et al.* 2012. Kiyma *et al.* 2016), while in other studies, with equal perch heights, perching level was fairly modest, generally less than 3% of the birds using perches (Oester *et al.* 2005, Pettit-Riley and Estévez 2001, Groves and Muir 2013). More frequent use of lower perches in previous studies (Pettit-Riley and Estévez 2001, Groves and Muir 2013) is supported by observations in this study. Another possible reason for the low perch use could be unsuitable perch thickness. However, in previous studies, perches of comparable thickness were used by broilers (Bizeray *et al.* 2002a, Bailie and O´Connell 2015).

Perching motivation

The fact that the broilers used platforms frequently, indicates that they were motivated to use elevated structures if given the possibility. Previously, several studies concluded that broilers were motivated to perch when offered an attractive opportunity to do so (Hughes and Elson 1977, Davies and Weeks 1995, Ventura *et al.* 2012). Thus, it seems probable that the observed restricted use of perches was not due to a lack of motivation as such. In our study, because the platform and perch structures were similarly distributed across the house, the distance could not have affected the difference in usage. Easy accessibility increased perching (LeVan *et al.* 2000, Sandilands *et al.* 2016). The structure provided should be so appealing that broilers are willing to make the extra effort to climb there, in spite of possible physical challenges. A Swiss study confirmed that instead of traditional perches, broilers more frequently used elevated platforms with ramp access (Oester *et al.* 2005). Also some laying hen strains preferred platforms over traditional wooden perches (Faure and Jones 1982). A recent study demonstrated that laying hens more easily mounted elevated slats using wire ramps that enabled better grip with toes. Also, slopes of less than 40° allowed a more effortless walk to the platforms, without assistance from wings (LeBlanc *et al.* 2016). Broilers using ramps with an angle of 25° assisted walking by using their wings (Balog *et al.* 1997). The 15° incline and grid surface in our prototype platform may have provided optimal access to the structure for broilers. Moreover, we noticed broilers inhabiting and resting on the ramps, which may indicate that also this part of the structure was a pleasant place to rest despite the inclination.

One possible explanation for the high use of platforms is that the perching behaviour was motivated by an urge to decrease density. More perching has been recorded at higher densities (Hughes and Elson 1977, Martrenchar *et al.* 2000, Pettit-Riley and Estévez 2001). However, studies show contradictory results as higher density was reported to decrease all activity, including perching (Ventura *et al.* 2012). At high densities, rest seems to be frequently disturbed (Murphy and Preston 1988, Lewis and Hurnik, 1990, Martrenchar *et al.* 1997, Hall 2001). Hence, high stocking density at slaughter age in the current study may have motivated broilers to use the platforms actively to reduce crowdedness at floor level and seek for more undisturbed rest on the platforms. If high density played a role in platform usage, apparently, it was not enough to encourage perch use. Due to a low number of flocks at varying densities we were not able to answer this question. The motivation behind willingness to occupy platforms even near slaughter age requires further research.

6.8 Effect of platforms on broiler walking ability (Study IV)

Our finding of better walking ability in birds with access to platforms indicates that broilers benefitted from the locomotion facilitated by the additional equipment. Walking ability is improved by any measures that increase the mobility of broilers, such as increased walking distances (Reiter and Bessei 2009, Ruiz-Feria *et al.* 2014), lower stocking density (Knowles *et al.* 2008, Aydin *et al.* 2010), exercise equipment (Bizeray *et al.* 2002b) or outside access (Fanatico *et al.* 2008). Also, swapping diets during the day may improve walking ability, probably due to decreased weight gain accompanied by increased activity (Bizeray *et al.* 2002d).

Apparently, more space alone, at a lower stocking density, is not enough to increase broiler mobility (Arnould and Faure 2004, Sherlock *et al.* 2010) sufficiently to promote improved gait (Sherlock *et al.* 2010). However, higher density increased the incidence of lameness (Sørensen *et al.* 2000, Sanotra *et al.* 2001a,b, Hall 2001, Thomas *et al.* 2004, Knowles *et al.* 2008), possibly by reducing general activity (Sørensen *et al.* 2000, Knowles *et al.* 2008, Simitzis *et al.* 2012). Furthermore, extra equipment occupying the floor space, when not used, might increase stocking density on the floor, possibly leading to decreased activity (Tablante *et al.* 2003). We intended to avoid this negative effect by providing platforms high enough to allow birds to use the floor space beneath the structures.

Although increased locomotion improves broiler leg health (Bizeray *et al.* 2002b, Reiter and Bessei 2009, Ruiz-Feria *et al.* 2014), the positive effect of perching on walking ability was not obvious in a number of earlier studies (Su *et al.* 2000, Hongchao *et al.* 2014, Bailie and O'Connell 2015), presumably because perching has been too scarce. Although the platforms did not facilitate general activity on the floor in an area with no platforms (Study III, results not presented in the thesis summary), in flocks of this study, broilers probably walked longer distances to reach the platforms, offering them additional exercise compared with control flocks, even if the birds aimed to go up to the platforms simply to rest. Because fast-growing broilers spend excessive time lying down (Weeks *et al.* 2000), even slightly increased movement may be sufficient to enhance agility. In addition, access to platforms offered a variety of locomotion: walking forward, up and down, grasping the platform by feet, as well as occasionally jumping or flying. Equipment that encourages versatile exercise triggers changes in both breast and leg muscles (Sandusky and Heath 1988a,b). Alterations in muscles could influence the way broilers walk (Paxton *et al.* 2013) and thus explain the improved walking ability. We suggest that the difference in the results of our and previous studies arises from the use of offered equipment. The enhanced walking ability was probably attributed to the wide use of platforms in this study. Moreover, activity at a young age may reflect activity at older age (Bizeray *et al.* 2000, Weeks *et al.* 2000). In that case, encouraging the locomotion of young chicks, at as early age as possible, with additional and attractive perching structures, could lead to increased activity at older age and thereby contribute to enhanced leg health. However, we must bear in mind that impaired walking ability is associated with higher body weight (Kestin *et al.* 1992, Kestin *et al*. 2001, Sanotra *et al*. 2001a, Venäläinen *et al*. 2006, Nääs *et al.* 2010). Therefore, no matter how effective the ways we develop to improve broiler agility, the advantage, unfortunately, may rapidly be lost due to the continuously increasing growth rate of the birds.

Gait scores

In this study, the number of birds with gait scores 0 and 1 was extremely low. In previous field studies 10% (Kestin *et al.* 1992) and 25% (Sanotra *et al.* 2003) of the tested birds demonstrated normal gait. Also in a large survey performed in the UK 29% of the birds had gait scores 0 and 1 (Knowles *et al.* 2008). The low number of birds with scores 0 and 1 in the present study could be due to the subjectivity of the gait scoring method, but, alternatively, could be caused by continuous genetic progress in growth rate and size of breast muscles, leading to the deterioration of the broiler's gait (Kestin *et al.* 1999), thus making comparison with older studies difficult. Our result, however, agrees the observation of Sandilands *et al.* (2011), who detected no birds with normal gait and a small number of birds scored 1. In contrast, a recent Norwegian field study allocated over 30% of the tested birds gait scores of ≤ 1 (Kittelsen *et al.* 2017). The gait score age greatly differs between the Norwegian (around 29 days) and our study, which, at least partly, may explain the differences between these results.

On average, 30% of the tested birds had a gait score ≥ 3, with the majority of birds being scored 2 or 3. This result is in agreement with those of several other studies (Kestin *et al.* 1992, Sanotra *et al.* 2001b, Knowles *et al.* 2008, Kittelsen *et al.* 2017). The difference between scores 2 and 3 is partly based on the birds' manoeuvrability; birds scored 2 do not face difficulties in moving around, while movement is compromised in birds scored 3 (Kestin *et al.* 1992, Welfare Quality® 2009), suggesting impaired welfare of the latter group (Kestin *et al.* 1992, Danbury *et al.* 2000). Therefore, our observation of a lower percentage of birds with gait score 3 in platform-equipped houses indicates better welfare in these flocks compared with control flocks.

Not surprisingly, access to platforms had no effect on the percentage of birds scored 4 and 5. These birds probably suffer from serious leg pathologies (Kestin *et al.* 1992, Aydin *et al*. 2010), reducing their movement in general (Weeks *et al.* 2000, Aydin *et al*. 2010), thus lessening their interest in using the equipment. The number of birds scored 4 and 5 is presumably underestimated since the recommended practice is to cull lame birds (Kestin *et al.* 1992, Bradshaw *et al*. 2002, Knowles *et al.* 2008, Butterworth and Haslam 2009). Furthermore, these birds might easily be missed in gait assessment because they tend to hide in the corners and under the feeders. Consequently, the number of birds scored 4 and 5 more likely describes the farmers' ability and willingness to recognise and cull these birds than the genuine walking ability of the flock.

Age has a clear effect on the way broilers walk (Vestergaard and Sanotra 1999, Sørensen *et al.* 2000, Kestin *et al*. 2001, Bassler *et al.* 2013), and thus our result of better walking ability at younger scoring age was expected. According to several studies, this could also be due to increases in body weight with age (Kestin *et al.* 1992, Kestin *et al*. 2001, Sanotra *et al*. 2001a, Venäläinen *et al*. 2006). We did not weigh the assessed birds, but at flock level, the mean live weight at slaughter age had no effect on walking ability. Because we scored the birds at a younger age in the summer, we cannot fully exclude that our result is partly affected by the season. In that case, however, our result contradicts the finding of an earlier investigation that showed better broiler gait in the winter and early spring and worst in late summer (Knowles *et al.* 2008). In contrast, a survey on turkey males has demonstrated worse walking ability during the cold season (da Costa *et al.* 2014).

Walking ability can be linked with litter condition, moister litter having a deleterious effect on broiler gait (Su *et al.* 2000, Dawkins *et al.* 2004, da Costa *et al.* 2014). Additionally, the presence of contact dermatitis was suggested to affect broiler gait (Martland 1984, Greene *et al.* 1985, Kestin *et al.* 1999, Su *et al.* 1999, Sørensen *et al.* 1999, Sørensen *et al.* 2000, Haslam *et al.* 2007, Kristensen *et al.* 2006, da Costa *et al.* 2014, de Jong *et al.* 2014, Hothersall *et al.* 2016). The effect of footpad dermatitis on lameness possibly depends on the severity of lesions. A recent Norwegian study, reporting low footpad scores, noticed no connection between footpad health and walking ability at flock level (Kittelsen *et al.* 2017). In the present study, skin lesions probably had a minor effect on gait performance because of the low proportion of contact dermatitis, particularly severe lesions, in tested flocks (Study II).

Higher density has been reported to restrict broiler walking ability (Sørensen *et al.* 2000, Hall 2001, Sanotra *et al.* 2001a,b, Dawkins *et al.* 2004, Knowles *et al.* 2008). The absence of impact of stocking density on walking ability in the present study could be attributable to the fact that lower densities were the consequence of higher mortality rates. The effect of compromised health could have hidden the otherwise positive effect of lower stocking density. *E. coli* infections particularly may have had a direct impact on leg health because they can cause tenosynovitis or osteomyelitis (Butterworth 1999), thereby impairing walking ability.

Whole wheat in the diet has the potential to improve broiler walking ability (Knowles *et al.* 2008). Whole wheat was added to the diet on all farms of this study, to maintain enteric health, reduce feeding costs, and assist farmers to achieve the target slaughter weight range by controlling growth. The study yielded no effect of wheat percentage on walking ability, which could, however, be due to absence of a negative control. Hence, we cannot draw definite conclusions about the impact of wheat added to the diet.

6.9 Effect of platforms on TD occurrence (Study IV)

Access to platforms resulted in a reduced occurrence and severity of TD, contradicting several former studies using perches (Su *et al.* 2000, Bizeray *et al.* 2002b, Tablante *et al.* 2003). Again, we could argue that due to the low usage of perches, previous studies may have failed to show an improvement in leg health. Diverse locomotion might affect bone characteristics (Bizeray *et al.* 2002b), supporting leg health. Hence, we can hypothesize that several movement patterns, stimulated by platforms, could have contributed to the lower prevalence and severity of TD in the present study.

Overall, TD prevalence was fairly moderate in this study compared with in a number of previous studies on commercially reared broilers (McNamee *et al.* 1998, Sanotra *et al.* 2001b, Sanotra *et al.* 2003, Dinev *et al.* 2012). However, comparison with older studies might not be relevant, since the incidence of TD has been reduced by genetic selection over decades (Kapell *et al*. 2012b). Moreover, the prevalence of TD varies depending on the country of origin (Thorp and Waddington 1997, Sanotra *et al.* 2003), which could be due to nutritional differences (Thorp and Waddington 1997). Dietary variations might also explain some of the differences among farms in our study.

Some studies report an association between impaired gait and TD (Vestergaard and Sanotra 1999, Sanotra *et al.* 2002), while other studies reveal no correlation (Lynch *et al.* 1992, Garner *et al.* 2002, Venäläinen *et al.* 2006). However, due to fairly low TD incidence in tested birds, we can conclude that TD was not a major cause of impaired walking ability in birds with gait score 3, but evidently other factors are also involved. Our suggestion is in line with those of previous studies (Garner *et al.* 1992, Paxton *et al.* 2013).

6.10 Significance for broiler and breeder general welfare

A good level of animal welfare is assured by combining good health, positive emotions and possibilities to perform natural behaviours (OIE 2016). In this thesis, only a few limited aspects of welfare were measured, while estimating welfare from a wider perspective would have required a broader range of measurements. Therefore, the results of this study cannot describe the overall welfare status of broilers and breeders. Also, the study did not focus on the major welfare-issues associated with fast growth rate. Hence, heart-related conditions and metabolic disorders in broilers, and severe feed restriction with its negative consequences in broiler breeders, were beyond the scope of the current study.

Gait assessment, especially the existence of severely lame birds in the flock, measures health and pain to a certain extent. Furnishing broiler houses with elevated platfoms focuses on a possibility to perform natural behaviour, perching. If the birds were motivated to perch due to a need to decrease animal density, perching possibility may offer a way to reduce discomfort in high densities. Additionally, offering an opportunity to perch may improve leg health. Furnishing broiler houses with elevated platfoms thus does improve broiler welfare at some level, but alone is insufficient to ensure good level of welfare.

The existence and severity of contact dermatitis is thought to reflect litter quality, housing conditions, management and broiler health in a broad sense (Haslam *et al.* 2006). Friable litter allows birds to express natural behaviours, like foraging, scratching (Hall 2001) and dustbathing more easily (Bokkers and Koene 2003, Appleby *et al.* 2004). For broilers dry litter also offers a comfortable resting place (Weeks *et al.* 2000). However, maintaining friable litter at the expense of air quality may lead to respiratory problems and discomfort due to dusty air. Dry litter enables breeders to perform litter-directed behaviours, thus improve their welfare. However, at the same time, from another angle, in spite of good litter condition, the compromised footpad health in breeder flocks evidently diminished welfare.

Welfare measurement relaying only on footpad health or litter condition assessment obviously offers a very one-dimensional perspective on welfare. Adding hock burn monitoring may be way to widen welfare assessment somewhat, because hock burns and footpad lesions have been suggested to partly display different risk factors (Haslam *et al.* 2007). However, the assessment of contact dermatitis still focuses on certain limited elements of welfare, such as health and the absence of injuries.

Broiler welfare is commonly measured at flock level even though welfare is defined from an individual animal point of view. It is worth noticing that good welfare at flock level, either assessed by single, narrow measurements or combining several assessments, does not guarantee good welfare status of every individual. Assuring the good level of welfare of every individual in large intensively reared flocks can be considered as an impossible task. Then again, in intensive broiler flocks, a great number of birds can derive benefit from procedures that improve welfare.

Clearly, no single method can evaluate all aspects of welfare as one procedure typically measures a small fraction of the total picture only. Keeping the above mentioned restrictions in mind, good litter, absence of contact dermatitis and lameness, and possibilities to perform litter-directed behaviours and perching, however, can enhance broiler and breeder welfare to a significant extent.

6.11 Suggested further research

The study highlighted awareness of the importance of footpad health on breeder welfare. However, due to a number of unanswered questions it is essential to investigate the subject further. Elevated structures as a means of enhancing broiler welfare in commercial situations also merit more attention in future research. Some more specific suggestions for research are listed below:

- ✓ Global assessment of breeder footpad health and the effect of footpad lesions on breeder production
- ✓ The influence of irritants in litter and regular addition and turnover of litter on the footpad health of broiler breeders
- ✓ The impact of slats and other possible risk factors on breeder footpads
- ✓ Further studies on the threshold moisture of peat bedding with regard to contact dermatitis
- ✓ The use of peat as broiler bedding under a wider variety of housing conditions
- ✓ The effect of peat bedding on broiler litter-directed behaviour that possibly assists in maintaining good litter condition in a commercial environment
- ✓ Changes in peat pH over time during production period, and effects of the lower initial pH of peat on bacterial composition in litter and influence on footpad health
- ✓ Possible adverse consequences of dry and friable litter on aerial dustiness, particularly regarding welfare and respiratory diseases
- ✓ Besides litter quality, other risk factors inducing hock burns in Finnish conditions
- ✓ More experience of perches and platforms in commercial broiler houses: the use of different kinds of equipment and their effects on litter condition (also other than peat litter) and contact dermatitis
- ✓ Perching on different types of elevated structures by broiler breeders and possible positive effects on their welfare
- ✓ The motivation behind the willingness to use platforms by broilers through the entire growing period, even near slaughter age
- ✓ On-farm testing and the modification of inexpensive elevated structures, that are practical for farmers to handle and attractive to broilers

7 Conclusions

Although dry and friable litter in breeder houses was associated with healthier footpads, good litter condition alone appears insufficient to maintain breeder footpads healthy for their entire life. In broiler production, the impact of farmer on the severity of contact dermatitis exceeded the effect of litter condition. Broilers on peat bedding had better footpad and hock skin health compared with when on wood shavings and ground straw. However, litter condition and moisture were unable to fully explain the differences. Our result indicates that broilers are motivated to use elevated structures, and platforms are better suited for broilers than conventional perches. Access to platforms most likely enables more versatile movement that may promote gait and leg health, without compromising litter condition and footpad health.

1. *Hypothesis: contact dermatitis and breast blisters in breeders become more common and severe with age*

The condition of breeder footpads deteriorated as birds aged. At slaughter 64% of the breeders had severe lesions, indicating compromised welfare. However, further studies are needed to determine if the situation is comparable in other countries. Hock burns and breast blisters were rarely detected. (Study I)

2. *Hypothesis: litter condition in broiler and breeder houses deteriorates over time, and inferior litter condition and higher moisture are associated with impaired footpad health in broilers and breeders*

In breeder houses litter condition deteriorated, but litter moisture decreased towards the end of the production period. In broiler houses, changes in litter condition and quality depended on the litter material. Litter condition evaluation revealed no substantial differences between breeder and broiler houses. Maintaining litter in a dry and friable condition is crucial for good footpad health. However, further risk factors, such as represented by slat area, appears to affect the footpads of breeders. Thus, sustaining satisfactory litter quality alone is not enough to ensure a good level of footpad health in breeders. In broilers, the impact of farmer on contact dermatitis severity exceeded the effect of litter quality. (Study I & II)

3. *Hypothesis: peat was expected to provide the best litter condition in broiler houses and promote the most favourable footpad and hock skin health in broilers, due to its low pH*

Broilers on peat litter exhibited less contact dermatitis compared with when on wood shavings and ground straw. Footpad and hock skin health were inferior on wood shavings than on peat, without there being differences in litter condition and moisture at the end of the production period. Moreover, the lack of difference in end moisture between ground straw and peat still resulted in poorer litter, and inferior footpad and hock skin condition on ground straw. Hence, these results suggest that the relationship between litter condition, moisture and contact dermatitis may be more complex than previously stated. In contrast to our hypothesis, low pH cannot explain the better footpad health on peat. Furthermore, the results underline the importance of the farmer's ability to manage litter conditions, regardless of the chosen litter material. (Study II)

4. *Hypothesis: extra equipment in broiler houses obstructs the airflow, and thus negatively affects litter condition, and possibly also footpad and hock skin health*

The study indicated no effects of additional equipment, in the form of elevated platforms, on broiler footpad health and peat litter condition and quality in a commercial production environment. (Study II)

5. *Hypothesis: platforms appear more popular among broilers than perches*

In commercial broiler houses the birds used elevated platforms with ramp access eagerly but the use of perches was negligible. The advantages of traditional perches for broilers should be re-evaluated because they remained largely unused. However, our prototype platforms show good potential as environmental stimuli for broilers. (Study III & IV)

6. *Hypothesis: perches and platforms could increase versatile locomotion sufficiently to improve broiler walking ability and leg health*

Adding attractive equipment, such as elevated platforms, to broilers' environment may promote their gait and leg health. In this study, access to platforms may have enabled more versatile movement, such as walking forward, up and down, grasping by feet, and jumping, that could have positively influenced walking ability and contributed to fewer and milder TD lesions. (Study IV)

8 Practical implications

Our results demonstrated that, at slaughter, the majority of the breeders had severe lesions, indicating compromised welfare. This highlights the need for close follow-up of breeder footpad health and increased efforts to establish practical solutions to improve the situation. If breeder footpad condition appears comparable in other countries, co-operation between researchers, the broiler industry and breeding companies is required. Nevertheless, maintaining litter in a dry and good condition is crucial for good footpad health and it is worth bearing in mind other positive effects of friable litter on breeder welfare: it enables birds to express litter-directed behaviour such as foraging, scratching and dustbathing more easily.

This thesis provides new knowledge about the applicability of peat as broiler bedding. According to our results regarding footpad health, peat seems to be the optimal litter material for Finnish conditions. However, from a practical point of view, the important conclusion is that, regardless of the chosen litter material, the farmer's ability to manage litter conditions plays a vital role in preventing contact dermatitis. Thus the other tested materials, wood shavings and ground straw, are worthy of consideration as bedding materials, under the control of a competent farmer. In Finland, hock burn monitoring could represent a more sensitive indicator of litter condition or possibly signal leg health status, therefore monitoring hock burns at slaughter should be considered.

This study clearly indicates that the advantages of traditional perches for broilers should be re-evaluated as they remained largely unused. Our prototype platforms show good potential as environmental stimuli for broilers. These results are directly applicable in future policy making. The eager and voluntary use of platforms with ramps suggests that broilers are motivated to perch on elevated structures. Hence, platform availability could enhance their emotional wellbeing. Further, elevated platforms offering additional possibilities for locomotion seem promising for improving broiler leg health, without compromising litter condition or footpad health. Based on all these findings, elevated platforms can be recommended as a way forward to enhance broiler welfare in commercial environments.

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