

## INVITED REVIEW

### Footpad dermatitis in poultry

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**ABSTRACT** Footpad dermatitis (FPD) is a condition that causes necrotic lesions on the plantar surface of the footpads in growing broilers and turkeys. This condition not only causes downgrades and condemnations of saleable chicken paws, the portion of the leg below the spur, but is also an animal welfare concern in both the United States and in Europe. Revenue from chicken paws in 2008 alone was worth \$280 million. Harvesting large, unblemished paws has become a priority to poultry companies all over the world. Research on this subject has been ongoing since the 1940s and has looked into many different areas including nutrition, environment, and genetics. Early research looked at nutritional deficiencies such as riboflavin and biotin main-

ly in turkey poult. This early research was most likely looking at a separate form of dermatitis than what is being investigated now. Recent findings have suggested that there is a myriad of interacting factors that lead to FPD. Litter moisture appears to be the most likely culprit in the onset of this condition. Research has also shown a possible genetic link in the susceptibility to development of FPD lesions. Current chicken paw prices have skyrocketed due to a large export market in Asia. To produce unblemished paws for both increased profit and comply with current animal welfare recommendations, further research is needed to understand how the condition develops and what strategies can be used to prevent it.

**Key words:** poultry, footpad dermatitis, paw, broiler, pododermatitis

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### INTRODUCTION

Footpad dermatitis (FPD) was first reported as a skin condition in broilers in the 1980s (McFerran et al., 1983; Greene et al., 1985). A similar condition has been reported in turkeys as covered by Mayne (2005). This condition is usually associated with wet litter in broilers (Greene et al., 1985; Martland, 1985) and turkeys (Martland, 1984; Mayne et al., 2007b). Footpad dermatitis is known by multiple names, such as pododermatitis and contact dermatitis, all of which refer to a condition that is characterized by inflammation and necrotic lesions, ranging from superficial to deep on the plantar surface of the footpads and toes. Deep ulcers may lead to abscesses and thickening of underlying tissues and structures (Greene et al., 1985).

Several skin conditions commonly affect broilers and turkeys. Some of these skin conditions are types of dermatitis that are associated with bacterial infections, such as infectious process and gangrenous dermatitis. Other dermatitis conditions such as hock burns and breast blisters are not usually associated with bacterial infections and are types of contact dermatitis. They are presumed to be manifestations of the same condition

that results in FPD (Greene et al., 1985; Martland, 1985; Bruce et al., 1990; Berg, 2004). Hock burns have been shown to be positively correlated with FPD ( $r = 0.76$ ; Meluzzi et al., 2008a).

Even though FPD was first described in the 1980s, these observations were certainly not the first cases of FPD. Rather, this time period was the beginning of the development of the broiler paw market and greater attention was being given to paw quality. By definition, the chicken paw is the portion below the spur, whereas chicken feet include the lower leg as well as the foot (Christensen, 1996). The terms paw and foot are interchangeable and both terms will be used in this review. Due to the market value of this product and increasing welfare issues, it is in the best interest of the poultry industry to reduce paw downgrades and condemnations. Therefore, factors associated with increased incidence of FPD and methods to reduce it need to be evaluated.

### Economics

Before the mid 1980s, chicken paws were of little economic value and were rendered with feathers, blood, and other unsaleable portions of the chicken. Footpad dermatitis was not considered to be a serious economic issue for companies at that time and little research had been conducted. In 1987, WLR Foods Inc. was the first

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US company to enter into the paw market on a large scale in southern China and Hong Kong (Christensen, 1996).

Recently, chicken paw prices have escalated due to an insatiable demand for high-quality paws in export markets. This demand has turned paws into the third most important economic part of the chicken behind the breast and wings, with paws accounting for approximately \$280 million a year (US Poultry & Egg Export Council, 2009). The lesions that are caused by FPD are a concern to the poultry industry as a cause of animal welfare, food safety, and product downgrade issues.

### **Animal Welfare**

Animal welfare audits in Europe often use foot, hock, and breast burns-lesions as an indicator of housing conditions and the general welfare of the birds (Haslam et al., 2007). In fact, the occurrence of FPD is now used as an audit criterion in welfare assessments of poultry production systems in Europe and the United States (Berg, 2004; Berg and Algers 2004; National Chicken Council, 2010). Birds with severe lesions may also show reduced weight gain due to pain-induced decreases in feed intake (Martland, 1984, 1985).

### **Food Safety**

These lesions can serve as a portal of entry for *Staphylococcus aureus* and other microorganisms (Jensen et al., 1970; Hester, 1994). It was suggested that the most important issue with FPD is that it may provide a route of systemic invasion by microorganisms that could gain entrance into the bloodstream and settle in the leg joints, causing leg weakness in older turkeys.

### **Paw Quality**

Paw quality refers to the overall health of the foot, including toes and footpad. Paw quality has been shown to be affected by a myriad of factors including genetics, environmental factors, nutrition, and bedding materials. Paw quality is judged both in the field and in the processing plant (Martland 1984, 1985; Nagaraj et al., 2007b; Sirri et al., 2007; Meluzzi et al., 2008b; Ask, 2010). In the field, several scales have been used to determine lesion severity including a 3-point scale that ranges from 0 to 2 (Bilgili et al., 2006), a 7-point scale that ranges from 0 to 6 (Ekstrand et al., 1997), or the modified Ekstrand score (Ekstrand et al., 1998), which uses a 1-to-3 scale. The highest number represents the most severe lesion in all 3 scoring systems. Currently, there is not a federal grading system for processed paws in the processing plant; however, they do fall under the Finished Product Standards, which means they are federally inspected. Paw scoring depends on consumer specifications. Some plants use an A, B, C, or condemn scale, whereas others use A, B, or condemn grade. Grading is based on the size of the lesion on the pad

from FPD, discoloration, mutilations from processing, and also trauma injuries that may occur during catching and live haul such as broken toes. Roughly 99% of the downgrades come from FPD lesions, with the other 1% encompassing both catching and live haul injuries and processing mutilations (our personal observation).

Paws are separated and priced according to size. Paws can be divided into small, medium, and large-jumbo sizes. Jumbo grade A paws fetch the most money per pound. The incentive to harvest grade A jumbo paws is immense but poses challenges to the growers and company. Controlling environmental factors may allow a company to manage FPD problems and ultimately harvest more unblemished paws, leading to increased productivity and subsequent profits.

## **HISTOPATHOLOGICAL FINDINGS**

In turkey poult, hyperkeratosis and separation of the keratin layers was seen at 6 wk of age. Hyperkeratosis refers to a rapid turnover of keratinocytes that are undergoing apoptosis to produce keratin, resulting in a thickened layer of underdeveloped keratin. This is thought to be in response to an external trauma. Lesions tended to be more superficial at this age, but by 16 wk, there were more severe ulcerations. Lymphocyte, granulocyte, and lymph follicle populations increased in the dermis adjacent to the lesions (Platt et al., 2001). Mild lesions show heterophils in the stratum germinativum and also defects in keratin formation (Martland, 1984). Heterophils were also found in the dermis, sub-epidermis, and epidermis along with basophilic cells in the stratum corneum (Greene et al., 1985). Vacuoles containing heterophils have also been found in the epidermis and inside blood vessels of the footpad (Harms and Simpson, 1975; Martland, 1984, 1985; Greene et al., 1985). Greene et al. (1985) observed complete destruction of the keratin and epidermal layer in the center of the lesion, with necrotic tissue exposed and a mass of heterophils.

In severe lesions, there was acute inflammation with a more dense cellular infiltration and a thickening of the stratum corneum, which were referred to as horned pegs (Martland, 1984; Whitehead, 1990). The epidermis was more eroded and the dermis was filled with fluid. There was congestion and dilation of blood vessels that were sometimes found to be necrotic (Whitehead, 1990).

## **ENVIRONMENTAL FACTORS ASSOCIATED WITH FPD**

### **Litter Material**

Litter management is an important aspect in rearing broilers to market age. It serves several functions that include thermal insulation, moisture absorption, protective barrier from the ground, and it allows for natural scratching behavior. Bedding material must not

only be a good absorber of moisture but also have a reasonable drying time (Grimes et al., 2002; Bilgili et al., 2009). Although litter refers to the mixture of bedding material, fecal droppings, and moisture, the term is used interchangeably with bedding materials. In this paper, litter will refer to both fresh bedding material and that which has fecal material and moisture. Litter material and depth is an important area of research for the understanding and prevention of FPD. Litter materials vary by region with regard to cost and availability. The most commonly used litter material is pine shavings in the United States, but straw is frequently used in Europe. Rice and peanut hulls are 2 other materials used regularly as bedding materials where it is economically feasible (Grimes et al., 2002).

Various materials have been examined for use as broiler litter and are generally tested for moisture absorption, caking, and bird performance. Caking refers to the compression of litter layers into a single wet layer on the very top of the bedding material. This thick, dense layer usually holds most of the moisture and fecal material in the litter. Therefore, a common management practice is to remove this caked litter between flocks, providing drier floors and better air quality for the next flock. The best-performing material was pine shavings and was followed by the following: rice hulls, ground corncobs, stump chips, pine sawdust, bark and chips, pine bark, and clay (Grimes et al., 2002). Differences in particle size of these materials were proposed to be the most important factor. No differences in paw quality or performance were observed between hay, bark, and wood chip litter as long as the particle size was less than 1 in. (2.5 cm). Lower FPD scores have been observed in pine shavings when compared with straw in broilers (Su et al., 2000; Sirri et al., 2007; Meluzzi et al., 2008b) and in turkeys (Mayne et al., 2007b). One explanation of this observation is that straw tends to have higher moisture content initially when compared with other materials such as pine shavings, rice hulls, and peanut hulls (Andrews and McPherson, 1963; Grimes et al., 2002).

Recycled paper products have been found, with proper management practices, to be as effective as pine shavings (Grimes et al., 2002). More recently, Grimes et al. (2006) looked at litter materials made from cotton waste, gypsum, and newspaper as a comparison to pine shavings. There was no significant difference in the occurrence of FPD lesions between the different materials used; however, there was more caking with the cotton waste products.

Particle size of some litter materials has been examined as a contributing factor in the development of FPD. Used particleboard, a by-product of secondary wood products, has been evaluated in turkeys as a possible litter material. Large litter particles were between 0.32 and 1.27 cm and the fine particles were similar to fine sawdust or powder. Turkeys raised on fine particleboard had significantly lower incidence of leg abnormalities than those raised on the coarse size. The

highest incidence of FPD was found with the coarse particleboard treatment (Hester et al., 1997). However, increased poult mortality was observed due to gizzard compaction from consumption of fine particles. Sand was found to be an acceptable litter alternative to pine shavings, consistently showing a lower incidence of footpad lesions compared with broilers raised on shavings (Bilgili et al., 1999a,b). Particle size is significantly different between these 2 materials and may explain why sand performed better as a litter material for broilers in that study. A more recent study looked at pine shavings, pine bark, chipped pine, mortar sand, chopped wheat straw, ground hardwood pallets, ground door filler, and cotton-gin trash. It was found that mortar sand and the ground door filler had significantly lower incidence of FPD than did the other treatments. It was theorized that the ground door filler performed well because of its moisture-holding capacity and the mortar sand performed well because of its ability to release moisture (Bilgili et al., 2009).

### **Litter Moisture**

Several factors, which include but are not limited to stocking density, ventilation, and drinker design, can affect litter moisture. One thing that is common among most previous research is that litter moisture is a significant factor in the onset of FPD. Martland (1985) found that wet litter appeared to be the only factor resulting in ulceration of broiler feet. Similar to findings with broilers, turkeys raised on wet litter have higher rates of FPD than those raised on dry litter (Martland, 1984). Mayne (2005) suggested that continually standing in wet litter will cause the footpad to soften and become more prone to damage, predisposing the bird to developing FPD. Drying out the litter and moving birds from wet litter to dry litter was observed to reverse the severity of FPD (Greene et al., 1985; Martland, 1985). Footpad dermatitis lesions have been found to be more severe as litter moisture increases, especially when the litter contains high moisture with sticky fecal droppings (Abbott et al., 1969; Harms et al., 1977; Greene et al., 1985; McIlroy et al., 1987; Ekstrand et al., 1997; Wang et al., 1998; Sørensen et al., 2000; Dozier et al., 2005, 2006; Meluzzi et al., 2008a,b; Allain et al., 2009). Although most of the literature suggests that litter moisture is a critical component in the development of contact dermatitis, other studies have found no significant correlation between litter moisture and the incidence and severity of FPD (Eichner et al., 2007; Nagaraj et al., 2007b).

### **Drinker Design and Management**

Drinker design can play an important role in the overall moisture of the litter and thus the occurrence of FPD. Ekstrand et al. (1997) found that flocks reared with small drinker cups had a higher prevalence of FPD than did those reared on nipple drinkers. Nipple

drinkers, however, have been shown to result in more scratches than other drinkers (Allain et al., 2009). In turkeys, small water cups have been shown to have a lower occurrence of FPD than bell drinkers (Ekstrand and Algers, 1997). Bray and Lynn (1986) found that nipple drinkers with drip cups were most efficient and resulted in better litter conditions than nipple drinkers alone and bell drinkers. Drinkers that are too low or have the water pressure set too high tend to result in wetter floors. Water lines that may have a biofilm or other particulates can result in leaky drinkers, which will result in increased litter moisture. Regular flushing and sanitizing of the water lines will reduce water leakage. This will keep litter drier and improve its quality, subsequently resulting in better paw and hock quality (Tucker and Walker, 1999; Mayne et al., 2007b).

### **Stocking Density**

Stocking density in general is a significant factor in broiler performance (Bilgili and Hess, 1995; Sørensen et al., 2000; Feddes et al., 2002; Heckert et al., 2002; Tablante et al., 2003). A survey of broiler production in Ireland over a 2-yr period reported that flocks stocked at a higher density ( $\leq 0.48$  ft<sup>2</sup>/bird) had 10% more hock lesions and 20% more breast lesions when compared with flocks at a lower stocking density [ $\geq 0.49$  ft<sup>2</sup>/bird (0.15 m<sup>2</sup>/bird)]. Although no FPD data were recorded in this study, it was stated that when litter quality suddenly deteriorated, the level of hock lesions doubled when compared with flocks in which litter quality did not suddenly deteriorate (Bruce et al., 1990). Some studies have reported that higher stocking densities are associated with a greater incidence of FPD than lower stocking densities (McIlroy et al., 1987; Ekstrand et al., 1997; Sørensen et al., 2000; Dozier et al., 2005, 2006; Haslam et al., 2007; Meluzzi et al., 2008b), whereas other studies have suggested that stocking density plays little or no role in the formation of footpad lesions (Martrenchar et al., 2002; Sirri et al., 2007; Meluzzi et al., 2008a). Buijs et al. (2009) found that FPD was only negatively affected when density reached 56 kg/m<sup>2</sup>, whereas Dawkins et al. (2004) reported that some leg health issues are compromised at or above a stocking density of 42 kg/m<sup>2</sup>. The sudden onset of poor litter conditions associated with higher stocking densities is considered to be the biggest influence on the development of FPD. Litter conditions deteriorate rapidly and litter moisture increases as stocking density increases (Bessei, 2006). Feddes et al. (2002) found that as stocking density increased, water consumption increased per bird. As birds drink more water, their feces may become more watery and thus contributes to overall litter moisture. However, although more birds in a house makes litter quality difficult to maintain, it has been concluded that stocking density has little effect as long as appropriate environmental conditions are maintained (Dawkins et al., 2004).

### **Seasonal Effect**

The time of year flocks are raised has been suggested as a contributing factor associated with the incidence of FPD. Dermatitis has been found more frequently during winter months than in summer and footpad condition has a high correlation with RH inside and outside the broiler house. When outdoor RH levels increased in winter months, there was an increase in paw lesions (Ekstrand and Carpenter, 1998). A 28% increase in the incidence of hock lesions has been observed in winter when compared with summer flocks (Bruce et al., 1990). Similar results were reported in other studies in which the incidence of paw lesions was greater in cold weather (Greene et al., 1985; McIlroy et al., 1987; Martrenchar et al., 2002; Dawkins et al., 2004; Haslam et al., 2007; Meluzzi et al., 2008a). Although outside RH is important, it is related to temperature so it is difficult to ascertain whether the main effect is RH or increased RH due to low outside temperatures. These seasonal effects are most likely caused by an increase in broiler house RH, which is due to decreases in ventilation rates typically observed in cold weather as operations try to avoid reducing house temperature and save on heating costs. Similar seasonal trends have been observed, with higher incidences of hock and breast lesions occurring during the winter months when compared with summer months (Mayne, 2005). Not all research has found the incidence of FPD elevated in the winter months. Wang et al. (1998) observed no cases of FPD in White Leghorn chickens when outside temperatures were between 48 and 59°F (9 and 15°C), but more birds with FPD were found when the temperature was warmer, between 68 and 79°F (20 and 26°C). It was suggested by the authors that a certain temperature may be required for FPD to develop regardless of litter moisture.

### **Litter Depth**

Most research agrees that litter quality and type are important predisposing factors in the onset of FPD. Less focus has been given to the actual depth of the litter being used. In one study, litter material was found not to influence the prevalence of FPD in broilers; instead, litter depth appeared to have more of an effect. Flocks reared on a thin layer (<5 cm) of litter had a lower prevalence of FPD than those raised on deeper layers (>5 cm) (Ekstrand et al., 1997). A similar study in France reported that high-quality flocks were raised on thin layers of litter and adding large amounts of litter may be a risk factor for FPD, but whether that was caused by litter conditions degrading was not determined (Martrenchar et al., 2002). In contrast to these results, Meluzzi et al. (2008b) found that broilers raised on deeper litter had a lower occurrence of FPD than those raised on a thin layer. This suggests that litter depth may be an important factor in foot health. An increase in final litter depth was found to have an overall

lower hock burn score; with every centimeter increase in final depth, there was a corresponding decrease in hock burn score of 0.015 points (Haslam et al., 2007). Tucker and Walker (1999) noticed lower hock burn scores when shavings were at a depth of 10 cm when compared with 2.5 and 5 cm. No data were recorded on FPD lesions.

The studies that involved litter depth and its relationship with incidence of FPD were conducted in Europe, where poultry houses have concrete floors, an aspect that differs from the packed dirt floors commonly found in the United States. Meluzzi et al. (2008b) gave a weight per volume measurement ( $\text{kg}/\text{m}^2$ ) for the amount of bedding material used. The initial depth could normally be explained by this measurement, but in this case, initial litter moisture was not taken into account, making it difficult to compare with other studies. In this paper, the authors suggested that the experimental design confounded the actual effect of the litter depth because stocking density and photoperiod varied among treatments.

### **Litter Amendments**

Litter amendments are often used in poultry production to reduce litter pH to control ammonia and as an intervention method in houses with a recurring disease issue such as gangrenous dermatitis. The most common type of litter amendments are litter acidifiers. These compounds lower the pH of the litter, inhibiting bacterial growth, which produces ammonia as a by-product of their metabolism. Some common litter amendments include aluminum sulfate, sodium bisulfate, and ferric sulfate. Sodium bisulfate influence on the incidence and severity of FPD in broilers has been evaluated. Application rates of  $\text{NaHSO}_4$  were 0.22 or 0.44  $\text{kg}/\text{m}^2$  at chick placement, whereas a third treatment had 0.22  $\text{kg}/\text{m}^2$  at both 0 and 21 d. However, no significant FPD differences were noted between the treatments. The researchers stated that there was a trend of decreasing incidence and severity of FPD with the use of  $\text{NaHSO}_4$  (Nagaraj et al., 2007c).

## **NUTRITIONAL FACTORS ASSOCIATED WITH FPD**

Nutrition is considered to be a major factor in the onset of FPD along with poor litter conditions. Early FPD research took place with turkey poults and focused on soybean meal inclusion in diets and also nutritional deficiencies such as biotin and riboflavin (Patrick et al., 1943, 1944; McGinnis and Carver, 1947; Abbott et al., 1969; Jensen et al., 1970; Murillo and Jensen, 1976). This dermatitis may not be the same as FPD, which is believed to be more of a contact dermatitis rather than a dermatitis caused by a deficiency. Biotin serves many roles in avian species, one of which is skin integrity, as reviewed by Mayne (2005). Research

has branched from earlier nutritional work that focused mainly on deficiencies and has looked at many different areas. Some areas include different protein sources and levels, different diet densities, mineral and vitamin supplementation, and also the use of enzymes.

### **Nutritional Deficiencies**

Deficiencies of vitamins and amino acids such as biotin, riboflavin, methionine, and cystine in the diets of growing birds have been reported to affect the incidence of FPD. Diets deficient in biotin have produced FPD lesions in turkeys (Patrick et al., 1943). When turkey poults were fed diets deficient in riboflavin and biotin, FPD was prevented by biotin supplementation but not with riboflavin supplementation (Patrick et al., 1944). Later, McGinnis and Carver (1947) found that riboflavin supplementation into turkey diets prevented dermatitis in poults. Jensen and Martinson (1969) observed severe dermatitis of the feet and around the head in poults that were fed a diet deficient in biotin. Additional supplementation of biotin was not found to alleviate FPD in several poults. Additional research has also shown that supplementation of biotin does not reduce the occurrence or severity of FPD lesions (Atuahene et al., 1984; Mayne et al., 2007a). An interaction between biotin supplementation and litter quality may exist. In a study by Harms and Simpson (1977), supplemental biotin resulted in significantly reduced footpad scores when given to poults grown on dry litter but was not observed when given to poults grown on wet litter. This finding either suggests that biotin alone is not responsible for the occurrence of these lesions or that it is not effective in conditions that are known to directly increase the incidence and severity of FPD.

### **Grain Sources**

The addition of the feed ingredient soybean meal has been researched as a possible cause of FPD. There are some indications that sticky indigestible carbohydrates from plant sources (primarily soybean meal) may be caustic and contribute to FPD (Hess et al., 2004). These carbohydrates are referred to as nonstarch polysaccharides (NSP) and are found in higher concentrations in wheat, barley, and other grains when compared with soybean meal. As the diet NSP concentrations increase, gut viscosity increases, resulting in manure that adheres more readily to the footpads of the birds. Diets containing wheat that have increased levels of viscous NSP tend to have lower ME values and higher digesta viscosity than normal wheat diets. These diets can be improved with addition of NSP-degrading enzymes, showing significantly lower digesta viscosity than the wheat diet alone (Choct et al., 1995). The viscosity of gut contents can affect fecal dropping adhesion to the foot and over time may deteriorate the epidermis and keratin layers. When diets contain high levels of

soybean meal, the incidence of dermatitis is very high with turkey poults, and it appears that the dermatitis is caused by manure sticking to the feet of the birds (Jensen et al., 1970).

Abbott et al. (1969) found that lesions were the result of wet, crusty litter and not dietary treatments differing in the amount of soybean meal fed to poults. These contradicting results suggest that dermatitis may be associated with independent and combined effects of soybean meal content in feed and litter moisture.

### **Vitamin, Mineral, and Amino Acid Supplementation**

Nutrients such as biotin, riboflavin, pantothenic acid, and sulfur amino acids have been shown to affect the structural components of the skin. The addition of vitamins and trace minerals did not significantly reduce FPD and it was concluded that factors other than nutrition might be involved (Burger et al., 1984). Footpad dermatitis in young poults has been associated with methionine deficiency, but the supplementation of sulfate and cystine to the diet yielded no improvement in FPD (Chavez and Kratzer, 1974; Murillo and Jensen, 1976). Footpad condition never fully corrected with the addition of the methionine either, but contact of the bird's feet with the excreta was suggested to play a major role in FPD (Abbott et al., 1969; Jensen et al., 1970). Hess et al. (2001) supplemented broiler diets with a zinc amino acid complex and observed no significant difference in FPD scores in males but did detect a decrease in lesions when given to females.

### **Protein Level and Source**

The incidence and severity of FPD is significantly affected by protein level and source (Nagaraj et al., 2007b). Birds reared on a low-protein diet and fed a diet based on vegetable and animal proteins showed the lowest incidence of FPD compared with other treatments. The most severe cases were associated with birds fed a high-protein diet consisting of only plant-based proteins (Nagaraj et al., 2007b). Eichner et al. (2007) observed similar results but found that the addition of corn gluten meal to an all-vegetable diet reduced the incidence of FPD when compared with a vegetable- and animal-based diet. Birds raised on an all-vegetable diet had a higher incidence of FPD than did birds raised on a mixed animal and plant diet. Studies on protein level and source have provided inconsistent results. For example, a second study by Nagaraj et al. (2007a) evaluating the effect that feed-grade enzymes may have on protein digestion and paw quality observed no differences between the high- and low-protein diets. However, it was noted that the litter moisture was greater in this study, possibly due to increased water consumption in response to high environmental temperatures experienced during that trial.

### **Diet Density**

In a study that examined the effects of diet density, 2 density levels were examined while keeping the feed formulation isocaloric and isonitrogenous. Diet density is related to the level of fat in the diet, with low-density diets having less fat than a high-density diet. Broilers raised on the low-density diet had significantly less incidence of paw lesions compared with the high-density diet due to reduced fecal viscosity from lower soybean meal content in the ration (Bilgili et al., 2006).

### **Enzymes**

Nagaraj et al. (2007a) evaluated a feed-grade enzyme in diets with or without animal protein on the subsequent incidence of FPD. The incidence of lesions was lower with the addition of the enzyme to the all-vegetable diet, with no differences noted when enzyme was added to the vegetable and animal protein diet. The improvement in footpad condition was noted in the later stages of the flock and could be confounded with healing of the lesions. It is unclear at this time whether the rate of healing is affected by these dietary treatments or if it was a direct effect on fecal composition that would influence footpad condition. Additional research on feed enzymes to enhance feed utilization and reduce nitrogen in the litter is needed to better understand the effect of these feed additives on footpad condition.

### **Electrolyte Imbalances**

Harms and Simpson (1982) found that dietary salt content had a direct influence on the severity of footpad lesions and that dermatitis was more severe with higher levels of salt. Birds with diets containing high salt content had fecal droppings containing more moisture, resulting in poor litter conditions. They observed a reduction in both body weight and FPD with the supplementation of salt, suggesting that body size is a predisposing factor in the development of lesions.

## **SEX, BODY SIZE, AND STRAIN-CROSS**

### **Sex and Body Size**

The sex and size of broilers have been investigated as possible factors for the onset of FPD. It has been shown that male broilers tend to have higher incidence and severity of FPD than females (Harms and Simpson, 1975; Greene et al., 1985; McIlroy et al., 1987; Bilgili et al., 2006; Nagaraj et al., 2007b). The increased incidence of FPD in male broilers could be related to body size because males are typically heavier than females and thus more weight is placed on their footpads. This leads to increased surface area contact with the litter,

possibly causing an increase in the incidence of burns and lesions. Body weight has been shown to be positively correlated with hock burns ( $r = 0.353$ ; Broom and Reefmann, 2005). Bruce et al. (1990) found that the prevalence of both hock and breast lesions was significantly higher in male broiler flocks than female broiler flocks.

Some research alternatively suggests that females have a higher incidence of footpad lesions than males (Harms et al., 1977; Kjaer et al., 2006). In contrast to their earlier findings (Nagaraj et al., 2007b) in which males had a higher incidence than females, Nagaraj et al. (2007c) observed a higher incidence of FPD in females than males. Other studies such as Martland (1985) and Nagaraj et al. (2007a) reported no relationship between body size and sex in the incidence of FPD. Because of the inconsistent results reported from research that has evaluated body size and sex on the incidence and severity of FPD, it is currently believed that these factors are not significant contributors in the occurrence of FPD. Ask (2010) stated that continued selection for increased BW without considering FPD in the breeding goal is likely to result in increased cases of FPD in broilers in the future.

### **Strain-Cross**

Bilgili et al. (2006) looked at the effect of strain-cross (SC) on the development of FPD along with diet densities. They found a significant SC  $\times$  diet density interaction at 42 d of age, which suggested that the susceptibility to FPD may vary by SC. Similar data have been reported by Kestin et al. (1999), in which FPD scores varied between 4 different crosses, which suggested that FPD was not merely the product of poor management but that there may be a difference between various strains in susceptibility to developing FPD. Sanotra et al. (2003) found a lower prevalence of FPD in Swedish Cobb chicks when compared with Swedish or Danish Ross chicks. The authors mentioned, however, that differences in housing conditions may have confound their findings. Later, Kjaer et al. (2006) reported that Ross 308 broilers had higher rates of FPD and hock burns than did a slow-growing dual-purpose strain. It was stated that it should be possible to decrease the incidence of FPD through genetic selection. Similar conclusions were made by Allain et al. (2009) when looking at a fast-growing strain versus a slow-growing strain, with the fast-growing strain having higher rates of FPD but fewer breast blisters. Genetic variation between and within 10 commercial broiler lines was present for both FPD and hock burns (Ask, 2010). The authors stated that it may be possible to select against both FPD and hock burns without negatively affecting BW. Chavez and Kratzer (1972) found that Large White turkey poults had more severe FPD lesions than did Broad Breasted Bronze poults when reared in the same conditions on wire floors.

## **OTHER FACTORS**

### **Feed Manufacturers**

Bruce et al. (1990) examined feed manufacturers in Northern Ireland as a possible factor in the development of FPD, hock burns, and breast blisters. It was found that between 1984 and 1985, flocks supplied by one feed manufacturer had a significantly lower level of hock burns and breast lesions than flocks supplied by 2 other feed manufacturers. However, it was found that between 1986 and 1987, flocks did not differ significantly with respect to hock burns and breast lesions in relation to feed manufacturer. These contradicting results may suggest that there is some variation between feed producers. McIlroy et al. (1987) and Ekstrand et al. (1998) reported significant differences in paw quality between feed manufacturers, with no obvious deficiencies or imbalances between the feed products. Feed quality variations between suppliers was hypothesized to have an effect by adding moisture to the litter through droppings or by an effect on skin integrity from insufficient levels of vitamins such as biotin (Haslam et al., 2007). The effect of feed manufacturer in the United States is probably minimal due to the vertical integration of feed mills within a company that produce the same feed for all contract farms.

### **Alternative Production Systems**

Recently, companies have considered alternative production systems to supply niche markets. Organic- and free-range-raised chickens have become more popular. The type of environment these birds are raised in has been compared with relation to paw quality. In a study by Pagazaurtundua and Warriss (2006), confined, organic, and free-range systems were compared. It was found that birds with the highest prevalence of FPD were those raised with access to the outside (free-range and organic). The researchers hypothesized that this could be due to sharp objects such as stones cutting the bird's feet and initiating the onset of the lesions or that they must be grown longer, giving them more time for lesions to develop. Alternatively, Broom and Reefmann (2005) found that organic-raised chickens had half as many hock burns as did commercially reared broilers. It was suggested that these results were due to drier litter conditions and greater leg strength in the organic birds. This may mean that birds with better leg strength spend less time sitting, thus reducing the contact time between the hocks and litter.

Although there has been considerable attention given to FPD in broilers and turkeys, the condition is still a welfare and economic problem as demand for high-quality paws increases. Although there is some understanding of the factors that affect the incidence and severity of footpad lesions, the exact multifaceted process that results in FPD is not clearly understood. Although of

concern a few decades ago, nutritional deficiencies are not the issue behind FPD today. Nutrition directly influences both fecal dropping and litter moisture, which are significant predisposing factors in the development of footpad lesions. The literature demonstrates that litter type and management is a critical component in maintaining optimum footpad and bird health. There is still a need to understand the histological changes that occur during the early stages of lesion formation in response to the factors discussed in this paper. Understanding these interactions between the footpad and the poultry house bedding material may lead to methods to manage this condition in the future.

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