Foot-Pad Dermatitis in Broilers and Turkeys

Prevalence, risk factors and prevention

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To my parents

Abstract

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Foot-pad dermatitis is a condition characterised by lesions on the ventral foot-pads of poultry. It is a type of contact dermatitis, which in an early stage results in hyperkeratosis, erosions and discoloration of the skin. The erosions can develop into ulcers. In severe cases, the foot-pad lesions may cause pain which together with a deteriorated state of health constitutes a welfare issue. It has also been indicated that broilers with severe foot-pad dermatitis show slower weight gain. The aim of the present work was to improve the knowledge concerning the epidemiology of foot-pad dermatitis in meat-type poultry in Sweden. The studies were focused on surveying the occurrence of foot-pad dermatitis on Swedish commercial broiler and turkey farms, identifying endogenous and exogenous risk factors for foot-pad dermatitis in meat-type poultry and to evaluate the function of foot health as an indicator of management, hygiene and housing standards.

The prevalence of foot-pad dermatitis in Swedish broilers at time of slaughter was estimated at 5-10 % for severe lesions and 10-35 % for mild lesions. The corresponding prevalence of foot-pad dermatitis in turkeys was estimated at approximately 20 % for severe lesions and 78 % for mild lesions. A significantly higher prevalence of foot-pad dermatitis was found in flocks reared on wet litter than on dry litter. In broilers, a significantly higher prevalence of lesions was found in flocks reared on thick layers of litter material than on thinner layers. There was an association between litter material and turkey foot-pad dermatitis. Type of drinker system, which is related to both water spillage and water consumption, was significantly associated with the prevalence of foot-pad dermatitis in both broilers and turkeys.

There was a significant seasonal effect on the prevalence of broiler foot-pad dermatitis, with the highest prevalence found during October to January. The prevalence and severity of foot-pad dermatitis in broilers decreased over time when a surveillance programme was initiated and executed. In summary, foot-pad dermatitis in both broilers and turkeys was shown to be linked to a number of management, hygiene and housing factors, and can thus be used as an indicator of the standard of these factors. Surveillance and advisory programmes can be used successfully to decrease the incidence of foot-pad lesions in broiler and turkey populations and thus improve the health and welfare of the birds.

Key words: broiler, chicken, foot-pad dermatitis, housing, litter, surveillance programme, turkey, ulcer, welfare

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Contents

Appendix

Papers I-V

The thesis is based on the following papers, which will be referred to in the text by their Roman numerals I-V.

I. Ekstrand, C., Algers, B., Svedberg, J., 1997. Rearing conditions and foot-pad dermatitis in Swedish broiler chickens. Preventive Veterinary Medicine, 31: 167-174.

II. Ekstrand, C., Algers, B., 1997. Rearing conditions and foot-pad dermatitis in Swedish turkey poults. Acta Veterinaria Scandinavica, 38: 167-174.

III. Ekstrand, C., Carpenter, T.E., Andersson, I., Algers, B, 1998. Prevalence and control of foot-pad dermatitis in broilers in Sweden. British Poultry Science, 39: 318-324.

IV. Ekstrand, C., Carpenter, T.E., 1998. Temporal aspects of foot-pad dermatitis in Swedish broilers. Acta Veterinaria Scandinavica, 39: 213-220: *in press*.

V. Ekstrand, C., Carpenter, T.E., 1998. Using a Tobit regression model to analyse risk factors for foot-pad dermatitis in commercially grown broilers. Preventive Veterinary Medicine, *in press.*

Introduction

Broiler and turkey production in Sweden

Chicken (*Gallus gallus*) originate from South East Asia (Guhl, 1962) and were domesticated 4-5000 years ago. They reached Scandinavia during the late bronze age, which means that they have been kept here for almost 2000 years (Ekelöf, 1915; Rasmusson, 1990). Hens are known from the Norse mythology, where Yggdrasil, the giant ash-tree, had branches which covered all human dwellings. In the top of the tree a cockerel named Gyllinkambi - 'the golden comb'- resided, waiting to wake up all brave warriors at Armageddon (Rasmusson, 1990).

Small back-yard flocks have dominated the scene for centuries. Although the breeding for specialisation of either meat-type or egg-type hybrids had already started in the US in the 1920s, the typical broiler production did not reach Sweden until after World War II (Odén, 1994). Up to that time, poultry meat was merely a by-product from the egg production, as the males were kept for fattening. These birds grew slowly, and were mainly available during the spring. Instead, spent hens were the most important source of poultry meat (Engström, 1994). During the 1950s, the first heavy meat-type strains were imported. At that time, the knowledge about feed composition, lighting schedules and disease prevention had increased and the development of coccidiostats had made it possible to keep the birds densely stocked in large flocks (Odén, 1994). Whereas most layer flocks were transferred to cages in the late 1950s, broilers have almost exclusively been kept loose housed in Sweden.

Turkeys (*Meleagris gallopavo*) were originally brought from North America to Europe by the Spaniards in the 16th century (Odén, 1994). The first turkeys are believed to have reached Sweden in the 17th century, but were not kept in any larger scale for commercial purposes until the 1970s, when modern hybrids became available (Engström, 1994).

Meat-type poultry production in Sweden is concentrated in the southern part of the country, where the climate is conducive and where most of the grain is grown. There are approximately 180 commercial broiler producers and 15 commercial turkey producers in Sweden. The map below shows areas where broilers and turkeys are grown commercially within the country (Ekstrand and Carpenter, 1998).

There are currently no commercial basic poultry breeding operations in Sweden (Engström, 1997a). The breeding stock is imported as day-old grandparent (GP) chickens, which are used for breeding the parent generation, to finally result in the production stock. Mainly two different broiler hybrids (Cobb and Ross) and one turkey hybrid (B.U.T.) are used.

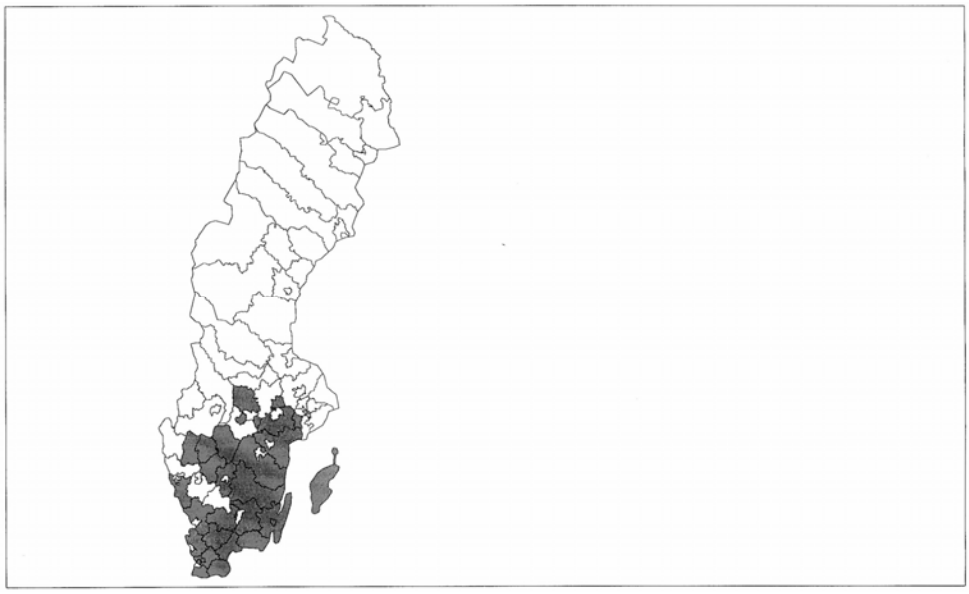

Figure 1. Map showing zip code areas (2-digit level) where broiler and turkey farms in Sweden are located (1994-1996). Reprinted from Ekstrand and Carpenter, 1998.

Broilers are usually slaughtered between 28 and 50 days of age, with a mean of approximately 35 days. Older birds are usually parted and sold as fresh, whereas younger birds are sold as frozen whole birds or further processed. Turkey poults are usually kept for a total of 9-10 weeks, and are mostly sold as whole birds. In 1997, 65 million broiler chickens and 0.2 million turkey poults were grown and slaughtered in Sweden (Svensk Fågel, 1998). In 1997, 8066 tonnes of poultry meat was exported from Sweden. The export was approximately twice as large as the import (Svensk Fågel, 1998).

Birds are raised indoors in modern insulated houses with concrete floors. All houses have heating, and the most common litter types are wood shavings and straw. Litter is discarded and replaced between each batch of birds, and the house is thoroughly cleaned between every batch. The photograph below shows the inside of a typical Swedish broiler house (Figure 2).

All commercial broiler and turkey growers take part in the Swedish Prophylactic Salmonella Control Programme (Wierup et al., 1995; SJVFS, 1992:135). The programme contains prophylactic measures such as biosecurity by the use of all-in-all-out procedures, hygiene barriers and cleaning and disinfection. It also comprises testing every broiler or turkey flock for *Salmonella* prior to slaughter. Samples are taken one to two weeks before slaughter. The producer is responsible

for taking most of these samples, but at least once a year an officially appointed veterinary officer visits the farm to collect the samples. Because of Swedish *Salmonella* regulations (SFS, 1983:738; SJVFS, 1993:179), all poultry flocks are given feed that is steam-pelleted or treated similarly to eliminate bacterial contamination. If any *Salmonella*, regardless of serotype, is found in a production unit the entire flock is destroyed and thorough cleaning and disinfection of the building is carried out. The flock level incidence of *Salmonella* in Sweden has been below 0.5 % for several years (Lindqvist, 1997). During 1997, *Salmonella* was found in two Swedish broiler flocks (Lindqvist, 1997). It has not been found in the Swedish turkey production since 1994 (Lindqvist, 1997).

The programme also aims at decreasing the incidence of *Campylobacter* in broiler chickens, which is currently about 9 % (Berndtson, 1997). No figures regarding the *Campylobacter* incidence in Swedish turkeys are available. The use of antibiotic feed additives for growth promoting purposes has been banned in Sweden since 1986, but both broilers and turkey poults normally receive feed containing anti-coccidials, which are under prescription by veterinarians (Svedberg, 1989). Broilers and turkey poults in Sweden are not vaccinated (Engström, 1997b).

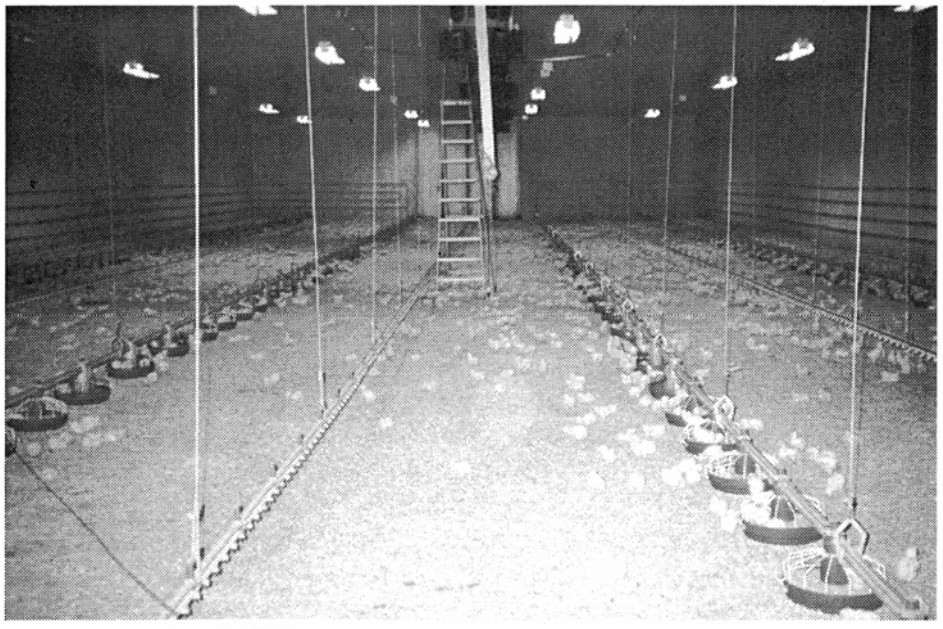

Figure 2. Broiler growing unit in Sweden, this compartment houses approximately 40 000 birds. Birds are placed as day-olds, and usually slaughtered at approximately 35 days of age.

Animal welfare

Animal welfare has been defined as the five freedoms: freedom from thirst, hunger and malnutrition; appropriate comfort and shelter; prevention, or rapid diagnosis and treatment of injury and disease; freedom to display most normal patterns of behaviour; and freedom from fear (Farm Animal Welfare Council, cited in Harrison, 1988). There are, however, a number of other definitions of animal welfare. For example, Dawkins (1983) and Duncan (1996) have claimed that animal welfare is mainly related to the subjective feelings of the animals, whereas Broom (1996) has stressed the animal's ability to adapt to and cope with its environment as crucial for animal welfare. The latter definition appears to be more useful when discussing animal welfare in relation to animal health. According to Broom's definition, it is not possible to talk about animal health without entering the area of animal welfare. When we monitor animal health, which we do mainly for economical reasons when it comes to production animals, we also indirectly monitor aspects of animal welfare. When enforcing a surveillance programme in order to improve animal health and thereby producer economy, it will in many cases also improve animal welfare. However, lately consumers have been demonstrating more primary concern for animal welfare (Harrison, 1988).

When we want to assess animal welfare, there are a number of different indicators which can be used, such as productivity, mortality and health, ethological measures and physiological and immunological measures (Broom, 1991). None of these indicators can give the full picture alone. Often ethical and political considerations must also be taken into account (Rushen and de Passillé, 1992; Sandøe and Simonsen, 1992). It is well known that animals are also able to produce well under conditions where we would regard their welfare as severely restricted. Mortality merely reflects the number of animals becoming so sick that they die prior to slaughter and thus is a measure of little value when judging a bird's state of health from an animal welfare point of view, unless the cause of death is known. Traditionally, health parameters seem to have been the most common way of assessing animal welfare, as many scientists in the field have had veterinary background, and also because heath parameters are often rather simple to standardise and quantify. Ethological measures have become increasingly important, as our knowledge of the behavioural patterns and needs of not only wild animals but also our domesticated species have increased. Physiological parameters, such as hormone levels related to 'stress', are important when trying to quantify the animals' reactions, although there is no simple link between e.g. cortico-steroid concentrations and animal welfare (Rushen and de Passillé, 1992). Ultimately, interpreting welfare measures will always involve subjective measurements which will be influenced by our concern for the animal under consideration (Mason and Mendl, 1993). Some scientists actually argue that instead of attempting to 'measure' animal welfare, the role of science should be seen as identifying, rectifying and preventing welfare problems (Fraser, 1995).

Foot-pad dermatitis: Implications for bird health and welfare and implications for the poultry industry

Foot-pad dermatitis is an important aspect of bird welfare. In severe cases, the foot-pad lesions may cause pain which together with a deteriorated state of health constitutes a welfare issue. In a review paper, Savory (1995) mentions poor litter quality as one of the three main categories contributing to welfare problems in broilers. Harms and Simpson (1975) reported that birds with foot-pad dermatitis had an unsteady walk, and Hester (1994) described how foot-pad dermatitis causes birds to walk with a hobbling gait. Nevertheless, it is very difficult to identify lameness caused by foot-pad dermatitis in a commercial flock. As broilers with foot-pad dermatitis usually get the same kind of lesions on both feet, severely affected birds are rarely seen limping, but are instead less likely to move. Poor litter is recognised as a welfare problem also in turkey production (Hocking, 1993). In addition, Geraedts (1983) found a correlation between leg problems and foot-pad dermatitis in turkeys.

Apart from animal welfare aspects, foot-pad dermatitis is relevant to the poultry meat industry for several reasons. It has been indicated that broilers with severe foot-pad dermatitis show slower weight gain (Martland, 1985; Ekstrand and Algers, 1997), which has been suggested to be a result of pain-induced inappetance (Martland, 1985). In a paper describing a study on turkey poults, Schmidt and Lüders (1976) suggested that the lesions cause pain, resulting in a reluctance to move and thus decreased feed consumption. Martland (1984) reported an association between wet litter and a reduction in body weight in groups which also had a high incidence of foot-pad dermatitis. If the problem is widespread in a flock, this can lead to substantially reduced profit for the producer. As flocks with a high incidence of foot-pad dermatitis often also show a high prevalence of other types of contact dermatitis, such as breast blisters and hock burns (Greene et al., 1985; Martland, 1985), in addition to lower body weights, downgrading may adversely affect the profitability of these flocks (Wise, 1978; Cravener et al., 1992). If the disease is affecting males in broiler breeding groups, it may have significant economic effect by interfering with mating efficiency (Nairn and Watson, 1972; Bracewell, 1982).

During recent years export of broiler feet for human consumption from Europe to East Asia has meant increasing revenues for several slaughterhouses (Anonymous, 1996; Anonymous, 1997a). This trade is based on a high quality product, i.e. broiler feet without severe lesions or discoloration. Finally, the lesions can be a gateway for bacteria which may spread hematogenously and cause joint lesions and impaired product quality in other ways (Schulze Kersting, 1996). In poultry, staphylococci are common inhabitants of the skin (Devriese, 1980). Staphylococci are found as secondary infections in foot-pad ulcers (Hester, 1994) and are involved in a number of different disease complexes (Scanlan and Hargis, 1989; Anonymous, 1997b; McCullagh et al., 1997). *Staphylococcus aureus* is important in poultry meat hygiene from its potential production of

enterotoxins which may cause food poisoning in humans (Devriese, 1980; Notermans et al., 1982).

The development of the Animal Welfare Programme

In the mid 1980s, broiler consumption in Sweden was approximately 4.2 kg per person per year. This roughly corresponded to the local production, and imports and exports were low. In society, there had been some debate about the way broilers were reared and broiler farming was often used as an example of 'factory farming', implying extensive welfare problems. The influence of the producers national branch organisation, called the Swedish Poultry Meat Association (SPMA), on the market was limited.

After a *Campylobacter* scare in the media (Granestrand, 1986), broiler consumption decreased by 40 %. A sanitation programme was soon enforced and the prevalence of *Campylobacter* decreased quickly, but consumption of broiler meat remained low. The industry realised that something had to be done as soon as possible to restore consumer confidence in broiler products. Together with production advisors, veterinarians and representatives from the Swedish National Board of Agriculture (SBA) the SPMA created 'The Animal Welfare Programme', a regulatory programme for broiler producers (Ekstrand, 1997).

The Animal Welfare Programme aimed at improving the general standard of rearing, considering housing facilities, equipment, management and stockmanship. Based on a set protocol, an evaluation was made of the livestock environment, the standards of buildings and equipment and management practices on every broiler farm in the country. All in all, a total of 31 items were scored from 1 (poor) to 4 (very good). These scores were then weighted by multiplying them by a factor ranging from 1 to 11, depending on the relative importance of the item concerned. The total score for each broiler house was presented as a percentage of the total possible score. Every house was judged separately; thus, it was possible for a given producer to receive different scores for different buildings at the same farm. All initial evaluations were made by the same person, called the 'national standards officer', in co-operation with the local veterinary inspector and the poultry manager at each slaughterhouse. Operations judged to maintain high standards have since been inspected by the 'national standards officer' every second or third year under the assumption that no unexpected changes have occurred, whereas operations that received lower scores have been inspected yearly. Producers believing that their operations have been unfairly judged have been able to appeal the decision by contacting the branch's central reference group, which also includes representatives from the SBA (Ekstrand, 1997).

The Animal Welfare programme has now been running for more than ten years. All producers who are members of the SPMA get their houses evaluated, but there is no formal way of forcing any producer to improve his housing or management

standard. Instead, the programme is built on the 'reward' theory: improvements should pay off economically. This is done by positively correlating the total score received in the programme to the maximum stocking density allowed at time of slaughter in each broiler house. Farmers outside the regulatory programme are not allowed by the SBA to exceed a stocking density of 20 kg/m^2 in their houses. The maximum stocking density allowed for farms within the programme is now 36 kg/m^2 (or 25 birds/m^2), and anything between those two values is set in relation to the score achieved.

A similar welfare programme is currently being developed for turkey poults. It will basically cover the same type of variables as the broiler programme, with some adjustments for conditions that are specific for the turkey industry.

The need for a new bird health and welfare parameter related to the Animal Welfare Programme

In relation to animal welfare discussions, it has been questioned if a farmer who improves conditions for the birds should be allowed to apply a higher stocking density.

The scientific results on the effect of stocking density on bird welfare are often confusing or even contradictory. It is difficult to compare different investigations on stocking density, as there is a confusion between 'number of birds per area' and 'total body weight of birds per area'. In both cases, age and weight at slaughter is essential information if any comparisons are to be made. Also, the international variation in what is considered as a 'high' stocking density is large. There have been investigations on how stocking density affects production traits, such as growth rate and feed utilisation, and the environment (ventilation needs) (see for example Bessei, 1993). From an animal welfare point of view, however, the health and behaviour of the birds are more important.

In general, with increasing stocking density, plumage becomes dirtier and the feathering deteriorates (Shanawany, 1988; Gordon, 1992). These problems can be attributed to the fact that as bird density increases the litter becomes dirtier and moister (Proudfoot et al., 1979; Blokhuis and Van Der Haar, 1990) and the risk of birds climbing over each other increases (Proudfoot and Hulan, 1985; Gordon, 1992). The moist litter increases the incidence of 'breast blisters', 'hock burns' and foot-pad dermatitis (Greene et al., 1985; McIlroy et al., 1987).

Broilers can suffer from many types of leg problems, all of which can make it difficult for the bird to reach feed and water, and in many cases are considered to be painful (Kestin et al., 1992). Leg problems often have a complicated aetiology, with several interacting factors, such as genetic predisposition, feed composition, infections, and insufficient physical activity all affecting the incidence (FAWC, 1992; Kestin et al., 1992). With an increase in stocking density birds tend to move

around less, and Grashorn and Kutritz (1991) showed that broilers were more plagued by leg problems when kept at a higher stocking density.

A majority of published studies have noted no effects of stocking density on mortality, even at levels that should be regarded as extreme (see for example Shanawany, 1988). However, mortality figures are believed to be of limited value when evaluating animal welfare, although reduced life expectancy can be regarded as an indicator of poor animal welfare (Broom, 1996).

It is always difficult to assess the degree of stress that animals experience, especially over longer periods. Stress in chickens has been studied primarily in connection with handling and transport and, consequently, little is known about stress during the rearing period. Neither Siegel (1960) nor Bolton and co-workers (1972) noted any differences in size between adrenal glands from young chickens kept at a high stocking density and those kept at a lower density.

Considering the world-wide interest in broiler farming, rather few studies have been carried out on the behaviour of broilers. However, in the discussion about optimal stocking density, bird behaviour should be taken into account (Bessei, 1993). There are several studies on the birds' movement patterns and the use of the total area available. The movement patterns have an important influence on the chickens' feed and water consumption, and thus indirectly affect their health. Lewis and Hurnik (1990) documented large individual variation in movement patterns. As stocking density and age (body weight) increase, the birds spend less time in motion, move shorter distances and devote less time to pecking and scratching in the litter. This has been ascribed to the fact that as stocking density increases it becomes more difficult for the birds to perform these behaviours without bumping into one another. This problem is most pronounced towards the end of the rearing period, when the birds are large and the stocking density (expressed in kg/m^2) is higher (Blokhuis and Van Der Haar, 1990; Lewis and Hurnik, 1990; Newberry and Hall, 1990).

When evaluating research on the effects of stocking density it is almost impossible to avoid the effect of group size, as changes in the stocking density is usually achieved by changing the number of birds in a given area. If not, the confounding factor will instead be the total available floor area. Feeding and drinking space per bird is another common confounder. It is also very rare to see investigations where the ventilation capacity has been adjusted to the stocking density. The idea behind the Animal Welfare Programme was that the improvements in facilities, e.g. alarms for systems failures, such as ventilation, power supply and water supply, ventilation capacity or maximum distance to feed and water dispensers, and improvements in management, should clearly overrule any disadvantages from the increase in stocking density.

There have, however, been some serious discussions about the welfare implications of the Animal Welfare Programme. Veterinarians and welfare activists have been worried that the limit has already been reached, and that there is no proper control of the birds' state of health from an animal welfare point of view. It has been suggested that the disease recording done by the meat inspectors at the abattoir has been focused only on meat hygiene aspects, and that signs of general unthriftiness or maltreatment in broiler flocks have either not been recorded or not been followed up. As a result of discussions on this issue, the SBA in 1994 decided that they wanted a new parameter entered into the Animal Welfare Programme. This parameter, at that time undefined, should give information on the rearing standard during the bird's entire life. It should be easy to standardise, cheap to monitor and not require any major extra resources. Thus the Broiler Foot-Health Programme was created, as a part of the Animal Welfare Programme (Figure 3).

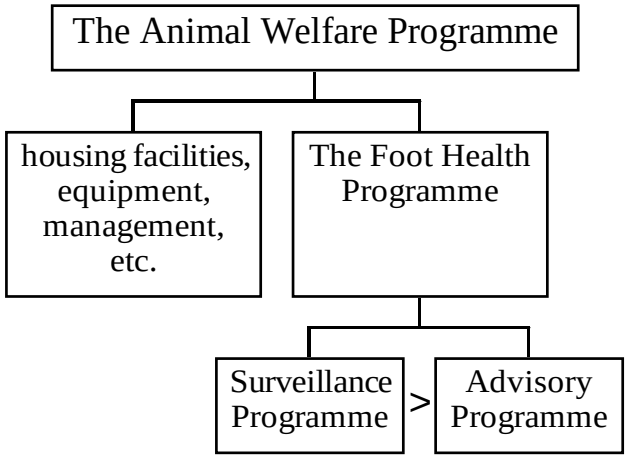

Figure 3. The structure of the broiler welfare programmes (from paper III)

Pathology of the foot-pad lesions

Foot-pad dermatitis, also known as plantar pododermatitis, is a condition characterised by lesions on the ventral foot pads of poultry (Nairn and Watson, 1972; Schmidt and Luders, 1976; Wise, 1978; Bracewell, 1982; Martland, 1985; Schulze Kersting, 1996). Broiler foot-pad dermatitis is a type of contact dermatitis (Nairn and Watson, 1972; Greene et al., 1985) affecting the plantar regions of the feet. In an early stage, discoloration of the skin is seen. Hyperkeratosis and necrosis of the epidermis can be seen histologically. The histopathological changes observed in the skin are similar to those described in many other types of

dermatitis, and no pathognomonic lesions have been observed (Greene et al., 1985; Martland, 1985). In severe cases, the erosions are developed into ulcerations with inflammatory reactions of the subcutaneous tissue (Greene et al., 1985). The ulcerations are often covered by crusts formed by exudate, litter and faecal material. The lesions are commonly called 'ammonia burns', as the dermatitis is thought to be caused by a combination of wet litter, high ammonia content and other chemical factors in the litter (Nairn and Watson, 1972; Harms et al., 1977; Greene et al., 1985; Martland, 1985; McIlroy et al., 1987; Schulze Kersting, 1996). Although not primarily caused by any particular microbial agent, the lesions often become infected by a variety of bacteria and fungi (Greene et al., 1985), especially *Staphylococcus spp*. (Hester, 1994).

Similar foot-pad lesions have been described in turkey poults (Abbott et al., 1969; Schmidt and Luders, 1976; Charles and Fortune, 1977; Harms and Simpson, 1977; Blair, 1978; Martland, 1984). Martland (1984) studied the lesions on turkeys under experimental conditions, and has described how early lesions, like morphological changes in the reticulae, later develops into papillae. In severe cases inflammatory reactions, necrosis and the forming of scabs are seen. The lesions mainly affect the metatarsal pad but may in severe cases also involve the digital pads of the turkey's feet. The role of the lesions as possible portals of entry for bacteria and the importance of secondary bacterial infections have also been discussed in turkeys (Schmidt and Lüders, 1976; Blair, 1978; Martland, 1984).

The foot-pad lesions can develop in less than a week and then progress to ulcers (Greene et al., 1985; Ekstrand and Algers, 1997). The lesions may heal. After healing, the foot pad does not show the normal skin fissure pattern and has a slightly paler colour (Greene et al., 1985).The healing is quicker if the litter quality is improved (Martland, 1985). For broilers, this rarely happens under commercial conditions, except when flocks are thinned as a portion of the flock is removed for slaughter. However, top-dressing (i.e. addition of new litter during the rearing period) is practised on some turkey farms (Geraedts, 1983).

Foot-pad dermatitis in meat-type poultry partly has a similar background to so-called 'breast blisters' and 'hock burns' in broilers (Harms and Simpson, 1975; Greene et al., 1985; Martland, 1985; Bruce et al., 1990), but these lesions usually develop more slowly and are less frequent (Stephenson et al., 1960). Similar types of lesions in turkeys, such as so called 'breast buttons" (focal ulcerative dermatitis; FUD), 'breast blisters' and 'scabby hocks', are also believed to have the same background as the foot-pad lesions (Martland, 1984; Gonder and Barnes, 1987).

In laying hens, the literature describes a wide variety of foot-pad lesions, ranging from mild hyperkeratosis to bumble foot lesions (Wang et al., 1998). Hyperkeratosis and inflamed and swollen claw folds are conditions most often present in the distal toe pad of caged birds (Tauson, 1980; Svedberg, 1988) but

hyperkeratosis can also be seen on the digital and metatarsal foot pads of loose housed layers (Gunnarsson et al., 1995). The bumble-foot syndrome is regarded as the most severe type of foot-pad lesion (Tauson and Abrahamsson, 1994). The syndrome has been described by Siegwart (1991) and Gunnarsson and co-workers (1995) as a severe inflammation including the presence of abscesses and swelling of the metatarsal foot pad, often visible also from a dorsal view. The bumble-foot syndrome thus differs macroscopically from the type of contact dermatitis commonly described in broilers and turkeys. Bumble-foot has also been reported in other types of birds, such as raptors (Rodriguez-Lainz et al., 1997).

Aetiology of the foot-pad lesions

Earlier research aiming at identifying factors influencing the foot health of meat-type poultry has been directed mainly towards the effect of different feed compositions on the incidence of foot-pad dermatitis (Patrick et al., 1942; McGinnis and Carver, 1947; Richardson and Wilgus, 1967; Jensen et al., 1970). For example, it has been shown that there is an increase in the incidence of foot-pad dermatitis when the birds' diets are deficient in biotin (Harms et al., 1977; Oloyo, 1991) or riboflavin (McGinnis and Carver, 1947) and that extra methionine added to the diet will reduce the incidence (Chavez and Kratzer, 1972; 1974).

When basic dietary requirements are fulfilled, which should be the case with modern composition of commercial feed (Schmidt and Lüders, 1976), the lesions are thought to be caused by a combination of moisture and chemical irritants in the litter (Abbott et al., 1969; Nairn and Watson, 1972; Charles and Fortune, 1977; Harms and Simpson, 1977; Harms et al., 1977; Martland, 1984; 1985; Greene et al., 1985; McIlroy et al., 1987).

A number of risk factors for wet litter have been suggested. Litter material and texture is regarded to be of importance. For example, Shanawany (1992) has shown that broilers raised on litter with high water-holding capacity had lower incidence of breast blisters than birds raised on litter with lower water-holding capacity. It has also been shown that turkeys raised on coarse, poor quality litter have higher incidences of breast and foot lesions than turkeys raised on soft, good quality litter (Tilley et al., 1990; Hester et al., 1997).

It has further been suggested that soybean based rations may be involved in producing an irritant litter (Nairn and Watson, 1972) or that soybean meal included in the diet may affect the consistency of the birds' faeces, resulting in sticky droppings and sticky litter, leading to an increase in the incidence of foot-pad dermatitis (Jensen et al., 1970). Tucker and Walker (1992) found an effect of dietary fat quality on litter surface friability. In a comprehensive longitudinal survey McIlroy and co-workers (1987) found a significant effect of feed manufacturer on the incidence of breast lesions.

Stocking density has been reported to influence litter quality, with deteriorated litter quality when stocking density is increased (McIlroy et al., 1987; Blokhuis and Van Der Haar, 1990; Noll et al., 1991; Gordon, 1992; Tucker and Walker, 1992) leading to an increased incidence of foot-pad dermatitis (Cravener et al., 1992; Gaardbo Thomsen, 1992; Martrenchar et al., 1997). Enteric infections, such as *campylobacter* infections, has been found to coincide with sudden appearance of poor litter in broilers (Neill et al., 1984).

Another factor which influences litter quality is climatic conditions, where high relative humidity both outdoors (Payne, 1967; McIlroy et al., 1987) and inside the house (Payne, 1967; Weaver and Meijerhof, 1991) is associated with poor litter quality. It has also been shown that there is an association between wet litter and drinker design (Elson, 1989; Lynn and Elson, 1990; Tucker and Walker, 1992; Cholocinska et al., 1997), mainly related to the variations in the amount of water spillage between different types of drinkers.

Aims

The aim of this series of studies was to improve the knowledge concerning the epidemiology of foot-pad dermatitis in meat-type poultry. Special interest was focused on the following general aims:

- To survey the occurrence of foot-pad dermatitis on Swedish commercial broiler and turkey farms.

- To identify endogenous and exogenous risk factors for foot-pad dermatitis in meat-type poultry.

- To evaluate the function of foot health as an indicator of management, hygiene and housing standards.

The first two studies (papers I and II) were designed to survey the point prevalence of foot-pad dermatitis at time of slaughter in broilers and turkeys respectively, and to identify possible local risk factors. The third study, on which papers III-V are based, was designed to investigate spatial, temporal and management aspects of foot-pad dermatitis in Swedish broilers. This study also aimed at evaluating the efficacy of a control programme for foot-pad dermatitis.
The specific aims of the different studies were, apart from estimating the prevalence and severity of foot-pad dermatitis in Swedish broilers and turkey poults, to test the following detailed hypotheses:

- There is an association between litter quality, litter depth, litter material, litter top-dressing and type of water system respectively and the prevalence of foot-pad dermatitis in broilers and turkeys.

- There is an association between age at slaughter, the sex of the birds, and hybrid, respectively and the prevalence of foot-pad dermatitis in broilers and turkeys.

- There is an association between slaughterhouse affiliation, feed manufacturer, county of origin and season respectively and the prevalence of foot-pad dermatitis in broilers.

- The occurrence of foot-pad dermatitis in broilers will decrease over time when a surveillance programme is initiated.

Methodological considerations

Detailed descriptions of the materials and methods used in the different studies can be found in the five papers respectively, however, some general issues will be discussed below.

The first two studies (papers I and II) were cross-sectional, observational studies of randomly selected farms. The birds' feet were sampled at different slaughter houses and then sent in for central classification. The producers were asked to fill in a simple questionnaire about rearing conditions and general health status for each flock.

The third study (papers III, IV and V) was designed as a cross-sectional observational study, covering all Swedish broiler flocks over a two-year period. The status of the birds' feet were classified by trained inspectors at the abattoirs. Information on possible risk factors such as hybrid, feed supplier and the geographical location of each farm was supplied by the Swedish Poultry Meat Association. Climate data were obtained from the Swedish Meteorological and Hydrological Institute (SMHI).

Observational studies based on results from commercial farms

Learning about causes of disease through epidemiological studies is generally a gradual process that requires different types of study designs, depending on the nature of the disease and possible etiologic agents being considered, as well as on the current state of knowledge and the aetiology of the disease (Kelsey et al., 1996). In this case, the knowledge of the occurrence of the disease within the country was very limited, which was the reason for basing the first studies on results from commercial farms. It would not have been possible to obtain knowledge about the prevalence of foot-pad dermatitis in Swedish broilers and turkeys from experimental studies, it was thus necessary to carry out the studies under field conditions. The randomly sampled farms were geographically well spread in the areas of Sweden where broilers are being reared, and we considered the size of farm and standard of equipment to be representative for Swedish broiler and turkey farms in general.

The third study was based on data gathered within a control programme for foot-pad dermatitis in broilers. The programme involved all broiler flocks slaughtered during a two-year period at the eleven major broiler abattoirs in Sweden, representing 97 % of the broiler producers. This extremely large sample did of course give us a good insight into the actual state of the broiler industry. Being involved from the very beginning of designing the control programme, we were able to influence the type of data to be collected and also in what way, which facilitated later analyses. The Swedish Poultry Meat Association co-operated openly with us in gathering and processing the data on possible risk factors.

One of the disadvantages of using this type of on-farm data is that the producers are inevitably aware of the existence of the studies, which may in fact influence their outcome. As the producers become aware of a health problem in their birds, they are likely to take action to reduce the incidence or severity of the disease. In the third study, based on the control programme, this was even more evident, as the programme itself contained an advisory system aiming at decreasing the occurrence of foot-pad dermatitis in the Swedish broiler population.

Descriptive studies are useful for generating hypotheses (Kelsey et al., 1996), and non-experimental studies can also be used for testing hypotheses about the possible association between exposure and outcome and the characteristics of the association (MacMahon and Pugh, 1970). Carefully designed analytical, observational studies can be used to test causal hypotheses (Kelsey et al., 1996). However, it is often recommended that one should not identify causal relationships on the basis of observational studies only but, if possible, to confirm such hypotheses using experimental studies (MacMahon and Pugh, 1970). It should be borne in mind that the type of cross-sectional, observational studies used here describe the patterns of disease prevalence, rather than the incidence, and that these will be affected by factors determining duration as well as incidence (MacMahon and Pugh, 1970).

One inclusion criterion used in all included studies was membership in the SPMA. This can be seen as a form of convenience sampling, as the identity, location and other information about these farms was easily accessible. As mentioned above, this association organises approximately 97 % of all commercial broiler and turkey producers in Sweden, which means that this criterion had only marginal effects on the characteristics of the units within the sampling frame in relation to the entire population. However, it should be noticed that farms not affiliated to the SPMA have to keep their flocks at a lower stocking density, and are generally regarded as having buildings and equipment of lower standard. In the first two studies (papers I and II) the sampling within this frame was then carried out using a simple random sampling technique. In the third study (papers III to V) all units within the sampling frame were sampled, which means that no further selection was made.

The risk of a systematic error as a result of the questionnaire design is limited. As the producers were aware that the information they supplied regarding, for example, type of water system, stocking density and hybrid, could also be obtained elsewhere, they were not likely to give incorrect information, even less so systematically incorrect information. Another possible source of information bias is improper masking. In the first two studies (papers I and II), the person classifying the foot-pad lesions was not aware of the identity of the flock, and should therefore not have been influenced by it. In the third study (papers III to V), the persons classifying the lesions were stationed at different slaughterhouses

and were thus aware of at least that variable and possibly also the flock identity. However, they were not aware of what other possible risk factors the birds had been exposed to, which limits the probability of bias.

Macroscopical classifications of the lesions

In the first two studies, the sampled broiler or turkey feet were all examined macroscopically by the same observer (papers I and II). The examination was blind, i.e. the observer did not know the identity of the flock at the time of the examination, although knowing which feet belonged to the same flock was unavoidable. The foot-pad status was classified according to a protocol designed by Ekstrand and Svedberg (paper I) as follows: 1) no visible lesions: smooth epidermis, no discoloration; 2) papillae only: hyperkeratosis but no discoloration; 3) mild/superficial lesions: discoloration or erosions in the epidermal layer; 4) mild/superficial lesions and papillae: hyperkeratosis and discoloration or erosions in the epidermal layer; 5) severe ulcerations: discoloration, ulcers and signs of inflammatory reactions, and 6) severe ulcerations and papillae: discoloration, hyperkeratosis, ulcers and signs of inflammatory reactions.

It was concluded that this method for quick macroscopical classification of foot-pad lesions originally developed for broilers could also be used for turkey poults (paper II). As a vast majority of the birds showed the same foot-pad status on both feet, another conclusion from these studies was that it will in future investigations be necessary to examine only one foot per bird if the purpose is to get a general impression of the foot-health status of a flock (papers I and II).
In the third study (papers III, IV and V), the classification of lesions was done by inspectors at the different slaughterhouses. From every slaughtered flock 100 single feet were systematically taken out for gross examination at the abattoir. The foot-pad lesions were assigned to three different classes:
0 = No remark; no lesions, only mild hyperkeratosis, no discoloration or scars; 1 = Mild lesions; superficial lesions, erosions, papillae and discoloration of the foot-pad; and 2 = Severe lesions; deep lesions, ulcers, and scabs.

When the foot-health programme was introduced, the abattoir veterinary inspectors were brought together and educated in the background and pathology of the lesions. They were also trained in the classification of broiler foot-health status. Each veterinarian was equipped with photographs showing typical cases of different severity, including instructions on how to score ‘borderline’ cases. The veterinary inspectors were allowed to delegate the classification of the foot-health status to their assistants but had to countersign the report for each flock.
This method has been evaluated in order to assure the repeatability and inter-rater agreement (Ekstrand et al., 1997). Kappa values have been calculated for the eleven different veterinary inspectors, resulting in a mean kappa value of 0.86 ± 0.15 (ranging from 0.50 to 1.0), which is very good (Altman, 1991). The kappa values were calculated as comparisons of the senior author and inspector observations.

Questionnaires

Questionnaires were used in our first studies of foot-pad dermatitis in broilers and turkeys respectively (papers I and II). From the literature, based on experimental and observational studies from other countries, we had gathered information about possible local risk factors for the disease, i.e. risk factors present inside the poultry rearing unit. This information was used when designing the questionnaires. The questionnaires were of a simple design where the producers were asked to check boxes related to questions about the equipment in the rearing houses and about management practices at the farm. More than 90 % of the broiler and turkey producers completed the questionnaires, and no evaluation of nonrespondents was considered necessary (MacMahon and Pugh, 1970).

For some of the questions in the questionnaire, such as type of water equipment, stocking density and hybrid, it was possible to validate the answers given by the producers by comparing them to information gathered by the SPMA's National Standards Officer prior to the study or by the abattoirs. This validation showed that the information supplied by the producers corresponded very well with that obtained from the other sources.

The surveillance programme

The broiler foot-health programme included classifying foot-pad lesions and estimating flock disease severity at slaughter (papers III, IV and V). It also included an advisory system. A flock was defined as a group of birds reared in the same compartment on the same farm, slaughtered at the same time. For each flock, information on producer, breed, feed manufacturer, region, abattoir, date of slaughter, age at slaughter, planned and actual stocking density was recorded. The method of classification of lesions used in the surveillance programme has been described above.

The veterinary inspectors at the slaughterhouses were responsible for the calculations made within the programme. The flock score was calculated as the cumulative total of the lesion scores and their relative frequency. The number of 'class 0-feet' was multiplied by 0, the number of 'class 1-feet' multiplied by 1, and the number of 'class 2-feet' multiplied by 2. If the total score was < 40 the flock was regarded as 'without remark'. If the total score was between 41 and 80 the flock was given a 'remark low level', and if the total score was > 80 the flock was given a 'remark high level'. A policy decision was made that no producer should be able to deliver flocks with more than 40 % mild foot-pad dermatitis or 20 % severe foot-pad dermatitis without getting a warning.

The different levels of flock prevalence leading to different 'remark' levels were connected to an advisory programme as a part of the surveillance programme. After the slaughter of each flock the producer was informed about the scores. The first time a producer delivered a broiler flock which was given any kind of 'remark' he was contacted by the advisor at the abattoir. If he continued to deliver

flocks with the same level of lesions the rearing conditions of the following flocks were followed up. If no improvement was noticed the maximum allowed stocking density was decreased gradually, until the problems were solved. When the producer was able to deliver flocks classified as 'without remark', the stocking density was gradually increased again.

The measures that should be taken in order to avoid the risk factors for foot pad dermatitis were believed to be in good agreement with what is mentioned in the Animal Welfare Programme, which meant that farmers who had designed their broiler houses according to the programme would have good opportunities to avoid foot-pad dermatitis in their flocks, if they also managed to look after the equipment and animals well.

The foot-health programme is monitored by the national authorities, and summaries of the results have been presented twice yearly to the Broiler Committee of the Swedish National Board of Agriculture. The foot-health programme is now an integrated part of the Animal Welfare Programme.

Statistical methods

In the first two studies (papers I and II), the prevalence of foot-pad dermatitis was calculated for each flock of birds slaughtered, and the proportions of some of the variables concerning rearing methods were calculated. The unit in the analytic procedures was the flock. Subsequent analysis involved pooling of rearing condition categories into gradations of practical relevance to the broiler and turkey industry, respectively. Data were analysed using the two-tailed t-test, with a confidence level of 95 %. A two-tailed linear regression technique (General Linear Models Procedure; GLM) (SAS/STAT, 1989) was used at the 95 % significance level to investigate associations or interactions between the different variables at the flock level.

In the third study, which contained data from approximately 7000 broiler flocks, a number of different analyses were carried out. In the first paper from this study (paper III), which was mainly descriptive, the analyses used were univariable or bivariable. The two-tailed t-test was used to compare differences between hybrids (Minitab, 1996). Distributions, means and standard deviations according to slaughterhouse, feed company and region were calculated (BestFit, 1996), and Duncan's multiple range test was used to compare group means by slaughterhouse, feed company and region (BMDP, 1992).

In the second paper from the third study (paper IV), time-series analyses were conducted to determine seasonality and secular trend of mean flock foot-pad lesion scores. The seasonal effects were evaluated using time-series decomposition (Minitab, 1996) and a classical multiplicative decomposition, exponential smoothing model (Forecast Pro, 1994). The time-series decomposition fits a trend line to the data, using least squares regression, then

detrends the data by dividing out the trend component. Then it smoothes the detrended data by using a centred moving average of length equal to the length of the seasonal cycle. Within each seasonal period, the medial value of the raw seasonals is found. These medians make up the seasonal indices, which are used to seasonally adjust the data (Minitab, 1996). The correlation between monthly outdoor air humidity mean values and monthly mean values for total foot-pad score was determined by calculating the Pearson product moment correlation coefficient between each pair of data (Minitab, 1996).

In the third paper deriving from this study (paper V), a so called Tobit regression model (Tobin, 1958; Amemiya, 1984) was used to identify risk factors for foot-pad dermatitis in broilers. Tobit models are regression models for a normally distributed dependent variable that is restricted in its range due to censoring or truncation. The assumption is that the dependent variable is normally distributed, however due to censoring or truncation, it appears to be or is reportedly non-normally distributed. For this type of data other types of commonly used regression models, such as the ordinary least squares regression model, can often not be used as they do not satisfy the assumption of normally distributed residuals. The modelling was made using the software programme Shazam (Shazam, 1993), which was originally developed for econometrics.

Results and discussion

Prevalence and severity of foot-pad dermatitis in Swedish broilers and turkeys

Foot-pad dermatitis was found to be wide-spread in Swedish broilers and turkeys. In the first study (paper I), where the point prevalence in broilers at time of slaughter was investigated, lesions were rather commonly observed. Approximately 62 % of the birds were classified as being without lesions, 32 % had mild lesions only (discoloration, erosions) and 6 % had severe lesions (ulcers).

When a similar study was carried out in turkey poults (paper II), lesions were very commonly observed. Only 2 % of the feet were classified as being without lesions, 78 % had mild lesions (discoloration, erosions), and 20 % had severe lesions (ulcers). Both in broilers and turkeys it was found that a vast majority of the birds (84 % and 77 % respectively) showed the same foot-pad status on both feet (papers I and II).

In the later, larger broiler study (paper III) which included more than 97 % of all broiler flocks slaughtered in the country during two years, a scoring system related to prevalence and severity of foot-pad dermatitis at time of slaughter was used. The flock specific score was calculated as the cumulative total of the lesion scores and their relative frequency. The total foot-pad score per flock ranged from 0 to 200, which were the lowest and highest scores possible to achieve. The median value was 20, which for a hypothetical flock corresponds to 20 % of the inspected feet having mild lesions, or 10 % of the feet having severe lesions, or a combination of, for example, 10 % mild lesions and 5 % severe lesions. In this study, a total of 820 flocks (11.7 %) were recorded as having no foot pad lesions, and 41 flocks (0.59 %) achieved the maximum score of 200.

There is only one previous publication regarding the prevalence of foot-pad dermatitis in Swedish broilers, and nothing on turkey poults. In a study published in 1995, Elwinger found a prevalence of Swedish broiler foot-pad lesions of 5.0 to 10.1 %, depending on stocking density and season when evaluating the clinical health of live birds one day prior to slaughter. In that study, however, only severe lesions (ulcers) were recorded (Ingvar Andersson, pers. comm., 1997).

Very few figures about the incidence of foot-pad lesions in turkeys are available. In one experiment designed to evaluate different floor types the incidence of foot-pad dermatitis ranged from 80 to 97 %, regardless of treatment, and in a similar experiment the range was 29 to 71 % (Chen et al., 1991). Blair (1978) reported field observations of 85 % incidence of foot-pad dermatitis in turkeys grown on wet litter and 5 % on dry litter. In another field study comprising 39 farms, Geraedts (1983) reported that 4-20 % of the turkeys' feet showed severe foot-pad

dermatitis (lesions with a diameter > 2 cm), 10-32 % showed moderate foot-pad dermatitis (1-2 cm) and the remaining feet showed slight foot-pad lesions (0-1 cm).

As the different broiler studies have estimated the prevalence of foot-pad dermatitis at time of slaughter to 5-10 % for severe lesions and 10-35 % for mild lesions, these figures should be regarded as reasonably reliable. For turkeys the data are more difficult to verify. However, the quoted studies all indicate that foot-pad dermatitis is more common in turkey poults than in broilers.

Endogenous risk factors for foot-pad dermatitis

There are a number of possible risk factors for foot-pad dermatitis which are mainly related to the birds themselves or to the environment and equipment in the broiler house. These factors are here referred to as 'endogenous risk factors'.
Litter quality, litter depth and type of water equipment were found to be statistically significantly associated with the prevalence of foot-pad dermatitis in broilers (paper I). However, no significant associations with age at slaughter, type of litter, top-dressing of litter, stocking density or hybrid were found. For turkey poults litter material, type of water equipment and top-dressing showed significant associations with the prevalence of severe foot-pad dermatitis, while no association with stocking density, litter depth, sex or age at slaughter was found (paper II).

The association between wet litter and broiler contact dermatitis (paper I) has been described previously, both for hock and breast lesions (Greene et al., 1985; Martland, 1985; Bruce et al., 1990) and for foot-pad dermatitis (Harms et al., 1977; Bracewell, 1982; Greene et al., 1985; Martland, 1985). An association between wet litter and the incidence and severity of foot-pad dermatitis has been described also for turkey poults (Abbott et al., 1969; Harms and Simpson, 1977; Geraedts, 1983; Martland, 1984). In our study on turkey foot-pad dermatitis (paper II) no producers checked the box for 'wet litter' on the questionnaire, therefore this variable was not further analysed. A similar experience has been described by Geraedts (1983) who in a field study found that the litter quality in turkey houses was often found to be bad when the turkey growers still regarded it as good.

The results published on the effect of litter depth are somewhat contradictory. While our results (paper I) show that the prevalence of broiler foot-pad dermatitis is significantly lower when the layer of litter is less than 5 cm thick compared to thicker layers, Tucker and Walker (1992) reported poorer litter quality when using thin layers of litter (2.5 cm) than deeper layers (10 cm), although this was not consistent for all litter materials. Stephenson and co-workers (1960) found no effect of litter depth on the incidence of broiler breast blisters. This inconsistency may be explained by differences in the structure, particle size and other quality aspects of the litter materials tested. For thin layers of litter to stay dry, good

ventilation is an absolute necessity, and it is also possible that ventilation practices did differ between the different countries where the studies were carried out due to differences in outdoor climate.

Our study (paper I) showed no significant effect of litter material on the prevalence of foot-pad lesions in broilers at time of slaughter, which is in agreement with Stephenson and co-workers (1960) and Bruce and co-workers (1990) who found no effect of litter material on the incidence of hock or breast lesions. However, Shanawany (1992) who compared the water holding capacity for different litter substrates found that birds raised on litter with high water holding capacity had the lowest incidence of breast blisters. Also Tucker and Walker (1992) found significant differences in friability when comparing different litter substrates such as wood shavings, paper and straw. For turkeys, the situation appears to be slightly different. Our study showed a statistically significant association between litter substrate and the prevalence of severe foot-pad dermatitis (paper II), where birds raised on wood shavings had lower prevalence than birds raised on straw. The quality and structure of the litter also seem to be of importance. It has been shown that turkey poults raised on poor quality, coarse wood shavings have higher incidence of breast blisters compared to those reared on soft good quality shavings or sawdust (Tilley et al., 1990), and that coarse particleboard residue used as litter increases the incidence of turkey foot-pad dermatitis compared to fine particleboard residue or wood shavings (Hester et al., 1997). Newberry (1993) found a higher incidence of breast buttons in turkey raised on coarse than on fine sawdust, and also concluded that wet litter is not an absolute prerequisite for the development of breast buttons. This indicates that although wet litter should be regarded as a risk factor for turkey foot-pad dermatitis, the structure of the litter particles is also important.

In our broiler study (paper I) we found that the prevalence of foot-pad dermatitis in broiler chickens was significantly lower when water nipples were used compared to when small cups were used. As only one broiler farm used large water bells, this farm was excluded from the statistical analysis on the effect of water equipment. Our findings are supported by other studies (Bray and Lynn, 1986; Meijerhof, 1989; Tucker and Walker, 1992; Cholocinska et al., 1997) who found that nipple drinkers reduce water usage and water splashing compared to traditional drinkers, and that this results in a reduction of litter moisture and an improvement of litter hygienic quality. Several studies have also shown a similar association between drinker type and the incidence of hock burn (Lynn and Elson, 1990) and breast blisters (Elson, 1989; Meijerhof, 1989). In the study on foot-pad dermatitis in turkey poults (paper II) we found a highly significant association between the type of water equipment and the prevalence of severe foot-pad dermatitis, where birds using large water bells had markedly higher prevalence of severe foot-pad dermatitis than birds using small cups. The explanation for this is likely to be the same as for broilers. Nipple drinkers are not used for turkeys in Sweden.

We were not able to demonstrate a significant effect of stocking density on the prevalence of foot-pad dermatitis in broilers (paper I), although such an association has previously been described both for foot-pad dermatitis (Cravener et al., 1992; Gaardbo Thomsen, 1992; Martrenchar et al., 1997) and for other types of broiler contact dermatitis (Proudfoot et al., 1979; McIlroy et al., 1987; Bruce et al., 1990; Cravener et al., 1992; Gordon, 1992). This could be explained by the fact that the stocking density in Swedish broiler farms is not freely decided by the producer, but is a result of the standard of equipment and management at the farm which are evaluated within the Animal Welfare Programme. Thus, the stocking density can not be regarded as independent from other risk factors for foot-pad dermatitis in this situation. In turkeys, it has been shown that the litter moisture is increased when flocks are raised under higher stocking densities (Noll et al., 1991). In our study, however, there was no significant association between the stocking density and the prevalence of turkey foot-pad dermatitis (paper II).

No effect of the age at slaughter was found in our studies, neither in broilers (paper I) nor in turkeys (paper II). The variation in age at slaughter for broilers was relatively small, 65 % of the birds in the study were slaughtered within the same four-day interval. The variation in age at slaughter for turkeys was slightly larger (paper II). Earlier studies (Harms and Simpson, 1975; Cravener et al., 1992) have shown higher incidence of foot-pad lesions in male broilers compared to females. This has been explained by differences in body weights and nutritional requirements between males and females. Stephenson and co-workers (1960) and Bruce and co-workers (1990) have reported associations between the age and sex of broiler chickens and the prevalence of hock and breast lesions. In our broiler study (paper I) all flocks were of mixed sex, therefore this variable could not be investigated. The turkeys were reared in sexed flocks, but no statistically significant difference between males and females with regard to foot-pad dermatitis was found (paper II). Other authors have speculated in the rapid growth and the pressure on the feet as the trigger of the disease in male turkeys (Schmidt and Lüders, 1976). In our studies (paper I and II) birds of both sexes were slaughtered at the same age. The relatively low age at slaughter means that the difference in body weight between males and females at time of slaughter may not have been big enough to result in any differences in the prevalence of foot pad dermatitis for either broilers or turkeys. In paper IV results from a slaughterhouse slaughtering only male broilers are presented. This slaughterhouse did not report higher prevalence of foot-pad dermatitis than the average slaughterhouse dealing with birds of mixed sexes. The conclusion is that at the age of slaughter applied in Swedish broiler and turkey production the sex of the birds is not associated with the prevalence of foot-pad dermatitis.

It has been shown under experimental conditions that when litter conditions are changed from wet to dry this results in rapid healing of foot-pad lesions in broilers, with a compensatory recovery in growth rate (Martland, 1985).

However, top-dressing of the litter is not commonly practised by Swedish broiler producers, and no significant association between top-dressing and the prevalence of foot-pad dermatitis was found (paper I). This finding is in agreement with results by Stephenson and co-workers (1960), who found no effect of top-dressing on the incidence of breast blisters in broilers. For turkey poults, which are older than broilers at time of slaughter and thus spend longer time on the littered floor, the situation is different. We found that flocks raised in compartments where top-dressing was used had a significantly lower prevalence of foot-pad dermatitis than flocks raised in compartments where no litter was added during the rearing period. This is in agreement with Geraedts (1983) who, after carrying out a field study of foot-pad dermatitis in turkeys, recommends a combination of top-dressing and cultivating for the best results in practice. It has also been shown under experimental conditions that when turkey poults are transferred to new wood shavings the incidence of foot-pad lesions is reduced (Charles and Fortune, 1977).

In our first broiler study no significant association between the hybrid (strain) of the birds and the prevalence of foot-pad dermatitis was found (paper I). In the later, larger study, a statistically significant difference between the two hybrids with regards to the prevalence of foot-pad dermatitis was found (paper III). This difference was, however, small and when the same data was analysed using a regression model the variable ‘hybrid’ did not come out as significant (paper V). In the turkey study (paper II) all birds were of the same hybrid.

Exogenous risk factors for foot-pad dermatitis

There are a number of possible risk factors for foot-pad dermatitis which are mainly related to factors outside the house, such as climate or slaughterhouse affiliation, which in turn may affect the birds inside the house. These factors are here referred to as ‘exogenous risk factors’. In our third study (papers III, IV and V), which covered all Swedish broiler flocks over a two-year period, these external risk factors for broiler foot-pad dermatitis were investigated.

We found a statistically significant association between slaughterhouse affiliation and foot-pad dermatitis in broilers (papers III and V). This should not be interpreted as a result of variations in the classification of foot-pad lesions at the slaughterhouses, as the inter-rater agreement has been shown to be very good (Ekstrand et al., 1997). Instead, this association could be an effect of other factors, such as management advice given by local advisors at the different slaughterhouses.

We also found a statistically significant association between feed supplier and foot-pad dermatitis in broilers (papers III and V). This is in agreement with McIlroy and co-workers (1987) and Bruce and co-workers (1990) who found significant differences in the prevalence of broiler hock and breast lesions between different feed manufacturers. It has been described how nutritional

factors, such as sodium or potassium levels, can lead to over-drinking and result in wet litter (Appleby et al., 1992; Tucker and Walker, 1992). Other researchers have shown an effect of the quality of the dietary fat and energy and protein levels on litter quality, and found an association with the incidence of hock burn in broilers (Bray and Lynn, 1986; Tucker and Walker, 1992).

There are other studies showing an effect of dietary deficiencies, mainly with respect to biotin, on the incidence of foot-pad dermatitis in both broilers and turkeys (Harms and Simpson, 1975; Harms et al., 1977; Oloyo, 1991). Charles and Fortune (1977) reported that dietary biotin supplementation failed to reduce foot-pad lesions in turkeys. However, they did find differences in the incidence of foot-pad dermatitis between two commercially available diets, both under field and in experimental conditions. An association between diets deficient in methionine or riboflavin and the development of foot-pad dermatitis in turkeys has also been reported (McGinnis and Carver, 1947; Chavez and Kratzer, 1974), which was hypothesised to at least partly be an effect of the diarrhoea arising among the birds given the deficient diets. Similar reports are available on the association between feeding the turkey poults soybean meal ratios, which affect the composition and consistency of the faeces (Jensen et al., 1970; Chavez and Kratzer, 1974). Already in 1976, Schmidt and Lüders had written that dietary deficiencies should be regarded as unlikely with modern composition of commercial poultry feed. Both biotin and other vital amino acids are added to Swedish broiler and turkey feed according to international standards and there is no reason to suspect any deficiencies, unless there are problems absorbing the substance into the body. However, as discussed above, the different components of the diet may still affect the consistency of the birds' faeces and thereby the litter quality.

When performing the time-series analyses on the foot-pad dermatitis prevalence data in relation to feed supplier, we found that although a majority (5/8) of the companies showed a decreasing trend over time during the study, three companies showed increasing trends (paper IV).

No studies of the geographical distribution of broiler or turkey foot-pad dermatitis have been previously published. In our study, we analysed the prevalence of broiler foot-pad dermatitis for different regions, based on the Swedish county borders (paper III). We found a statistically significant association between county of origin and the prevalence of foot-pad dermatitis; the prevalence was higher in the south western part of the country, and generally lower in the northern broiler producing regions. This was confirmed in the subsequent regression analysis (paper V), where several regions significantly influenced the foot-pad dermatitis model. These data have been further evaluated using different types of analyses to investigate the occurrence of spatial and spatio-temporal clustering (Ekstrand and Carpenter, 1998).

In addition to regional effects, we also found a statistically significant seasonal effect on the prevalence of broiler foot-pad dermatitis (paper IV). When evaluating the seasonal effects using classical multiplicative decomposition time-series analysis, we found a seasonal component of 48.7 % and a trend-cycle component of 10.4 % resulting in a total adjusted R-square value of 58.5 % for the total foot-pad score (paper IV). This means that almost 60 % of the variation in flock foot-pad score can be explained by the variable 'time', and that this variation was mainly related to seasonal effects but also to a general decreasing trend over the study period. The highest average prevalence of foot-pad dermatitis was found during October to January, when outdoor relative humidity (RH) is high, and the lowest prevalence was found during May to August, when outdoor RH is lower.

There is an association between season and litter quality, mainly related to the outdoor relative humidity, which in turn affects indoor relative humidity (Payne, 1967; Dobrzanski and Mazurkiewicz, 1984; McIlroy et al., 1987; Bruce et al., 1990; Weaver and Meijerhof, 1991). In northern Ireland, field studies have shown a highly significant correlation between average monthly outdoor relative humidity and the average monthly prevalence of hock lesions in broilers, with highest prevalence during the winter months (McIlroy et al., 1987; Bruce et al., 1990). The seasonal variation in the prevalence of foot-pad dermatitis is seen in Figure 4. Experimental studies have shown that there is a significant effect of indoor relative humidity on the percentage dry matter of the litter, and that the incidence and severity of swollen, callused foot-pads was significantly higher for 75 % RH than 45 % RH (Weaver and Meijerhof, 1991). McIlroy and co-workers (1987) stated that although the ventilation capacity might be good, adequate ventilation is often wrongly constrained by the desire to conserve heat and frequently leads to a humid atmosphere with associated wet litter conditions. This situation is well known in Sweden.

The Tobit analysis carried out on the data from the third study (paper V) showed that there was a number of statistically significant interactions between the exogenous risk factors. There were interactions present between slaughterhouse and geographical region and between slaughterhouse and feed supplier. There were also interactions between the time variable and the variables mentioned above. For example, one slaughterhouse showed improvements in the prevalence of foot-pad dermatitis over time that were significantly larger than the mean improvement. These biologically relevant interactions do not generally alter the main conclusions regarding the importance of the different risk factors. However, the interaction analyses are useful when identifying the exceptions from the rule and make it possible to follow up these events in detail, in order to improve the surveillance programme.

Effects of intervention

The surveillance programme for broiler foot-pad dermatitis started in July 1994 and our evaluation covers the first two years of the continuing programme. There was a general decreasing trend in the prevalence of broiler foot-pad dermatitis over the study period (papers III, IV and V). As the programme did not only include passive recording of disease prevalence but also an active advisory programme, its existence is likely to have affected the prevalence of foot-pad dermatitis in the population (Figure 4).

When evaluating the seasonal effects using time-series analysis, we found a trend-cycle component, illustrating the long-term development, of 10.4 % (paper IV). The trend-cycle component for the severe lesions was 12.6 % and for mild lesions 3.1 %, which means that the general decrease in the prevalence of foot-pad dermatitis was mainly due to a decrease in the total prevalence of severe lesions. The mean prevalence of severe foot-pad dermatitis has decreased from 11 % in 1994 to 6 % in 1996 (paper IV) and 5 % in 1997 (Ingvar Andersson, pers. comm., 1998).

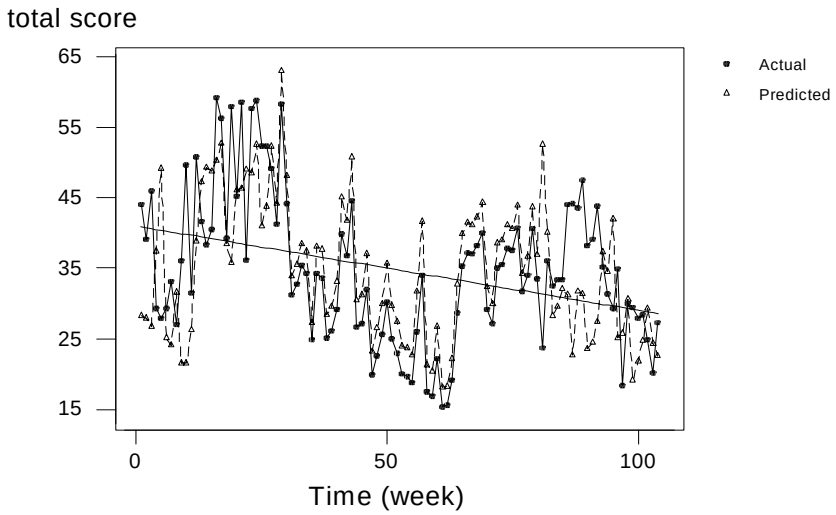

Figure 4. Total foot-pad dermatitis score over the entire study period (104 weeks). An exponential smoothing model for classical multiplicative decomposition showed a trend-cycle component of 10.4 % and a seasonal component of 48.7 % resulting in a total adjusted R-square value of 0.585 for the total foot pad score ($P<0.05$). Actual (■) and predicted (Δ) values are shown. (Paper IV)

This improvement in broiler foot-health may have been stepwise, i.e. producers initially delivering flocks with a high number of birds with severe foot-pad dermatitis improved the rearing conditions enough to later deliver birds with only mild lesions, while farms initially having mainly mild lesions improved to a similar extent, resulting in lesion free birds. This hypothesis has, however, not been investigated.

We found substantial differences in the development over time of the prevalence of foot-pad dermatitis for the different regions, slaughterhouses and feed suppliers included in the study.

We have not found any other studies concerning the occurrence of broiler foot-pad dermatitis over a longer time period. In a survey with a large integrated broiler organisation in Northern Ireland, Bruce and co-workers (Bruce et al., 1990) reported a reduction in the prevalence of breast blisters from 1984-85 to 1986-87. The prevalence of hock lesions was similar in both time periods, but the degree of variation between flocks decreased. During the same time interval there was a reduction in the average age of removal, and also a change of feed manufacturer. In the published report there is no description of other measures taken or any type of intervention during the survey period, but the authors discuss improved management procedures in general in relation to the decrease in the prevalence of breast blisters.

Future development

The broiler welfare programme has attracted much attention internationally, and the idea of combining an evaluation of the rearing equipment and conditions with a follow-up of the actual results represented by the foot-health programme has been appreciated. Also within the country organisations and producers in other livestock areas have shown an interest in creating similar programmes. A programme for evaluating the welfare of caged layers has been running since 1997 and the dairy farmer's organisation has begun to discuss a similar development. During that process the experiences from the broiler programmes will be invaluable.

For all types of welfare programmes it is essential that the standard is kept well above the minimum level of acceptance, which is usually indicated by animal welfare legislation. For a programme to gain credibility it must not be suspected of trying to 'cover up' defects in the existing production system, but instead clearly aim at checking the status and encourage improvements in animal husbandry. Again to gain credibility, the results of the program must be available both to the authorities and to the public, not necessarily at the farm or company level but as a whole. Also, an animal welfare programme must not stagnate, but be revised and developed at regular intervals. It is of course also very important that the producers are continuously informed about their own status in the programme and of the results of any scientific investigation carried out within the

programme. This feedback can be anything from detailed written reports from the slaughterhouse after each slaughtered batch of animals or annual visits by representatives for the programme to monthly newsletters or gatherings where scientists present their results.

In accordance with this, there is an ongoing development within the Swedish broiler welfare programme. Currently a working group appointed by the Swedish National Board of Agriculture is discussing other possible follow-up health parameters, to be used as a complement to the foot-health scoring system. An animal welfare programme for turkeys already exists but needs some revision and alterations, as the conditions for the industry has changed lately. The turkey industry is moving towards larger birds for cut parts, which means a higher age and higher weight at slaughter. Changes in the legislation regarding stocking density for turkeys (number of birds per m^2 and kg per m^2) are currently being discussed.

The results presented in this thesis (papers I to V) mainly cover the areas of prevalence, surveillance and risk factors for broiler and, to some extent, turkey foot-pad dermatitis. Other studies carried out by the same research group have covered the development of the lesions over time in individual birds (Ekstrand and Algers, 1997) and the prevalence of, and risk factors for, similar lesions in laying hens (Ekstrand, 1996; Wang et al., 1998).

However, there are other areas in the field of poultry foot-pad dermatitis where further studies would be beneficial. One such area is the possible association between foot-pad dermatitis and food hygiene. As stated in the introduction some authors claim that the lesions can be a gateway for bacteria which may spread hematogenously and thereby lead to impaired product quality (Schulze Kersting, 1996). To investigate the occurrence and possible consequences of this should be a priority in the near future. Also, further investigations of how to decrease the incidence of foot-pad dermatitis in turkeys are needed, especially as the turkey sector is expected to expand within a few years. Hitherto, our studies have concentrated on foot-pad dermatitis in turkeys slaughtered at a relatively young age (9-10 weeks), but as consumers' interest in cut parts from larger birds is increasing an investigation of the prevalence and severity of foot-pad dermatitis in birds grown to a higher age (16-20 weeks) would be relevant.

Conclusions

The prevalence of foot-pad dermatitis in Swedish broilers at time of slaughter are estimated to be 5-10 % for severe lesions and 10-35 % for mild lesions. The corresponding prevalence of foot-pad dermatitis in turkeys has been estimated to approximately be 20 % for severe lesions and 78 % for mild lesions. The turkey figures are, however, based on a considerably smaller study than the broiler figures.

There is an association between litter quality and the prevalence of foot-pad dermatitis in both broilers and turkeys. There is an association between litter depth and broiler foot-pad dermatitis.

There is an association between litter material and turkey foot-pad dermatitis and also an association between litter top-dressing and foot-pad dermatitis in turkeys. There is an association between type of water system and foot-pad dermatitis in both broilers and turkeys.

There is no association between age at slaughter and foot-pad dermatitis or between the sex of the birds and the prevalence of foot-pad dermatitis, neither in broilers nor in turkeys. There is also no association between hybrid and broiler foot-pad dermatitis.

There is an association between slaughterhouse affiliation and between feed manufacturer and foot-pad dermatitis in broilers. There is an association between county of origin and foot-pad dermatitis in broilers and also an association between season and the prevalence of foot-pad dermatitis in broilers.

The prevalence and severity of foot-pad dermatitis in broilers decreased over time when a surveillance programme was initiated.

Foot-pad dermatitis in both broilers and turkeys was shown to be linked to a number of management, hygiene and housing factors, and can thus be used as an indicator of the standard of these factors. Surveillance and advisory programmes can be used successfully to decrease the incidence of foot-pad lesions in broiler and turkey populations and thus improve the health and welfare of these birds.

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