Impacts of diet composition and litter quality on development and severity of foot pad dermatitis in growing turkeys

I.M.I. Youssef[1], A. Beineke[2], K. Rohn[3] and J. Kamphues[1]

[1]Institute of Animal Nutrition, [2]Institute of Pathology, [3]Institute of Biometry and Information Processing, University of Veterinary Medicine Hannover, Foundation, Germany

Introduction

Foot pad dermatitis (FPD) is a widespread problem in broiler and turkey production, affecting not only the welfare of the animals but also the quality of the product. FPD is a type of contact dermatitis where the lesions appear on the plantar surface of the bird's feet (Ekstrand *et al.*, 1997). It was observed that turkeys of almost all ages suffer from FPD and the disease can start at a very early age (Mayne *et al.*, 2006b). The prevalence of FPD in turkeys can be extremely high, e.g. only 2.8 % of the animals showed no lesions at slaughter in a study by Grosse Liesner (2007). Lesions caused by FPD range from discoloration and hyperkeratosis – often combined with erosion and necrosis of the epidermis - to deep ulcers in severe cases (Greene *et al.*, 1985). The lesions mainly affect the metatarsal pads but may also involve the digital pads of the feet in severe cases. The cause of this disease is complex and apparently "multifactorial" (Mayne, 2005). Many contributing risk factors have been associated with the prevalence such as genetic disposition, management and nutrition. FPD is thought to be caused by a combination of wet litter, high ammonia content and other chemical substances in the litter from excreta (Martland, 1985). The type of litter may have an effect on the incidence of FPD due to either the physical structure or the water binding capacity of the litter (Bilgili *et al.*, 2009; Youssef *et al.*, 2010). The contact of the turkeys' feet with the excreta may also induce FPD (Jensen, 1985; Tucker and Walker, 1992). High dietary protein is thought to increase the incidence of FPD (Nagaraj *et al.*, 2006; 2007b). High dietary levels of soybean meal (SBM) may contribute to a higher incidence of FPD in turkeys as a result of sticky/wet excreta and subsequent irritation of the pad (Jensen *et al.*, 1970). It is not clear from these findings whether the effect on FPD was related to certain carbohydrates or due to the potassium content of SBM, resulting in higher water intake and excretion (Youssef *et al.*, 2011c). There is obviously a great need to find out preventive measures against FPD. Specific dietary supplements (such as biotin, zinc, mannan oligosaccharides) are thought to reduce FPD due to their role in maintaining skin integrity and stimulating immunity.

Since diet composition affects excreta and litter quality, the effects of different nutrients were tested in this study in relation to litter moisture (standardized by experimental water application). The aim of the present study was to determine possible causes of FPD and to develop strategies which can help to prevent or minimise the incidence of FPD. Several factors were investigated mainly concerning litter quality and bedding materials, specific nutrients (protein, macro elements, biotin, zinc) and distinct dietary factors (soybean meal, soybean oligosaccharides, mannan oligosaccharides). Each litter/dietary factor was evaluated simultaneously under the influences of dry and wet litter, respectively.

Material and methods

Five consecutive experiments (Youssef *et al.*, 2010/2011a-d) were conducted on 2-week-old female turkeys (BUT, Big 6) for a period of 3 or 4 weeks. The animals in each experiment were divided into 4 groups, each with 20 or 29 birds. The turkeys in every experiment were exposed to wet litter for 8h / day to simulate the litter quality under field condition, where only specific areas are very wet, especially around drinkers. The wet litter was always maintained at about 27 % DM content by adding water as required. The foot pads of all birds were examined at the start and end of each experiment and at weekly intervals and assessed macroscopically and histologically according to external and histological scores of Mayne *et al.* (2007c; Fig. 1 - 2). External foot pad scores ranged from 0 (no evidence of FPD) to 7 (more than half of the foot pad covered in necrotic scales). Histopathological scores for foot pad lesions also ranged from 0 (normal) to 7 (ruptured epidermis and widespread inflammatory cells covering at least one-third of the foot pad). Moreover, the dry mater (DM) content of the litter was measured throughout the experiments.

Figure 1:
External FPD score 0: skin of the foot pad and digital pads appears normal.

Figure 2:
External FPD score 7: over half of the foot pad covered in necrotic scales.

Experiment 1: Effects of protein metabolites and litter quality

The main products of the protein metabolism in the excreta are uric acid and secondary ammonia. The effects of these protein metabolites as well as of the litter quality on the development of FPD were investigated. The turkeys were housed in floor pens on dry, clean wood shavings litter which was replaced daily with fresh material to maintain the litter clean and dry. The control animals were kept continuously on this litter throughout the experiment (3 weeks), whereas the experimental animals were exposed also to wet (27% DM) wood shavings for 8 h /d only in adjacent boxes. This wet litter contained water alone or water with NH_4Cl or uric acid. Ammonium chloride and uric acid were mixed with water and added to the litter to achieve the concentration of ammonia and uric acid in the litter as found in fresh excreta of turkeys (about 0.50g ammonia and 20g uric acid/kg). The wet litter was cleaned from excreta twice daily and changed twice a week. The foot pads of all birds were examined and assessed by an external scoring at the start and end of the experiment, and at weekly intervals. Three birds were selected from each group at the start, then weekly for histopathological examination of the foot pads. The remaining turkeys per group were sacrificed at the end of the experiment and the pads were assessed histopathologically. Additional details of the experiment are presented in Youssef *et al.* (2011a).

Experiment 2: Effect of macro elements oversupply in the diet

The excess of macro elements in the diet can lead to FPD by irritation of the foot pad when excreted in the droppings or by increasing the excreta/litter moisture. Groups 1 and 2 were fed a control diet that contained low levels (minimum requirements) of specific macro elements (6.65 Ca, 4.43 P, 1.40 Mg, 1.12 Na, 3.16 Cl g/kg diet) while groups 3 and 4 were fed an experimental diet containing high levels of these elements, about twice the minimum requirements (17.1 Ca, 7.73 P, 2.79 Mg, 2.32 Na, 4.58 Cl g/kg diet). One half of the birds were housed in floor pens on dry wood shavings, the other half (groups 2 and 4) were exposed to wet litter (with excreta) for 8 h/d throughout the experiment (3 weeks). The wet litter was maintained at about 27% DM by adding water as required. The foot pads were examined externally and histopathologically. Further information on material and methods are presented in Youssef *et al.* (2011b).

Experiment 3: Effects of high dietary level of soybean meal and its constituents

Soybean meal (SBM) is the most common protein source for use in turkey diets. The “indigestible” carbohydrate part of the soybean meal is thought to be responsible for contact foot pad dermatitis. Stachyose and raffinose are the main components in soy oligosaccharides that cannot be digested by the intestinal enzymes in turkeys (but fermented by intestinal bacteria). It is also suspected that higher levels of potassium in such diets of high SBM lead to a higher moisture content in litter and might be predisposing for FPD. We wanted to elucidate which constituents in SBM, i.e. soybean oligosaccharides (especially stachyose and raffinose) and/or the potassium content, are associated with the higher incidence and severity of FPD.

The birds were randomly allotted to four groups that were fed a control, high SBM, high potassium (K) or high oligosaccharides (OS) diet for 3 weeks. During the experiment, half of the birds were kept on dry wood shavings, the other half exposed to wet litter for 8 h/d in adjacent pens. The wet litter was maintained at a dry matter content of about 27% by adding water as required. All diets were formulated to have identical nutrient contents (except K, stachyose and raffinose). The high SBM diet was formulated to contain about 44% SBM and the high K and OS diets were designed to have the same content of K or oligosaccharides as the high SBM diet. Potassium bicarbonate was added to the high K diet to increase its content of K to be nearly identical to the SBM diet (about 12g K/kg). Also, a commercial soybean oligosaccharides product was used to increase the stachyose and raffinose content of the OS diet to be the same as in the high SBM diet (15g stachyose + raffinose /kg). The foot pads of birds were examined externally and histopathologically at the start and end of the experiment, as well at weekly intervals. Details of the material and methods are documented in Youssef *et al.* (2011c).

Experiment 4: Effect of litter type

Different bedding materials that can be used for turkeys were tested in this trial in order to evaluate the effect of these litter types on the development of foot pad dermatitis. The birds were housed on: wood shaving, lignocellulose (SoftCell®), chopped straw (Strohfix®) or dried maize silage. Half of the turkeys in each treatment were additionally exposed to wet (27% DM) litter for 8 h/d throughout the experiment (4 weeks). The foot pads were examined externally and histopathologically. The material and methods of this experiment are described in detail in Youssef *et al.* (2010).

Experiment 5: Effect of dietary supplementation of biotin, zinc and mannan oligosaccharides

Two week-old female turkeys were randomly allotted to 4 groups, with 29 each, and housed on wood shavings for a period of 4 weeks. Four diets were fed: control, high biotin, high Zn or mannan oligosaccharide (MOS) diet. The control diet contained required amounts of biotin (300 µg/kg) and Zn (50 mg/kg), while the high biotin or Zn diet comprised 2000 µg biotin or 150mg Zn/kg. The MOS diet was formulated by adding mannan oligosaccharide (Bio-Mos®) at a level of 1% (higher than commonly used [0.05-0.20%] to provoke its effect on FPD) but with amounts of biotin and Zn like the control diet. Half of the turkeys in each group were exposed to wet litter (27% DM) for 8 h/d. Foot pads of all birds were assessed macroscopically on day 0, 7, 14, 21 and 28. Three birds per litter treatment were selected from each group on day 0, 7, 14 & 28 and 4 birds on d 21 for histopathology of foot pads. The DM content of litter as well as plasma biotin and Zn levels were measured at the start, once a week and at the end of the experiment. Details of the material and methods are published in Youssef *et al.* (2011d).

Results:

- Experiment 1:

The severity of FPD was markedly higher on wet than on dry litter (Fig. 3), and no differences in foot pad scores were found between various treatments within wet litter. Similar results were also obtained by histopathology of foot pad lesions. These findings indicate that the high litter moisture solely can cause FPD in turkeys and the high protein content in the diet does not play a dominant role in the development of FPD.

- Experiment 2:

There was no difference between birds housed on dry litter and fed low vs. high levels of macro elements (Fig. 4). The severity of FPD was higher on wet than on dry litter, and birds fed the high macro elements diet and exposed to wet litter had slightly higher FPD scores, especially at the end of experiment. Nevertheless, the effect of macro elements was slight in comparison to that of high litter moisture. The results of histological foot scores were consistent with the external FPD scores.

Figure 3: Effect of litter treatment on external FPD scores at the end of the experiment.

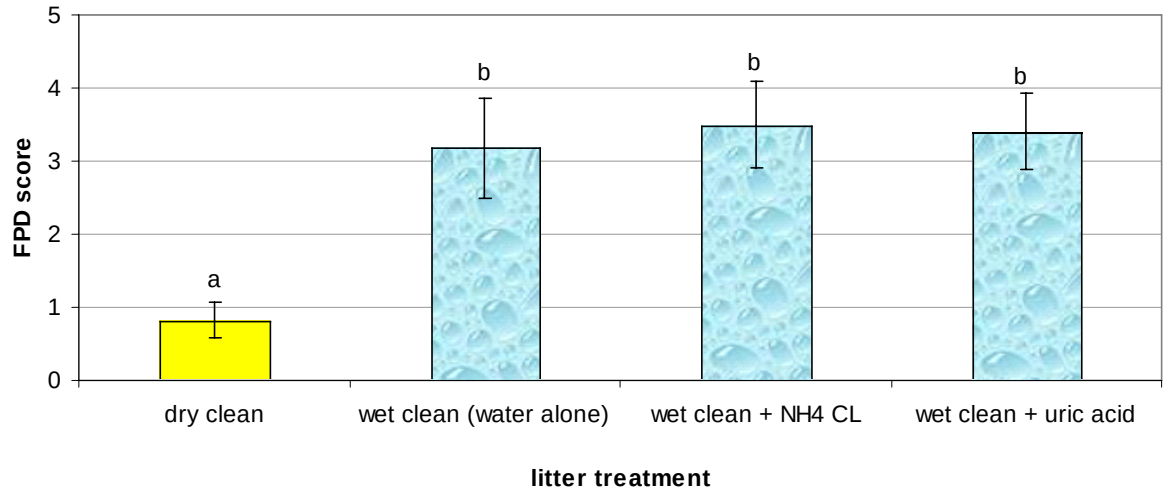
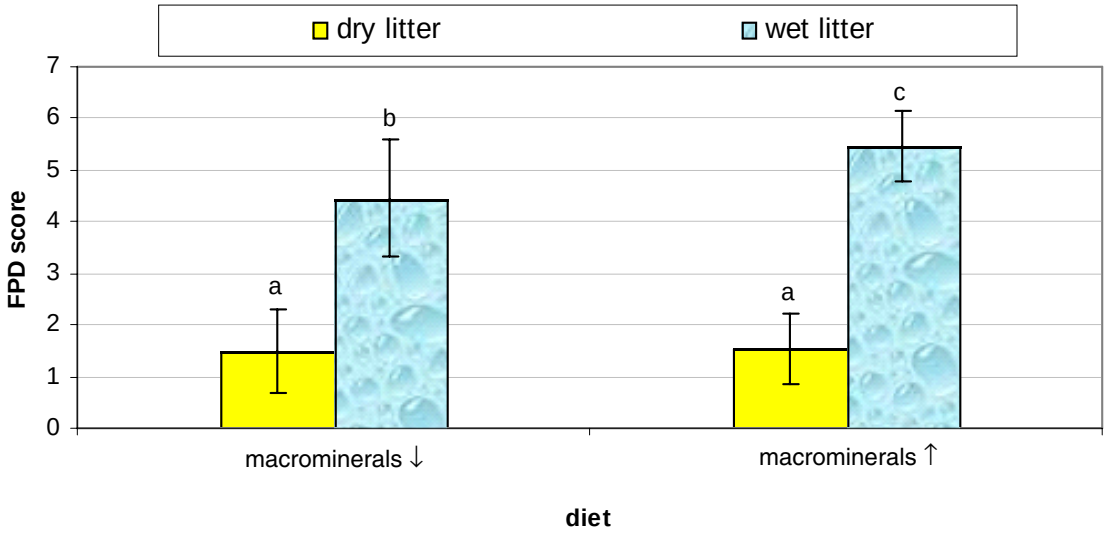


Figure 4: Effect of macromineral diet on external FPD scores at the end of the experiment (Youssef *et al.*, 2011b).



- Experiment 3:

There was no difference in the severity of FPD between the birds housed on dry litter, but the severity was higher in turkeys fed high SBM, K or OS diet and exposed to wet litter when compared to the control diet (Fig. 5). The severity was generally higher on wet litter than on dry litter. However, there were no histopathological differences between the animals housed on dry litter or between those exposed to wet litter. The birds fed the high SBM diet had a markedly higher water intake than the other groups (SBM > K > OS > control), and their excreta appeared wet or sticky by visual inspection (Fig. 6).

Figure 5: Effect of high dietary SBM, potassium and oligosaccharides on external FPD scores at the end of the experiment.

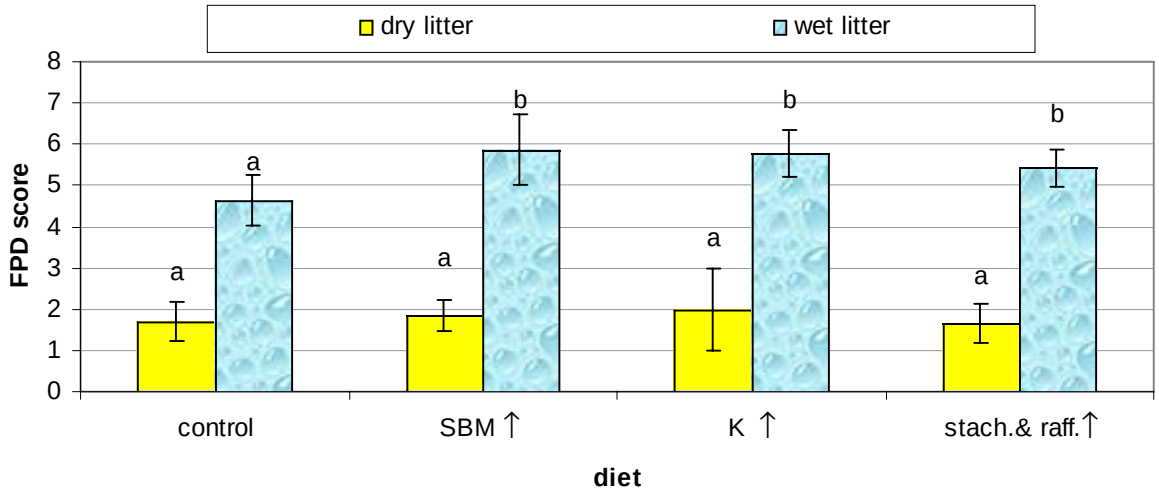
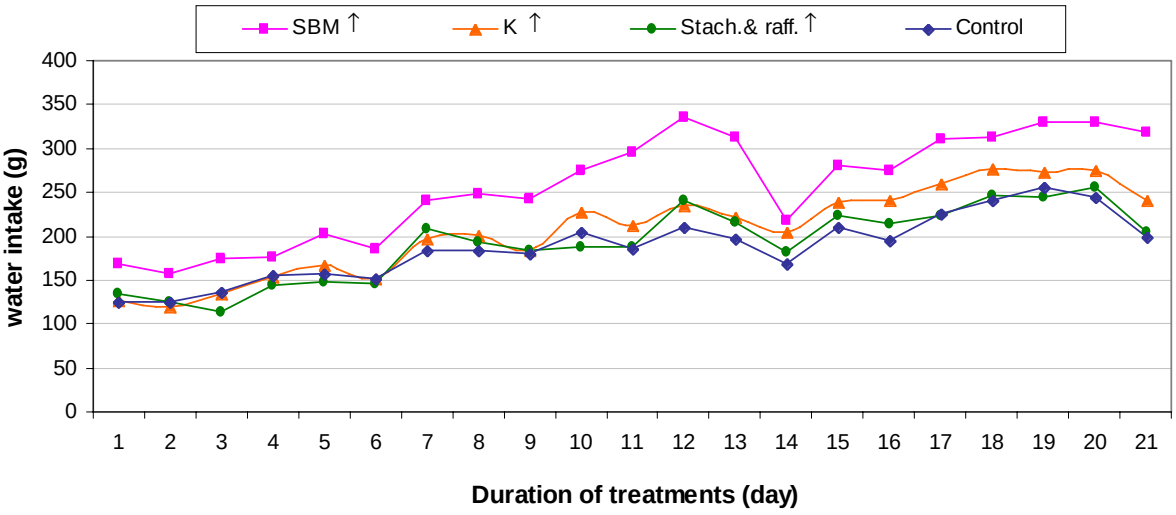


Figure 6: Water intake (g) of turkeys fed different experimental diets throughout the experiment (Youssef *et al.*, 2011c).



- Experiment 4:

Lignocellulose litter showed the lowest severity of foot pad lesions on dry and wet litter (Fig. 7). However, chopped straw (dry treatment) was associated with higher foot pad scores. Moreover, the severity of FPD was higher on wet than on dry litter in each litter type. The histology of foot pads showed similar results to the external FPD scores, with significantly higher scores on chopped straw. With identical diets and stocking density, the DM content in the pens with dry litter treatment was 76.7, 83.2, 68.8 and 75.0% for wood shavings, lignocellulose, chopped straw and dried maize silage, respectively (Fig. 8). Foot pad scores and the moisture content of litter materials were highly correlated (R^2 = 0.96).

Figure 7: Effect of different litter material on external FPD scores at the end of the experiment.

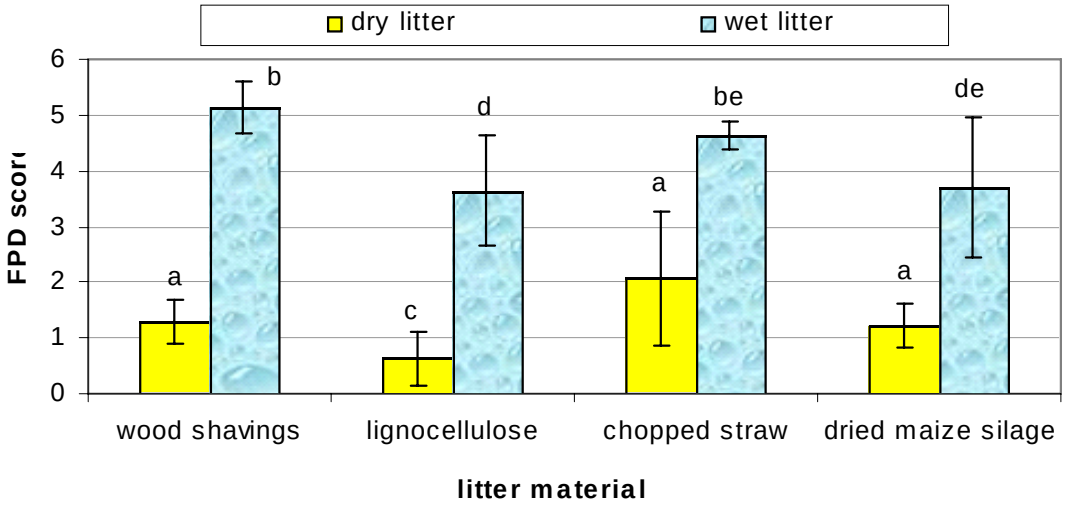
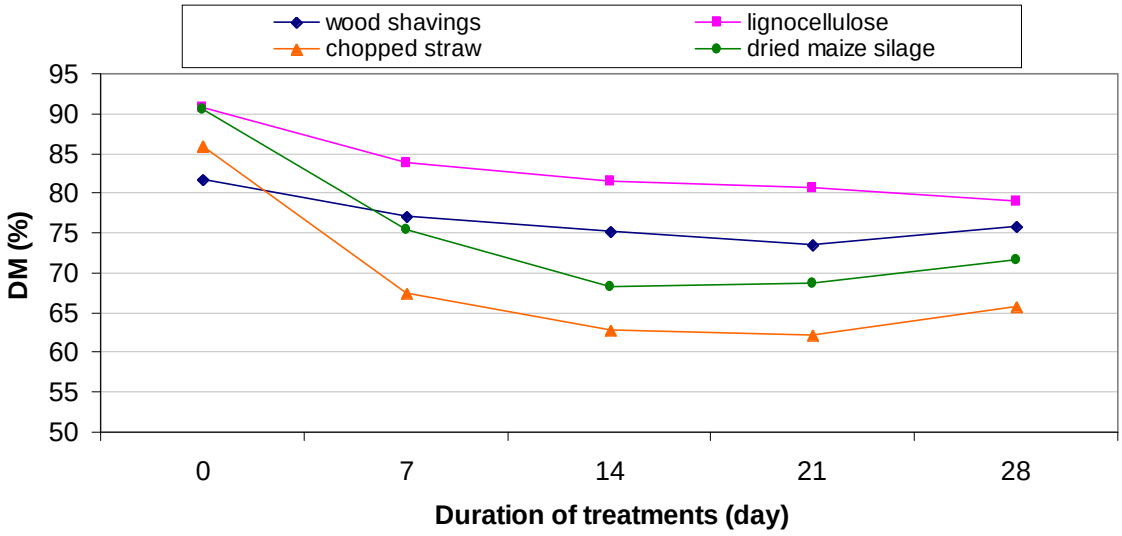


Figure 8: DM content (%) of bedding materials for dry treatments (Youssef *et al.*, 2010).



- Experiment 5:

The severity of FPD was much higher in all pens with wet litter (Fig. 9). High dietary levels of biotin or Zn significantly reduced the severity on dry litter (75% DM), but had no preventive effects on wet litter (27% DM). The histological FPD scores showed similar results to external scores. Plasma biotin and Zn levels increased in turkeys fed a high biotin or Zn diet (Fig. 10).

Figure 9: Effect of dietary supplementation of biotin, Zn and MOS on external FPD scores at the end of the experiment.

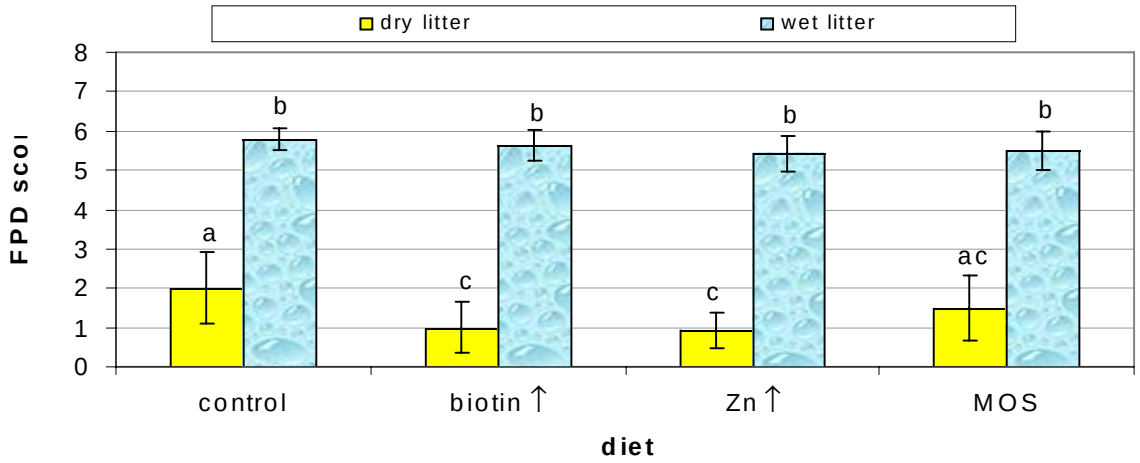


Figure 10: Plasma biotin (ng/l) and Zn (ug/dl) levels at the end of the experiment (Youssef *et al.*, 2011d).

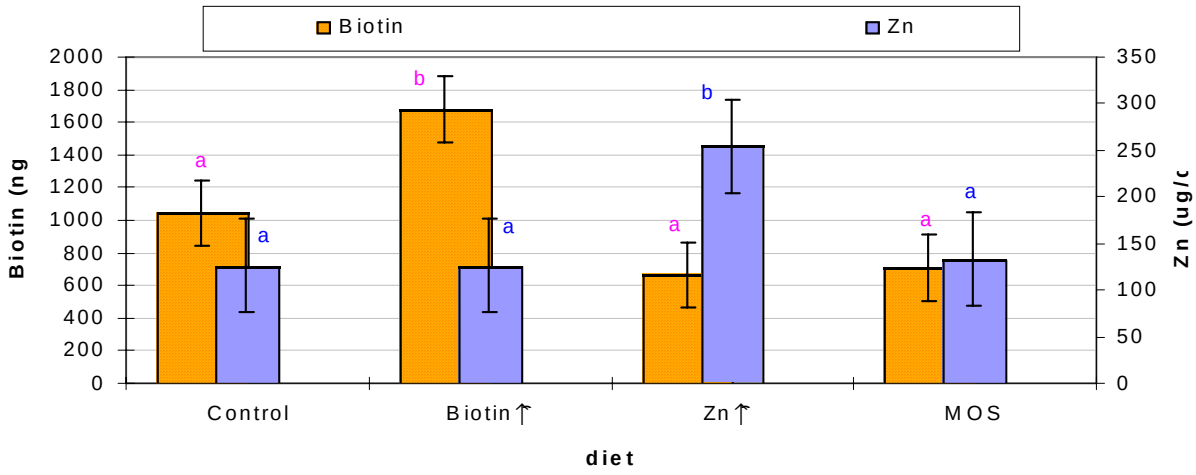


Table 1 Averages of external/histopathological scores on dry and wet litter (8 h/d) at the end of the experiments, independent of litter type/constituents and dietary contents

FPD score	Litter	Exp. 1 (water, NH_3, uric acid in litter)	Exp. 2 (macrominerals)	Exp. 3 (SBM/K/OS)	Exp. 4 (litter material)	Exp. 5 (biotin/Zn/MOS)
	excreta	-	+	+	+	+
external	dry	0.82 ^{aA}	1.53 ^{bcdA}	1.80 ^{bA}	1.30 ^{cA}	1.36 ^{cdA}
	wet	3.36 ^{aB}	4.95 ^{bB}	5.43 ^{bdB}	4.28 ^{cB}	5.59 ^{dB}
histologic	dry	1.41 ^{aA}	2.37 ^{abA}	1.88 ^{abA}	1.91 ^{abA}	2.16 ^{bA}
	wet	3.75 ^{aB}	5.39 ^{bB}	5.89 ^{cB}	5.25 ^{bB}	5.81 ^{cB}

Means with different small letters indicate significant differences between the experiments, whilst those with capital letters indicate differences between dry and wet litter within external or histological scores ($P < 0.05$).

Exposure of turkeys to wet litter for only 8 h per day was sufficient to induce foot pad lesions. Mayne *et al.* (2007c) found that fully developed lesions were induced within 2 to 4 days after continuous housing of the birds on wet litter. The foot pad scores were always much higher on wet than on dry litter in all trials, regardless of the effects of litter type/constituents and of dietary factors (Table 1). Comparing the results of foot pad scores across all experiments, especially at the end, the scores were slightly higher on wet dirty litter than on wet clean litter. This indicates that the contact with excreta can aggravate the effect of wet litter.

Discussion

High dietary protein level has been found to increase the incidence and severity of FPD in broilers (Nagaraj *et al.*, 2006 and 2007b), which may be due to increased nitrogen excretion and NH_3 formation in the litter. In our study, the water content in the litter was the major causative agent of FPD, whereas the main protein metabolites (uric acid, NH_3) in wet litter had no significant negative effects. This suggests that the focus on high protein content of the diet as a possible cause of FPD is probably unjustified. The higher ammonia content of the litter may be a causative agent of FPD, but volatile ammonia in the litter was not confirmed as a cause of FPD in several studies. Nagaraj *et al.* (2007c) found that a high dietary protein level did not affect the prevalence of FPD in broilers, despite the increased excretion of nitrogen in the litter and higher release of NH_3.

The results of the present experiments showed that high amounts of macro-minerals, SBM, K or oligosaccharides in the diets slightly increased the severity of FPD on wet litter only, but had no negative effects as long as the litter was dry. The effects of these dietary factors were very slight in comparison to the effect of wet litter per se. Wet litter probably softens the epidermis which makes the skin more susceptible to contact dermatitis (Mayne *et al.*, 2007c). Prolonged contact with excreta and high litter moisture contributes to a higher prevalence of FPD, which is thought to be caused by a combination of wet litter and chemical substances in the litter or unidentified irritants in excreta. The findings of our study agree with the results of Steenfeldt *et al.* (2005), who found no effect of different levels of calcium and phosphorus on the incidence and severity of FPD in broilers. The impact of high SBM levels could be related to its content of both K (increasing excreta moisture) and oligosaccharides (producing viscous/sticky excreta).

High litter moisture (for only 8 h/d) potentiated the prevalence and severity of FPD in all experiments. This clearly shows that litter moisture is the major factor causing FPD. Similar results were observed in previous experiments after continuous exposure to wet litter. In our study, the exposure to wet litter for only 8 h/d was sufficient to provoke FPD. This implies that all factors which affect the litter moisture either directly or indirectly are of interest. The prevalence of FPD paralleled high litter moisture as also reported by Bilgili *et al.* (2009). The severity of foot pad dermatitis began to increase when the litter contained more than 30% moisture.

Of all tested bedding materials, lignocellulose showed the lowest severity of FPD. This could be due to higher water binding capacity and to faster release of water from lignocellulose. These findings are consistent with the results of Berk (2007). In dry litter treatments, chopped straw was associated with higher FPD scores, probably due to lower water evaporation and caking (Bilgili *et al.*, 2009), resulting in a higher moisture content in this litter. Several other studies reported that chopped straw was associated with the highest FPD severity scores in broilers and in turkeys. The ability of litter to bind and/or quickly release water is aparently a very important factor in the etiology of FPD. The physical structure of the litter either soft (lignocellulose) or sharp edges (chopped straw) may also contribute to lower or increase the prevalence of FPD. The FPD scores on wood shavings and dried maize silage were similar on dry treatments. On wet litter treatments, there was no difference in FPD scores between wood shavings, straw or wet maize silage (histologically only). The FPD scores on wet maize silage were decreased, probably due to change of this litter each week (as a result of mould growth) or due to low pH and lactic acid content (formed during ensiling) which might have bactericide effects (Bosse and Meyer, 2007; Wilms-Schulze Kump, 2007).

Mayne *et al.* (2006b, 2007a) found that FPD is associated with massive increases in heterophils and macrophages and the loss of surface keratin. These cellular changes are an inflammatory response

and not an allergic reaction. The correlation between external and histopathological scores was very high (about 0.90), while the relationship between external and histological FPD scores was much lower (r = 0.56).

Depending on severity, foot pad lesions are probably painful. Mayne *et al.* (2007c) found that turkeys (23 days old) had an extreme inflammatory response and were reluctant to move after only 2 days continuous exposure to wet litter. The external FPD scores of these birds varied around 6.70, indicating signs of inflammation. In this study, the external FPD scores on dry litter ranged from 0 to 4, while those on wet litter varied from 1 to 7. Regardless of the experimental treatments, the incidence of severe external scores (6.0, 6.5 and 7.0) at the end of the experiments was 13.7%, 3.59% and 1.43%, respectively. However, no signs of discomfort or pain during movement were observed in this study. Platt *et al.* (2001) found that the incidence of superficial lesions decreased in turkeys after 14 weeks, while more severe ulceration increased, indicating that the lesions become more severe in older birds and consequently may be become painful.

High levels of dietary biotin or Zn could help to reduce the incidence of FPD. However, the effects of these nutrients appear to depend largely on DM content of the litter. As observed in this study, inclusion of high levels of biotin or Zn reduced the severity of FPD on dry litter, but not on wet litter. It was reported that supplementation of biotin decreased the severity of FPD in turkey poults raised on dry litter, but not in poults maintained on wet litter (Harms and Simpson, 1977; Mayne, 2005). Several studies reported that biotin supplementation reduced the prevalence of FPD, while others could not confirm that high dietary biotin levels prevent FPD. Some studies reported that dietary Zn reduced the incidence and severity of foot pad lesions (Hess *et al.*, 2001; Bilgili, 2009), but found no effect of Zn on the severity of FPD when birds were reared in cool weather (4 – 15 ºC), indicating that the effect of Zn varies with environmental conditions (which may affect the litter moisture). High concentrations of biotin or Zn failed to reduce the severity of FPD on wet litter. Perhaps the potentially positive effects of these additives on healing of the lesions were suppressed by the stronger negative effect of high litter moisture. The foot pad lesions on wet litter may also be complicated by secondary bacterial contamination which inhibits the healing process induced by biotin or Zn. The lesions on wet litter were more severe (necrosis or ulcer) and accompanied with inflammatory reaction as indicated histologically by infiltration of inflammatory cells. This inflammatory response is probably related to bacterial infection. Foot pad lesions on dry litter, on the other hand, were mild and not associated with bacterial invasion, so that the lesions could respond to biotin or Zn supplementation.

Conclusions

The results indicate that high dietary protein is not a major cause of FPD and may only have an indirect effect by increasing litter moisture. High amounts of macro-minerals in the diet had only slight effects on foot pads when the animals were exposed to wet litter. High dietary levels of SBM, K and OS slightly increased the FPD severity, but only on wet litter. Presumably, water softens the epidermis which makes the skin more susceptible to contact dermatitis. Lignocellulose as litter material reduced the incidence of FPD, whereas chopped straw increased it compared to wood shavings. High dietary levels of biotin or Zn may help to lower the severity of FPD, but only on dry litter and not on wet litter. Moreover, the severity of FPD was always much higher on wet than on dry litter, indicating that high litter moisture is the dominant factor causing FPD. Exposure of animals to wet litter for 8 h/d was sufficient to cause FPD. All dietary factors which increase water intake and excreta or litter moisture may contribute to FPD. Therefore, control of litter moisture (optimum diet composition and ventilation) is likely to be highly effective in diminishing the prevalence and severity of FPD in commercial turkey flocks. The present results suggest that litter moisture should not exceed 30% to minimize the incidence of foot pad lesions.

Summary

Foot pad dermatitis (FPD) is a common problem in growing turkeys. FPD is an animal welfare issue and accompanied with reduced growth rate (due to lower feed intake) and lameness in severe cases. Nutrition affects directly and indirectly the development of FPD. The litter quality plays also an important role in the incidence of FPD, which in turn is influenced by the diet composition. This study was conducted on young turkeys to determine the most relevant causes and possible preventive measures. Effects of wet litter and/or protein metabolites (uric acid, NH_3) in the litter and of excessive dietary macro-minerals on FPD were investigated as well as influences of high dietary soybean meal (SBM) and its contents from potassium and certain oligosaccharides. Also, the impact of litter type (wood shavings, lignocellulose, chopped straw, dried maize silage) and litter quality (especially moisture content) was assessed. Effects of specific dietary supplements [biotin, Zn, mannan oligosaccharide (MOS)] as preventive measures were also tested. Each factor investigated was evaluated under dry and wet litter conditions (73% moisture; achieved by adding water). High litter moisture was found to be the dominant factor contributing to the development of FPD. Presence of ammonia or uric acid in the litter did not aggravate the effect of wet litter. All dietary factors which increase excreta or litter moisture may contribute to FPD. Lignocellulose litter reduced the severity of FPD, whereas chopped straw showed higher foot pad scores. High dietary levels of biotin or Zn might be able to lower the severity of foot pad lesions, but only on dry litter and not on wet litter. To minimise the development and severity of FPD in commercial turkey flocks, the litter should be kept dry.

Zusammenfassung

Beeinflussbarkeit von Fußballenentzündungen bei Mastputen durch Futterzusammensetzung und Einstreuqualität

Die Fußballenentzündung (foot pad dermatitis, FPD) ist eine in der Putenhaltung weit verbreitete Erkrankung, die in schweren Fällen mit eingeschränkter Bewegungsaktivität (Schmerzen) und Leistungseinbußen (reduzierte Futteraufnahme) einhergeht. Insbesondere aus Tierschutzgründen sind Lösungen erforderlich, die zu einer Entschärfung des Problems führen. Ursächlich spielt die Einstreuqualität eine wesentliche Rolle. Diese wiederum wird auf vielfältige Weise durch die Fütterung beeinflusst. Vor diesem Hintergrund wurden mit jungen Mastputen die Auswirkungen von Endprodukten des Proteinstoffwechsels (Harnsäure und Ammoniak in der Einstreu), die Effekte bedarfsüberschreitender Mengenelementgehalte und die Bedeutung von Sojaextraktionsschrot für die Entwicklung der FPD näher untersucht, wobei jeweils parallel die Feuchtigkeit in der Einstreu mit variiert wurde. Des Weiteren wurde auch der Einfluss des Einstreumaterials (Hobelspäne, Lignozellulose, Stroh, getrocknete Maissilage) untersucht. Schließlich interessierten mögliche Auswirkungen verschiedener Futterzusätze [Biotin, Zink, Mannan-Oligosaccharide (MOS)] zur Prävention dieses Bestandsproblems. Es zeigte sich, dass der Feuchtegehalt der Einstreu ganz entscheidend das Vorkommen und die Ausprägung der FPD bestimmt. Metaboliten des Proteinstoffwechsels (Harnsäure/Ammoniak) und eine bedarfsüberschreitende Mengenelementaufnahme (außer Kalium), bleiben ohne wesentlichen Einfluss. Hohe Sojaschrotanteile wirkten eindeutig nachteilig, und zwar durch ihren hohen K-Gehalt, aber auch wegen ihres Oligosaccharidgehaltes (Effekte auf die FPD waren Folgen einer forcierten Wasseraufnahme und -abgabe über die Exkremente); unter den geprüften Einstreumaterialien war die Lignozellulose sowohl unter den Bedingungen einer trockenen Einstreu als auch bei (experimentell) nasser Einstreu besonders vorteilhaft (jeweils signifikant günstigere FPD-Scores). Schließlich verdient Erwähnung, dass unter den Bedingungen einer trockenen Einstreu (und nur hier) eine Zulage von Zink oder Biotin eindeutig günstig wirkte. Insgesamt basieren die Zusammenhänge zwischen der Fütterung und Futterzusammensetzung einerseits und dem FPD-Geschehen andererseits ganz wesentlich auf den Veränderungen in der Wasseraufnahme und der Exkremente- bzw. Einstreuqualität.

This paper is summarized from five original papers published in international journals:

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2010): Experimental study on effects of litter material and its quality on foot pad dermatitis in growing turkeys. International Journal of Poultry Science 9 (12), 1125-1135.

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

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011b): Effects of macrominerals - surplus in the diet and high litter moisture on development and severity of foot pad dermatitis in growing turkeys. Journal of European Poultry Science, (In Press).

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011c): Effects of high dietary levels of soybean meal and its constituents (potassium, oligosaccharides) on foot pad dermatitis in growing turkeys housed on dry and wet litter. Archives of Animal Nutrition, **65**, 148-162

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011d): Influences of increased levels of biotin, zinc or mannan-oligosaccharides in the diet on foot pad dermatitis in growing turkeys housed on dry and wet litter. Journal of Animal Physiology and Animal Nutrition, Article first published online: 4 January 2011.

A complete list of references may be obtained from the corresponding author:

I.M.I. Youssef
Institute of Animal Nutrition,
University of Veterinary Medicine Hannover, Foundation
Hannover, Germany
E-mail: Ibrahim.Youssef@tiho-hannover.de