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Ammonia emissions from broiler litter: response to bedding materials and acidifiers

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Abstract 1. In a pen study, NH_3 flux estimates were performed when clean wheat straw or wood shavings were used as bedding materials in combination with two NH_3 control amendments: sodium bisulphate and a commercial premix of phosphoric + hydrochloric + citric acids.
2. Ammonia emissions from wood shavings were 19% greater than from wheat straw around waterers, but statistically similar around feeders. These results could be due to the greater caking observed when wheat straw was used.
3. Sodium bisulphate reduced NH_3 emissions significantly only in the first half of the rearing period; the loss of efficacy in the second half resulted in total NH_3 volatilisation not statistically different from the untreated control. The treatment containing phosphoric + hydrochloric + citric acids did not have a significant effect in decreasing NH_3 emissions.
4. Bird mortality was not affected by the treatments, but broiler weight gain when wheat straw was used was significantly lower than with wood shavings, which could have been caused by the greater caking observed with wheat straw.

INTRODUCTION

Ammonia volatilisation from broiler litter has multiple potentially adverse effects on people, broilers, air quality and the fertiliser value of the litter itself by lowering its N concentrations.

Ammonia emissions lead to the formation of ammonium nitrate and ammonium sulphate in the atmosphere, which are two major forms of fine particulate matter in the air that have been linked to a host of negative effects, including premature mortality, chronic bronchitis and asthma attacks. Research findings indicate that a 10% reduction in livestock NH_3 emissions could result in excess of \$4 billion (£2·1 billion) annually in particulate-related health benefits in the USA (McCubbin *et al.*, 2002).

Reece *et al.* (1981) observed that broilers exposed continuously to 50 ppm NH_3 during brooding (4 weeks) had an 8% reduction in body weight by week 7 of age, and that the corresponding reductions for exposures to 25 ppm (continuous) and 50 ppm for 12 h/d were 4 and 3%, respectively. Chickens exposed continuously to 20 ppm of NH_3 for 6 weeks suffered pulmonary oedema, congestion, haemorrhages and increased susceptibility to respiratory disease (Anderson *et al.*, 1964). When NH_3 concentrations were increased from 25 to 50 ppm, Kleven and Glisson (1997) observed reduced body weights (0·23 kg less at 49 d) and feed efficiency with increased airsacculitis, whereas Nagaraja *et al.* (1983) reported loss of cilia and decreased clearance of *E. coli* from lungs and air-sacs. At NH_3 concentrations of 60 to 70 ppm, Kristensen and Wathes (2000) observed the development of keratoconjunctivitis in chickens.

Bedding materials for broiler production have been selected based mostly on their capacity to absorb water, density, low cost, absence of toxicity to the birds and suitability as a fertiliser

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or livestock feed after removal from the chicken house. The most commonly used bedding materials in Georgia are pine shavings and coarse pine sawdust (Ritz *et al.*, 2005), but their costs have increased lately because of limited supply. Wheat straw could be an alternative because it is readily available in Georgia, and it is used routinely as bedding material in other countries (Elwinger and Svensson, 1996). Acidifiers such as sodium bisulphate, aluminium sulphate and clay with sulphuric acid are commonly used to control NH_3 emissions from broiler litter. Some acidifying and disinfectant products currently used in broiler meat processing, such as a combination of phosphoric + hydrochloric + citric acids, could potentially reduce NH_3 emissions.

The objective of this study was to measure NH_3 emissions under pen conditions when wheat straw or wood shavings were used as bedding materials, and when sodium bisulphate or a commercial premix of phosphoric + hydrochloric + citric acids were applied as acidifying agents.

MATERIALS AND METHODS

The study was conducted at the University of Georgia Poultry Research Center, in pens 1·2 m wide by 3·0 m long. Treatments included a complete factorial combination of two bedding materials (wood shavings and wheat straw) and three acidification treatments (a commercial premix containing phosphoric + hydrochloric + citric acids, sodium bisulphate, and no treatment or control), replicated 4 times. The product containing phosphoric + hydrochloric + citric acids has the brand name FreshFx (SteriFx, Inc., InterTech Science Park, Shreveport, LA, USA) and is a liquid concentrate that contains diluted phosphoric, hydrochloric and citric acids, with each acid listed as <5% by weight in water, but the proportions are not disclosed because it is a proprietary composition. Sodium bisulphate was formulated as PLT (Jones-Hamilton Co., Newark, CA, USA) in granules containing sodium hydrogen sulphate 91·5 to 94·7% by weight, sodium sulphate 4·8 to 8·0% by weight and water 0·1 to 0·8% by weight (Jones-Hamilton Co., 2003). Wood shavings and wheat straw were purchased locally, and spread to a depth of approximately 5 cm, which is the commercial practice. Acidification agents were applied 2 d before chick placement following manufacturers' recommendations. PLT was spread manually at 0·244 kg/m^2, and the mixture of phosphoric, hydrochloric and citric acids was sprayed as a 1:25 dilution of the FreshFx concentrated formulation in tap water at the rate of 0·5 l/m^2 using a hand-held liquid sprayer. The spray rate was comparable to that used commercially for amendments.

Fifty-four newly born Cobb 500 (Cobb-Vantress Incorporated, Siloam Springs, AR, USA) male chicks were placed in each pen having a mean weight of 2·33 kg/pen (SD 0·03 kg/pen). Initially a standard starter crumble feed with 22·5% protein was offered, and at 14 d the chickens were placed on a developer feed with 205 g protein/kg and remained on that feed until processing. The feeders were Choretime hanging feeders, model CT 25280 (Chore-Time Poultry Production Systems, Milford, IN, USA), and the nipple watering system was made by Ziggity Systems Inc. (Middlebury, IN, USA) and had 8 nipples per pen.

Air temperature averaged 29·7°C (SD 3·1°C) and relative humidity averaged 59·9% (SD 14·9%) during the 6-week rearing period. Mean air temperature was 34·2°C (SD 0·7°C), 32·5°C (SD 1·1°C), 30·1°C (SD 1·1°C), 28·2°C (SD 1·0°C), 27·9°C (SD 0·9°C) and 25·3°C (SD 1·2°C) for weeks 1 to 6, respectively. Temperature control was achieved by activating either heating or ventilation at any given time that a 1·5°C differential from the programmed target temperature was measured. The house environment was controlled by an Aerotech Stage House Controller, model SU2000-1 (Aerotech, Inc., MI, USA) which regulated the mixing fans, exhaust fans and LB White Guardian Heaters (L.B. White Co., Onalaska, WI, USA). The birds were kept on a 24 L:0 D lighting regimen.

Ammonia diffusing into air in each pen was measured at 4, 6, 8, 11, 15, 18, 25, 32 and 40 d after the application of the agents using static chambers that consisted of plastic 21 buckets placed upside down on the floor at two different locations: next to the waterer line and around the feeder (Figure 1). Each bucket covered an area of 0·02 m^2 and sampling was randomised with the restriction that it was never repeated on the same spot. The NH_3 released into the bucket was trapped by 25 ml of 1·4 N H_2SO_4 contained in a beaker. The beakers containing the NH_4^+ were replaced by clean ones, always at the same time of day, to facilitate the calculation of the NH_3 flux on a daily basis. Ammonia was subsequently measured colourimetrically as NH_4^+-N by the salicylate–hypochlorite method (Crooke and Simpson, 1971). The milligrams of NH_4^+-N collected in the beakers were transformed into mmoles of NH_3 emitted per m^2 of floor and per d for data analysis. A heavy block was placed on the bucket to ensure proper contact between the bucket rim and the litter, and to prevent the chickens from knocking it over.

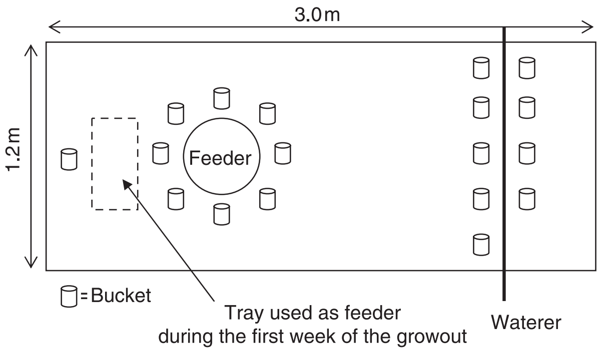

Figure 1. *Diagram of a pen used in the study showing its dimensions, and the positions of the buckets used to sample the emitted NH_3 around feeders and the waterer line. Drawing not to scale.*

Despite this precaution, several buckets were knocked over at the last two sampling dates.

At the end of rearing, composite samples of the litter made up of 4 to 5 sub-samples were separately taken from the feeder and waterer areas of each pen. Due to unforeseen storage problems the litter samples experienced variable water loss, which prevented the meaningful analysis of the effect of the treatments on their water content. Nevertheless, the litter samples were ground to homogenise them and their water content determined by drying in a forced air oven at 65°C for 48 h. Total C and N concentrations were determined by combustion using a LECO CNS 2000 instrument and the results were corrected by the water content of the samples and expressed on a dry matter basis. The litter was analysed for pH using a glass electrode in a 1:5 suspension of litter in deionised water and for NH_4^+-N by steam distillation (Mulvaney, 1996).

Live weight production was determined by weighing all the chickens in each pen after 7, 21 and 39 d.

SAS for Windows v. 9.1.3 (SAS Institute, 2005) was used for the analysis of variance, mean comparisons and to calculate the total NH_3 emissions by integrating the daily fluxes over the duration of the sampling using the trapezoid rule in Procedure Expand. Means were compared using the Least Significant Difference test, *t*-test or Multiple Range Test (MRT) depending on the effects under consideration. A 5% significance level was used.

RESULTS

The evolution of NH_3 flux from all treatments is shown in Figure 2. For the first 8 d, NH_3 emission rates were close to zero around waterers and feeders, and significantly lower from the sodium bisulphate-treated pens than from the untreated pens, whereas the results from the pens treated with the phosphoric + hydrochloric + citric acids premix were more variable. With both bedding materials, NH_3 emission rates from around waterers increased markedly by the second week of the growout, whereas from around feeders the increase was observed 2 weeks later.

Sodium bisulphate reduced NH_3 emission rates significantly at most sampling dates during the first 3 weeks, whereas the effects from the mixture of phosphoric + hydrochloric + citric acids were not statistically different from the control at most sampling dates. However, the mean total amounts of NH_3 emitted from the pens treated with sodium bisulphate (3·10 moles/m^2) or with phosphoric +hydrochloric + citric acids (2·87 moles/m^2) did not differ statistically ($\alpha = 0{\cdot}05$) among them or from the control (2·74 moles/m^2). The effects of bedding materials on total NH_3 emissions depended on the area sampled, as shown in Table 1. Mean total NH_3 emissions from wheat straw and wood shavings were not statistically different when measured around feeders, but mean total NH_3 emission from around waterers was 19% higher when wood shavings were used than when wheat straw was used, a significant difference. Although NH_3 volatilisation from around the waterers was significantly higher than from around the feeders, the differences depended on the bedding material. When wood shavings were used, mean total NH_3 emissions from around waterers were 107% higher than from around feeders, but when wheat straw was used that increment was 56%.

By the end of rearing the pH of broiler litter was above 8 for all agents, bedding materials and sampling areas (Table 2). However, there were some persistent effects as reflected by the significantly lower pH in the litter from sodium bisulphate-treated pens than in the untreated pens or in those treated with phosphoric + hydrochloric + citric acids. Also, the pH in the litter with wood shavings or from around the feeders was significantly lower than with wheat straw or from around waterers, respectively.

Carbon concentrations in the litter were significantly lower when wheat straw was used (mean 385 g/kg, SD 12 g/kg), than when wood shavings were used (408 g/kg, SD 11 g/kg). The effects of the acidifying agents on C concentrations depended on the area sampled. The C concentration in litter treated with sodium bisulphate and sampled around waterers (mean 383 g/kg, SD 16·8 g/kg) was significantly lower than in the litter from all the other agent by sampling area combinations: phosphoric + hydrochloric + citric acids by feeders (mean 401 g/kg, SD 11 g/kg), phosphoric + hydrochloric + citric acids by waterers (mean 398 g/kg, SD 14 g/kg), sodium bisulphate

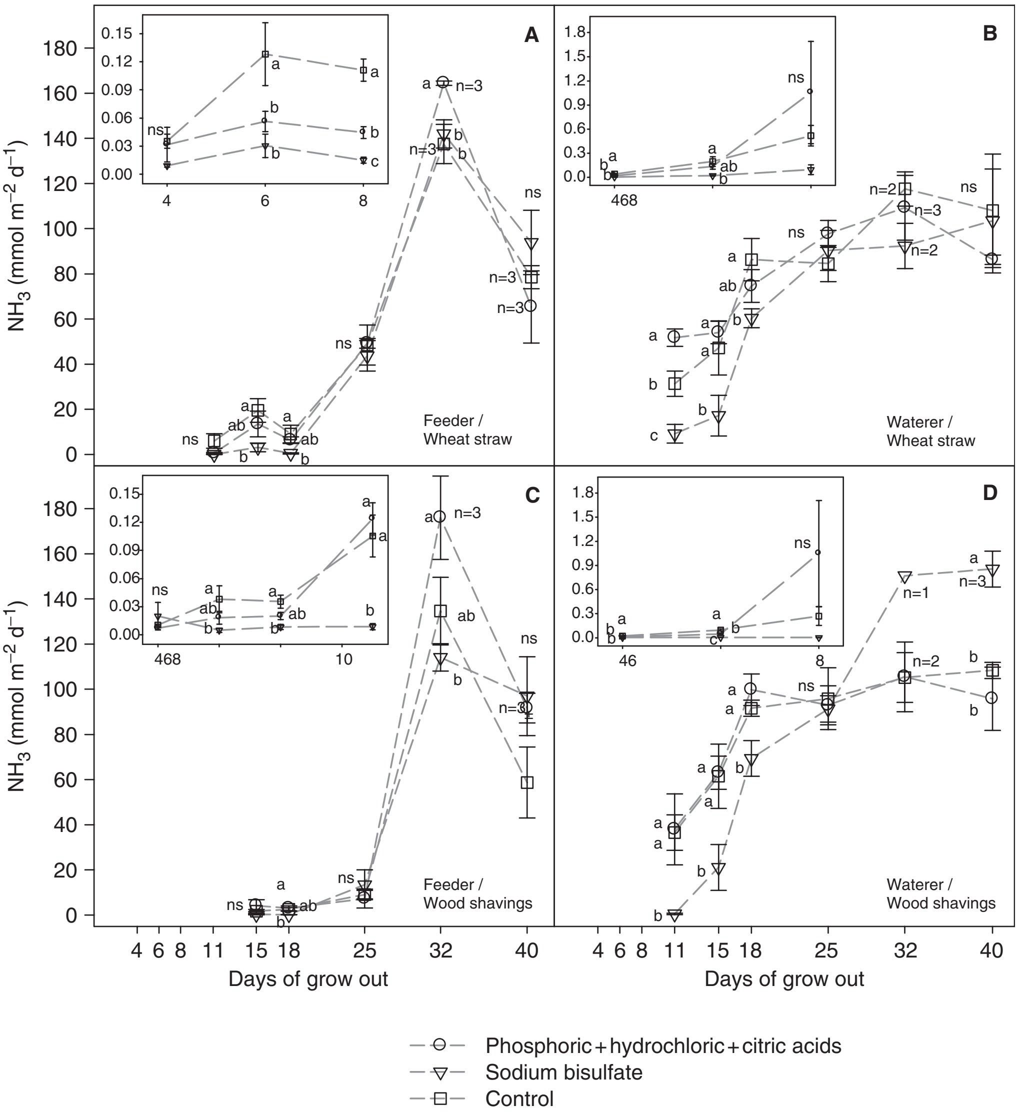

Figure 2. *Effect of phosphoric + hydrochloric + citric acids and sodium bisulphate on NH_3 emission rates from around feeders or waterers when wheat straw or wood shavings were used for bedding. Insets show data for the first three or 4 samplings. Means based on n = 4, except as noted. Values with the same letters for each sampling date within each combination of sampling area and bedding do not differ statistically according to Duncan's MRT at α = 0·05. Bars correspond to ± one standard error.*

Table 1. *Mean total NH_3 emissions (moles/m^2) averaged across agents during the 7-week study based on n observations from around feeders and waterers when wheat straw and wood shavings were used as bedding materials. Value in parentheses is one standard deviation*

Bedding	Sampling position	
	Feeder	Waterer
Wheat straw	2·21 (0·41) $n = 11$	3·45 (0·85) $n = 12$
Wood shavings	1·98 (0·60) $n = 12$	4·10 (0·95) $n = 11$

Probabilities > |t| for H0:
Mean(Wheat straw/feeder) − Mean(Wheat straw/waterer) = 0·0001.
Mean(Wheat straw/feeder) − Mean(Wood shavings/feeder) =0·4504.
Mean(Wheat straw/feeder) − Mean(Wood shavings/waterer) = <0·0001.
Mean(Wheat straw/waterer) − Mean(Wood shavings/feeder) = <0·0001.
Mean(Wheat straw/waterer) − Mean(Wood shavings/waterer) = 0·0322.
Mean(Wood shavings/feeder) − Mean(Wood shavings/waterer) = < 0·0001.

by feeders (mean 397 g/kg, SD 21 g/kg), untreated by feeders (mean 398 g/kg, SD 19 g/kg) and untreated by waterers (mean 401 g/kg, SD 12 g/kg).

Ammoniacal N concentrations in the litter treated with sodium bisulphate were twice as high (mean 1255 mg/kg, SD 475 mg/kg) as in the control pens (mean 619 mg/kg, SD 222 mg/kg) or in litter containing phosphoric + hydrochloric + citric acids (mean 623 mg/kg, SD 211 mg/kg), but that difference did not result in significant differences in total N concentrations. Mean total N concentrations in the litter were not significantly affected by the acidifying amendments or bedding materials, but were significantly lower around waterers (mean 33·6 g/kg, SD 2·6 g/kg) than feeders (mean 37·4 g/kg, SD 5·6 g/kg).

The effects of acidifying agents on chicken live weight (Figure 3) varied according to the

Table 2. *Means for pH based on* n *observations, measured at the end of rearing for broiler litter treated with two agents, using two bedding materials and sampled at two positions*

	Agents ($n=16$)			Bedding materials ($n=24$)		Sampling position ($n=24$)	
	Phosphoric + hydrochloric + citric acids	Sodium bisulphate	Control	Wheat straw	Wood shavings	Waterers	Feeder
pH	9·03 a (0·42)	8·36 b (0·31)	8·98 a (0·33)	8·91 a (0·46)	8·66 b (0·44)	8·91 a (0·45)	8·66 b (0·45)

Values followed by the same letter within agents, bedding materials or sampling positions do not differ statistically at the 5% level of probability according to the Least Squares Means test. Value in parentheses is one standard deviation.

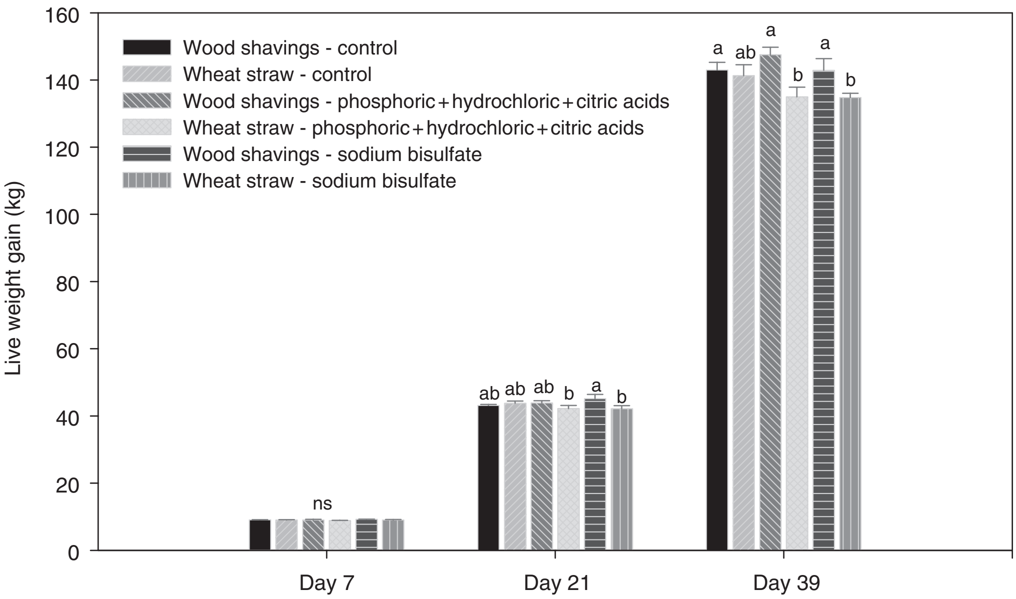

Figure 3. *Live weight gain of broilers (average of 4 pens) at three intervals after amendment application, following the placement of 54 birds per pen with wood shavings or wheat straw amended with phosphoric + hydrochloric + citric acids or sodium bisulphate. Bars correspond to one standard error. Columns with the same letter, within each sampling date, are not statistically different ($\alpha = 0{\cdot}05$) according to t-test.*

bedding material used and sampling date. There were no statistical differences between the combinations of agents and bedding materials at the first evaluation but at later stages there were differences in live weight. By the second evaluation, the live weight of the birds in the sodium bisulphate-treated pens with wheat straw was significantly lower than with wood shavings. At the end of rearing the differences in bird weight between wheat straw (mean 137 kg, SD 6 kg) and wood shavings (mean 144 kg, SD 5 kg) were statistically significant both in the pens treated with phosphoric + hydrochloric + citric acids and sodium bisulphate.

No statistical effects of the agents, bedding materials or their interaction on feed conversion efficiency or chicken mortality were detected.

DISCUSSION

By avoiding air circulation, the static chamber method used in this study potentially underestimates NH_3 emissions; nevertheless, the method is useful to compare relative differences in NH_3 evolution between treatments and to characterise the variation in NH_3 emission rates during rearing. The temporal pattern of change in NH_3 emission rates observed in this study was similar to what other researchers have found. Brewer and Costello (1999) reported a peak in NH_3 flux rate at around 25 d in a second flock of broilers with rice hulls as bedding material, which was interpreted as caused by seasonal weather and ventilation. Guiziou and Beline (2005) observed an important increase in NH_3 emission rates between d 10 and 12, followed by a second increase from d 31 until the end of the experiment. However, none of the cited studies analysed the evolution of NH_3 volatilisation separately from around feeders and waterers.

Sodium bisulphate successfully decreased NH_3 emissions during the first half of rearing, which is longer than the 3-d effect reported by Lind (2003). Broiler managers and growers are especially concerned about the brooding period, and the determination of thresholds for NH_3 in the air (Reece *et al.*, 1981) has focused on this phase. However, sodium bisulphate did not succeed in reducing overall NH_3 emissions in comparison to the control. These results could be explained by the consistent increase in NH_3 emission rates observed in the sodium bisulphate-treated pens as rearing progressed, that seem to have overridden the lower initial NH_3 release rates. Sodium bisulphate acts by decreasing pH (Blake and Hess, 2001) and although the initial pH was not measured immediately after its application, it is reasonable to assume that pH was low at the beginning of rearing. The litter analysis at the end of rearing showed that the acidifying effect from sodium bisulphate was still evident (Table 2), although the pH was already above 8.

The NH_3 flux from the untreated litter and the litter treated with phosphoric + hydrochloric + citric acids, suggests that their high initial NH_3 volatilisation could have led to an early loss of most of the NH_4^+, and as rearing proceeded, their low remaining NH_4^+ concentrations resulted in decreased NH_3 release rates.

Our data suggest that low pH at the beginning of rearing in the sodium bisulphate-treated litter helped to keep NH_3 as NH_4^+ and as the period progressed, the pH and NH_3 losses increased. Therefore, the application of sodium bisulphate could be beneficial in reducing NH_3 emissions inside chicken houses during the brooding period, but ineffective in diminishing NH_3 emissions outside the chicken house throughout the duration of rearing.

Despite similar NH_3 losses in comparison to the control and phosphoric + hydrochloric + citric acids, the sodium bisulphate-treated litter had higher NH_4^+-N concentrations at the end of the growout. However, higher NH_4^+-N concentration in the sodium bisulphate-treated litter did not change total N concentrations, thus limiting its potential impact in improving the fertiliser value of the litter.

Like Elwinger and Svensson (1996), we detected no significant differences in total N concentrations between wheat straw and wood shavings. However, total N concentrations were lower in litter around waterers than around feeders, which may indicate greater N losses around waterers or N additions from feed spillage around feeders; this is consistent with previous work (Tasistro *et al.*, 2004). The existence of conditions more conducive to NH_3 volatilisation around waterers has been reported, and could be related to the effects of greater water availability on microbial and enzymatic activities (Pelczar and Reid, 1958), or greater manure deposition around the water lines (Brewer and Costello, 1999). However, in our study the results of total NH_3 emissions showed a significant interaction between sampling areas and bedding materials, which might be related to the differences in water holding capacity between wheat straw and wood shavings. Wheat straw has lower water holding capacity than wood shavings, probably because of its lower cellulose content, and the cutin to waxy coating of plant stems (Ward *et al.*, 2000, 2001). Thus, we could expect wheat straw to dry faster and lead to the formation of a crust or cake that can decrease NH_3 volatilisation by acting as a physical barrier (Miles *et al.*, 2006). Although we could not obtain data on the water content of the litter at the end of the study, it was evident that the areas around waterers in the pens with wheat straw were more caked than when wood shavings were used. Caking was reported when using wheat straw in horse stalls by Ward *et al.* (2001), who found it to be the most difficult material to work with in terms of physical discomfort to workers, including extreme odour and eye and nasal irritations experienced after 2 d due to the large amount of NH_3 released while cleaning the stalls.

Although the caked litter that formed on wheat straw might have helped by decreasing NH_3 volatilisation, the chicken weight gain data suggest that it was adverse to broilers. We hypothesise that the greater proportion of caked litter observed in the pens with wheat straw affected the chickens and led to lower body weights.

The lower C concentration in litter from wheat straw seems to be consistent with the greater susceptibility of this material to microbial decomposition compared to wood shavings. However, Elwinger and Svensson (1996) did not find significant differences between wheat straw and wood shavings in their C concentrations measured at 35 or 46 d of age of the birds. The low C concentration in the litter treated with sodium bisulphate and from around waterers was not anticipated considering the disinfectant effects of this agent.

In conclusion, NH_3 volatilisation can be influenced by the choice of bedding material and the application of acidifying agents. However, the magnitude and temporal variation of the responses might vary significantly. Sodium bisulphate seems a good choice to suppress NH_3 emissions during the brooding period only. Wheat straw appears to be a better choice than wood shavings for reducing NH_3 volatilisation, especially under the adverse conditions surrounding waterers. However, the potential for wheat straw as a bedding material seems to be limited by the chickens' sensitivity to the caking that resulted in reductions in weight gain.

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