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Research article

Water activity of poultry litter: Relationship to moisture content during a grow-out

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ABSTRACT

Poultry grown on litter floors are in contact with their own waste products. The waste material needs to be carefully managed to reduce food safety risks and to provide conditions that are comfortable and safe for the birds. Water activity (A_w) is an important thermodynamic property that has been shown to be more closely related to microbial, chemical and physical properties of natural products than moisture content. In poultry litter, A_w is relevant for understanding microbial activity; litter handling and rheological properties; and relationships between in-shed relative humidity and litter moisture content. We measured the A_w of poultry litter collected throughout a meat chicken grow-out (from fresh pine shavings bedding material to day 52) and over a range of litter moisture content (10–60%). The A_w increased non-linearly from 0.71 to 1.0, and reached a value of 0.95 when litter moisture content was only 22–33%. Accumulation of manure during the grow-out reduced A_w for the same moisture content. These results are relevant for making decisions regarding litter re-use in multiple grow-outs as well as setting targets for litter moisture content to minimise odour, microbial risks and to ensure necessary litter physical conditions are maintained during a grow-out. Methods to predict A_w in poultry litter from moisture content are proposed.

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1. Introduction

Meat chickens (broilers) are commonly raised in open plan sheds on a litter floor. Litter is a mixture of bedding materials (e.g. pine shavings, other wood products, rice hulls or peanut shells) and excreta (Miles et al., 2011). The birds are in constant contact with the litter and therefore the condition of the litter needs to be managed to provide a safe and comfortable environment. One function of litter is to absorb and store water from excreta and drinking-system spillage until the water can be evaporated and removed from the shed by the ventilation system. The amount of water in litter has been found to affect microbial activity (Bessei, 2006; Eriksson De Rezende et al., 2001; Himathongkham et al., 1999; Wadud et al., 2012), thermal insulation (Agnew and Leonard, 2003), ammonia emissions (Miles et al., 2011), odour emissions (Clarkson and Misselbrook, 1991; Murphy et al., 2014) and friability (Bernhart and Fasina, 2009).

'Wet litter' has been described as a multi-factorial problem in poultry production (van der Hoeven-Hangoor et al., 2013) that requires a multi-disciplinary approach to develop solutions (Tucker and Walker, 1992). One definition for wet litter is that it has greater than 25% moisture content and compromised cushioning, insulating and water holding capacity (Collett, 2012). Wet litter has been implicated as a primary cause of contact dermatitis in poultry (Shepherd and Fairchild, 2010) and also negatively affects feed conversion ratio and carcass yields (de Jong et al., 2014). Wet litter can be caused by a combination of diet/nutrition factors (Collett, 2012); shed design, ventilation management and environmental factors (Hermans et al., 2006); and/or flock infections with organisms such as *Clostridium perfringens*, the causative agent of necrotic enteritis (M'Sadeq et al., 2015). Avoiding the consequences of 'wet litter' is one important reason to manage the moisture content of litter during a grow-out.

Water activity (A_w) is arguably a better measure of water in litter than moisture content (mass of water divided by mass of moist

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litter, expressed as a percentage) since it is more closely related to microbial, chemical and physical properties of litter (van der Hoeven-Hangoor et al., 2014). A_w is a thermodynamic property relating to the relative freedom or availability of water in a sample and its tendency to escape. Reid (2007) defined A_w as the ratio of the fugacity of water in a system, and the fugacity of pure liquid water at the same temperature, where fugacity is a measure of the escaping tendency of a substance. A_w can be approximated by the equilibrium relative humidity (ERH, expressed as a %) of a substance (Carr et al., 1995; Reid, 2007). In fact the two terms, A_w and ERH, are effectively interchangeable (A_w = ERH/100). A_w is temperature dependent and generally increases with temperature when moisture content is constant, although the relationship can reverse at high A_w (Labuza and Altunakar, 2007b).

A_w provides a measure of the thermodynamic forces driving the movement of water within and between media (including air). Water will migrate from higher A_w to lower A_w until equilibrium is achieved and A_w is constant throughout the system (assuming isothermal conditions). Different materials can have the same A_w but different moisture content (or vice-versa), but it is A_w that regulates water movement (Labuza and Altunakar, 2007a). A_w theory can be used to explain the movement of water between excreta, litter and air in poultry sheds, but is a guide only because A_w applies only to equilibrium conditions (constant temperature, no air velocity and no air exchange), which do not occur in commercial poultry sheds. If temperatures are unbalanced, with the litter surface being below the dewpoint temperature, then water will also condense on the litter surface (Tucker and Walker, 1992). Additionally, the effect of increasing air velocity in the poultry shed may reduce water absorption into the litter surface, resulting in lower litter moisture content for a given relative humidity condition (Foong et al., 2009).

It has been demonstrated that the microbiological properties of poultry litter are directly related to A_w, and that maintaining litter below a critical A_w value corresponds with reduced growth of pathogens including *Salmonella* and *Escherichia coli* as well as other microbiota (Carr et al., 1995; Chinivasagam et al., 2012; Eriksson De Rezende et al., 2001; Hayes et al., 2000; Himathongkham et al., 1999; Macklin et al., 2006; Payne et al., 2007). A_w has also been related to physical handling properties of litter including cohesion, adhesion, compressibility and flowability (Bernhart and Fasina, 2009; Reed and McCartney, 1970; Roudaut, 2007).

The purpose of this study was to explore the relationship between A_w and moisture content of litter from a meat chicken shed throughout a grow-out period. The relationship between A_w and litter moisture content during a grow-out has implications for litter management, the microbial properties of poultry litter and the potential for environmental impacts with the formation of nuisance odours. These are relevant for making decisions regarding litter re-use for multiple grow-outs, setting targets for litter moisture content to minimise microbial risks and to ensure necessary litter physical conditions are maintained during a grow-out.

2. Materials and methods

2.1. Farm description and collection of litter and bedding materials

Litter samples were collected in a previous study (Dunlop et al., 2015). In brief, litter samples were collected from a commercial broiler shed that was stocked with Ross 308 meat chickens at a stocking density of 19.4 birds/m^2. Pine shavings were used at the start of the grow-out at a depth of 5 cm. Litter samples were collected on days 0 (pine shavings), 10, 17, 24, 31, 38, 45 and 52 of a grow-out. Samples were stored at 4 °C until the end of the grow-out period.

Samples of bedding materials (not containing excreta) including hardwood sawdust, rice hulls and peanut shells were also tested and compared with pine shavings. These materials were stored in as-received condition until testing.

2.2. Sample preparation

A 0.5–1.0 L sample from each litter collection day and each bedding material was dried in an oven at 40 °C until a constant mass was reached. Each sample was then divided into seven sub-samples that were designated with a target moisture content value: 10.0, 16.3, 22.5, 28.8, 35.0, 47.5 and 60% (wet basis; mass of water divided by mass of moist sample). Target values were arbitrarily chosen to represent the normal range of litter moisture content found in meat chicken production. The required amount of water to achieve each target moisture content value was then added to each sub-sample, which were then mixed and sealed in individual containers for 24–48 h prior to A_w analysis.

2.3. Water activity analysis

A_w was measured using an AquaLab® dewpoint water activity meter (model 4TE, Decagon Devices Inc., Pullman, WA, USA—measurement range 0.030–1.000 A_w, accuracy ±0.003 A_w, repeatability ±0.001 A_w). The temperature controlled sample chamber was set to 25 °C. Between each A_w measurement, dry activated charcoal was placed in the sample chamber to remove any residual moisture or volatiles.

Litter samples for each of the seven moisture contents from each of the eight sampling days were analysed in random order in triplicate. The experimental design (7 × 8 × 3) produced a total of $n = 168$ measurements. Bedding material samples for each of the seven moisture contents for each of the four materials were analysed in random order in duplicate. The experimental design (7 × 4 × 2) produced a total of $n = 56$ measurements. When each A_w measurement was complete, the litter sample was placed in a pre-weighed tray and dried in an oven (model 8150, Contherm, Hutt City, New Zealand) at 65 °C to determine matching moisture content value for each A_w value.

2.4. Data analysis

2.4.1. Non-linear regression analysis

The relationship between A_w and moisture content of bedding and litter materials was investigated using grouped non-linear (exponential) regression analysis with a grouping factor for bedding material or litter sampling day, respectively. *GenStat* 16th Edition (VSN, 2014) was used to fit the exponential function (Eq. (1)). Significance of the grouping factor on curve parameterisation was assessed when *p*-values were less than 0.05.

$$A_w = A + B \times (R^m) \quad (1)$$

where: A_w is water activity; m is litter moisture content (wet basis, expressed as a decimal value); and A, B & R are parameters to be estimated.

2.4.2. Application of the empirical 'Henderson' model

Theoretical and empirical models have previously been used to describe the relationship between A_w and dry basis moisture content (Maia et al., 2011). (Note the use of *dry basis* moisture content in this section, where moisture content is calculated from the mass of water divided by the mass of the dry solids. Equations to convert moisture content between wet and dry basis are provided in the supplementary material.) One such empirical model, the 'Henderson model' (Henderson, 1952), has been used extensively to describe the water sorption behaviour of biological materials

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