Review of litter turning during a grow-out as a litter management practice to achieve dry and friable litter in poultry production

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ABSTRACT Maintaining dry litter that chickens can "work" is a key objective for successful meat chicken production as it reduces the likelihood of health and welfare issues by breaking down and working excreta and contributing to the water evaporation process. Litter turning is a practice that may help reduce moisture content within the litter by accelerating the drying process when it is combined with effective ventilation. However, information and research about the practice and the effects it could have on the health and well-being of meat chickens (broilers) are minimal. A recent survey of Australian meat chicken growers reiterated the concerns they have about its impact on chicken well-being, but it also demonstrated how growers thought it could enhance the effectiveness of their operation. The aim of this review paper is to identity information relevant to litter turning and the potential effects of this practice on litter quality, ammonia emissions, litter moisture, and animal welfare. This review demonstrates the need for additional research to validate perceptions and address potential concerns and impacts that this practice may have on broiler production. Closing this knowledge gap will improve litter turning practices leading to safer and more consistent outcomes.

Key words: broiler chicken, litter management, conditioning, tilling, wet litter

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INTRODUCTION

Currently, there is a strong global focus to improve and maintain effective litter management practices in meat chicken (broiler) rearing to provide permanent access to "dry and friable" litter. This is because it has been demonstrated that wet litter increases the risk of certain health issues including footpad dermatitis (**FPD**) and less than optimal welfare (de Jong et al., 2014; Dunlop et al., 2016a,b,c,d). It is also necessary to manage litter to avoid overly dry and dusty conditions because these have been associated with inflammation and chicken respiratory diseases and reduced body weight gain (Carpenter et al., 1986; Al Homidan et al., 2003; Lai et al., 2009) and may increase the occurrence of scratches, skin tears, and ammonia exposure (Lister, 2009). High litter moisture and caking are made worse by several management practices and house design features including high density at placement (to allow for later thinning), concrete floors, pop holes in the sides of free-range houses or inadequate litter depth, floor preheating, and airflow within the houses. Caking is therefore not a natural consequence of indoor chicken rearing but a consequence of dictated production parameters that vary internationally and regionally due to climate, industry culture, consumer expectations, legislation, and third-party accreditation schemes. Litter turning was developed and implemented as a management practice to complement effective ventilation to reduce the occurrence of wet and litter caking issues during the grow-out period for meat chickens, although litter turning may not always be beneficial and may increase the risk of detrimental outcomes (Núñez Casas, 2011; Taira et al., 2014; Malone and Marsh Johnson, 2017; Stein, 2019).

"Litter turning" has many alternative names (Table 1), and a variety of equipment and methods are used to achieve similar outcomes.

The mechanisms involved in litter turning have not previously been described. We suggest that litter turning involves machinery to break up caked litter, reduce the size of litter clumps (with a cutting or pulverizing action), mix wet litter with dry (to reduce areas of high moisture content and the start of surface caking and

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Table 1. Alternative terminology for litter turning.

Terminology	References
Litter turning/cultivating/conditioning/ agitating	Dunlop (2009); Collett (2012); Taira et al. (2014); Dunlop et al. (2015); Dunlop et al. (2016a,b,c,d); Santonja et al. (2017); Stein (2019)
Tilling/pulverizing	Dunlop (2009); Chai et al. (2018); Stein (2019)
Rotary tilling/rotary hoeing	Koon et al. (1994); Stein (2019)
Litter working and "working litter"	Lister (2009); Dunlop (2016a,b,c,d)
Litter stirring	Chai et al. (2018)
Volteo de la cama (Spanish for "flip/turn the litter bed")	Estellés et al. (2011); Villagrá, J.J. et al. (2011)
Decaking, "caking out" *Note: this is not litter turning but uses a similar mechanism to break up and remove caked litter at the end of a grow-out.*	Sistani et al. (2003); Trabue et al. (2010); Dunlop et al. (2016a,b,c,d); Malone and Marsh Johnson (2017); Cabrera et al. (2018); Bucher et al. (2020)
Litter aeration *Note: this is not litter turning but* forces aeration by mechanical means or air induction	van Middelkoop (1994); Allen et al. (1998); Dunlop (2009); Núñez Casas (2011); Bodí et al. (2013)

crusting), exchange litter that is at the surface, and redistribute litter at the back of the machine in a friable and homogeneous surface layer. These mechanisms improve friability, support litter drying processes, and mix wet and dry litter together to deliver more uniform conditions that are simultaneously less dusty and less cohesive. We are not suggesting that litter turning is the only mechanism capable of maintaining litter friability. When litter is friable, the chickens are able to "work" the litter (Lister, 2009); where this process involves fresh excreta being incorporated into friable litter by chicken movement. However, if litter becomes less friable and litter particles become cohesive, for example, during periods of high relative humidity or if the chickens have unusually wet excreta, mechanical litter turning may be required to get the litter working again.

Litter turning has been reported to be practiced or researched in Japan (Taira et al., 2014), Spain (Estellés et al., 2011; Núñez Casas, 2011; Villagrá, J.J. et al., 2011), and France (Dezat and Gohier-Austerlitz, 2020). In the USA, some turkey growers practice tilling during the grow-out period, targeting under drinker lines, to assist in minimizing wet areas, but litter turning during a grow-out is not practiced with meat chickens (Mayne et al., 2007; Malone and Marsh Johnson, 2017). Decaking is commonly undertaken in between meat chicken grow-outs, although it has slightly different aims to litter turning. Decaking removes caked litter from the house, whereas litter turning breaks up and mixes it in. In contrast, litter turning rejuvenates the surface condition by reducing peak moisture content as well as increasing friability and porosity, which maximize litter drying rate when combined with effective ventilation and air relative humidity control. In Europe, some farmers report that they turn their problem litter by hand or using equipment not specifically designed for the purpose (Dezat and Gohier-Austerlitz, 2020). This is despite litter turning not generally being recommended due to ammonia and dust surges, gaseous emissions, potential health problems, and blooms of clostridium and coccidiosis due to aeration (Santonja et al., 2017; Dezat and Gohier-Austerlitz, 2020). Although, the risks associated with litter turning depend on the litter condition, management history, and cake management with ventilation to assist in keeping the litter working.

Litter turning is a management practice used in the author's region. A survey of Australian meat chicken growers and integrator company staff was recently conducted to garner background information for this review. The aim of the survey was to improve understanding of the motivations for litter turning, methods used, results observed, and concerns with the practice. The authors received 82 responses from meat chicken farm owners, managers, and staff (collectively known as "growers"), with extra responses ($n = 2$) from integrator or meat chicken growing company representatives (whose responses would be consistent with general trends and broader experience of multiple farms rather than detailed experiences on an individual farm). The survey revealed that litter turning is actively practiced during grow-outs in Australian meat chicken houses, with 89% of growers indicating that they use ventilation, heating, drinker management, topping up with dry litter and litter turning machinery to improve litter dryness and friability as part of a combined approach to litter management. Of the growers undertaking litter turning, 45% indicated that they schedule it at regular intervals (most commonly weekly) and 55% indicated that it is undertaken in response to caking litter. Litter turning is generally not done within the first 14 d of a grow-out and may be postponed when the size of the chickens or flock density within the house is not conducive to performing the task safely, effectively, or when it is considered by the grower to be unsuitable from an animal welfare perspective.

When considering the mechanisms, outcomes, and potential concerns relating to litter turning, we speculate that there are 4 periods of time that require specific attention: 1) history of the litter and conditions prior to litter turning; 2) during the litter turning operation; 3) several hours immediately following litter turning;

and 4) longer term (days–weeks) after litter turning (Table 2, with additional detail in Supplementary Table 1). Turning the litter and exposing particles to the litter surface would be expected to coincide with a potential surge in the release of ammonia, moisture, heat, pathogens, fungal spores, and other biological or microbial contaminants. We suggest that the presence and release of these depend on the initial litter conditions, with less of a surge expected from litter that was dry, friable, and already being "worked" by the chickens (or recently and regularly turned by the grower). Growers need to be ready to respond to potential risks with a possible increase in effective ventilation or other mitigation measures. While one of the aims of litter turning is to maximize water evaporation, growers need to be aware that litter temperature may reduce due to evaporative cooling, which may be undesirable when chickens are young or sensitive to cool temperatures and heat loss.

Many of the undesirable litter conditions that litter turning addresses relate to excess moisture in the litter. Sources of moisture include: drinker spillage and leaks, condensation, and absorption from humid air, and frequent bird droppings (Dunlop et al., 2015; Dunlop et al., 2016a,b,c,d). As moisture increases, the cohesiveness between litter particles increases, causing them to stick together tightly (Bernhart and Fasina, 2009). This prevents excreta being mixed in and forms what is known as caked litter on top of the litter surface. Caked litter requires large amounts of energy to break up and return to a friable state, which the chickens cannot do alone through natural behaviors of working the litter (Lister, 2009; Dunlop et al., 2016a,b,c,d). Using machinery during litter turning provides the energy required to effectively break down the tight cohesiveness of particles. Litter turning and drying reduce the bulk density and particle size and increase the flowability and friability of the litter (Bernhart et al., 2010). How long the litter remains friable depends on the average moisture content of the turned and homogenized litter.

Aeration of the litter, through turning, promotes aerobic microbial activity, which creates heat (if there is sufficient carbon to ensure correct C:N ratio) that promotes water evaporation from the litter and accelerates decomposition of organic material (Lister, 2009). In general, aerobic decomposition of animal manures produces less odor than anaerobic processes (Zhu, 2000; ASABE, 2016; Dunlop et al., 2016a,b,c,d), and therefore we suggest that maintaining drier and more aerobic conditions within the litter is likely to reduce long-term odor emissions from poultry houses, although the practice of turning may contribute to a short-term surge of odor release as moisture, gases, and particles are released (Santonja et al., 2017).

A variety of different machines are available that can be used to turn litter, including walk-behind machines, tractor or loader-mounted attachments, and autonomous, self-guided machines that require no operator (Supplementary Table 2). A common feature of most machines is a set of rotating blades, hoes, hammers, pulverizers, or augers. These are necessary to impart the energy required to break up cake and interparticle bonds to improve friability. Compact, walk-behind machines tend to be used for targeting small, caked areas within the house, for example, under drinker lines and can operate in the house with a single operator without lifting drinker and feeder lines. Due to the narrow width of the machine (typically 0.3–1.0 m), we suggest that they have lesser ability to mix wet litter with

Table 2. Litter conditions before, during, and after litter turning with different starting conditions.

Stages of the litter turning process	Litter starting condition		
	Wet and caked	Mixture of wet and dry	Dry and friable
Prior to litter turning	Wet and caked	Patches of caked litter surrounded by friable litter	All litter is dry and friable. Minor crusting (thin and small patches only) may occur, but will appear dry
During litter turning (while litter is being mixed)	High moisture content **Risks to consider:** Surge of ammonia, moisture, pathogens, other biological or microbial contaminants trapped below caked	Patches of medium, or possibly high moisture content **Risks to consider:** May have a surge of ammonia, moisture, pathogens, other biological or microbial contaminants	Low moisture content **Risks to consider:** Airborne dust concentration Ammonia may release in a surge
Immediately after litter turning (0 to several hours after turning)	Wet and sticky—litter compacting and cake forming—fresh excreta smear on the surface **Risks to consider:** Ongoing surge of ammonia and moisture	Litter is moist and friable Chickens "work" the litter—fresh excreta is mixed in **Risks to consider:** Ongoing surge of ammonia and moisture	Litter is dry and friable Chickens "work" the litter—fresh excreta is mixed in **Risks to consider:** Short-lived surge of ammonia and dust
Longer-term (days–weeks) after litter turning	Wet and caked **Risks to consider:** Ongoing surge of ammonia and moisture Litter surface is wet and cold	Litter remains friable IF sufficient water is lost and ventilation is effective—chickens, "work" the litter **Risks to consider:** Possible ongoing surge of ammonia and moisture, but will reduce as litter dries	Litter is friable—chickens "work" the litter **Risks to consider:** Nil—"Normal conditions"

neighboring drier litter, unless the operator makes multiple passes. Larger machines, such as tractor or loader-mounted attachments, are more suited for turning the litter throughout the entire house, but require drinker and feeders to be raised out of the way and often require more than one operator, for example, one person to operate the machine and a second person to clear chickens from around the machine. Anecdotal comments made to the authors by growers, who have used both small and large litter turning machines, suggest that one of the benefits of the larger machines is that they more readily mix wet and dry litter together, which reduces the average moisture content and is more effective at preventing cake from re-forming. Finally, autonomous machines, that is, robots, are becoming increasingly available as technology and industry demand for these increases. They are generally small and move freely throughout the house using self-guiding and obstacle avoidance systems. They are battery-powered and automatically recharge when required. While they tend to be smaller than other litter turning machines, they are able to work nearly continually and more frequently because they do not need an operator. We suggest that frequent operation of these machines is likely to be beneficial in keeping litter working and preventing cake formation.

The machinery for litter turning is designed to break up caked litter, incorporate excreta and mix, homogenize and aerate litter; however, the effects of machinery operations on the well-being of the chickens are unknown, especially the noises, physical disturbance, and potential exposure due to a surge in the release of dust and gases from the litter. With minimal published information available on litter turning, we suggest the potential benefits, consequences, and implications of litter turning on the chickens have not previously been considered together and therefore require further investigation. In this literature review we aim to identify and discuss the effects of litter turning on litter qualities, ammonia emissions, litter moisture, and animal welfare, and review potential benefits and consequences that the practice has on poultry production, with a focus on meat chicken (broiler) rearing, based on published information, industry survey responses, and applied knowledge.

MATERIALS AND METHODS

The terms listed in Table 1 were used to search for information on litter turning. The search platforms to find relevant studies included poultry journals, search engines, and online databases. The reference lists of relevant articles were also used to locate additional material. The studies were then categorized into the following topics: litter conditions, wet litter, litter working, animal welfare, and litter turning machinery (Figure 1). These are important to understand what litter turning is, how it works, and the benefits it provides as a poultry litter management practice.

RESULTS AND DISCUSSION

Very few research studies were found that specifically investigated effects of litter turning on litter conditions or properties, wet litter management, productivity, environmental impacts, ammonia production, or chicken health and behavior. Similarly, there were no studies that compared different types of litter turning machinery or practices. With minimal research identified specifically relating to litter turning, it was necessary to focus on the mechanism involved in litter turning and the

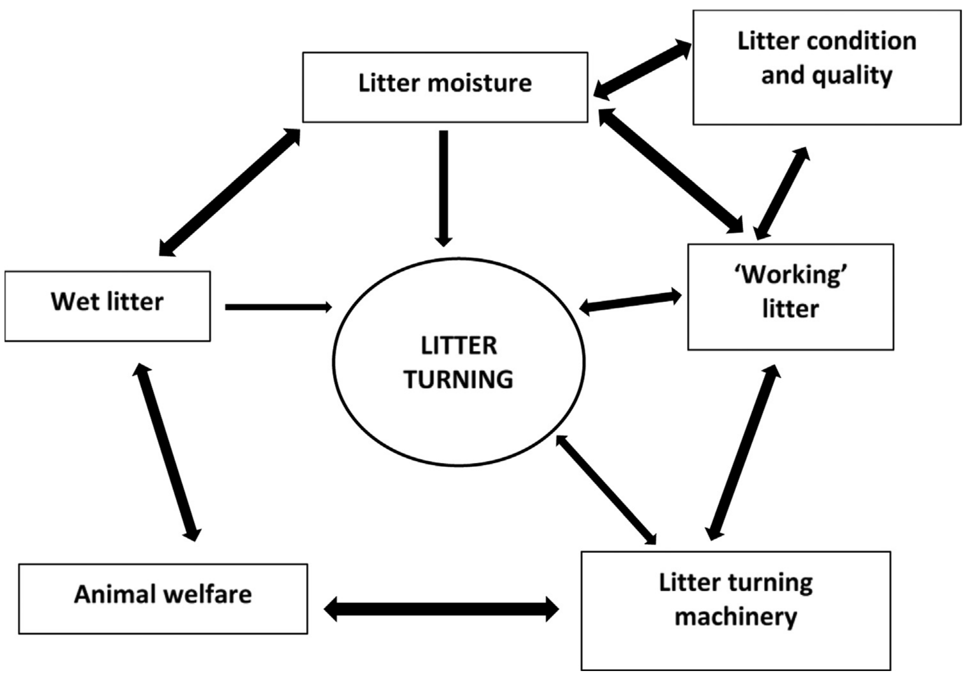

Figure 1. Topics relating to litter turning that were included in this review.

Table 3. Studies that mentioned a form of "litter turning" or focused on relevant topics (including litter conditions).

Research topic	References
Litter aeration—forced aeration, elevated platforms, tilling, stirring, turning	Koon et al. (1994); Allen et al. (1998); Hicks (2007); Mayne et al. (2007); Bilgili et al. (2009); Bodí et al. (2013); Collett (2012); Dunlop (2009); Estellés et al. (2011); Núñez Casas (2011); Villagrá, J.J. et al. (2011); Malone and Marsh Johnson (2017)
Welfare issues—relating to litter conditions	Dawkins et al. (2004); Mayne et al. (2007); Bilgili et al. (2009); Lister (2009); Bassler et al. (2013); Bodí et al. (2013);Adler et al. (2020); Dunlop et al. (2016a,b,c,d); Kaukonen et al. (2016); Malone and Marsh Johnson (2017); Shepherd and Fairchild (2010); Núñez Casas (2011)
Litter conditions contributing to microbiota issues—Salmonella and others	Eriksson De Rezende, Mallinson et al. (2001); Lister (2009); Villagrá, J.J. et al. (2011); Bodí et al. (2013); Dunlop (2016a,b,c,d)
Floor design—including perforated and elevated floors	van Middelkoop (1994); Allen et al. (1998); Adler et al. (2020); Boggia et al. (2019); Heitmann et al. (2020)
Water activity—water movement in the litter	Eriksson De Rezende, Mallinson et al. (2001); Dunlop et al. (2015); Dunlop et al. (2016a,b,c,d)
Odor emissions—natural gases from litter quality	Allen et al. (1998); Dunlop (2009); Dunlop et al. (2016a,b,c,d)
Dust emissions—during litter turning	Villagrá, J.J. et al. (2011); Santonja et al. (2017)
Ammonia emissions—decaking and litter turning/tilling	van Middelkoop (1994); Allen et al. (1998); Czarick et al. (2006); Ritz et al. (2006); Macklin et al. (2008); Dunlop (2009); Harper et al. (2010); Núñez Casas (2011); Lopes et al. (2013); Chai et al. (2018); Malone and Marsh Johnson (2017); Stein (2019)
Ammonia emissions—litter quality and moisture	Carr et al. (1990); Hayes et al. (2003); Xin et al. (2003); Dawkins et al. (2004); Miles et al. (2004); Patterson and Adrizal (2005); Liu et al. (2007); Tasistro et al. (2007); Miles et al. (2008a,b); Topper et al. (2008); Bilgili et al. (2009);Lister (2009); Harper et al. (2010); Kníz Atová, Mihina et al. (2010); Meda et al. (2011); Miles et al. (2011); Núñez Casas (2011); Dunlop et al. (2016a,b,c,d); Boggia et al. (2019)
Litter quality—"workability," friability, cohesiveness, caking	Eriksson De Rezende, Mallinson et al. (2001); Bernhart and Fasina (2009); Lister (2009); Bernhart et al. (2010); Núñez Casas (2011); Collett (2012); Bassler et al. (2013); Bodí et al. (2013); Dunlop (2016a,b,c,d)
Poultry litter—bedding materials	Koon et al. (1994); Bilgili et al. (2009); Dunlop (2014); Núñez Casas (2011); Dunlop et al. (2015); Dunlop et al. (2016a,b,c,d)
Litter moisture	Koon et al. (1994); Eriksson De Rezende, Mallinson et al. (2001); Dawkins et al. (2004); Bilgili et al. (2009); Bernhart and Fasina (2009); Bernhart et al. (2010); Shepherd and Fairchild (2010); Núñez Casas (2011); Collett (2012); Dunlop (2014); Dunlop (2016); Dunlop et al. (2015); Dunlop et al. (2016a,b,c,d); Kaukonen et al. (2016); Lister (2009); Malone and Marsh Johnson (2017); Mayne et al. (2007)
Wet litter—water moving in and out of litter	Mayne et al. (2007); Bilgili et al. (2009); Shepherd and Fairchild (2010); Núñez Casas (2011); Collett (2012); Dunlop (2016a,b,c,d); Kaukonen et al. (2016); Lister (2009)
Nutrition—contribution to litter quality	Lister (2009); Collett (2012); Dunlop et al. (2016a,b,c,d); Sharma et al. (2017)

expected outcomes, so that the potential benefits or consequences of litter turning on poultry production could be inferred. These mechanisms and outcomes included litter quality and properties, litter moisture, litter aeration, caked litter, litter friability and cohesiveness, litter workability, ammonia formation and emission mechanisms, and interactions between litter conditions and chicken behavior, health, and litter preferences. These have been the focus of multiple research investigations (Table 3), and we have attempted to investigate and discuss the relevance of these to litter turning as a litter management tool in meat chicken production.

Litter Conditions, Properties, and Moisture Content

Litter conditions are influenced by properties of the bedding material, addition and incorporation of manure, and litter moisture content. Maintaining "ideal" litter conditions assist poultry to grow to their genetic potential by managing pathogens, controlling dust, reducing odor and ammonia, supporting normal digestive physiology and gut ecology, and reducing the risk of health issues that may occur due to contact between chickens and litter, for example, footpad dermatitis, lesions, and hock burn (Allen et al., 1998; Collett, 2007; Mayne et al., 2007; Lister, 2009; Shepherd and Fairchild, 2010; Cengiz et al., 2011; Collett, 2012; Bodí et al., 2013; de Jong et al., 2014; McGahan et al., 2014; Dunlop et al., 2016a,b,c,d). "Dry and friable" is a term that is frequently used to describe litter conditions that are required by poultry rearing standards (European Union, 2007; AHA, 2017; RSPCA Australia, 2020) and refers to litter that is dry but not dusty, well-mixed, free-flowing, and may contain a large percentage of manure but no large pieces of caked litter (Dunlop, 2014). Caked litter can be defined as the compression of litter layers into a single wet layer on top of the bedding material, resulting in a thick, dense layer holding most of the moisture and fecal material in the litter (Shepherd and Fairchild, 2010). Litter moisture content should be maintained at 15 to 30% and ideally below 25% (Dunlop, 2014; McGahan et al., 2014; Malone and Marsh Johnson, 2017). Litter with greater than 25% moisture content has previously been described as "wet litter" and has compromised cushioning, insulating, and water holding properties (Collett, 2012; Dunlop et al., 2016a,b,c,d). Wet litter also potentially contributes to welfare concerns including footpad dermatitis, as well as increased odor and ammonia (Mayne et al., 2007; Shepherd and Fairchild, 2010; Cengiz et al., 2011; McGahan et al., 2014; Dunlop et al., 2016a,b,c,d). It is equally as important that litter is not too dry (less than 15% moisture content) because it can increase dust-related health risks for chickens and workers and reduced productivity (Lai et al., 2009; Lister, 2009; Lai et al., 2012).

Descriptions often used to describe litter conditions generally relate to litter moisture content, friability, and/or stickiness (Table 4). As moisture content within the litter increases, the wetter, stickier, and less friable it becomes and the more difficult it is to return to good conditions.

Poultry litter becomes wet when addition of water exceeds the rate of removal by evaporation. Large volumes of water are continually added to litter from multiple sources including excretion, drinking spillage, leaking drinkers, condensation, and house leaks (Collett, 2012; Dunlop et al., 2016a,b,c,d). This highlights the importance of removing moisture from the litter using effective management practices, especially ventilation. Without removing water from the litter with ventilation, the floor of a meat chicken house would be covered with water to a depth of 10 cm by the end of a grow-out (de Gussem et al., 2015; Dunlop et al., 2015). The important role of ventilation to improve water evaporation at the litter–air interface and transport it out of the house is only one part of the litter moisture management paradigm. The other necessity is to move water to the surface so that it can be removed by ventilation. This process is greatly assisted by litter turning, which physically brings the wettest litter to the surface, reducing the size of litter particles to maximize the surface area for water evaporation, and opens pores to maximize the diffusion of water molecules through the litter. In contrast, Dunlop et al. (2016a,b,c,d) reported that when litter is compressed, pore size is reduced and movement of water molecules through the litter to the surface is substantially slowed because water has to diffuse randomly through tortuous pathways to reach the surface before it can be removed by ventilation. By mechanically bringing moisture to the surface, water is removed much more rapidly due to turbulence in the air boundary layer above the litter surface. We speculate that this dries the litter and is supported in part by the findings of Koon et al. (1994), who reported that litter was dryer after successive litter turning events that were undertaken between grow-outs. Litter turning, therefore, complements ventilation at times when conditions are conducive for accelerated litter drying, particularly when warm, low relative humidity air is combined with air speed. Relying on continuously high ventilation rates can increase energy costs drastically (Wheeler et al., 2000; Tabler and Wells, 2018), therefore litter turning may be a complimentary practice that reduces the constant need for ventilation by accelerating the release of water through a mechanical practice, thus reducing energy costs. However, there needs to be

Table 4. Litter condition descriptions and associated moisture content (McGahan et al., 2014).

Litter description	Moisture content (%, wet basis)
Dusty	<15
Dry to friable	15–20
Friable to moist	20–30
Sticky—beginning to cake	30–40
Wet and sticky—heavy caking	40–50
Very wet and sticky	>50

further research to better understand the benefits and effectiveness of litter turning on drying litter especially as different types of bedding materials with different amounts of incorporated/accumulated manure are likely to have different drying properties (Dunlop et al., 2015). Research is also required to investigate the effect of increased water evaporation on emission of ammonia and other gases from the litter.

Water contributes to particles sticking together (cohesion) and energy is required to break those bonds and return the litter to a more friable and homogeneous state. Bernhart and Fasina (2009) concluded that greater force was required to overcome cohesive bonds between litter particles when litter was wetter. Litter moisture content is often not uniform across the floor or within the litter depth profile. Areas of the floor that are wetter are more inclined to start caking. This is supported by responses from our survey of Australian meat chicken growers, in which 41% of respondents indicated that caking occurs under drinker lines, with about 6% of respondents indicating that caking starts along the side walls or near migration fences. In friable materials, not specifically poultry litter, the moisture content at which caking of granular materials commences has previously been referred to as the "critical hydration level" (Roudaut, 2007). To prevent caking from occurring, the moisture content needs to stay below this critical hydration level. This is not referring to the "average" litter moisture content that is reported in many research papers, but the specific moisture content at any location within the litter. If an area of the litter becomes overly wet and is above the critical hydration level, water must be removed, or dry material added to reduce the moisture content and prevent the cohesive bonds from re-forming. Adding dry material is achieved by physically removing wet litter from the house and replacing it with dry material (Carrol, 2012), which may be new material or dry litter that is transferred from the surrounding floor if there is sufficient quantity. The practice of litter turning may assist with this where wet litter is adjacent to dry litter. If the litter turning machine effectively mixes and homogenizes the litter as it moves through the litter, it may be capable of reducing the maximum litter moisture content below the critical hydration level for caking. This may require the operator to plan their operation to ensure that wet litter is mixed with dry, rather than just turning wet litter.

The occurrence of caking is also influenced by the type of bedding material. The shape and size of individual particles contribute to matting, and water absorbency affects water holding capacity and the ability to release water and dry out. Pine shavings are often considered the "industry standard" (Bilgili et al., 2009; Dunlop et al., 2016a,b,c,d; Shepherd et al., 2017) and one of the most suitable bedding materials due to absorbency, reasonable drying time, and friability. On the other hand, materials such as straw (>25 mm cut length), rice hulls, wood fiber products, bagasse, and pine needles have been reported to be more prone to caking (Grimes et al., 2002). Once caked, chickens cannot naturally mix excreta into the litter resulting in the top layer of litter "slicking" over, causing cake to form on the litter surface (Miles et al., 2008a,b). The properties of all bedding materials change during the grow-out as the ratio of manure to bedding increases, and litter used for multiple grow-outs can have superior water holding and water activity properties (Dunlop et al., 2015; Dunlop et al., 2016a,b,c,d) and be more cost-effective than new bedding (Roll et al., 2011), even if chemical litter amendments are added to manage ammonia production (Worley et al., 2000; Cockerill et al., 2020).

Maintaining good litter conditions allows chickens to "work" the litter as they bask and scratch, which aerates, increases porosity, keeps litter flowing to prevent cake formation, incorporates fresh excreta, and accelerates release of water. These aerobic conditions promote aerobic microbial activity that generates heat for comfort, which further contributes to water release from the litter and encourages breakdown of organic material deposited with feces (Lister, 2009). Maintaining the litter in "working" condition reduces or prevents the need for litter turning, although small areas of high-water application or high bird density may still cake over and require mechanical turning to return to a friable state.

In summary, the practice of litter turning alters the conditions by cutting up cake, reducing size of clumps and particles, increasing friability, exchanging litter particles at the surface, mixing wet litter with dry, and aerating the substrate. These actions change processes going on in the litter that we suggest are likely to result in increasing the rate of water evaporation, reduce the amount of caking on the litter surface, and reduce moisture content of the wettest spots—assuming that dry litter is adjacent and is mixed together with wet litter. It needs to be stated that litter turning may not be appropriate or effective if litter condition is too poor or heavily caked. In these situations, it may be necessary to remove poor litter and cake from the house altogether. Reducing the maximum moisture content reduces the stickiness of litter particles, and if moisture content is lower than the "critical hydration level,' then caking will not readily occur. The combined result is that litter remains friable and the birds will be able to "work" it, which will naturally lead to incorporation of fresh excreta and maximum drying rate, resulting in ongoing good litter conditions.

Litter Turning Effects on In-House Ammonia Concentration and Emission Rates

Ammonia concentrations within poultry houses can be detrimental to the health of the chickens and farm workers. It is recommended that ammonia concentration is maintained below 10 to 25 ppm, depending on the relevant standard and jurisdiction (McGahan et al., 2014; Malone and Marsh Johnson, 2017; Aviagen Inc., 2018; RSPCA Australia, 2020). High ammonia concentration can reduce bird performance, increase susceptibility to disease, and increase occurrence of mortalities (Weaver and Meijerhof, 1991; Miles et al., 2004). Management practices such as ventilation and litter management, especially minimizing litter moisture content (Miles et al., 2011; Miles, 2012), play an important role in minimizing ammonia concentration within the poultry house, but how does litter turning affect ammonia?

Minimal published information was found that directly focused on the impacts of turning or breaking up litter on ammonia concentration. The concentration of ammonia in the house is affected by multiple factors (Cockerill et al., 2020) including amount of ammonia produced in the litter (affected by diets, temperature, manure and moisture content (Miles et al., 2006; van Emous et al., 2019)), amount of ammonia exchanged between the litter and the air, amount of fresh air brought into the house (to dilute the ammonia), and amount of ammonia extracted from the house through the ventilation exhaust fans. Litter turning will not directly affect dilution or removal of ammonia by the ventilation system but will alter litter conditions affecting formation and emission of ammonia from the litter. In this paper, we have already discussed how litter turning breaks caked litter into smaller pieces (which increases the emitting surface area), aerates the litter, increases ammonia generation potential of cake (Czarick et al., 2006), releases ammonia that is trapped below the caked surface (Miles et al., 2008a,b), exchanges material at the litter surface, and increases friability (which enables the chickens to continue to exchange materials at the litter surface and also increases ammonia and moisture exchange between the litter and air (Chai et al., 2018)). Accelerated moisture, gas, and particle emissions from the litter will occur at the time of litter turning due to increased surface area and potential exchange sites for molecules of water and other compounds (Czarick et al., 2006; Estellés et al., 2011; Dunlop et al., 2016a,b,c,d; Malone and Marsh Johnson, 2017). Aerating the litter will also promote aerobic microbial activity and heat production that will further increase volatilization of water vapor and promote microbial decomposition of uric acid in the litter, which is one of the recognized sources for ammonia production (Cockerill et al., 2020). Also, long-term aeration of litter has previously been shown to reduce ammonia production emissions (Allen et al., 1998). While rapid evaporation of water results from litter turning, in the short term, litter moisture content remains elevated and will continue to support ammonia production (Weaver and Meijerhof, 1991; Nimmermark and Gustafsson, 2005; Czarick et al., 2006; Miles et al., 2011; Xiong et al., 2017). Miles et al. (2011) reported that ammonia production occurs when litter moisture content is as low as 20% and increases substantially until peak ammonia production occurs at 37.4 to 40.4% moisture content when litter temperature was 18.3°C, or 46.8 to 51.1% moisture content when litter temperature was 40.6°C. This means that litter needs to be very dry to significantly restrict production of ammonia. Litter turning may assist with litter drying but managing relative humidity in the poultry house will have the greatest influence on maintaining dry litter (Weaver and Meijerhof, 1991).

Under commercial production situations, disturbing litter by turning produces a spike of ammonia by increasing the ammonia generation potential or releasing ammonia that was trapped beneath the caked surface (Ritz et al., 2006; Bilgili et al., 2009; Núñez Casas, 2011; Malone and Marsh Johnson, 2017; Chai et al., 2018; Tabler and Wells, 2018). Effective ventilation and low RH are required to accelerate water loss and extraction of water and ammonia from the house to deliver anticipated long-term ammonia reductions. It is possible, however, that a litter management strategy that includes scheduled regular litter turning may contribute to lower long-term ammonia concentrations and avoid spikes during turning, as it has been previously shown that constant litter aeration and disturbance produce drier litter and reduce occurrence of ammonia (Koon et al., 1994; Allen et al., 1998). We suggest that regular litter turning is likely to be beneficial from an ammonia perspective as this will help to dry the litter and keep it in a state that it is workable by the chickens with minimal caking (assuming that in-house relative humidity is kept low and ventilation is effective at removing water from the litter and the house). Additional research is needed to understand how litter turning interacts within the house environment and the chickens.

Litter Turning Effects on Health and Welfare

Maintaining “dry and friable” litter, and avoiding “wet” litter, can reduce potential health and well-being issues in a flock (Dunlop et al., 2016a,b,c,d). Legislation and animal welfare standards specify the quality of litter and conditions to be maintained throughout production. A European Directive states “All chickens shall have permanent access to litter which is dry and friable on the surface” (European Union, 2007). Within Australia, the acceptable litter quality conditions are specified in the *Model Code of Practice for the Welfare of Animals: Domestic Poultry* (PISC, 2002) which is being replaced by *Australian Animal Welfare Standards And Guidelines For Poultry [proposed draft]* (AHA, 2017), and additional standards specifying this condition are by the RSPCA in their *Farming Scheme Standards* (RSPCA Australia, 2020) and FREPA in their *Chicken Meat Standard* (FREPA, 2020), for participating growers. The AHA (2017) standard requires that litter must be suitable for species and good quality, have minimal risk of being contaminated with toxic agents, and be managed to avoid excessive caking, dustiness, or wetness that would impact on the welfare of the chickens. While these growing standards specify goals of maintaining a certain level of litter quality, they do not specify actions or strategies that should be employed to achieve the required litter conditions.

Litter condition is not easy to assess, and there are many different aspects including litter moisture content (the inverse of dry matter content), friability, stickiness, manure content, pH, microbial activity and diversity, particle size, caking (thickness, area coverage, wetness), and temperature, to name a few. To standardize the process, there have been attempts to develop and apply litter assessment scoring procedures (Weaver and Meijerhof, 1991; Mayne et al., 2007; Welfare Quality, 2009; Bassler et al., 2013; AssureWel, 2017; Kheravii et al., 2017; Vinco et al., 2017) and these have been used to relate litter quality to welfare outcomes (Mayne et al., 2007; Bassler et al., 2013; Kheravii et al., 2017; Vinco et al., 2017; Ben Sassi et al., 2018; BenSassi, Averós et al., 2019; Granquist et al., 2019). Litter scoring procedures tend to focus on perceived wetness, friability, stickiness, caking, and the proportion of wet and caked litter to dry and friable litter. The focus on these properties and their proven relationships to welfare outcomes supports the hypothesis that litter conditions relate to animal welfare outcomes.

The purpose of this review is not to focus on the effect of litter conditions on chicken welfare, but to focus on aspects of litter turning that may affect health and welfare. The effect of wet and caked litter conditions has previously been reported, these conditions increase risks associated with contact dermatitis (including hock burn, footpad dermatitis, and breast blisters), increased risks associated with microbial infections and pathogens, and reduced insulating and cushioning properties (Carr et al., 1995; Shepherd and Fairchild, 2010; Collett, 2012; de Jong et al., 2014; Dunlop et al., 2016a,b,c,d; Mench, 2018). These not only cause health and welfare issues but can also result in downgrades at slaughter. Overly dry litter can also cause problems relating to dust, which can cause inflammation and respiratory system or eye issues (Carpenter et al., 1986; Al Homidan et al., 2003; Lai et al., 2009). The aim is to provide friable litter that is neither wet nor dry enough to impact on welfare, that can be worked by the chickens to support aerobic decomposition of excreta (Dunlop et al., 2016a,b,c,d), and allows the chickens to scratch and dust-bathe (Shepherd and Fairchild, 2010; Collett, 2012). The question to ask here is what contribution litter turning makes to these objectives, and are there aspects of litter turning that have their own risks in terms of animal welfare and health?

Our survey of Australian meat chicken growers indicated that concerns for chicken welfare (as felt by the grower) were the second greatest reason that prevents litter conditioning (67% of respondents). The survey did not ask what the specific welfare concern was (e.g., ammonia surge, extra dust, injuries resulting from fear of the machinery operation); however, 2 of the leading things that prevented undertaking litter conditioning were chicken density (88% of respondents) and chicken age/size (49% of respondents) (*note that respondents were able to select multiple options that prevented them from litter conditioning*). We speculate that these responses are linked, and growers are primarily concerned that operating machinery in densely populated chicken houses would negatively impact animal welfare. Our speculation is further supported by comments in the survey from several growers that they take advantage of reduced number of birds after a thin-out—a common practice in Australia to harvest a portion of the chickens (up to half of the flock) from the house for slaughter, usually between 30 and 35 d of the grow-out—to perform litter turning, which suggests that dust and ammonia surges are of lesser concern than operating machinery when chicken density is high. Despite concerns highlighted by Australian meat chicken growers about using litter turning machinery in the meat chicken houses, minimal literature was identified relating to potential effects/impacts the operation could have on chicken health and well-being.

There are mixed opinions and evidence in the literature about potential health and welfare implications of litter turning. We suggest that contrasting results are somewhat related to the period of time in focus (during turning; immediately after turning; or long-term outcomes) and the condition of the litter prior to turning. When considering surges in dust concentration, Estellés et al. (2011) reported that litter turning caused a spike in dust (PM_{10} and $PM_{2.5}$) concentrations and emission rates during litter turning; however, these spikes dissipated and returned to preturning values within 2 h of commencement of litter turning. Dust concentrations were higher in the litter turning treatment rooms; however, concentrations recorded in both the control and treatment rooms were generally lower than occupational 8 h TWA (time-weighted average) exposure standards for softwood dust in Australia (5 mg/m^3) (Safe Work Australia, 2019).

Malone and Marsh Johnson (2017) and Dezat and Gohier-Austerlitz (2020) report that litter turning is not recommended due to the spike in ammonia emission that it causes during and after turning (and is unnecessary in the USA due to lower chicken density), although both authors mention that a few turkey growers do perform litter turning as a matter of personal preference to address wet (and presumably caked) litter. Santonja et al. (2017) also recommended against litter turning because "agitating manure" should never be undertaken, or at least only rarely, because it increases emissions of ammonia and particles. To address the spike in ammonia release caused by litter turning, Malone and Marsh Johnson (2017) suggest that the application of ammonia reducing litter amendments is critical. While litter turning was not recommended, Malone and Marsh Johnson (2017) explained that litter turning increases surface area and releases moisture (and ammonia), which assists with managing moisture content in the longer term (Koon et al., 1994). Despite the water loss associated with litter turning, Núñez Casas (2011) did not report a long-term effect on litter moisture content, but arguably the litter was drier in both the treatment and control scenarios (10–26% moisture content in the control and 15–26% with litter turning, during weeks 4–6 of their trial) than would be found under commercial farming conditions (Estellés et al., 2011; Villagrá, J.J. et al., 2011). We speculate that the lack of effect of litter turning reported by Núñez Casas (2011) was related to the dryness of the litter prior to turning. This highlights the importance of considering litter conditions prior to conditioning when measuring the effectiveness or potential risks associated with the practice.

While the emission rate of dust and gases from the litter may increase due to litter turning, the in-house concentration may not necessarily increase if ventilation is increased to dilute the emitted compounds and exhaust them from the house. Therefore, the increase in aerial contaminant emissions from the litter is not directly an animal welfare concern if they are appropriately managed. However, unduly increasing ventilation may have adverse effects on the shed environment in terms of removing stored heat, energy, introducing too much moisture by bringing air into the shed through uncontrolled inlet vents or detrimentally changing in-house air circulation that may result in higher relative humidity, wetter litter, and more ammonia in the longer term. We suggest that growers should take advantage of modern ventilation controllers that can monitor in-house gas concentrations using specialized sensors (e.g., to measure ammonia) and automatically alter ventilation rate to manage gas concentrations below required thresholds.

In addition to litter moisture content, Núñez Casas (2011) and Villagrá, J.J. et al. (2011) evaluated the effect of litter turning on a variety of production, health, and welfare-related measures. While they concluded that conditions in the trial and treatment (ammonia and litter moisture content) were below thresholds reported to be potentially detrimental to chicken health, they reported that litter turning contributed to a slightly higher prevalence of tibial dyschondroplasia, higher feed intake (although the food conversion rate (FCR) in both control (1.15) and treatment (1.38) being considerably lower than for chickens with similar genetics), and a slightly higher incidence of mild cases of hock burn and conjunctivitis.

Observations by the authors of litter turning operations indicated that chickens quickly returned to the freshly turned litter and actively scratched and dustbathed. Caked litter that was present before litter turning was converted to friable litter, and dusty dry litter was replaced by nondusty, dry-moist litter. The machines used to turn the litter were tractor-powered and 1.5 to 2.4 m wide. Based on visual and textural observations of litter exiting the machinery, they effectively mixed wet and caked litter with neighboring dry litter that was in the path of the machine.

With limited information published on the possible health and welfare implications of litter turning, it is suggested that this is an area that needs to be investigated further to understand the potential consequences and/or impacts it may have on chickens and their health, growth, and behavior. We further suggest that investigations should consider the effect during turning, immediately after turning and long-term outcomes. Investigations should also consider litter conditions and management practices prior to litter turning, as all of these will influence potential health and welfare effects of litter turning.

CONCLUSION

Maintaining "dry and friable:" litter is favorable in maintaining effective shed conditions and allows chickens to "work" the litter material, contributing toward successful meat chicken production outcomes. Litter turning may be useful to assist with reducing litter moisture by accelerating the drying process and in turn decreasing the risk of harmful pathogens, dust, and gases present in the chicken's environment although there may be potentially harmful surges of these and ammonia during litter turning. More research is required to boost the currently limited knowledge on effects of litter turning and to provide greater understanding of the benefits and risks associated with the practice, including those relating to potential spikes in ammonia and odor concentrations.

Maintaining optimal litter conditions will likely continue to be an ongoing challenge particularly when other factors greatly affect litter conditions, especially in terms of litter moisture content. Litter turning is just one of many management practices that meat chicken growers can use to manage and effectively maintain litter quality and conditions in the house. Ventilation remains the primary tool for growers to manage litter conditions, but litter turning may be a useful complementary practice to accelerate water loss and keep litter working, assuming that conditions are conducive to this outcome and risks associated with potential ammonia spikes are managed appropriately.

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DISCLOSURES

The authors declare no conflicts of interest for this paper.

SUPPLEMENTARY DATA

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