Review of Fresh Litter Supply, Management and Spent Litter Utilisation

by K. Watson and S.G. Wiedemann
August 2018

AgriFutures™ Chicken Meat

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AgriFutures Australia is the new trading name for Rural Industries Research & Development Corporation (RIRDC), a statutory authority of the Federal Government established by the Primary Industries Research and Development Act 1989.

Foreword

The chicken meat industry requires reliable, on-going supplies of safe and effective litter materials. The spent litter then becomes a by-product that can, ideally, provide a modest revenue stream and is easily disposed of. The Australian poultry industry predominantly utilises straw, wood shavings or sawdust, depending on the region, and the spent litter is removed after each batch of chickens so that fresh litter can be introduced. Most spent litter is then sold as a fertiliser to broad acre, horticulture, dairy farms or composters.

The supply and cost of litter products has increased substantially over recent years and, in the future, supply of wood products may be constrained or may only be available at a higher cost. There is a close relationship between the chicken meat industries' capacity to pay for fresh litter and the market demand and cost for spent litter. Ideally, the sale of spent litter would match or exceed the cost of purchasing fresh litter, therefore, both aspects should be considered simultaneously during research and management. It is also notable that there are alternative uses for spent litter, such as bioenergy, which may increase sales in the future and could create a better market for spent litter products to enable the industry to comfortably cover the cost of fresh litter.

This current project considers both the supply of fresh litter and its disposal options, with an aim to identify novel litter materials or management systems. Optimal systems should be able to reduce fresh litter demand, increase spent litter demand and/or decrease the overall cost burden associated with litter supply and disposal, while maintaining ideal production conditions with respect to bird health and performance.

This research is important in providing knowledge about issues related to the use and management of litter in the Australian chicken meat industry. This project aims to benefit the Australian chicken meat industry stakeholders by reviewing the current litter trend and alternative litter, management and processing options.

This review has identified many alternative litters and management options that could be used by the Australian chicken meat industry. The choice of litter materials and litter management strategies is dependent on individual chicken growers' circumstances and the availability and cost of materials, which will vary between regions. While bird welfare and performance will continue to be the primary threshold criterion, the cost and availability of fresh litter will be the ultimate factors that determine whether alternatives are adopted by the industry.

This report recommends further research into alternative litter options and their optimisation to Australian conditions. Furthermore, it is recommended that AgriFutures Australia collects industry alternative trial data, so it can be communicated to the whole industry.

This report is an addition to AgriFutures Australia's diverse range of over 2000 research publications and it forms part of our chicken meat R&D program objective to manage the environment for sustainable development.

Most of AgriFutures Australia's publications are available for viewing, free downloading or purchasing online at www.agrifutures.com.au

John Harvey
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Abbreviations and definitions

ACMF	Australian Chicken Meat Federation
Aspergillus	Common genus of fungal species
Aspergillosis	A respiratory disease caused by fungal species under the genus *Aspergillus*, which can affect chickens, turkeys, humans and other mammals. It is less frequently found in ducks, pigeon, geese and other wild and domestic birds.
Breeder farms	The breeder farms raise animals dedicated to reproduction rather than meat production, i.e. breeder farms produce progeny that will stock commercial chicken meat farms.
Caking	Undesirable compaction of the surface of litter
CCA	Copper Chrome Arsenate
CPI	Consumer Price Index
EMS	Environmental Management Services
Fresh litter	Fresh litter, or fresh bedding, refer to new litter materials placed in a shed before a new batch of birds are housed there.
Grandparent farm	Grandparent farms raise pure-bred lines that produce progeny, which will become commercial meat chicken breeders in a breeder farm.
Litter	Litter in use (combination of bedding and faecal material)
Litter reuse	Chicken litter reuse is the practise of housing multiple batches of chickens on the same bedding material (litter) before removing litter from the sheds for utilisation off site (e.g. as fertiliser)
Meat Chicken	A chicken (*Gallus gallus domesticus*) grown for meat. Also referred to as a broiler in some Australian states.
1 Million cubic metres	M m^3
NSW	New South Wales
QLD	Queensland
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SA	South Australia
Spent litter	Litter that is removed from the sheds for utilisation off site (e.g. as fertiliser)
TAS	Tasmania
Traditional litters	Wood shaving, saw dust, rice hulls and straw
VIC	Victoria
WA	Western Australia

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Introduction

The chicken meat industry has been consistently growing in Australia since the 1960s. Growth in chicken meat production is projected to continue growing at approximately 3% per annum, which will put more pressure on the ability to source enough quality bedding materials needed for chicken meat production. This report identifies and discusses a range of issues associated with the supply, management, disposal and use of litter in the Australian chicken meat industry. It contains a review of the literature on alternative bedding materials and provides a ranked list of alternative bedding materials and management practises.

Target audience of the report

The report was designed to provide information to help the AgriFutures™ Chicken Meat Advisory Panel evaluate the current state of litter use and identify industry issues and possible alternatives for meat chicken bedding materials. Additionally, this report will provide a valuable source of information for chicken growers and other industry participants on the possible alternative litter materials and management practises that are available to the industry. It will also be of value to scientists interested in identifying research needs and opportunities in this area.

Locations of relevant industries in Australia

The major centres of chicken meat production have been developed in close proximity to the major markets in large cities, however, development is becoming more regionalised as urbanisation spreads. The major regions of chicken meat production are:

- NSW - outlying districts of Sydney, Mangrove Mountain, Newcastle, Tamworth, Griffith and Bryon Bay
- Queensland - Redland Bay, other areas south and south west of Brisbane and Mareeba
- Victoria - Mornington Peninsula, East Melbourne, Geelong and Bendigo
- South Australia - outlying districts of Adelaide, Murray Bridge, Gawler and Two Wells
- Western Australia - outlying districts Perth
- Tasmania - outer metropolitan areas

Background

Fresh litter is a small but appreciable cost for the chicken meat industry, but the prices have increased at levels above the Consumer Price Index (CPI) over the past decades. This, combined with shortages of cost-effective litter sources in some regions, has caused the issue to become a concern for the industry. Previous studies have suggested that the combined requirements for fresh litter in the Australian chicken meat industry have grown substantially, from 0.95 million cubic metres (M m^3) in 2001 to 1.49 M m^3 in 2009, although different assumptions regarding litter depth had a large effect on these results.

Upward price pressure has been common for wood and straw supplies for many regions in recent years, in response to a declining volume of wood products and the presence of high value alternative uses for straw. For example, straw prices have exceeded $200/t in some regions during drought. These factors amplify the need to find alternative litter sources, reduce litter volume requirements, or increase the price received for spent litter.

Aims/objectives

This project addresses four main objectives regarding litter supply and litter utilisation in the Australian chicken meat industry. The specific objectives of this project were to:

- Complete a current situation analysis of litter types and availability to provide information on litter use trends
- Review potential new sources of litter (novel, low cost, including recycled materials) that meet industry requirements for bird health, performance and welfare
- Review management options that reduce the volume of litter required, while providing similar conditions with respect to bird health, performance and welfare
- Consider options for spent litter management and/or disposal associated with changed litter type and/or management.

Methods used

The project consisted of an audit of chicken meat producers, growers, industry professionals, transport companies and litter producers, to investigate the current state of litter use and demand. A literature review was completed to investigate alternative litter materials and management methods, including published and unpublished reports from global research trials and surveys. Based on the information from the audit and review, potential new sources of fresh litter and management options for spent litter were screened and evaluated. Screening was performed using a customised litter performance matrix system that was developed by the authors. All potential alternative litter materials were ranked using the litter performance matrix. All litter types were ranked, and basic characterisation data was recorded. A full description was developed and supplied for the most promising litter types in each category.

Results/key findings

The audit of litter management showed that the Australian chicken meat industry used an estimated 1.8 M m^3 of fresh litter in 2017, based on average bird densities and batches per year. Litter depth ranged from 40 to 100mm, with a national average of 56 mm. Over 90% of survey participants reported litter depths that complied with the 50mm RSPCA litter standard. Litter reuse is practised by approximately 13.5% of the industry, predominantly in Queensland.

The litter material types vary from region to region, depending on availability and cost. Overall, growers showed the following preference for litter materials: wood shavings > sawdust > rice hulls > straw, providing the materials were available in good condition. Compared to previous audits, the use of sawdust, shaving and rice hulls has decreased, while the use of straw and 'other' litter types have increased, despite being less preferable due to limitations in the price and availability of preferred materials. The cost of fresh litter materials in 2017 was found to range from $10 to $40 per cubic metre ($m^3$) landed on-farm, with the variation caused by region and material type. The cost of wood shavings ranged from $22-40 m^3, sawdust ranged from $18-30 m^3, rice hulls ranged from $16-25 m^3, straw range from $10 -15 m^3 and other ranged from $15-25 m^3. Between 2008 and 2018, the cost of wood shavings and sawdust has increased at considerably higher rates than the CPI, confirming industry concerns about rising litter costs.

Five major issues with litter, identified by survey participants, were: cost, quality, supply, management and RSPCA standards, in order of significance. These are all inter-linked and can all influence each other in different ways.

The review of alternative litter sources and review of litter management rated the overall feasibility rating of each alternative litter, management and litter processing option in comparison to commonly used litters. It was found that recycled wood pallets, peat, switchgrass, miscanthus, straw pellets and sand litters were good examples of alternative litter materials. Reuse and litterless systems are potential management practises that could reduce litter requirements, while practises such as straw processing (chopping or crushing) were found to be alternative options to improve litter quality and management.

Implications for relevant stakeholders

The findings of this report will inform the industry about alternative litter and management options. The report highlights knowledge gaps and provides research and extension recommendations for consideration by the AgriFutures Chicken Meat Program.

Recommendations

This report contains several recommendations for consideration by industry stakeholders and the AgriFutures Chicken Meat Program. The recommendations have been developed from the literature review, feasibility study and via industry input from a survey of fresh litter suppliers, growers and producers. The choice of litter materials or litter management strategies is dependent on individual chicken growers' circumstances and the availability and cost of materials, which will vary significantly between regions. It should be noted that the estimated costs presented in the report were not inclusive of all associated costs, and for several alternatives there were limited cost data sources to draw cost estimates from. Consequently, these should be considered indicative, and readers should consider all factors and use local quotes before making financial decisions.

A range of general recommendations has been provided in the section below, and a comprehensive list of recommendations is provided at the end of the report.

General recommendations

- **Collection and communication of farm trial data across the industry, 'Litterpedia'**: It would be beneficial to communicate the results of the litter trials to the whole industry. This could be achieved by establishing a database of litter types and trial results in a more dynamic form, (such as a website) where producers could submit information on litter types used.
- **Development of a litter cost calculator:** The industry survey found that material costs, transport, treatment, spreading and management costs vary significantly between litter types, farms and regions. The industry could benefit from the development of a litter cost calculator to help producers understand and compare full cost of litter in a specific area using local quotes.
- **Further research on depth requirements of litter:** The current RSPCA depth requirement of 50mm is highly prescriptive, which could limit the uptake of several litter types. Further research by the industry is needed to determine the optimal depth of traditional and alternative litters, to ensure ideal production and welfare conditions without causing greater cost burdens than are necessary.
- **Further research into alternative litter types and management practises where limited information was available:** Further research or industry trials would be beneficial to determine if alternative litters or management practises that were identified in the review but had had limited information are suitable for the Australian chicken meat industry.
- **Further research on the optimisation of alternative litters to Australian conditions**: Further research is needed to optimise alternative litters to Australian commercial conditions, which would require more than a one batch trial in an optimised system.
- **Provision of extension materials and information in the Environmental Management System (EMS)**: In several instances, it was found that litter materials were being applied successfully in one region due to particular management practises, but these practises were deemed 'unsuitable' in other regions. This suggests that litter management extension material would be beneficial, and this information could potentially be integrated into industry EMS training materials to improve management.

The review performed in this project has identified many alternative litters, management practises and litter processing options that could be used by the Australian chicken meat industry. The following were rated the most promising alternatives for the Australian chicken meat industry:

- Alternative litter options
    - recycled wood pallets
    - miscanthus grass or switchgrass
    - straw pellets
    - sand
- Alternative management options
    - reuse
    - litterless systems, such as slats
- Alternative litter processing options
    - pelletisation
    - on-farm straw processing (chopping, crushing) to improve litter properties.

The audit revealed that practises could be improved to increase the suitability of cereal straws across the industry, and extension activities could be directed towards this.

Introduction

Industry overview

Australia's production of chicken meat has increased by more than 160% over the last 20 years, and the industry is wholly Australian-owned. Chicken meat is now Australia's most significant source of meat protein, with 90% of the population consuming chicken meat a least once a week (ACMF, 2014). As there is minimal import or exports of chicken meat in Australia, all chicken consumed in Australia is locally produced. The Australian Chicken Meat Federation (ACMF) forecasts a continual, steady growth in domestic production and consumption of Australian chicken meat (Figure 1) (ACMF, 2011).

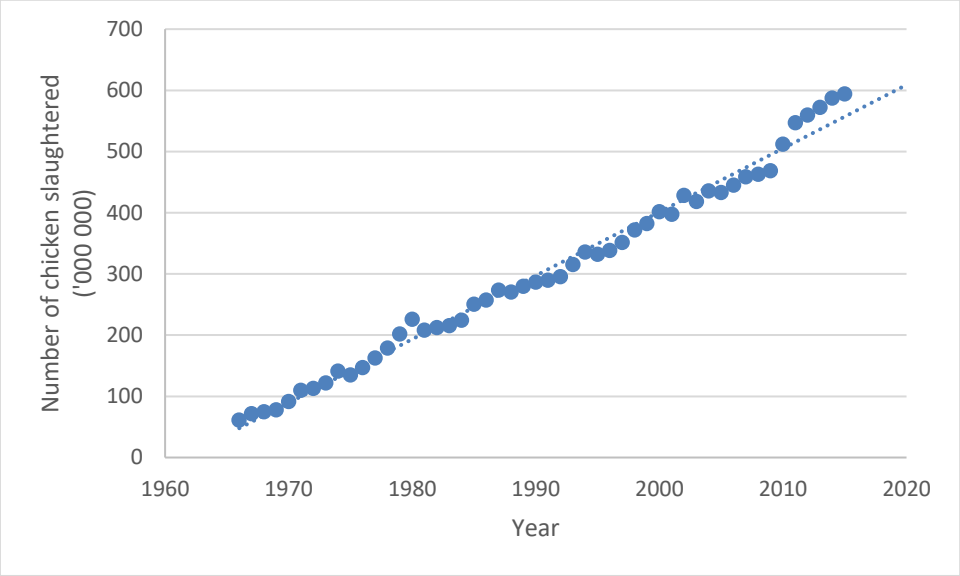

Figure 1. Australian chicken production (ABS, 2016a) with dotted trend line.

The Australian chicken meat industry is largely integrated, and companies own or control most aspects of their supply and production chain. Large chicken meat companies may include; breeder farms, hatcheries, chicken meat farms, processing plants, feed mills and laboratories. Smaller companies will have some of these facilities and use third parties for others. The larger Australia chicken companies' sub-contract the growing stage of production. Chicken meat growing farms are generally located within 100km of a processing plant, near a feed mill, with guaranteed water, power and access to services. The region where chicken meat is produced dictates the availability, type and cost of litter that is used. The major chicken meat producing regions of Australia are outlined in Figure 2.

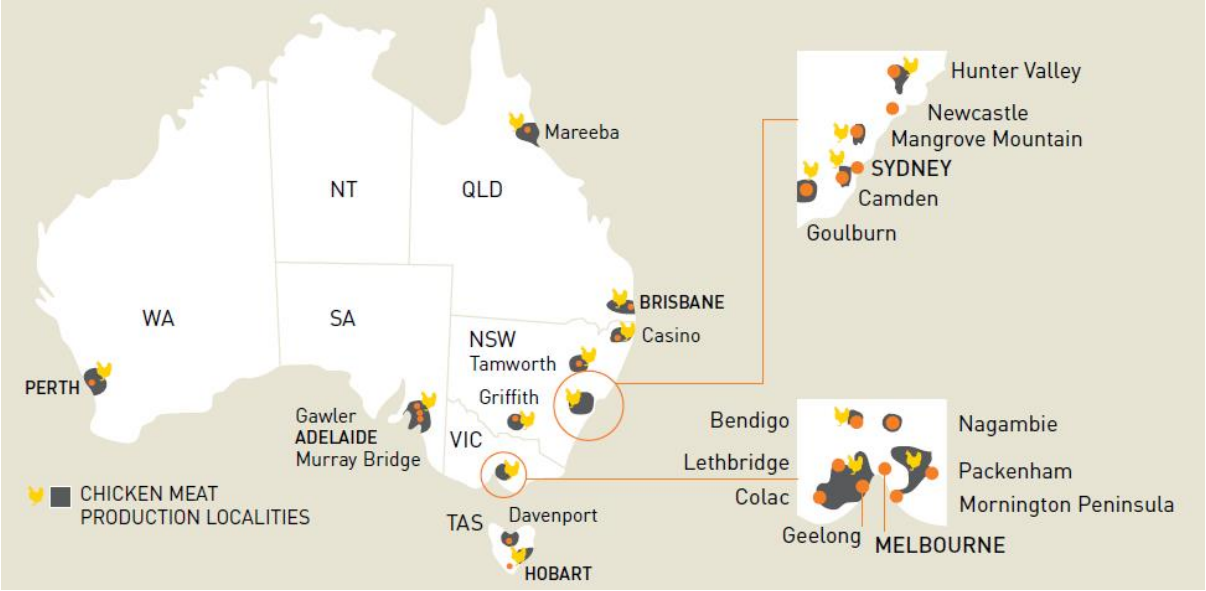

Figure 2. Major chicken meat producing regions of Australia (ACMF, 2011).

There are three different chicken meat production systems common in Australia; conventional, free range and organic. The majority of meat chickens in Australia are raised indoors in sheds with litter bedding (conventional system), but a proportion of the industry allows access to an outdoor range area (free range). Shed floors are required to be constructed with impervious material, such as concrete or compacted clay, to allow for thorough cleaning and disinfection between batches (McGahan et al., 2014). Compacted limestone has also been used.

There are two general types of housing sheds used in Australian chicken meat production:

- **Curtain sided sheds (older style):** these have soft walls that can be raised or lowered at different times to control air movement and temperature within the shed. They are often tunnel ventilated with fans and cooling pads to assist in maintaining shed temperature and air quality.
- **Solid wall sheds with tunnel ventilation (modern style):** these have cooling pads at one end, large fans at the opposite end and mini vents placed along the length of the shed. This design allows air to be drawn across the entire length of the shed at different times for air quality and for cooling during summer months.

The industry utilises a variety of litter types that are used within the housing shed, and they vary between regions. The most common types of litter used in Australia are wood shavings, sawdust, cereal straw and rice hulls. The ability to source sufficient volumes of litter at a suitable price is a constant area of interest for the industry.

Past surveys of litter use and management

Two AgriFutures Australia (formerly, RIRDC) surveys have been previously conducted to study the use of litter within the chicken meat industry. The first survey was conducted in 2001 and focused predominantly on issues associated with the sourcing and use of litter supply (Runge et al., 2007), and the second predominantly focused on the production and end-use of spent litter as a fertiliser, and the volatility of the market it's sold to (Dorahy and Dorahy, 2008).

Other studies, such as Playsted et al. (2011), have also provided estimates of fresh litter requirements and spent litter production as a feedstock for bioenergy, however, no comprehensive study has been conducted since the 2001 survey by Runge et al. (2007).

Desirable characteristics of litter

Litter type can significantly affect bird performance, welfare and carcass quality. Economic losses associated with poor litter and litter management in poultry include foot and leg problems, breast blisters, respiratory infections, poor weight gain and a low feed-conversion ratio. As chickens can consume as much as 4% of their diet from litter, any litter used must not contain contaminants that might be consumed or absorbed by the bird, such as pesticides or metals. The basic requirements of chicken litter include moisture absorbing capacity, drying time, cost, availability and poultry safety (Musa et al., 2012). Additionally, litter protects and insulates chickens from cold floors and conserves heat, providing a warm and soft surface for the comfort of the chickens. Another requirement is that the material should have a useful purpose once it has been used as a bedding material, to reduce overall costs and ensure that spent litter does not accumulate to unmanageable levels. Figure 3 shows a summary of desirable characteristics of litter.

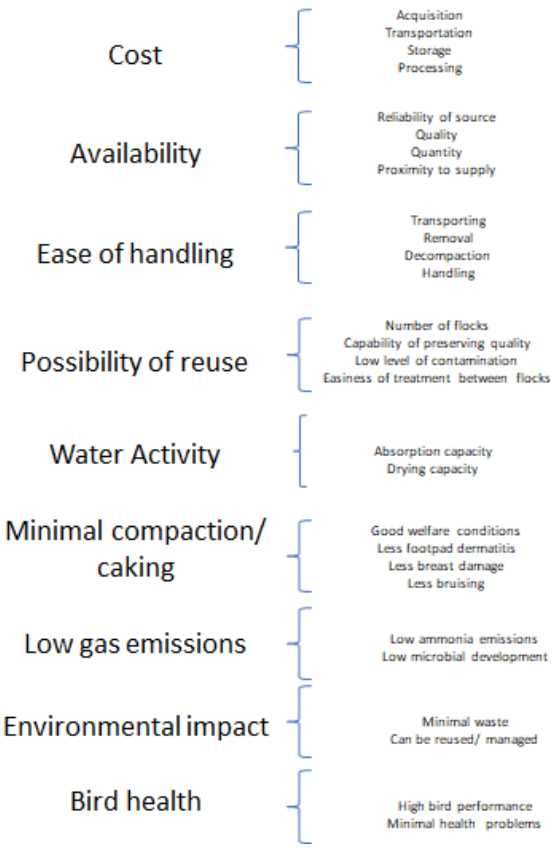

Figure 3. Desirable characteristics of litter.

Globally, many types of litter are used in the poultry industry, including sawdust, wood shavings, cereal straw, rice hulls, bark, sugar cane stalks, peat, peanut hulls and inorganic materials, such as sand. While some alternative litter sources have been successfully proven experimentally, they have not been utilised commercially by the industry due to cost competitiveness, availability or industry need. Alternative bedding materials should be carefully scrutinised, and the following factors should be considered:

- Will it keep chickens dry and clean?
- Will it maintain a healthy environment?
- Will it provide a comfortable, safe bed for chickens?
- Is it readily available?
- Is it cost effective?
- Can it be easily stored?
- Can the resulting spent litter be used?
- What effect does the subsequent manure have on the land and future crop growth?

Along with the type of litter used, there are many factors that influence whether litter management will be successful. These factors need to be considered in chicken meat production and include;

- Type of litter
- Seasonal influences, such as change in humidity and ventilation requirements
- Depth of the litter
- Floor space per bird
- Feeding practises
- Disease
- Nutrition
- Floor type
- Ventilation, and
- Watering devices.

Factors influencing litter use in Australia

Litter cost and availability

Fresh litter is a small, but appreciable cost for the chicken meat industry. Dorahy and Dorahy (2008) found the cost of fresh litter to average $\$20.50/m^3$, and range between $\$12\text{-}25/m^3$ from region to region. Costs are known to be higher in regions where there is a scarcity of supply, which prompts concerns that the price of fresh litter will continue to increase over time.

Upwards price pressures have been common for wood and straw supplies in many regions in recent years, in response to declining volumes of wood products, and an increase in high value alternative uses for straw. For example, straw prices have exceeded $200/t in some regions during drought. These factors amplify the need to source alternative litter sources, reduce litter volume requirements, or increase the price received for spent litter.

Litter reuse

Litter reuse is a management practise that reduces the requirement for clean litter and, therefore influences litter requirements. It involves housing of multiple batches of chickens on the same litter before removing that litter from the sheds for utilisation off site (e.g. as fertiliser), opposed to the normal practise of changing the litter between every single batch of chickens. This management approach is widespread in some countries (e.g. USA), but is not commonly practised in Australia, and when it is, it is typically reused for 3-5 batches. In the USA, litter is sometimes reused for several years (for more than 15 batches of chickens).

The RSPCA Approved system

The RSPCA Approved system was introduced in 2010, accrediting chicken meat farms to RSPCA Standards. The approval system is used to brand chicken meat at the point of sale, which enables differentiation and marketing of products with RSPCA Approval. Compliance is checked every 3-6 months by a RSPCA Accessor and a significant proportion of the chicken meat industry is now

RSPCA approved. However, some supply chains in Australia are not accredited under this system and, therefore, do not have the same restrictions on litter management.

The RSPCA chicken meat litter standard is as follows (RSPCA, 2013).

> 3.14 Litter material must be of good quality, water-absorbing material and provide for the bird's behavioural need to dust bathe, scratch and forage.
>
> 3.15 Litter supplies must be accompanied by documentation specifying source, type and volume.
>
> 3.16 The floor of the shed must be completely and evenly covered in litter to a minimum average depth of 50mm.
>
> 3.17 Litter must be actively maintained in a dry and friable condition.
>
> 3.18 Litter condition must be monitored daily, and prompt action taken where crusts and/or wet areas are identified.
>
> 3.19 Litter management equipment must be available on-farm.
>
> 3.20 Irreparably wet or fouled litter must be removed and replaced with dry, friable litter.
>
> 3.21 Where litter is re-used at the end of a batch, it must be treated to address pathogen loads and ammonia concentrations and be dry and friable at bird placement.
>
> 3.22 Where used litter is placed in the brooding area, it must have 50mm of fresh litter placed on top

Spent litter utilisation

Most spent litter produced in Australia is sold as a fertiliser to broad acre, horticulture, dairy farms or composters (Dorahy & Dorahy 2008). The supply and cost of litter products has increased substantially over recent years and the future supply of wood products may be constrained, or only available at a higher cost. There is a close relationship between the industries' capacity to pay for fresh litter and the market for buying spent litter. Ideally, sales would match or exceed costs, and maintaining the markets for spent litter must be considered when changing litter management or investigating alternative litter types.

Objectives

This project covers four main objectives regarding litter supply and litter utilisation;

- analyse the current use of litter types and availability to provide information on litter use trends
- review potential new sources of litter (novel low cost, including recycled materials) that meet industry requirements for bird health, performance and welfare
- review management options that reduce the volume of litter required, while providing similar conditions with respect to bird health, performance and welfare
- consider options for spent litter management and/or disposal associated with changed litter type and/or management.

Methodology

The project was conducted in a series of stages. First, an audit of industry practises and issues was conducted, followed by an analysis of alternative litter types and management practises. These alternatives were then screened to select the most suitable options, which were then described in more detail. The methods used in each of these stages are described below.

Current situation analysis – survey

A survey of key chicken growers, processors, sub-contractors and litter suppliers was undertaken to quantify the use and disposal of litter. The objective was to obtain information on costs, volumes, types, management practises and utilisation of litter in the Australian chicken meat industry.

Identification of alternative litter types and management practises

A published literature search, including internet web pages and additional industry consultation, was undertaken to identify current knowledge and worldwide trends related to alternative litter types and alternative management practises in chicken meat production and other similar industries. Alternative litter materials, alternative housing management (including litter reuse), options to improve litter properties for reuse and the implications for spent litter resulting from changed practises were investigated. An audit of available materials with similar properties was then conducted to develop an extensive list of possible litter materials.

Matrix construction

Based on the results of the literature review, further analysis was undertaken to identify the best options for industry uptake. This was performed as a desk-top assessment of cost effectiveness and barriers and/or opportunities for implementation. A decision matrix rating system was developed and applied to rate alternative litters and management practises.

Alternative litter decision matrix rating system

A decision matrix rating system was developed for the project to compare alternative fresh litter types against one another. The matrix is broadly based on the tool developed by Garcia et al. (2012) and was modified by the authors in collaboration with Australian litter industry experts. Specific criteria were outlined in the matrix based on desirable litter characteristics for average Australian commercial conditions. Each criterion was rated from 0 to 4 and a rating of 0 was assigned when there was very little information available. Additionally, a litter type was also rated a 0 if it was found to be detrimental in any criteria. Low, average and excellent were assigned a rating of 2, 3 and 4, respectively, and a rating of 1 was assigned when there were inconsistent results in criteria. These ratings were then summed together to assess the overall percentage of feasibility of the litter for use in the Australian chicken meat industry.

Matrix rating criteria

Commercial bird performance attributed to each alternative litter type was rated based on whether the litter created a favourable production environment and isn't detrimental to bird performance or welfare. Further details are supplied in Table 1.

Table 1. Rating criteria for commercial bird performance.

Matrix value	Bird performance	Description
0	No information	No information on bird performance could be found
1	Inconsistent results	Inconsistent information on bird performance
2	Fair bird performance	Bird performance issues are moderate (<20% flock affected)
3	Average bird performance	Bird performance issues are low (<10% flock affected)
4	Excellent bird performance	Bird performance issues are minimum (<5% flock affected)

Management practises attributed to each alternative litter type were rated based on the ease and feasibility of transport, removal and decompaction of the litter, shed management, and whether the handling of the litter was overly difficult, or required tilling or specialist equipment. Further details are supplied in Table 2.

Table 2. Rating criteria for management/ease of handling.

Matrix value	Management/ease of handling	Description
0	No information	No information on management could be found
1	Inconsistent results	Inconsistent information on management was found
2	Hard to manage	Hard to manage and handle
3	Average to manage	Average to manage and handle
4	Easy to manage	Easy to manage and handle

The water absorption and drying rate of alternative litter types were evaluated in regard to absorption capacity, drying capacity and water activity. Further details are supplied in Table 3.

Table 3. Rating criteria for water absorption and drying rate.

Matrix value	Water absorption and drying rate	Description
0	No information	No information could be found on water absorption and drying rates
1	Inconsistent results	Inconsistent information on water absorption and drying rates was found
2	Fair water absorption and drying rate	High water activity, low absorption and low drying capacity
3	Average water absorption and drying rate	Moderate water activity, moderate absorption and average drying capacity
4	Excellent water absorption and drying rate	Low water activity, good absorption and high drying capacity

Table 4 outlines details of the criteria used for evaluating the rate of caking (compaction) of alternative litter types.

Table 4. Rating criteria for caking (compaction).

Matrix value	Rate of caking	Description
0	No information	No information on caking rates
1	Inconsistent results	Inconsistent results on caking rates
2	High caking	High caking rates
3	Average caking	Average caking rates
4	Low caking	Low caking rates

Table 5 outlines details of the criteria used for evaluating the rate of gas (ammonia) emissions from the alternative litter types.

Table 5. Rating criteria for gas emissions (ammonia).

Matrix value	Gas emissions	Description
0	No information	No information on gaseous emissions
1	Inconsistent results	Inconsistent results on gaseous emissions
2	High gas emissions	High gaseous (ammonia) emissions
3	Average gas emissions	Average gaseous (ammonia) emissions
4	Low gas emissions	Low gaseous (ammonia) emissions

Environmental impacts attributed to each alternative litter type were rated based on their effect on growing, manufacturing and processing of chickens, and the effect on the transport, use and disposal of the litter. Further details are supplied in Table 6.

Table 6. Rating criteria for environmental impacts.

Matrix value	Environmental impacts	Description
0	No information	No information on environmental impacts
1	Inconsistent results	Inconsistent results of environmental impact
2	High environmental impacts	High environmental impacts
3	Average environmental impacts	Average environmental impacts
4	Low environmental impacts	Low environmental impacts

Table 7 outlines details of the criteria used for evaluating the end products that were possible for the alternative litter types. The spent litter must be easily used as a fertiliser or soil amendment and must be suitable for composting.

Table 7. Rating criteria for spent litter disposal/end-of-life.

Matrix value	Spent litter disposal/end-of-life	Description
0	No information	No information on spent litter disposal
1	Inconsistent results	Inconsistent results on spent litter disposal
2	Hard to dispose of	Hard to dispose of
3	Moderate to dispose	Moderate to dispose of
4	Easily disposed	Easily disposed

The thermal insulation capacity of each alternative litter type was rated based on whether it had low thermal conductivity, to retain warmth and act as insulation, and the protect the chickens from the cold floor. Further details are outlined in Table 8.

Table 8. Rating criteria for thermal insulation.

Matrix value	Thermal insulation	Description
0	No information	No information on thermal insulation
1	Inconsistent results	Inconsistent results of thermal insulation
2	low thermal insulation	Low thermal insulation
3	average thermal insulation	Average thermal insulation
4	excellent thermal insulation	Excellent thermal insulation

Table 9 outlines details of the criteria used for evaluating the depth that the litter can be applied to the floor of commercial production sheds.

Table 9. Rating criteria for depth.

Matrix value	Depth	Description
0	No information	No information on depth for commercial use
1	Inconsistent results	Inconsistent results on depth for commercial use
2	≥75 mm	Commercially used at a depth of ≥75 mm
3	50-75 mm	Commercially used at a depth of 50-75 mm
4	≤49 mm	Commercially used at a depth of ≤49 mm

Table 10 outlines details of the criteria used for evaluating the cost per metre cubed of alternative litter types.

Table 10. Rating criteria for cost per m^3.

Matrix value	Cost per m2	Description
0	No information	No information on commercial cost
1	Inconsistent results	Inconsistent results for commercial cost
2	≥$26	Commercial cost ≥$26
3	$15-25	Commercial cost $15-25
4	≤$14	Commercial cost ≤$14

Table 11 outlines details of the criteria used for evaluating the operation costs of alternative litter types. This includes any additional costs required for using a new litter type, such as extra tilling, or extra management.

Table 11. Rating criteria for operational costs.

Matrix value	Operational costs	Description
0	No information	No information on operational costs
1	Inconsistent results	Inconsistent results of operational costs
2	High operational cost	High operational costs
3	Average operational cost	Average operational costs
4	Low operational costs	Low operational costs

The abundance (availability) of each alternative litter type was rated based on whether it came from a reliable source that had high quality litter, stocked in a high amount and was in close proximity to the chicken meat sheds. Further details are outlined in Table 12.

Table 12. Rating criteria for abundance of product.

Matrix value	Abundance of product	Description
0	No information	No information on abundance of product
1	Inconsistent results	Inconsistent results on abundance of product
2	Limited	Limited abundance of product
3	Regional	Regional abundance of product
4	Commonly	Product is readily available

Table 13 outlines details of the criteria used for evaluating the use and application of the new litter types within the chicken meat industry.

Table 13. Rating criteria for application in the chicken meat industry.

Matrix value	Application	Description
0	No information	No information on the application in commercial industry
1	Inconsistent results	Inconsistent results on the application in commercial industry
2	Limited use	Limited application in the commercial industry
3	Regularly used	Regularly used in the commercial industry
4	Commonly use	Commonly used in the commercial industry

The choice of litter materials depends on individual circumstances and the availability and cost of materials, which varies in different regions and means that several different litter types might be suited in different chicken meat production sheds. Consequently, a small change was made in the scope of the project following the screening of litter materials. Based on the recommendation of the steering committee, the project now had an objective to provide examples of a larger range of potential litter types, rather than selecting “the best” alternative litter types (See section: Potential new litter types and management options). This provided the industry with a broader overview of potential sources of litter, rather than limiting it to a few best options that may not be applicable in all regions.

Audit of litter management

An industry audit was conducted via surveys to determine current types, volumes, costs and disposal practises of litter throughout the chicken meat industry in Australia. The review includes consultation with growers, companies, and litter suppliers in the major production regions, and a copy of the different surveys used are supplied in Appendix 1.

Characteristics of the Australian chicken meat industry

Summary of past surveys

Error! Reference source not found. outlines a summary of past surveys performed for chicken meat litter in Australia. As the total shed area has increased, the use of chicken litter and production of spent litter has also increased. The average price of litter strongly rose between 2001 and 2008, however, this may have also been influenced by methodological differences.

Table 14. Summary of Australian surveys and estimates of litter requirements and production.

	Runge et al. (2007)	Dorahy and Dorahy (2008)	Playsted et al. (2011)
Year of study	2001	2007	2009
Number of meat chickens produced	397,237,700	469,708,517	468,711,600
Total shed area (m^2)	4,274,000	N/A*	5,310,000
Batches (batch/ year)	5.5	N/A	5.5
Depth (mm)	50-65	N/A	75
Partial Reuse (%)	30	10	10
Fresh litter usage (M m^3/year)	0.95	N/A	1.49
Litter production (M m^3/year)	1.66	1.74	2.62
Litter production (tonne/year)	664,000	775,019	1,049,000
Average purchase price of fresh bedding (AUD/m^3)	$11.71	$20.50	N/A

*Not assessed

Error! Reference source not found. outlines the litter material used per state from the 2001 survey performed by Runge et al. (2007). In this survey, sawdust was the most commonly used bedding material in Australia, with wood shavings a close second. Rice hulls were only used in States that had significant rice production and paper was used by less than 2% of the industry. Interestingly, South Australia used a significant percent of straw compared to the other states, due to that lack of a large lumber industry in South Australia.

Table 15. Litter material used per state in 2001 (based on shed floor space) (Runge et al. 2007).

	Sawdust (%)	Shavings (%)	Rice hulls (%)	Straw (%)	Paper (%)
NSW	40.2	34.7	23.7	1.0	0.4
QLD	26.4	71.2	0.0	0.9	1.5
SA	0.0	65.9	0.0	34.1	0.0
TAS	100	0.0	0.0	0.0	0.0
VIC	0.0	50.0	50.0	0.0	0.0
WA	100	0.0	0.0	0.0	0.0

Industry location and chicken meat production

From a review of data from the Australian Bureau of Statistics (ABS), the majority of chicken meat production in Australia occurs within about 150 km of major cities (ABS, 2017). Chicken processing plants are generally within 50 km of a capital city in order to be close to markets, labour sources, and to keep transport costs to a minimum. Chicken grow-out farms are generally within 100km of the processing plants.

The main areas of chicken meat production in each state are:

- Queensland – Redland Bay, Beaudesert region, Caboolture region and Mareeba region
- NSW – outskirts of the Sydney metropolitan area, central coast, Newcastle, Tamworth, Griffith and Byron Bay
- Victoria – Mornington Peninsula, east of Melbourne, and Geelong, Bendigo and west towards Swan Hill
- South Australia – outskirts of Adelaide, the Two Wells and Murray Bridge areas
- Western Australia – Perth's outer metropolitan areas
- Tasmania – outer metropolitan areas.

The majority of meat chickens are processed between the age of 32 and 56 days, depending on market requirements. In 2016, 623 million birds were processed in Australia (ABS, 2016b).

Distribution of chicken meat production in six states (NSW, QLD, VIC, WA, SA and TAS) is shown in Figure 4.

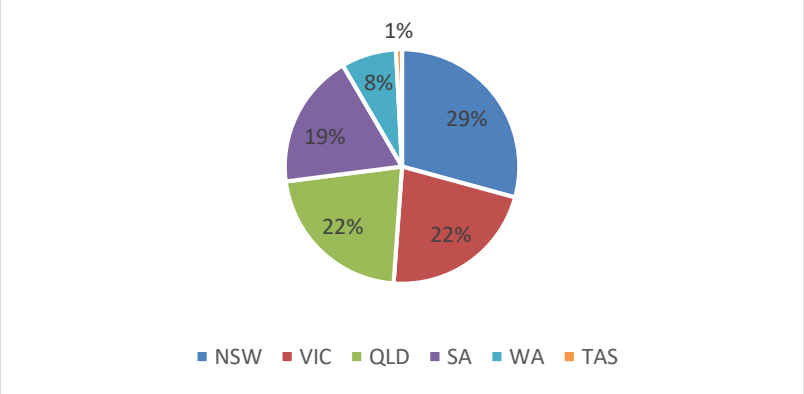

Figure 4. Percent of total Australian production from different regions (ABS 2016).

Note: Production estimates for South Australia, Western Australia and Tasmania were determined via industry consultation.

Pathways to source litter

The four pathways for fresh litter supply in Australia are:

- **Producer companies-** large buying power, consistent supply (via direct contracts with litter producers), and lower prices
- **Individual growers** *(direct sourcing or via transport companies/specialist commodity suppliers)*- smaller buying power (because of competition with other industries), uncertain supply and quality (dependent on transport companies), increased costs, and are subjected to increases in market prices
- **Grower collectives-** intermediate levels of buying power, price certainty, and consistent supply (via direct contracts with litter producers)
- **Self-supplied-** farms produce their own material and can, therefore, ensure quality and reduce costs, and commonly produce straw.

Survey results

Type and availability of litter

Litter materials commonly used in Australia include, soft or hardwood shavings, sawdust, rice hulls and straw (see Figure 5 and Figure 6). The litter material types vary from region to, depending on availability and cost. Since 2001 (Runge et al., 2007), the use of sawdust, shaving and rice hulls has decreased, while the use of straw and 'other' litter types have increased. A summary of litter properties is provided in Appendix 2.

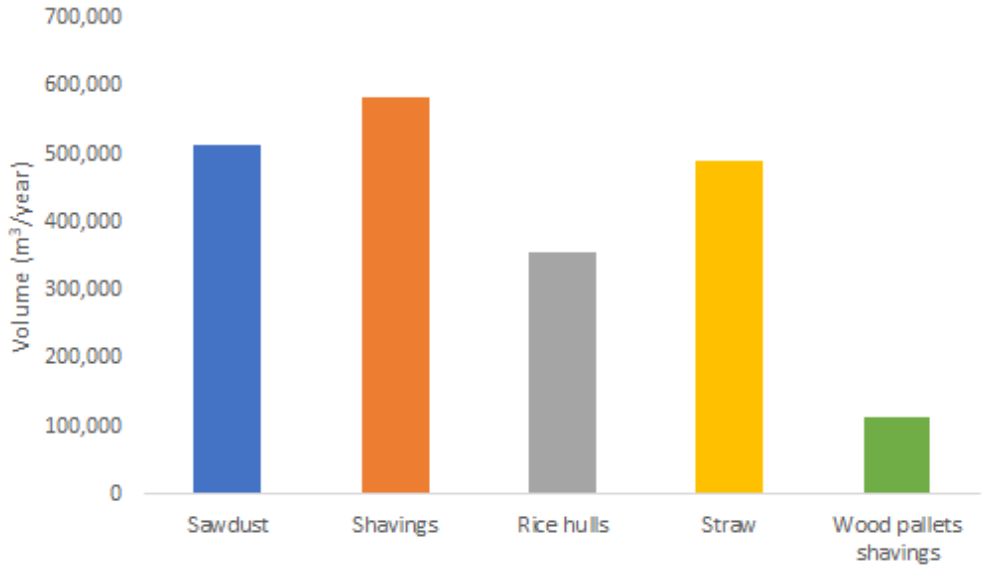

Figure 5. National volume of litter used in 2017.

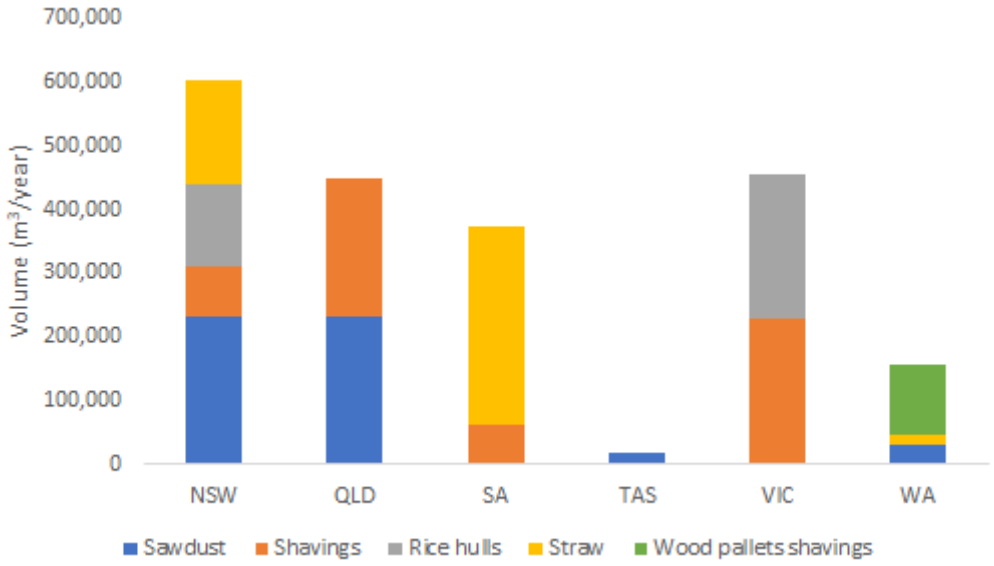

Figure 6. Volume of litter used in each state in 2017.

In all regions, breeder and grandparent farms were found to use more expensive litter types (e.g. kiln dried wood shavings/soft wood shavings).

Overall, growers showed the following preference for litter materials: wood shavings > sawdust > rice hulls > straw, providing these materials are all equally dry and friable. The differences between individual States' usage is primarily due to availability and cost. The use of rice hull and (to a lesser extent) straw is dependent on crop yields in southern states. Recently, there have been large crops of rice and straw in the southern regions due to favourable climatic conditions, however, in times of drought there are significant problems with the litter supply. Southern growers will commonly use sawdust during drought seasons, which significantly impacts the cost of litter in the southern regions of Australia. There are minimal climatic effects on the growers that use wood-based products (e.g. wood shaving, saw dust and recycled pallets) in other regions.

Estimated national volume of fresh litter used

Fresh litter requirements can be estimated from the area of shed space occupied by the industry (a function of bird numbers and stocking density) and litter depth. The estimated national shed area has increased from 4,274,000m^2 in 2001 (Runge et al., 2007), to 5,310,000m^2 in 2011 (Playsted et al., 2011), to 6,640,706m^2 in 2017. The total shed area estimate was calculated using the following assumptions (Geoff Runge and Eugene McGahan pers. comm. and Runge et al., 2007) for annual clean bedding usage (Table 16).

Table 16. National annual estimated clean litter usage.

Parameter	National average
Total estimated shed area based on density	6,640,706 m^2
Batches per year	5.6
Reuse litter	13.5%
Average depth of bedding used	56mm
Total fresh litter used	1,801,384 m^3

Table 17 outlines the current national average bird density, batches per year, litter depth and percent of industry that reuses litter between batches. Litter depths have increased since the Runge et al., (2007) study, which is most likely due to the introduction of the RSPCA standard in 2013. Over 90% of survey participants reported litter depths that complied with the RSPCA standard (Figure 7).

Table 17. National average bird density, batches, litter depth and reuse in 2017.

	Audit results (2017) from the present report			Runge et al. (2007)	Playsted et al. (2011)
	Minimum	Maximum	Average	Average	Average
Bird density (birds/m^2)	14	18	16.9	-	-
Batches per year	4	6	5.6	5.5	5.5
Litter depth (mm)	40	100	56	40-75	75
Reuse (%)	N/A	N/A	13.5%	30%*	10%

* According to Dorahy and Dorahy (2008), this value was likely to be an overestimation.

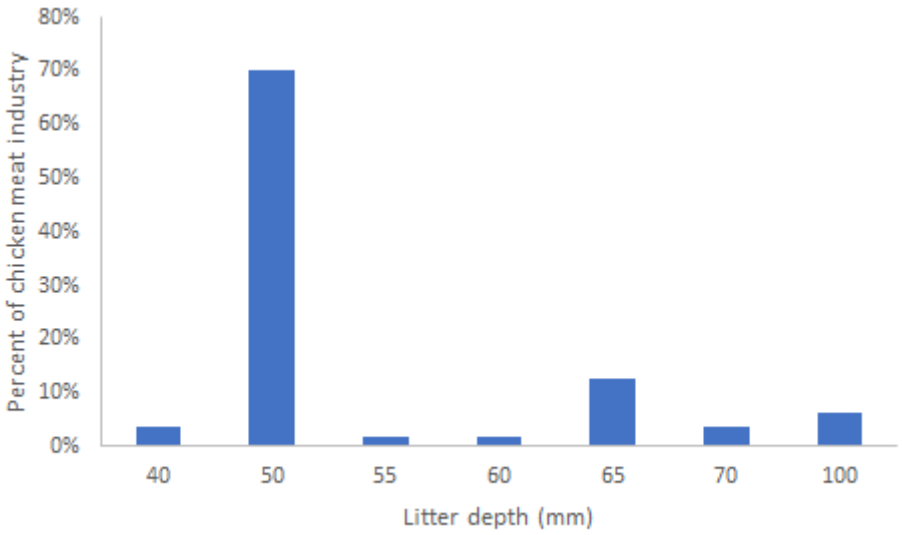

Figure 7. Estimated range in litter depth (nationwide) in 2017.

Cost of fresh litter

The 2017 survey found that the cost of litter ranges from $10 to $40 per cubic metre (shavings, sawdust, rice hull and "other", landed on-farm) (Figure 8). In addition to the primary cost of litter, the cost of transport can be a significant factor for many chicken meat producers.

Figure 8. Range of costs between different litter types.

Consumer Price Index (CPI)

Figure 9 through 12 show the maximum and minimum costs of litter adjusted with the CPI (average of 2.5% p.a) from Runge et al. (2007), compared to the real maximum and minimum costs and increase in litter prices. In each figure, the yellow line depicts the real increase of the maximum price of each litter type, and the orange dotted line shows the CPI adjusted price. The grey line depicts the real increase of the minimum price of each litter type, while the blue dotted line shows the CPI adjusted price. Over the last 10 years, the cost of shaving and sawdust litter types in Australia has increased more than the rate of the CPI, while only the minimum cost of rice hulls and straw have increased more than the rate of the CPI. On average, the prices of shaving, sawdust, rice hull and straw have changed over the CPI adjusted prices by +44%, +28%, +6% and -7%, respectively. Compared to the CPI, there were greater increases in the minimum than maximum prices of litter. The increase in the maximum prices for rice hulls and straw roughly equated to that of the CPI, however, the increases in the minimum price for all litters were above the CPI.

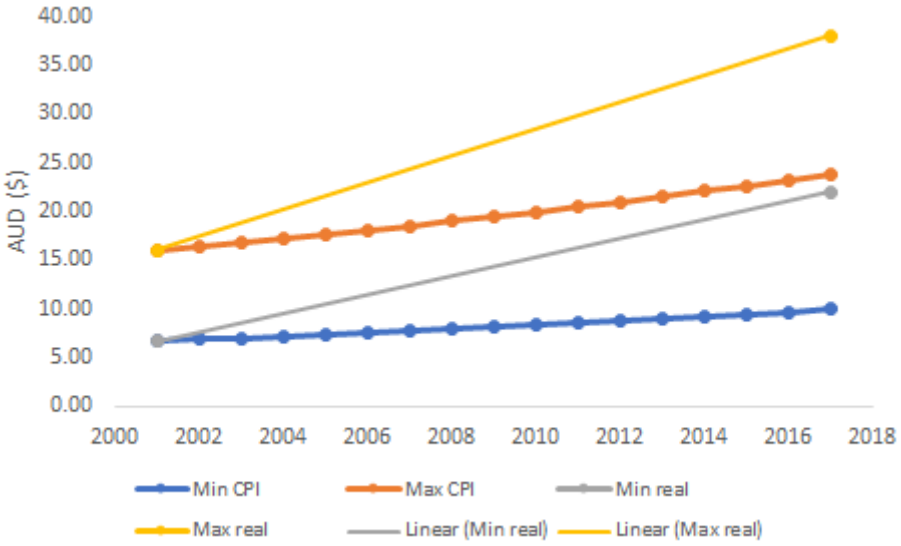

Figure 9. Maximum and minimum wood shaving prices from 2001 (Runge et al., 2007) corrected with the CPI, compared to actual prices of the litter in 2017.

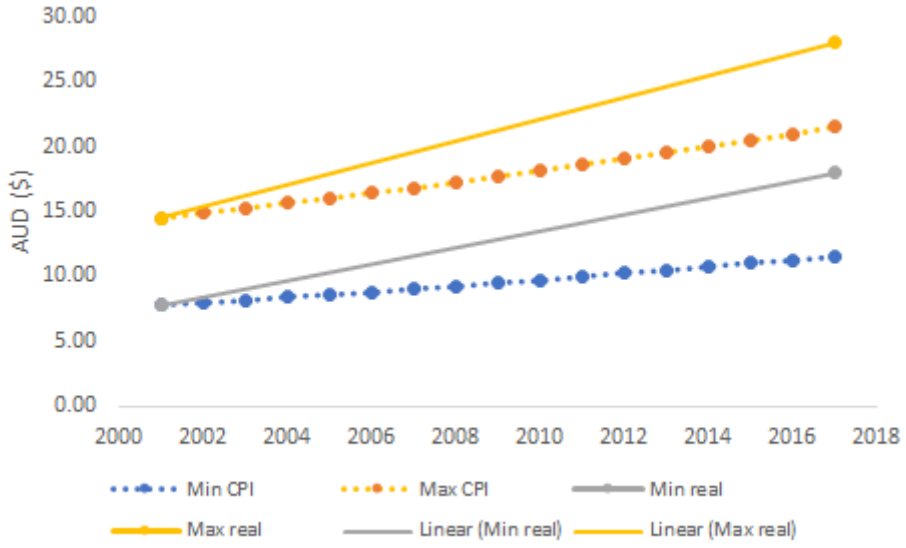

Figure 10. Maximum and minimum sawdust prices from 2001 (Runge et al., 2007) corrected with the CPI, compared to actual prices of the litter in 2017.

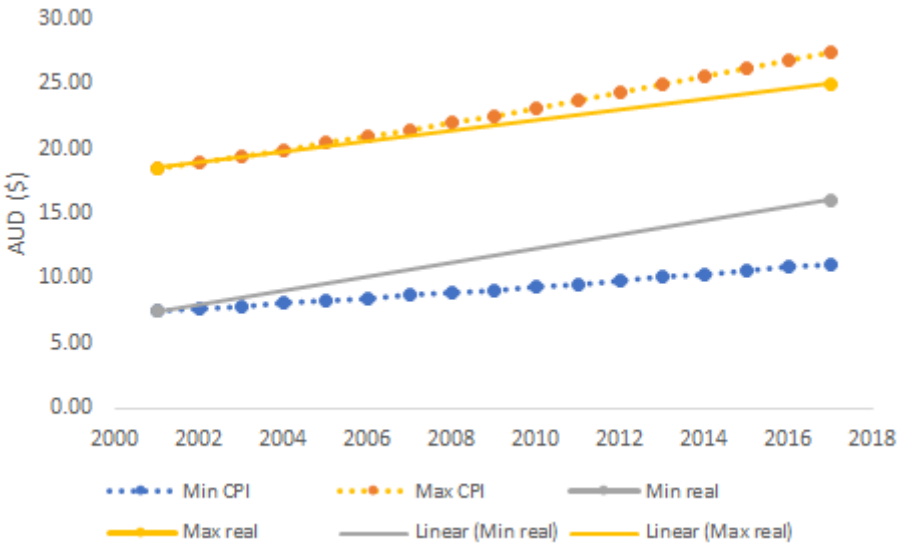

Figure 11. Maximum and minimum rice hull prices from 2001 (Runge et al., 2007) corrected with the CPI, compared to actual prices of the litter in 2017.

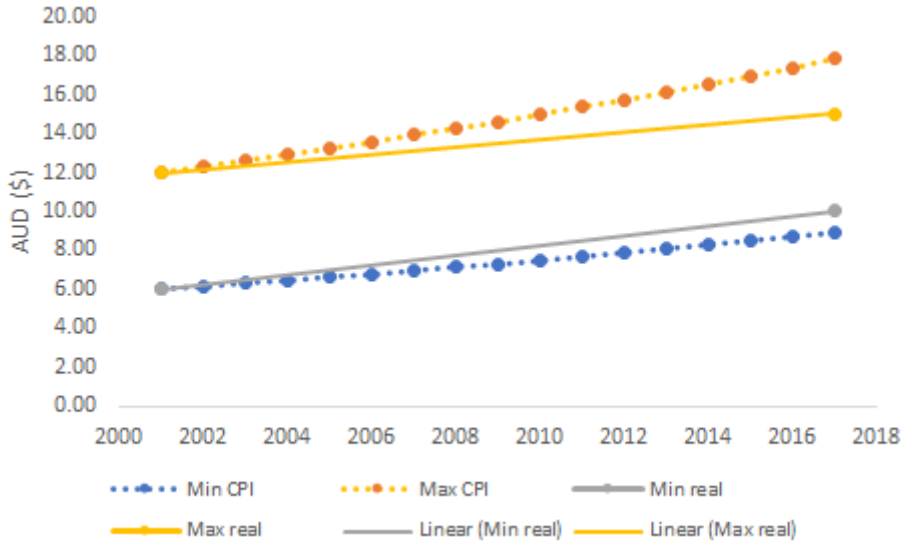

Figure 12. Maximum and minimum straw prices from 2001 (Runge et al., 2007) corrected with the CPI, compared to actual prices of the litter in 2017.

Current issues with litter

Five major issues were identified with litter by the survey participants, which are (in order of significance) cost, quality, supply, management and RSPCA standards (Table 18). These are all inter-linked and can all influence each other in different ways.

Table 18. Major issues associated with litter use.

Issue rating	Issue category	Major issue	Minor
1	Cost	Initial costs Transport costs Drying costs (southern states)	Spreading costs
2	Quality	Water content / wet litter	Contamination: dead birds, rodents and chemicals
3	Supply	Increased cost of wood products Droughts affecting supply in southern states	Competition with other industries
4	Management	Wet litter requires additional management to keep birds healthy	Straw requires more tilling than other litters
5	RSPCA	Additional cost to growers Audits are time consuming Additional tilling	Prescriptive standard, favours deep litter Inhibits innovation and trialling alternative sources of litter

Cost

All survey participants identified cost as the most significant issue affecting them in relation to obtaining litter. Over 65% of survey participants were looking for alternative litter sources due to cost and supply.

Producers have indicated that the price of rice hulls has recently increased. Historically, rice producers viewed rice hulls as a waste product, however, they have recently identified the chicken meat industry as a market for rice hulls and increased their prices accordingly.

Quality

Overall, growers believe that the quality of litter has been decreasing over the past 20 years, with water content the greatest concern in regard to quality. Rodent contamination can also be an issue for all litter types and some litter suppliers use rodent proof (inside) storage to minimise this problem, however, this adds to the cost of litter. Straw bales can also have dead animal contamination, due to the process of baling.

Low quality litter and/or litter with high initial water content can cause operational problems, which will require additional management practises to ensure bird health, such as extra tilling and drying. Due to the large volumes needed, it can be challenging for growers to find other sources of litter if they have quality problems with their suppliers. All survey participants have practises in place to manage litter problems that arise from poor quality and/or wet litter to ensure bird health and performance, and they have indicated that these practises can add significant cost to production. Several producers in southern Australia dry the wet litter with gas heaters once it is laid in shed, which is highly inefficient and expensive.

Supply

The surveys showed that various issues can affect the supply streams for litter in Australia. For example, droughts affect the supply of litter in states that are dependent on rice hulls or straw, and the supply of wood-based products has been impacted by increasing costs, competing uses and changes in primary product demand and associated contamination issues.

States such as QLD, NSW, VIC and TAS have large timber industry suppliers that have been mostly regular in their supply over the last 20 years. However, growers have acknowledged that the increasing price of wood-based products, and the possibility of change in government policies for the timber industries, may force them to search for alternative sources of litter. For example, the Runge et al. (2007) study identified that there has been a significant increase in the use of recycled wood pallets as litter in WA, primarily due to the closing of several major wood mills in in the state, which forced poultry producers to find alternatives.

Recycled wood pallet litter is sourced from the Eastern Metropolitan Regional Council recycling facility. It is made from timber pallets, packaging and timber off-cuts. There were initial problems with contamination, but after consultation and communication with the growers, polices were enacted to ensure the quality and safety of the litter supplied. This has been successful due to the stringent operating procedures in the recycling plant, as well as the chemical testing of each batch of litter to ensure quality. Recycled wood pallet litter was also trialled in Victoria, but there were severe issues associated with contamination and low-quality products, which was the result of the wood recycling plant operation practises.

Management

The need for additional management of poor-quality litter adds to the total cost of production. Different litters require different management practises, which is most evident with straw, as it has high caking properties and requires more maintenance to keep the litter dry and friable. While it is not a preferred litter, growers that have had success with straw have established additional management practises to increase its efficiency.

RSPCA standard

The RSPCA Standard for poultry litter has increased the operational costs and management required for growers in the Australia chicken meat industry. The standard is prescriptive toward litter use and management with regards to the minimum depth requirements. Several growers have identified RSPCA compliance as an inhibition to litter innovation and trialling alternative sources of litter.

Litter reuse

In Australia, approximately 86% of meat chickens are reared on single-batch litter, while approximately 14% are reared on partially reused litter (rather than full reuse, like in the USA). Litter is composted in the shed and is then re-spread on the floors between every batch of chickens. The composting process creates heat, which acts to kill pathogens and viruses that may be present in the litter, however, the effectiveness of this can be constrained by the time available between batches. Generally, new bedding material is spread in the brooding area prior to placement of the next batch of chickens, and research is currently underway to improve this management technique.

Reuse predominantly occurs in NSW and QLD, with sawdust or a mixture of sawdust and shavings. Numerous growers have contractual obligations that dictate that their litter is managed as single use. Further, several growers identified that reusing litter may make it harder to comply with the RSPCA standard and there is a perception that it will increase poor bird health, ammonia and odour issues, which may lead to increased management costs. Although there is the potential for these problems to occur, they can be avoided with proper management.

Spent litter

Interviews with growers and producers indicated that most spent litter continues to be used in the agricultural sector (e.g. pastures, turf farms, market gardens, broadacre, local small farms, mushrooms farms, dairy pastures). Some producers have diversified farms and use their litter for soil improvement, or as fertiliser for crops. Some growers indicated that litter was supplied to composters or fertiliser manufacturers for additional processing. While most growers were responsible for litter sales, it was found that the poultry company in one region supplied litter and handled spent litter sales.

Limitations continue to exist in WA regarding the use of raw poultry manure, due to of problems with stable fly breeding. Consequently, composting, or transport to regions where untreated spent litter can be used, is required. This affects several shires and city councils on the Swan Coastal plain, from Gingin to Harvey.

It was also noted by growers that the nutrient concentration of spent litter has declined over time, in response to lower bird density and minimum litter depth requirements in the RSPCA standard. This, in turn, has reduced the value and sale price of spent litter as a fertiliser and growers also noted that the synthetic fertiliser market directly impacted the sale price of spent litter.

Summary of possible alternative litter sources and management practises identified from the industry survey

VIC, NSW, QLD and TAS producers are content with the current litter types available, but growers were concerned with the increasing price and reduced quality of litter and acknowledge that alternatives may be needed in the future. There is more limited availability of litter in WA and SA, and growers were actively looking for alternatives in these regions. Table 19 and Table 20 outline the possible alternative litter sources and management practises identified from the industry survey, respectively. Seven alternative litter materials were identified from survey, including miscanthus grass, peat, recycled wood material, nut husks, oat hulls, stubble pellets and sustainable buffer tree-litter. Three alternative management strategies were also identified, namely; reuse, layering and mixing. Table 21 summarises alternative litter materials that the industry identified as unlikely to uptake.

It is interesting to note, that while there have been many trials on alternative litter by individual growers in Australia, results are not effectively communicated between growers and the industry is unaware of outcomes, which has led to multiple trials on the same product.

Table 19. Possible alternative litter sources identified by chicken industry survey participants.

Alternative litter	Trialled in Aust.	Trial outcome	Positives	Negatives	Notes
Miscanthus grass	No	N/A	Excellent performance and used overseas.	Untested in Australian commercial chicken meat production.	Miscanthus is used in the UK and is a cost-effective alternative to wood shavings. While growers in UK purchase miscanthus grass from a third party, there is also the potential for it to be a litter source produced on farm, if chicken growers have space to grow. http://www.fwi.co.uk/poultry/new-poultry-bedding-from-miscanthus.htm http://www.iecsolutions.co.uk/softlay-bedding/
Peat	No	N/A	Excellent performance commonly used overseas. Lower depth requirements, which reduces volumes needed.	Higher price than litters currently used. RSPCA/animal welfare legislation concerns. Untested in commercial Australian chicken farms.	Peat is used overseas at a much lower depth (commonly around 8-10mm) without bird health problems. Potential problems could arise with RSPCA Standard and some licencing requirements prescribing a minimum depth of 50mm. Additionally, there could be problems sourcing enough material at an acceptable price in Australia.
Recycled wood material	Yes	Mixed	Commonly used in WA.	High risk of contamination.	Victorian producers will not use it due to problems with contamination in certain recycling facilities. Most producers surveyed would prefer new product to recycled when possible. It is sometimes found to be hard and doesn't absorbed as well as sawdust or straw. It is sometimes found to be hard and doesn't absorbed as well as sawdust or straw. Plant that produces this in WA has stringent operating procedures and chemical testing of products to ensure that it meets the chicken meat industry's requirements.
Nut husks	Yes	Mixed	Almond nut production has increased in several regions	Untested in Australian commercial chicken meat production.	Although not common in commercial chicken production, several sources in the USA indicate that almond husks can be used as a bedding product for the poultry industry. There has been a successful trial with other nuts husks (hazelnut) overseas. http://www.agramarketing.com/about-us

			around Australia.		
Cereal hulls	No	N/A	Similar properties to rice hulls.	Untested in Australian commercial chicken meat production.	Includes canola, wheat, barley etc. Limited information for application to meat chickens.
Oat hulls	Yes	Negative	Widely available. Similar properties to rice hulls.	Untested in Australian commercial chicken meat production. Untested in Australian commercial chicken meat production.	The use of oat hulls for chicken litter has been mentioned in review, but there is very limited information on it. Dust caused chickens severe eye irritation making them harder to handle and dust in large quantities is combustible. Limited information for application to meat chickens.
Stubble / bagasse pellets	Yes	Positive	Product sterilised.	Cost of product, transport and harvest is high. Possible pesticide contamination. Producers have raised concerns that it looks similar to feed.	A litter supplier mentioned the KRONE Premos 5000, a field palettization machine (coming to Australia in 2019), which could enable the production of cheaper crop stubble pellets for the chicken meat industry. http://landmaschinen.krone.de/english/products/pellet-harvester/premos-5000/
Sustainable buffer tree-litter	No	N/A	Self-sufficient litter source.	Area and time it takes to grow sustainable levels of greengage for litter. Capital cost of machinery required. Dry out – possible problems birds with contamination.	Capital investment costs are high. Would require harvesting, drying and processing. Additional storage facilities may be required to protect material from contamination.
Diatomaceous earth	Yes	Positive	Highly absorbent. Insecticide and anticaking properties.	Dusty. Long-term inhalation of the crystalline form is associated with silicosis, chronic bronchitis, and other respiratory problems.	Trials were positive. Bird health and productivity was not affected by this material. It did not cause problems with processing machinery, however, it poses potential health risks to workers and industry has moved away from this material.
Spongolite	Yes	Positive	Highly absorbent.	Dusty. Long-term inhalation of the crystalline form is associated with	Trials were positive. Bird health and productivity was not affected by this material. It did not cause problems with processing machinery, however, it poses potential health risks to workers and industry has moved away

			Large deposits in WA.	silicosis, chronic bronchitis, and other respiratory problems.	from this material. However, it poses potential health risks to workers and industry has moved away from this material.
Charcoal/ biochar	No	N/A	Highly absorbent. By-product.	High price. Competition with other industries.	Charcoal and biochar have not been used/trialled for chicken litter before and would require extensive testing before being applied commercially. Could be used in mixes.
Invasive native scrub (INS) chips/ shavings – cypress	No	N/A	Sustainable. Product would be similar to wood chips trialled overseas.	Capital cost of chipping.	Cypress saw dust is already used in commercial chicken meat farms.
Peanut hulls	Yes	Mixed	Absorbent	Can have severe mould/Aspergillosis problems when damp.	Has been used in Peanut growing regions in Australia, although not common. Increased risk of Aspergillosis

Table 20. Litter management strategies identified by chicken industry survey participants.

Management strategies	Trialled in Australia	Trial outcome	Positives	Negatives	Notes
Reuse (50:50) After batch – 50% of litter is reused (sanitised by composting), 50% is replaced with fresh litter.	Yes	Positive	Used widely with wood shavings by a large producer in Australia for 30+ years. Excellent results. Reduction in odour problems and bird health is excellent.	Will take time to optimise litter management strategy.	There have been some problems with council approvals/licencing conditions. This has been from the perception that this management strategy will increase odour problems. Rice hulls and straw have not been reused in this fashion in any Australian commercial chicken farms. However, there are several studies (e.g. Abreu et al., 2011) that indicate they could be used, with further investigation and optimisation for Australian conditions.
Layering (layering litter in shed)	Yes	Positive	Reduces overall cost of litter.	Must often coordinate with multiple suppliers of litter. Will become mixed during use.	Litters are layered in commercial duck and turkey production. 70% cheap litter on bottom and 30% expensive litter on top. Turkeys require litter at least 100mm depth. There have been trials for commercial meat chickens, but success depends on the litter types used.
Mixing (mixed before litter is laid in shed)	Yes	Mixed	Reduces overall cost of litter.	Some mixes can lead to more worker-handling.	Litter suppliers commonly mix litters based on producers' preference. There is also unintentional mixing of litter. There have been a few cases that had increased caking problems with certain mixes. Success depends on material mixed, producer, producer preferences and litter management strategies in place.
Concrete floors	Yes	Positive	Reduces moisture Litter spread more evenly in shed	High capital cost. Similar performance results as clay floors.	The processer requires sheds with concrete floors.
Wood shaving/ saw dust drier	No	N/A	Reduces wet litter problems. Meets RSPCA compliance.	Increased cost of litter. Capital and operation costs. Additional handling of litter.	Additional drying by litter suppliers may increase litter price by $8-10 per cubic metre. For large farms it may be economically viable for producers to dry their own litter before laying.
Chopping machine: for straw	Yes	Positive	Guarantee cut-size of straw.	Capital cost of machine and labour cost.	A producer changed to chopped straw for economic reasons. It was economically viable to purchase machine and chopping their own straw guarantee the quality of litter material.
Growing your own litter	Yes	Positive	Lowers cost. Lowers supply issues	Land requirements.	Common with southern small growers with straw – could be expanded with wood or grass.

Table 21. Other alternative litter types identified by chicken industry survey that are unlikely to be applied in Australian chicken meat industry.

Alternative litter	Commercial Use/ Trials in Australia	Trial outcome	Reason
Paper pellets	Yes	Negative	There have been several trials with this material on a commercial scale. Severe caking issues arise from this litter and it requires increased management.
Shredded paper	Yes	Positive	Successfully trialled before RSPCA standard was introduced. Shredded phone books were used at a much lower depth than current RSPCA standard. Crust forms on top of litter, which must be managed by drying out and breaking up.
Mix: Saw dust and paper	Yes	Negative	Unsuccessful trial – severe caking issues.
Wheat husks	Yes	Negative	Unsuccessful trial – didn't perform well.
Sand	Yes	Mixed	Sand has been assessed for use in TAS but was found to be unsuitable for use due to its high density and thermal conductivity/heating requirements. This is likely the case for other temperate regions of Australia. Producers have raised concern with damage to processing machinery caused by sand in gizzards. Sand is used in multi-batch litter systems and can be used for several years. High transport and initial placement costs. Similar cost to wood shavings when total years used is factored into costs. Initial weight of the sand is typically 8-9 times greater than wood shavings, which may require modifications in methods that are typically used in handling litter. Potentially, moisture levels of sand are higher when first placed which will require longer drying periods before chick placement. Commonly used in Africa, southern USA and Israel.
Crusher dust	Yes	Negative	Chicken naturally ingest small rock, grit, sand and/or gravel into gizzards. This caused significant problems with the processing machinery in a single-batch, crusher dust Australian trial. While sand is commonly used in meat chicken production in the USA and Israel litter is used for multiple batches, which reduces this problem overseas. However, the chickens produced are smaller/younger than Australian meat chickens.
Litter-less flooring systems "slatted flooring system" "grated flooring system"	No	N/A	Legislative requirements, RSPCA/welfare standards and consumer expectations hinder the application of this system. Commonly used overseas. Several producers that do not have minimum litter requirement and are unsure of how these systems would work. These systems have a high capital cost in comparison to other alternatives and producers are not willing to trial. Additionally, this system would require a level concrete floor to function and it limited thermal retention capacity which would require heating in cold weather.
Glass beads	Yes	Negative	Commercial trial with glass bead by-product from glass manufacturing. Concern that glass looked similar to feed and chickens would ingest large quantities.

Shredded bark	Yes	Negative	Unsuccessful trial – matted down.
Layering: straw and hardwood	Yes	Negative	Unsuccessful trials. Trial 1: Hard wood shaving top (20mm) and Straw bottom (30mm), straw stuck to floor when it was applied to lower layer. Trial 2: Straw top (20mm) and Hard wood shavings bottom (30mm) and severe caking issues.
Corn stubble	No	N/A	Milled corn stubble – low absorbance.
Sunflower husk	No	N/A	Successfully used overseas. Not absorbent but was used at a much deeper depth than usual to compensate. Would have to compete with stockfeed, which is likely to make this economically unviable.
Cottonseed husks	No	N/A	Successfully used overseas. Would have to compete with stockfeed, which is likely to make this economically unviable.

Review of alternative litter sources

Alternative litter sources were identified and evaluated, including bird performance, availability, cost effectiveness and general suitability to the chicken meat industry. While bird performance is the most significant threshold criterion, cost and availability ultimately determine the adoption of suitable alternative litter materials by the poultry industry.

Litter options reviewed in screening stage

From a literature review of journal papers, industry publications and other relevant literature sources, several alternative litter materials were identified (summarised in Appendix 3). Alternative sources for litter material were categorised into two broad classes; inorganic and organic litter materials. Organic materials were further classified into subcategories: paper, wood products, cereal crop residuals, crop and nut hulls, biomass crops, miscellaneous, mixed or layered materials and unknown. Table 22 and Table 23 detail the overall feasibility rating of each common and alternative litter type, with a maximum score of 52, based on the sum of individual rating criteria scores from the decision matrix (see methodology section for categories and scores)

Table 22. Commonly used litters overall rating.

Commonly used litters in Australia	Overall feasibility rating	Overall feasibility rating
Sawdust *	49	94%
Rice hulls *	49	94%
Wood shaving *	48	92%
Straw- chopped *	43	83%
Peanut hulls *	41	79%
Average	46	88%

*rating is based on litter used with good management practises

Table 23. Alternative litter overall rating.

Category	Alternative litter material	Overall feasibility rating	Overall feasibility rating
Inorganic materials	Sand	41	79%
	Recycled sheetrock	27	52%
	Vermiculite	25	48%
	Zeolite	24	46%
	Gypsum	23	44%
	Bentonite clay	21	40%
	Clay	19	37%
	Recycled rubber tyre	10	19%
Mined organic materials	Peat	41	79%

	Recycled wood pallets (with stringent protocols)	50	96%
Wood products	Pine leaves/needles/ straw	33	63%
	Pine-bark	33	63%
	Pine-chipped	32	62%
	Invasive native scrub (INS) chips or shavings – cypress	14	27%
Paper materials	Paper- shredded	35	67%
	Paper-dried sludge (short fibres from paper recycling)	20	38%
	Paper- pellets	10	19%
Cereal crop residuals	Straw pellets	43	83%
	Rice straw	40	77%
	Soybean straw	39	75%
	Rye straw	38	73%
Crop and nut hulls	Corn cobs (crushed)	35	67%
	Nut husks (general)	34	65%
	Almonds husks	34	65%
	Oat hulls	28	54%
	Sun flower husks	28	54%
	Hazelnut husks	9	17%
Other crop residuals	Grass- miscanthus	41	79%
	Grass- switchgrass	41	79%
	Grass- general	39	75%
	Rape (canola) straw	37	71%
	Composted leaves	32	62%
	Kenaf core (*Hibiscus cannabinus*)	15	29%
	Fibre remaining after tea tree oil distillation	3	6%
Miscellaneous organic material	Composted municipal garbage	11	21%

A detailed matrix rating system heat map is presented in Appendix 6, as well as a summary of alternative litters that scored zero. The following alternative litters were found to be within 25% of the average rating of common litters (i.e. the litters that scored >39); recycled wood pallets, peat, switchgrass, miscanthus, straw pellets, straws, grass and sand. This indicates that these alternatives may be a viable litter source for the Australian chicken meat industry. However, it should be noted that many of the other litters assessed had limited information on their potential commercial application, which resulted in lower scores. With further research, these litters may be shown to be viable litter source.

Review of litter management

In addition to alternative litter types, alternative management options were also identified that were able to reduce litter requirements or improve litter availability or suitability. These management options were evaluated against the same criteria as applied for the alternative litter sources. The results are shown in the following sections.

Litter management options reviewed in screening stage

From a literature review of journal papers, industry publications and other relevant literature sources, several alternative litter management practises were identified (summarised in Appendix 4). From this literature review and consultation with steering committee, alternative litter management practises were ranked with the matrix rating system (Table 24).

Table 24. Overall rating of alternative litter management practises.

Alternative management system	Overall feasibility rating	Overall feasibility rating
Caged (with manure belts)	48	92%
Reuse - partial (50:50)	47	90%
Reuse - full	47	90%
Litterless (slats)	46	88%
Seasonal use of different litters	39	75%
Using different litter types in different shed sections	36	69%
Layering different litter types	28	54%
Mixing different litter types	28	54%

A detailed matrix rating system heat map is presented in Appendix 6, showing the full range of alternative litter management options that were evaluated. The following alternative litter management options were found to have a score of >39 (within 25% of the average rating of common litters); reuse, litterless, caged and seasonal use of litter. This indicates that these alternatives may be a viable litter management option for the Australian chicken meat industry. However, it was noted that other factors not included in the rating system will also influence the acceptability of these options. For example, raising meat chickens in cages would conflict with welfare standards or perceptions, and is therefore very unlikely in Australia. The acceptability of litterless systems has not been tested and may be acceptable. Litter reuse is also controlled by poultry companies, and differing opinions exist regarding its acceptability. Importantly, growers have few options to use this system when the poultry company does not support the decision.

It should be noted that many of the other management options assessed had limited information on their potential commercial application, which resulted in lower scores. With further research, these may also be shown to be viable management options.

Review of litter processing

A review was also conducted of alternative litter processing options that were able to reduce litter requirements or improve litter availability or suitability. These options were evaluated against the same criteria as applied for the alternative litter sources. The results are shown in the following sections.

Litter processing options reviewed in screening stage

From a literature review of journal papers, industry publications and other relevant literature sources, several alternative litter processing options were identified (summarised in Appendix 5

Alternative processing options). From this literature review and consultation with steering committee, alternative litter processing options were ranked with a matrix rating system (Table 25).

Table 25. Overall rating of alternative litter processing options.

Alternative litter processing options	Overall feasibility rating	Overall feasibility rating
Straw pelletisation	46	88%
Crushing pellets	43	83%
Straw chopping	42	81%
Wood shaving/ saw dust drier	5	10%

A detailed matrix rating system heat map is presented in Appendix 6, showing the alternative litter processing options. The following alternative litter processing options were found to have scores >39 (within or over 25% of the average rating of common litters); pelletisation, straw chopping machine and crushing pellets. This indicates that these alternatives may be a viable litter processing option for the Australian chicken meat industry.

Potential new litter types and management options

The following section provides a general outline of each category, a summary of each alternative application and suitability to the chicken meat industry and an example from each category. The examples give an overview of the general properties, chicken meat industry current application, practical considerations to be addressed before uptake, and economic considerations. Costs were based on 2017/2018 financial year data and a representative shed size (150 x15m) and number of batches per year (5.6). It should be noted that estimated costs are not inclusive of transport to farm, treatment (e.g. straw needs to be chopped), spreading cost or sale value of spent litter, as these factors vary from region to region and farm-to-farm. Additionally, for several alternatives there were limited cost data sources to draw cost estimates from, thus readers should consider the cost estimates to be indicative and these should not be used for making financial decisions on-farm. For making decisions on farm, all factors would need to be included and local quotes would be required.

Alternative litter types

Mined inorganic materials

Mined inorganics materials are any chemical compound not classified as organic and most contain carbon and are derived from mineral sources (Table 26). Several inorganic materials are used for animal bedding, including sand, gypsum, bentonite and vermiculite. When properly maintained, inorganic material can provide a suitable medium for bedding, however, inorganic materials can be difficult to handle, which increases wear on equipment and may present a manure handling challenge. They can also be a concern in cold weather, as they have little insulating value and draw heat away from the birds. Depending on the material, some also hold moisture very effectively, which leads to caking problems.

Table 26. Examples of inorganic materials used for animal litter.

Category	Suitability	Application	Notes
Sand	Suitable	Applied commercially	Used overseas in warm regions. Used for 2-5 years with multiple batches.
Gypsum (litter amendment)	Unsuitable	Not applied commercially	Not applied commercially as a litter (is used as a litter amendment).
Bentonite clay (litter amendment)	Unsuitable	Not applied commercially	Not applied commercially as a litter (is used as a litter amendment). Very high moisture holding capacity and low release rate may lead to caking problems. Was found to reduce ammonia emissions in trial research (Redding 2013).
Vermiculite	Further research needed	Not applied commercially	Not applied commercially as a litter. High water absorption and may elevate ammonia losses (Miles et al. 2011).
Clay	Unsuitable	Not applied commercially	Significant clumping and management problems.

Example of an inorganic material; Sand

Sand is a granular inorganic material composed of fine rock and mineral particles. The most common component of sand is silica; usually in the form of quartz. It is defined by size, being finer than gravel

and coarser than silt, and Table 27 outlines its main properties. When properly maintained, sand provides an ideal litter material for chickens and is typically graded into particles sizes ranging from fine to coarse (0.05 - 5mm) (Figure 13). Coarse natural sand consisting of variable particle sizes has been used as chicken litter (Mormino, 2018), however, the use of sand manufactured by crushing can create dust problems.

Figure 13. Coarse sand that could be used for litter (Mormino, 2018) and a chick on sand litter (The Happy Chicken Coop, 2018).

General properties

Table 27. Typical sand properties.

Property	Average values
Bulk density (kg/m^3)	1100 - 1600kg/m^3
Moisture (%)	0.1
pH	5.64
Thermal conductivity W/(m.°C)	0.15 - 2
Water absorption %	N/A
Surface area (cm^2 g^{-1})	444.4

(Curry et al., 2004, Miles et al., 2011, Pennell, 2016)

When used as litter, sand is commonly used for 2-5 years. During this time, manure will breakdown and accumulate in the litter. This accumulated biomass then increases the absorption and thermal retention in a similar fashion to reuse litter. Thus, the properties of sand litter after several years of use are significantly different to the properties of the original sand.

Application in the Australian chicken meat industry

Sand has been used as bedding successfully in commercial chicken meat production in many countries (Aviagen, 2009, Ritz et al., 2017). It is commonly used on concrete floors in arid/desert regions where litter supply is limited (Aviagen, 2009, Jordaan, 2004). It is managed in a similar way to sawdust, however, birds have difficulty moving about if it is spread to deeply (Jordaan, 2004). Many studies have shown that birds raised on sand performed as well as, or better than, those raised on traditional litter materials (Bilgili et al., 1999, Grimes et al., 2002). According to Bilgili et al. (2000), using sand as litter can help poultry producers reduce pollution, improve production and lower costs, as it can be reused for long periods (with de-caking). Additionally, sand can be washed to remove organic matter and then used again without segregation.

Sand litter makes it more difficult to maintain suitable floor temperatures during cold weather and there needs to be ample time and ventilation prior to brooding to assure dryness after the previous flock. While cold floors can be detrimental to starting chicks, Grimes et al. (2002) found that cold floors can be of benefit for older birds in hot weather because sand acts as a heat sink (in southern USA). A commercial trial in TAS found that sand litter was unsuitable for their temperate conditions, due to its high density and thermal conductivity/heating requirements. Sand has not been used extensively for litter in chicken meat production in Australia, which is likely due to the different operational management systems required to optimise the use of it as a bedding material, i.e. full reuse over several years.

Practical considerations of sand for litter use

Table 28 describes the practical considerations that need to be assessed before the application in the Australian chicken meat industry.

Table 28. Practical considerations of sand litter application.

Practical Considerations		Sand litter
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	Further research needs to optimise its use in Australian conditions. Sand would be more suited for warmer regions.
	Would it be available if demand was high?	Yes
	What might it cost with high demand?	Bulk purchasing could reduce cost significantly.
Management	Additional management practises needed?	Yes- reuse would require optimisation and additional management practises. Cleaning/ disinfecting between batches would be different. Denser than other litters.
Regulation	Regulatory / market barriers	No
Other	Gizzard stones	The size of sand particles should be given consideration so as not cause problems for the machines that remove the gizzard.
	Temperature regulation	The sand would need to be brought to the right temperature before chicks are placed. Given the area of an average meat chicken shed, this could increase heating costs.
	Reuse	Long-term reuse (2-5 years) potential with de-caking. Ample time and ventilation is needed prior to brooding to assure dryness.

Cleaning

As sand is an inert inorganic material, it can be flame disinfected (removing/ burning off organic material) without the risk of the litter igniting or degrading (Gernat, 2009). Furthermore, if a producer had sufficient space, the sand could be washed and dried, and then used again. While washing occurs overseas, the economic feasibility of washing in an Australian context has not been assessed.

Economic considerations

The costing was based on the domestic price of natural river sand at a cost of $96.53 per tonne (as of 05/06/2018) (BC Sands). Table 29 outlines the assumptions used to estimate the cost of sand litter, however, the cost of transport or spreading has not been included. It is expected that transport would be a significant cost with this material due to its high density.

Table 29. Assumptions of sand litter and cost estimate.

Assumptions	Unit	Sand
Depth spread	mm	55
Shed length	m	150
Shed width	m	15
Litter required	m^3	123.8
	Tonnes	198
Sand cost	$/ tonne	96.53
Cost per shed	$/shed	~ $19,306
Cost per year (5.6 batches)	$/shed/ year	~ $19,306*

*litter reused between batches

Reuse and cost of raw materials per batch

Table 30 outlines the cost per batch of sand, with differing prices and years of use. While the initial cost of sand is significantly higher than other litters, it becomes price competitive with other litters if it is reused between batches.

Table 30. Cost per batch with differing prices for the initial sand, and a different number of years of use.

Cost per shed	Batches	$50/m^3$	$75/m^3$	$100/m^3$	$200/m^3$
Initial cost	N/A	$ 6,188	$ 9,281	$ 12,375	$ 24,750
1-year use	5.6	$ 1,105	$ 1,657	$ 2,210	$ 4,420
2- year use	11.2	$ 552	$ 829	$ 1,105	$ 2,210
3-year use	16.8	$ 368	$ 552	$ 737	$ 1,473
4-year use	22.4	$ 276	$ 414	$ 552	$ 1,105
5-year use	28	$ 221	$ 331	$ 442	$ 884

Mined organic materials

Mined organics materials are any organic based chemical compound that are harvested by mining. The main example of a mined organic material that can be used for animal litter is Peat. It is already applied commercially in Northern European countries and is suitable for use in the Australian chicken meat industry.

Example of a mined organic material; Peat

Peat is the partly decomposed remains of organic matter, which forms a deposit on acidic, boggy, ground (peatlands). Peat forms in the absence of oxygen, which slows the decomposition process and creates a homogeneous material that is highly absorbent (Figure 14). Finland has the largest peatlands in the world, followed by Canada, Ireland and Sweden. The majority of commercially available peat is mined from these countries, and although Australia does have peatlands, they are not currently mined. Table 31 outlines the main properties of peat.

Figure 14. Peat used in Ireland (McCabe, 2017).

General properties

Table 31. Typical peat properties (Ghaly et al., 1999, OZ Gardener, 2013, Gonzalez et al., 2016).

Property	Average values
Bulk density (kg/m^3)	151
Moisture (%)	7.1
pH	4.4
Thermal conductivity (W/(m.°C))	0.08
Water absorption (%)	317.5
Surface area (m^2 g^{-1})	10.8

Application in the Australian chicken meat industry

Peat has been successfully used as bedding in commercial chicken meat production in Europe (de Jong and van Narn, 2012) and is commonly used in Northern European and Scandinavian countries that mine peat commercially. It is managed in a similar way to sawdust, however, it is used at a much lower depth because it expands greatly with use. Dust may be an issue, until enough moisture has been added by the birds (Shepherd et al., 2017). Several studies have found that peat bedding does not affect bird weight or the feed conversion ratio. Furthermore, peat has been found to outperform traditional litter materials, in respect to production and bird health outcomes. Kaukonen (2017), Aviagen (2009) and Shepherd et al. (2017) found that peat is an acceptable bedding material and its use has no significant effects on meat chicken performance. Interestingly, Everett et al. (2013) found that the addition of peat may be a useful amendment for reducing bacteria, yeasts and moulds in poultry litter. Peat is commonly used as a soil conditioner, so it may also add to the value of spent litter.

Practical considerations of peat as a litter

Table 32 describes the practical consideration that need to be assessed before the application of peat litter in the Australian chicken meat industry.

Table 32. Practical considerations of peat litter application.

Practical Considerations		Peat
Supply	Commercially available in Australia?	No, currently most commercially available peat is imported in small quantities.
Operation	Optimisation of product in an Australian context?	Depth of litter needs to be optimised to Australian conditions (usually 8-20mm, has been used as low as 2mm). Reuse needs to be investigated.
	Could it be available if demand was high?	Known deposits in NSW or could be imported in bulk.
	What might it cost with high demand?	Bulk purchasing could reduce cost significantly.
Management	Additional management practises needed?	No, management is similar to sawdust.
Regulation	Regulatory / market barriers	RSPCA- litter depth.
Other	Greenhouse gas (GHG) environmental impacts	Peat mining could have negative perception problems due to greenhouse gas emissions from mining and use of this product.

GHG environmental impacts

Peatlands store a third of the worlds soil carbon, and mining peat (with the resultant CO_2 release) accounts for up to 5% of human-caused GHG emissions that contribute to climate change (Higgins, 2017). Australia has peat reserves that could be mined, however, it would release large amounts of GHG emissions and would have a significant impact on the Australian GHG reduction target (26-28% of 2005 levels by 2030). In addition to the impacts from mining and use, imported peat would have additional GHG environmental impacts from transport and the use of peat would also increase the carbon footprint of the industry.

Economic considerations

As there is no large scale Australian peat production, the costing was based on the domestic price of Sphagnum peat imported from Canada, at a cost of $45 per 220L (as of 05/06/2018) (Nudgee Road Landscape Supplies, 2018). Table 33 shows the assumptions used to estimate the cost of peat litter, however the cost of transport or spreading has not been included. While peat litter at a depth of 10mm is expensive, it is still economically feasible. Increasing the depth to the RSPCA standard depth of 50mm is not economically feasible.

Table 33. Assumptions of peat litter and cost estimate.

Assumptions	Peat assumptions		
Depth spread (mm)	10	20	50
Shed length (m)	150	150	150
Shed width (m)	15	15	15
Litter required (m^3)	4.5	18	45
Litter required (litres)	22,500	45,000	112,500
Cost (per litre)	45	45	45
Cost per shed	~ $4,602	~$9,205	~$23,011
Cost per shed per year (5.6 batches) *	~$25,775	~$51,546	~$128,863

*5.6 batches with no reuse

Wood products

Wood materials include any compounds that come from trees or shrubs and are generally by-products of milling or production of other wood products (though 'purpose produced' wood products also exist). The common wood sawdust and shavings products are not evaluated, as they have many other uses, and Table 34 outlines example of wood materials that can be used for animal litter.

Table 34. Examples of wood materials used for animal litter.

Example	Suitability	Application	Notes
Pine leaves/ needles/ straw	Suitable	Applied commercially	Has been used as an alternative overseas, although not regularly. Requires additional management.
Pine bark	Suitable	Applied commercially	Has been used as an alternative overseas, although not regularly. Requires additional management.
Pine chipped	Suitable	Applied commercially	Has been used as an alternative overseas, although not regularly. Requires additional management.
Pine shavings	Suitable	Applied commercially	In Australia there has be a recent introduction of shavings machines from overseas, and anecdotally it has been reported that these have been used to convert logs to shavings.
Invasive native scrub (INS) chips or shavings – cypress	Further research needed	Not applied commercially	INS is just chipped or shaved hardwood, which means the most likely influencing factor will be chip/shaving size and the amount of contamination.
Ground door filler	Further research needed	Not applied commercially	Potential contamination issues.
Particleboard residue	Further research needed	Not applied commercially	Potential contamination issues.
Recycled wood pallets (shavings)	Suitable	Applied commercially	Requires strict manufacturing processes to control contamination issues.
Sawdust pellet	Suitable	Used overseas	Similar properties to sawdust.
Wood pellets	Suitable	Used overseas.	Similar properties to sawdust. Trial being conducted with wood pellets litter for chicken meat breeders in QLD.
Tree branches pellets	Further research needed	Not applied commercially	
Horticultural tree pruning residues pellets	Further research needed	Not applied commercially	

Example of a wood material; Recycled wood pallets

Wood pallets used in the warehouse and transport industries may be recycled into litter products (Figure 15 and Figure 16). The resulting wood chips fines provide a soft and insulating surface for chickens. The General properties of recycled wood pallets are outlined in Table 35.

Figure 15. Australian recycled wood pallets used for litter (EMRC, 2018).

Figure 16. Direct BioBedding (Premium grade); pallets chipped and dust extracted (Direxit Pallets®, 2018).

General properties

Table 35. Typical recycled wood material properties (Anval Valves, Bouffier et al., 1996, Porschitz and Schwarz, 2000).

Property	Average value
Bulk density (kg/m^3)	160
Moisture (%) *	12
pH *	5.0 to 6.4
Thermal conductivity W/(m.°C) *	0.00045
Water absorption % *	540
Surface area (cm^2 g^{-1}) *	n.d.

* data was based on pine wood shavings data. n.d.- no data.

Application in the Australian chicken meat industry

There have been mixed outcomes with the use of recycled wood material as chicken litter in Australia. The major issue is chemical contamination, although physical contamination can also be a problem. It has been reported that recycling was tried in Victoria unsuccessfully, due to problems with contamination in certain recycling facilities (pers. comm.). However, recycled wood materials are now

successfully used in WA for a large portion of their chicken meat industry (EMRC, 2018). The Eastern Metropolitan Regional Council (EMRC) recycling plant that produces this material has stringent operating procedures and chemical testing of products to ensure it meets the chicken meat industry's requirements. A small proportion of chicken meat producers in NSW also use recycled wood materials for litter, supplied by a private pallet company (Direct Pallets®, 2018).

Practical and economic considerations

The major concern of using recycled wood pallets is the risk of chemical and physical contamination. Pallets that are used for transport of goods internationally are made of treated timber (copper chrome arsenate - CCA). Pallets may also have been used to transport toxic materials, leading to contamination with paint, fuel, pesticides, solvents, and other flammable materials and nails can be a source of physical contamination. The following section details the manufacturing process of recycling plants that can successfully produce a safe, high-quality litter from wood materials.

EMRC case study

A shortage in shaving/sawdust material in WA has led the industry to seek alternatives and a large proportion of WA growers now use recycled pallet wood chip fines bedding. Initially, there were some contamination issues, but these were overcome through consultation with the WA Broiler Growers Association to develop a safe and fit-for-purpose wood chip product.

The manufacturing process

Strict processing and quality controls are in place to ensure that chicken meat industry specifications are consistently met, and contamination is minimised. Specific screening equipment is used, and plant operators are educated to minimise contamination in incoming timber. Processed materials are stored away from incoming timber to avoid cross-contamination and undergo the following process;

- pallets are screened by plant operators and only untreated and unpainted end-of-life Australian timber pallets, packaging and off-cuts are used
- all pallets are tested for chromated copper arsenate (CCA) by operators before processing
- pallets are then processed into wood chip and fines
- each batch is analysed for organic and inorganic contaminants
- products are regularly tested by an independent third party for organic and inorganic contaminants.

Cost: $\$15.10/m^3$ (domestic price). The bulk commercial price is less for growers, as they have contractual agreements with EMRC to guarantee supply and price.

Direct Pallets® case study

Direct Pallets® uses the Specification for the Supply of Recycled Urban Wood for Broiler Chicken Bedding 2012 guidelines (TDA & EPA NSW, 2012) to ensure that the material they produce is acceptable to the chicken meat industry in NSW. The Specification was prepared by the Timber Development Association (TDA) in partnership with the NSW Environment Protection Authority (EPA) to assist timber recyclers with producing bedding material (from recycled urban wood materials predominantly comprising end-of-life wood pallets or packaging) that meets the requirements of the poultry industry. It was developed in consultation with poultry growers, chicken meat processors, timber recyclers and industry experts and details acceptable particle size, moisture content, sampling and testing regime and quality control requirements. This document is available at the National Timber Product Stewardship Group website.

The Direct BioBedding manufacturing process

Direct Pallets and Recycling adhere to the following process to produce the bedding:

- clean end-of-life timber pallets are either picked-up or received by Direct Pallets and recycling at their facility in Ingleburn
- CCA treated timber and medium density fibreboard (MDF) is not accepted. However, Methyl Bromide fumigated (stamped MB) and Heat Treated (stamped HT) timber pallets and offcuts are used
- recovered pallets are sorted, and those unable to be reused, but are suitable for recycling are processed into animal bedding
- pallets for recycling into bedding are double-checked for quality and any remnant plastic wrapping/rubbish/cardboard/MDF is removed
- timber pallets are shredded and screened multiple times before being graded to specifications agreed to by poultry farmers
- shredders are fitted with dust extractors to remove dust, and high-powered rotating magnets to remove metal and nails
- finished bedding is stored onsite in stainless steel lined bays inside a large secure concrete panelled factory to protect it from excess moisture and cross-contamination
- graded bedding is transported in specialised clean, covered walking floor trucks to users
- all bedding is regularly tested to ensure conformity. Tests are conducted for presence of CCA treated timber, other contaminants, sizing and moisture levels. Every load comes with a signed Direct BioBedding guarantee as to the quality of the load and the cleanliness of our delivery trucks.

Cost: Average $20/m^3 delivered. (Ranges from $15/m^3 picked up to $25/m^3 delivered).

Economic considerations

Table 36 outlines the assumptions used to estimate the cost of recycled wood materials (pallets) litter, however the cost of transport or spreading has not been included.

Table 36. Assumptions of recycled wood materials (pallets) and cost estimate.

Assumptions	Unit	EMRC	Direct Pallets®
Depth spread	mm	55	55
Shed length	m	150	150
Shed width	m	15	15
Litter required	m^3	123.75	123.75
Recycled wood materials cost	$/ m^3	$15.10	$20
Cost per shed	$/shed	~$1,900	~$2,500
Cost per year (5.6 batches)	$/shed/ year	~$10,600*	~$14,000*

*5.6 batches with no reuse

Paper materials

Paper materials are thin sheets made from the pulp of wood or other fibrous substances, used for writing, drawing, printing on, or as wrapping matter. Table 37 outlines paper materials that are used for animal litter.

Table 37. Examples of paper materials used for animal litter.

Example	Suitability	Application	Notes
Paper-sludge	Further research needed	Not applied commercially	Paper-dried sludge (short fibres from paper recycling)
Paper- pellets	Suitable	Not applied commercially	Significant caking issues that require additional management
Paper-shredded	Suitable	Applied commercially	Significant caking issues that require additional management
Paper sludge ash	Further research needed	Not applied commercially	Paper sludge ash (short fibres and lime slurry from paper recycling)

Example of a paper material; Shredded paper

Shredded paper is paper that has been pre-used and chopped into small pieces and recycled as bedding material for poultry. Figure 17 and Table 38 outline details of shredded paper as a litter material.

Figure 17. Shredded newspaper used for animal bedding (Equisearch, 2005) and meat chickens (Wiedemann and Yan, 2014).

General properties

Table 38. Typical paper properties (Miles et al., 2011, Voyles and Honeyman, 2006, Reinhart, 2004, Curry et al., 2004).

Property	Average value
Bulk density (kg/m3)	228
Moisture (%)	~6
pH	Acidic
Thermal conductivity W/(m.°C)	0.05
Water absorption %	208
Surface area (cm^2 g^{-1})	n.d.

n.d. no data

Application in the Australian chicken meat industry

Shredded paper has been used as alternative litter material both internationally and in Australia (Aviagen, 2009). It tends to compact and cake more than the other traditional litters, but the manner in which paper is shredded improves absorption and prevents sharp edges that can cut birds legs (Equisearch, 2005). Concerns can exist with ink in recycled paper, and while most printing ink is soy-based, care must be taken to avoid contamination of litter with heavy metal inks.

Paper is managed in similar way to straw but requires more management to control caking and ammonia production. Several studies have found that shredded paper bedding does not significantly affect bird weight or the feed conversion ratio, and if manged properly, has the same performance outcomes as other litter types (Jacob, 2015, El-Deek et al., 2011, Garcês et al., 2013, Martinez and Gernat, 1995). Paper is broken down readily and can be spread on farm land after use. At present, only a small proportion of the Australian industry use this litter, and only sporadically, which is due primarily to limited availability at a suitable cost.

Practical considerations

Table 39 describes the practical considerations that need to be assessed before expanding the use of paper as litter in the Australian chicken meat industry.

Table 39. Practical considerations of paper litter application.

Practical Considerations		Paper
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	Further research needed to optimise in Australian conditions
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	Bulk purchasing could reduce cost significantly
Management	Additional management practises needed?	Yes- management of caking
Regulation	Regulatory / market barriers	Caking would require extra tillage for RSPCA approval

Economic considerations

Table 40 outlines the assumptions used to estimate the cost of paper litter, however, the cost of transport or spreading has not been included.

Table 40. Assumptions of paper and cost estimate.

Assumptions	Unit	Paper
Depth spread	mm	55
Shed length	m	150
Shed width	m	15
Litter required	m^3	123.8
	Tonnes	35.64[a]
Paper cost	$/Tonne	90
Cost per shed	$/shed	~ $3,200
Cost per year (5.6 batches)	$/shed/year	~ $18,000[b]

[a] Based on a density of 288 kg/m^3 for compacted paper was used.
[b] 5.6 batches with no reuse.

Cereal crop residues

Cereal crops are members of the grass family that are grown for their edible seeds. Cereal crop residues are the stalk and leaf materials that are left after harvesting. Table 41 outlines examples of

cereal crop residue materials used for animal litter, although wheat and barley straw have not been evaluated as they are commonly used.

Table 41. Examples of cereal crop residue materials used for animal litter.

Example	Suitability	Application	Notes
Straw pellets	Suitable	Applied commercially	High cost
Crushed straw pellets	Suitable	Not applied commercially	High cost
Rice straw	Suitable	Applied commercially	Common overseas
Rye straw	Suitable	Applied commercially	Common overseas
Stubble- canola, bean, etc.	Further research needed	Not applied commercially	
Soybean straw	Further research needed	Not applied commercially	
Stubble - corn or sorghum	Suitable, would need to be cut/crushed	Applied commercially	Common overseas
Corn Stalk pellets	Further research needed	Not applied commercially	

Example of a cereal crop residue material; Straw pellets

Cereal crop residuals are materials that have been pelletised, including wheat, barley, rye, rice, oats, soybean straws (Abreu et al., 2013, Adapa et al., 2010, Slobodzian–Ksenicz and Kuczynski, 2002). The pelletisation process usually requires straw to be crushed and potentially dried to approximately 13-15% moisture content and a size of 4-5mm before pelletisation (Engineering, 2018) (Figure 18). Straw is then pressed into pellets under the pressure of between 115-300MPa and a temperature of 100-130°C in a straw pellet miller (Whittaker and Shield, 2017).The heat treatment reduces the microbial loads from litter, and both the temperature and pressure applied in the pelletisation process influence the durability of pellets and physical characteristics. Straw pellets are commonly used overseas in biomass feedstock for heat and power applications. In Australia, straw pellets are used for equine and small animal bedding and a significant portion of straw pellets produced in Australia are currently exported. The General properties of straw pellets are provided in Table 42.

Figure 18. Wheat straw pellets (Strawcomfort, 2016), barley straw pellets (National Pond Service, 2018) and rice straw pellets (Nam, 2018).

General properties

Table 42. Typical straw pellets properties (Strawcomfort, 2016, Renergy UK Ltd, 2018).

Property	Average value
Bulk density (kg/m3)	550-600
Moisture (%)	8
pH	n.d.*
Thermal conductivity W/(m.°C)	n.d.*
Water absorption %	400
Surface area (cm^2 g^{-1}) [a]	n.d.*

*is expected to be similar to straw used. n.d.- no data

Application in the Australian chicken meat industry

Internationally, straw pellets have been used as alternative litter material, however, it is not cast effective for use in Australia. Once straw pellets are placed in sheds, the pellets will gradually break down into absorbent fibrous bedding (Kosanović, 2015). Straw pellets are more absorbent, can last longer, cakes less than chopped straw and are usually less dusty than other litters, however, this depends on the manufacturing process and the portion of fines used in the production of pellets, which will vary between pellet manufactures. A Premos 5000 (Krone UK, 2018) is a machine that allows for the harvest of straw and the production of pellets in one single operation directly in the field and could strongly benefit the use of straw pellets in Australia. It will significantly reduce the cost of straw pellet production, making straw pellets cost completive with other litters.

Practical considerations

Table 43 describes the practical considerations that need to be assessed before the application in the Australian chicken meat industry.

Table 43. Practical considerations of straw pellets litter application.

	Practical Considerations	Straw pellets
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	Manufacturing process is different between species of cereals crop residuals.
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	Cost could be reduced with new pelletisation machines if demand was high enough.
Management	Additional management practises needed?	No
Regulation	Regulatory / market barriers	Depth- straw pellets will expand by ~308% when they absorb moisture and could be spread at a lower depth. While initial depth would be below the RSPCA standard, once used it would expand and reach the standard depth. This would require consultation with the RSPCA.
Other	Cost	Depth of spread.

Economic considerations

Table 44 outlines the assumptions used to estimate the cost of straw pellets litter, however, the cost of transport or spreading has not been included.

Table 44. Assumptions of straw pellets and cost estimate.

Assumptions	Straw pellets assumptions		
Depth spread (mm)	55	20	14
Shed length (m)	150	150	150
Shed width (m)	15	15	15
Litter required (m^3)	123.75	45	31.5
Litter required (tonnes)*	74.25	27	18.9
Straw pellets cost ($/tonne)	170	170	170
Cost per shed	~12,625	~4,590	~3,213
Cost per shed per year (5.6 batches)	~70,686	~25,704	~17,993

*Based on a density of 600 kg/m^3 for straw pellets

Crop and nut hulls

Crop and nut hulls (also known as husks or shells) are the protective outer covering of a seed/ kernel, legume, fruit or vegetable. They are usually composed of mostly indigestible silica and lignin, and Table 45 outlines examples that can be used for animal litter.

Table 45. Examples of crop and nut hulls materials used for animal litter.

Category	Example	Suitability	Application in chicken meat industry	Notes
Cereal Hull	Rice hull	Suitable	Applied commercially	
	Barley hull	Further research needed	Not applied commercially	Likely to have similar properties to rice hulls. Trials should be conducted before the commercial use of this product.
	Wheat hull	Further research needed	Not applied commercially	
	Oat hull	Unsuitable	Not applied commercially	Cause eye irritation and made flock harder to handle.
	Buckwheat Hulls	Further research needed	Not applied commercially	
	Rye	Further research needed	Not applied commercially	
Nut hulls	Almond	Suitable	Applied commercially	Success depends on management.
	Macadamia	Further research needed	Not applied commercially	
	Walnut	Further research needed	Not applied commercially	
	Hazelnut	Further research needed	Not applied commercially	
	Cashew	Further research needed	Not applied commercially	The unprocessed cashew contains toxins inside shell.
Oilseeds hulls	Cottonseed Hulls		Not applied commercially	

Sunflower Hulls	Sunflower Hulls		Applied commercially	
Legume hulls	Soybean Hulls	Further research needed	Not applied commercially	
Pellets	Peanut shell pellet	Further research needed	Not applied commercially	
	Rice hull pellets	Further research needed	Not applied commercially	Expensive and not currently produced in Australia.
	sunflower husk pellets	Further research needed	Not applied commercially	
	Sugarcane bagasse pellets	Further research needed	Not applied commercially	
	Grape pomace pellets	Further research needed	Not applied commercially	
	Olive pomace pellets	Further research needed	Not applied commercially	
	Palm biomass waste pellets	Further research needed	Not applied commercially	
	Citrus pulp pellets	Further research needed	Not applied commercially	

Example of a crop material; Nut hulls

Nut hulls are the hard, usually fibrous, outer layer of nuts that protects the kernel (Figure 19). In Australia, nut hulls have been used for abrasive media, feed stock, mulch, biochar and bioenergy. Nut shell would most likely need to be crushed or ground before use as a meat chicken litter.

Figure 19. Crushed hazelnut hulls (KP's Harvest Time Products, 2016), macadamia nut hulls (SMaRT@UNSW, 2017) and crushed pecan hulls (Thomson Stone Materials, 2018).

General properties

Table 46 present the properties of almond hulls; however, it should be noted that other nut hulls will have different properties.

Table 46. Typical almond hull properties (Aydin, 2003, Dingke and Fielke, 2014).

Property	Average values
Bulk density (kg/m3)	475
Moisture (%)	16.6
pH	n.d.
Thermal conductivity W/(m.°C)	n.d.
Water absorption %	n.d.
Surface area (cm^2 g^{-1})	n.d.

n.d. no data

Application in the Australian chicken meat industry

Nut hulls are not commonly used as chicken meat litter, either internationally or in Australia. One USA agricultural business sells ground almond hulls as dairy and poultry bedding (AGRA Marketing Group, 2016) and one trial was conducted on almond hull in Australia (personal communication). While the outcome of the trial was not successful, the interviewee was of the option that it was due to management rather than the almond hull litter. A more thorough trial is needed to fully assess the potential of almond hulls and other nut hull as a litter for the Australian chicken meat industry.

Practical considerations

Table 47 describes the practical considerations that need to be assessed before application in the Australian chicken meat industry.

Table 47. Practical considerations of nut hull litter application.

Practical Considerations		Nut hull
Supply	Commercially available in Australia	Yes
Operation	Optimisation of product in an Australian context	Needs to be optimised for Australian conditions
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	Bulk purchasing could reduce cost significantly.
Management	Additional management practises needed?	Further research is needed
Regulation	Regulatory / market barriers	n/a

Economic considerations

Table 48 shows the assumptions used to estimate the cost of almond hull litter, however the cost of transport or spreading has not been included.

Table 48. Assumptions of almond nut hull and cost estimate.

Assumptions	Unit	Nut hull
Depth spread	mm	55
Shed length	m	150
Shed width	m	15
Litter required	m^3	123.75
	Tonnes *	58.8
Almond hull cost	$/Tonne	$117
Cost per shed	$/shed	$6,885
Cost per year (5.6 batches)	$/shed/year	$38,560

* Based on a density of 475 kg/m^3 for almond nut hulls

Grasses

The true grasses are a broad group that includes cereals, bamboo, pasture and turf. Grasses have stems that are hollow except at the nodes, slender sheathing leaves and flowers borne in spikelets of bracts. They may be annual or perennial and have a wide variety of uses including food, pasture, paper, fuel, insulation and clothing. While the grasses category does include several cereals, Table 49 outlines examples that are used for animal litter.

Table 49. Examples of grasses used for animal litter.

Category	Example	Suitability	Application
Leaf and stem crops	Bamboo	Further research needed	Not applied commercially
	Marram grass	Further research needed	Not applied commercially
	Meadow-grass	Further research needed	Not applied commercially
	Reeds	Further research needed	Not applied commercially
	Ryegrass	Further research needed	Not applied commercially
Other grasses	Sugarcane trash	Suitable	Applied commercially
	Elephant grass	Suitable	Applied commercially
	Miscanthus	Suitable	Applied commercially
	Switchgrass	Suitable	Applied commercially
Pellets	Bamboo pellets	Further research needed	Not applied commercially
	Bamboo dust pellet	Further research needed	Not applied commercially
	Reed canary grass pellets	Further research needed	Not applied commercially

Example of a grass material: Miscanthus Grass (M. *Giganteus*)

Miscanthus spp. is a large perennial grass species native to eastern Asian regions, including eastern Russia, eastern China, Japan, Korea, Taiwan, Indonesia and the Philippines. There are many species and hybrids of miscanthus grasses and currently in Australia, miscanthus grass is only cultivated for domestic ornamental use. *Miscanthus sinensis* is the most common species of miscanthus grass in Australia and is regarded as an environmental weed in New South Wales and as a potential environmental weed in Victoria. However, a sterile hybrid species (*Miscanthus giganteus*) is available that will not propagate in the wild, overcoming problems with the grass spreading by seed.

Miscanthus *giganteus* (commonly known as the Japanese Silver Grass) is a hybrid of *Miscanthus sinensis* and *Miscanthus sacchariflorus* and is cultivated commercially as an energy/biomass crop, as a source of heat and electricity, or converted into biofuel products. *Miscanthus giganteus* grows in erect clumps that can reach 2.4-3.6m tall, and as it is a sterile hybrid, it propagates vegetatively underground through its rhizomes (Figure 20). Miscanthus can grow in a large range of conditions, including different soil types (clay-sand) and levels of soil fertility, pH (alkaline, neutral, acidic) and partial shade to full sun. It has been grown in many different regions in other parts of the world, including meadows, marshes, hillsides, and on mountainsides up to 1500 metres. Additionally, it is a C4 plant (C4 carbon fixation), has high photosynthetic efficiency, high nitrogen use efficiency, low water-use requirements and very low nutritional requirements. Due to these characteristics, it is capable of growing on marginal farming land without the aid of heavy fertilization. Recently chopped *Miscanthus giganteus* has been used in Europe and the USA as animal bedding material (Figure 20) and has been successfully used commercially for chicken meat production. Australian commercial *Miscanthus giganteus* production is not as developed as other countries, due to import biosecurity, the rigorous quarantine process and plant availability. However, there is an Australian biotech company that can supply *Miscanthus giganteus* rhizome for commercial application (Plant Biotech Pty. Ltd., 2018).

Figure 20. Miscanthus giganteus (Arbortanics Incorporated, 2016), miscanthus grass used as bedding in a poultry house (Thompson, 2015) and chopped miscanthus grass (Dunkley and Ritz, 2017).

General properties

Chopped *Miscanthus giganteus* is an absorptive lightweight material that is softer than most other grasses, because the sheaths have a unique internal honeycomb structure that is exposed in chopping/shredding processes. It can absorb up to three times its own weight in moisture and weight-for-weight, it has been found to bed double the area of wood shavings at standard 15mm, 30mm and 50mm litter depths (PW Reporters, 2012). That is, *Miscanthus giganteus* can cover twice the area as the same weight of wood shavings. Table 50 shows the typical properties of *Miscanthus giganteus*.

Table 50. Typical *Miscanthus giganteus* properties (PW Reporters, 2012, Azeus, 2015).

Property	Average value
Bulk density- chopped (kg/m3)	70-100
Moisture- chopped (%)	10-15
pH	n.d.
Thermal conductivity W/(m.°C)	n.d.
Absorbency Factor (g water/g bedding)	2.97
Surface area (cm^2 g^{-1})	n.d.

n.d. no data

Application in the Australian chicken meat industry

Chopped *Miscanthus giganteus* has been used as bedding successfully in commercial chicken meat production in Europe and the USA (DeBruyn, 2015, Dunkley and Ritz, 2017, PW Reporters, 2012). It is managed in similar way to straw and several studies have found that chopped *Miscanthus giganteus* bedding does not affect bird weight or the feed conversion ratio. There were no significant production or bird health differences between miscanthus and traditional bedding material. In the USA, *Miscanthus giganteus* bedding was reused for six flocks, researchers found no statistical difference between miscanthus grass and pine shavings for ammonia emissions, moisture content and effects on paw quality (Dunkley and Ritz, 2017). Spent litter generated has similar nutrient content as that generated from the use of pine shavings.

Practical considerations

Table 51 describes the practical considerations that need to be assessed before application in the Australian chicken meat industry.

Table 51. Practical considerations of miscanthus grass litter application.

Practical Considerations		Miscanthus grass
Supply	Not commercially available in Australia	Could establish sales agreement with biomass growers
Operation	Optimisation of product in an Australian context	Bale size, chop length, harvest time, litter depth, management
	Could it be available if demand was high?	Yes - Australian biotech industry has started to sell.
	What might it cost with high demand?	Comparable to wood products.
Management	Additional management practises needed?	Similar to straw
Regulation	Regulatory / market barriers	Unlikely to be problem
Other	Opportunity for farmers to produce bedding themselves	Easy crop to grow.

Economic considerations

Table 52 shows the assumptions used to estimate the cost of miscanthus grass litter, however the cost of transport or spreading has not been included.

Table 52. Assumptions of miscanthus grass litter and cost estimate.

Assumptions	Unit	Miscanthus grass
Depth spread	mm	55
Shed length	m	150
Shed width	m	15
Litter required	m^3	123.75
Miscanthus grass cost*	$/ Tonne	$141.6
Cost per shed	$/shed	$4,030
Cost per year (5.6 batches)	$/shed/ year	$22,570

*Cost based on UK market price of market is €60 per tonne and €20 per tonne chipping bales. This is an estimate of the market returns of miscanthus that includes costs from cultivation to harvesting with an average inflation rate of 3% (Caslin et al., 2011). Price was converted to AUD with the exchange rate was 1.77, current on the 10/07/2018. As this price is reasonably comparable to hay production and can be grown on less fertile ground with good yields, the costs are expected to be adequate to promote production.

Miscellaneous organic materials

Miscellaneous organic materials are any organic compounds that could not be classified in the previously defined categories and are detailed in Table 53.

Table 53. Examples of cereal crop residuals materials used for animal litter.

Category	Example	Suitability	Application	Notes
Other	Rice hull ash	Further research needed	Not applied commercially	Not available in Australia
	Cotton-gin trash	Further research needed	Not applied commercially	Historically, there have been contamination problems, which have reduced in recent years. Provided contamination issues could be managed, this has potential as an alternative litter.
	Coffee chaff	Further research needed	Not applied commercially	Availability of coffee chaff is limited in Australia.
	Dried rose dreg	Further research needed	Not applied commercially	Availability of rose dreg is limited in Australia.
	Citrus pulp	Further research needed	Not applied commercially	Citrus pulp is used as a feed stock in Australia.
	Reused Tea	Further research needed	Not applied commercially	Availability of reused tea is limited in Australia.
	Banana fibre	Further research needed	Not applied commercially	Supply is regional
	Oil palm frond fibre	Further research needed	Not applied commercially	Availability of oil palm frond fibre is limited in Australia.
	Composted municipal garbage	Unsuitable	Not applied commercially	Contamination issues
	Pomace/marc (grape, olive, fruit pressings)	Further research needed	Not applied commercially	It contains the skins, pulp, seeds, and stems of the fruit from pressing. High moisture content and would require drying before use.
Pellets	Coconut hull pellets	Further research needed	Not applied commercially	Availability/ production of coconut is limited in Australia.
	Coffee bean hull pellets	Further research needed	Not applied commercially	Availability/production of coffee beans is limited in Australia.
	Cotton stalks pellets	Further research needed	Not applied commercially	Historically, there have been contamination problems, which have reduced in recent years. Provided contamination issues could be managed, this has potential as an alternative litter.
	Pineapple peels pellets	Further research needed	Not applied commercially	Production of pineapples is regional, which would limit supply.
	Palm shavings pellets	Further research needed	Not applied commercially	Availability/production of palm is limited in Australia.

Example of miscellaneous organic material: Grape Marc

Grape marc is the solid residuals left after the pressing of grapes, olives or other fruit for juice or oil. This section will focus on grape marc, however, other types could be used.

Grape marc usually includes the skins, pulp, seeds and stems. The moisture content of fresh grape marc can be up to 65-68% water (Février and Willequet, 2009), therefore, grape marc must be dried or ensiled to preserve if not used immediately (Figure 21). Grape marc is of low digestibility due to its high content of fibre and the presence of phenolic compounds (Heuzé and Tran, 2017). It can be used to feed ruminants in conjunction with higher nutritive feeds, however, it is not recommended for pigs or poultry as a source of energy or protein (Heuzé and Tran, 2017). Other uses include, compost and a source of bioactive compounds (antioxidants) (García-Lomillo and González-SanJosé, 2017). In Australia, grape marc is usually used as compost or as a feed for ruminants.

Figure 21. High moisture grape marc, a close up of grape marc and dried grape marc (images from Farm Tender, accessed February 15th, 2018).

General properties

The physical and chemical composition of grape marc is dependent on many factors, including the purpose of the crop (white wine, red wine, spirits, juice, oil etc.), grape variety and maturity, and techniques and/or machinery used throughout the process (Ye et al., 2015). Further research on dried grape marc is needed before it could use as a chicken litter, and Table 54 outlines its General properties.

Table 54. Typical grape marc properties (Burg et al., 2014).

Property	Average value
Bulk density (kg/m3)	400-600
Moisture (%)	n.d.
pH	acidic
Thermal conductivity W/(m.°C)	n.d.
Water absorption %	n.d.
Surface area (cm^2 g^{-1})	n.d.

n.d. no data

Application in the Australian chicken meat industry

Grape marc has not been used as chicken meat litter internationally or domestically and further research into its potential as litter is required. Specifically, the optimal initial moisture content, water activity and overall suitability to the chicken meat industry would need to be assessed. Additionally, trials would be needed to optimise the litter for Australian conditions.

Practical considerations

Table 55 describes the practical considerations that need to be assessed before application in the Australian chicken meat industry.

Table 55. Practical considerations of grape marc litter application.

Practical Considerations		Grape marc
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	Needs to be optimised for Australian conditions
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	In grape growing regions cost, would compare favourably to other alternative litters
Management	Additional management practises needed?	Further research is needed before application to industry
Regulation	Regulatory / market barriers	N/A
Other	Moisture content	Grape marc would need to be sufficiently dried before use

Economic considerations

Table 56 shows the assumptions used to estimate the cost of grape marc litter, however, the cost of transport or spreading has not been included.

Table 56. Assumptions of Grape marc and cost estimate.

Assumptions	Unit	Dry grape marc
Depth spread	mm	55
Shed length	m	150
Shed width	m	15
Litter required	m^3	123.7
	Tonnes *	55.7
Grape marc cost	$ / Tonne	70
Cost per shed	$/shed	$3,898
Cost per year (5.6 batches)	$/shed/ year	$21,830

* Based on a density of 450 kg/m^3 for grape marc was used

Mixed or layered materials

Mixed or layered materials are any mixture of litter types, and examples of these are outlined in Table 57. Both internationally and domestically, many mixtures of litter types have been used or trialled by the chicken meat industry with inconsistent success. The success of these mixtures varies greatly between producers, due to the specific application, variation in management and individual housing conditions. Additionally, there is also a logistical issue, given that many of the litters come from different sources.

Table 57. Examples of cereal crop residuals materials used for animal litter.

Example	Suitability	Application	Notes
Sugar cane + wood shavings	Suitable	Applied commercially	Sugarcane litter supply is regional
Sugar cane + rice husks	Further research needed	Not applied commercially	Sugarcane litter supply is regional
Paper +wood shavings	Suitable	Applied commercially	
Paper + barley straw	Suitable	Applied commercially	
Reused Paper +wood shavings	Suitable	Applied commercially	
Rice hull ash + pine shaving	Further research needed	Not applied commercially	Rice hull ash not commercially available in Australia
Reused Paper + barley straw	Further research needed	Not applied commercially	
Dried rose dreg + pine shaving	Further research needed	Not applied commercially	Dried rose dreg not commercially available in Australia
aGroChips	Further research needed	Applied commercially	Not available in Australia
Aspen wood particles and ground wheat pellets	Further research needed	Not applied commercially	Aspen not commercially available in Australia
Recycled paper and aspen hardwood sawdust pellets	Further research needed	Not applied commercially	Aspen not commercially available in Australia
Wood shavings-vermiculite	Further research needed	Not applied commercially	
Wheat and rapeseed straw	Further research needed	Applied commercially	Straw mixes- overseas
Sawdust and bark pellets	Further research needed	Not applied commercially	

Example of mixed or layered materials: Wheat straw pellets and sawdust

Wheat straw residuals that have been pelletised mixed with sawdust. Please refer to the previous sections on Cereal crops, as well as Appendix 2, for further information.

Application in the Australian chicken meat industry

This mixture has not been used by the chicken meat industry, either internationally or domestically, but both products have been used independently and are not expected to cause issues if blended. Further research is needed to determine whether this would be a viable alternative to the Australian chicken meat industry.

Practical considerations

Table 58 describes the practical consideration that need to be assessed before the application in the Australian chicken meat industry.

Table 58. Practical considerations of straw pellets and sawdust litter application.

	Practical Considerations	Straw pellets and sawdust
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	No, will need further research.
	Could it be available if demand was sufficient?	Yes
	What might it cost with sufficient demand?	Bulk purchasing could reduce cost significantly.
Management	Additional management practises needed?	No
Regulation	Regulatory / market barriers	No
Other	Cost	Dependent on the price of the straw pellets.

Economic considerations

Table 59 shows the assumptions used to estimate the cost of mixed straw pellets and sawdust litter, however, the cost of transport or spreading has not been included. Mixing straw pellets with sawdust at a 50:50 ratio can reduce cost compared to 100% straw pellets by 38% and could be an option where the supply of both materials was constrained.

Table 59. Assumptions of sawdust and wheat straw pellets and cost estimate (sawdust= $24/m^3$ and wheat straw pellets = $102/m^3$).

Assumptions	Unit	100% straw pellets	25:75 pellets to sawdust	50:50 pellets to sawdust	75:25 pellets to sawdust
Depth spread	mm	55	55	55	55
Shed length	m	150	150	150	150
Shed width	m	15	15	15	15
Litter required	m^3	123.75	123.75	123.75	123.75
Cost per shed	$/shed	$12,623	5,383.13	7,796.25	10,209.38
Cost per year (5.6 batches)	$/shed/year	$70,686	30,145.50	43,659.00	57,172.50
Cost reduction	% of $	0%	57%	38%	19%

Unspecified cereal crop residual materials

Unknown category are materials that have been described in patents, but have not been applied commercially, and are detailed in Table 60.

Table 60. Examples of cereal crop residuals materials used for animal litter.

Example	Suitability	Application
Papermill effluent + bark mix	Unknown	Not applied commercially
Clay + cedar mix	Unknown	Not applied commercially
Wood + peat pellets	Unknown	Not applied commercially
Peat, wood pulp and coir pitch	Unknown	Not applied commercially
Dried citrus peel	Unknown	Not applied commercially
Foamed polymer	Unknown	Not applied commercially
Foamed polymer- general animal bedding	Unknown	Not applied commercially
Thermoplastic polymer and starch.	Unknown	Not applied commercially
Chlorophyll-containing agent and a vermiculite or perlite mix	Unknown	Not applied commercially
Cellulosic material or clay and volcanic rock mix	Unknown	Not applied commercially
A porous, inert solid substrate and a dry particulate polymer compound.	Unknown	Not applied commercially
Coated extruded animal litter	Unknown	Not applied commercially
Amorphous silica	Unknown	Not applied commercially
Deodorizing litter for poultry farms	Unknown	Not applied commercially
Peat and peat mix with wood shavings	Unknown	Not applied commercially
Tobacco stalk	Unknown	Not applied commercially
Lightweight expanded polystyrene chips.	Unknown	Not applied commercially

Due to the lack of information on the unknown category of litters, an example could not be provided.

Alternative management options

Tables 61 outlines alternative management options for litter use in the Australian chicken meat industry.

Table 61. Examples of alternative management options used for animal litter.

Example	Suitability	Application	Notes
Reuse-partial (50:50)	Suitable	Applied commercially	Successfully used by several Queensland producers with sawdust.
Reuse – full	Suitable	Applied commercially	Successfully used overseas.
Layering of different litter materials	Suitable	Applied commercially	Inconsistent results, which are dependent on litters used.
Mixing of different litter materials	Suitable	Applied commercially	Inconsistent results, which are dependent on litters used.
Growing your own litter - straw or grass system	Suitable	Applied commercially	Would require land to grow trees and machines to process.
Sustainable tree buffer system-growing trees for litter	Suitable	Not applied commercially	Would require land to grow trees and machines to process.
Seasonal use of different litters	Suitable	Applied commercially	
Using different litter types in different shed sections	Suitable	Applied commercially	
Litterless systems such as slats	Suitable	Applied commercially	RSPCA and consumers may have concerns with this system.
Caged system	Suitable	Applied commercially	RSPCA and consumers may have concerns with this system.

Examples of alternative management options: Reuse (sawdust)

Chicken litter reuse is the practise of housing multiple batches of chicken s on the same bedding material (litter) before removing that litter from the sheds for utilisation off site (e.g. as fertiliser) (Figure 22). Reuse in Australia is generally only partial reuse, rather than full reuse like in the USA. After a batch, litter is composted in the shed prior to being re-spread in the sheds. The composting process creates heat, which acts to kill pathogens and viruses that may be present in the litter, however, the effectiveness of this can be constrained by the time available between batches. Generally, new bedding material is spread in the brooding area prior to placement of the next batch of chickens. It should be noted that reuse will require a longer break between batches for composting pasteurisation. This can impose additional costs onto the production system, including the need to vaccinate birds for Mareks Disease and the need for greater floorspace on account of the increased downtime between batches.

Figure 22. Australian meat chickens on reused litter, piling litter into a composting windrow, and composting of spent litter after a batch (Wiedemann, 2015).

General properties

Table 62 outlines the General properties of reused litter.

Table 62. Typical reused litter properties (AAF, 2005).

Property	Range
Bulk density (kg/m3)	330
Moisture (%)	25% or less
pH	6.5-7.5
Thermal conductivity W/(m.°C)	n.d.
Water absorption %	n.d.
Surface area (cm^2 g^{-1}) [a]	n.d.

n.d. no data

Application in the Australian chicken meat industry

This management approach is widespread in some countries (e.g. USA), but is not currently practised widely in Australia. In cases where litter reuse is practised in Australia, it is typically reused for only 3-5 batches, whereas in the USA, litter is sometimes reused for several years (for more than 15 batches of chickens). Reuse predominantly occurs in NSW and QLD with sawdust, shavings or a mixture of both, while overseas, reuse a wider variety of litter materials has been undertaken, including shavings, sawdust, corn cobs, rice hulls and straw pellets.

Partial litter reuse has been successfully used in NSW and QLD for over 30 years. It initially takes time to optimise systems and management practises, however, once established, it reduces costs without detrimental impacts on bird health. Some factors may require more management when reusing litter, such as ammonia emissions. With appropriate monitoring and management, suitable levels of ammonia can be maintained for bird production (Wiedemann, 2015). Pathogens associated with food safety and bird health may be treated by heaping/piling litter between batches, and standard operating procedures are under development to assist in minimising pathogen load (Wiedemann, 2015).

Interestingly, in the USA producers use propane torches to flame sanitise litter (Figure 23). The heat kills pathogens and insects, flares off ammonia vapour and dries litter. Flame sanitation could be used in addition to current management strategies in Australia to ensure the safety of reuse litter.

Figure 23. Propane poultry house flame sanitizer (Flame Engineering Inc, 2017).

Practical considerations

Table 63 describes the practical consideration that need to be assessed before expanding the application of reuse in the Australian chicken meat industry.

Table 63. Practical considerations of reuse litter application.

Practical Considerations		Reuse
Supply	Commercially available in Australia?	Yes
Operation	Optimisation of product in an Australian context?	Would need to be optimised for each farm, and with each litter type.
	Could it be available if demand was high?	Yes. With further research reuse could be expanded to other regions for different litter types.
	What might it cost with high demand?	Very low cost
Management	Additional management practises needed?	Yes
Regulation	Regulatory / market barriers	No Several growers identified that reusing litter may make it harder to comply with the RSPCA standard and there is a perception that it will increase bird health, ammonia and odour issues, which may lead to increased management costs. Although there is the potential for these problems to occur, with proper management practises they can be avoided. There may also be the need for vaccination against Mareks Disease.

Economic considerations

Table 64 outlines the assumptions used to estimate the cost of 50% reuse (continual) and 100% reuse (yearly full change) of sawdust litter.

Table 64. Assumptions of reused litter and cost estimate.

Assumptions	Unit	Reused litter – sawdust, 50%	Reuse 100% for 1 year
Depth spread	mm	55	55
Shed length	m	150	150
Shed width	m	15	15
Litter required	m^3	123.75	123.75
Sawdust cost	$/ Tonne	$24	$24
Cost per shed	$/shed	$1,485	$2,970
Cost per year (5.6 batches)	$/shed/ year	$8,316	$2,970

Reuse and cost per batch

Table 65 details cost per batch for differing litters at a 100% reuse and years of use. If 100% reuse was adopted for several years (like in the USA), the overall price per batch substantially decreases. With litter reuse, some of the higher cost alternative litters become price competitive with current commonly used litters.

Table 65. Cost per batch with differing litters reuse and years of use (all at 100% reuse, 55mm depth, 15x150m shed).

		Sawdust	Wood shavings	Rice hulls	Peat	Recycled wood pallets	Straw pellets
Cost per shed	Batches	$24/m3	$30/m3	$20/m3	$205/m3	$15.1/m3	$102/m3
Initial cost	-	2970	3712.5	2475.0	25368.8	1868.6	12622.5
1-year use	5.6	530.4	662.9	442.0	4530.1	333.7	2254.0
2- year use	11.2	265.2	331.5	221.0	2265.1	166.8	1127.0
3-year use	16.8	176.8	221.0	147.3	1510.0	111.2	751.3

Examples of alternative management options: Litterless systems

Litterless systems use slat flooring as the housing surface for the birds. Usually, the manure and waste feed fall below the slats and are later removed. Air flow from under slats can also cool birds and reduce ammonia levels and the use of mechanical harvesting is limited in most of these systems, as the slats are not designed to support the weight of large machines. As litter is not used, the end manure product is more concentrated and would have a higher end-use value. This system is common in Russia, Asia and the Americas. Effectively there are two major variations of this system: low and high litterless systems.

Low litterless systems

Low litterless systems are when a plastic flooring is directly applied/laid on shed floor. Interestingly, the AviHome ™ system (Figure 24) has been developed to allow the use of heavy machinery on the floor, however, videos on the manufacturers' web site show that faeces build up on top of the flooring dries and is then scraped off with machinery. This is not ideal and has the potential to cause bird health issues. Other low litterless systems like the "golden broiler floor" (FIT, 2018) have larger spaces between slats, allowing for manure to fall below, although heavy machinery cannot be used.

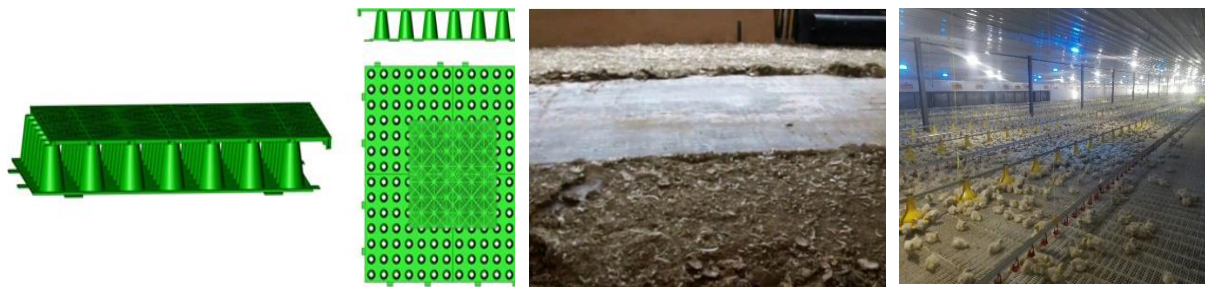

Figure 24. Schematic of AviHome ™ litterless flooring systems, AviHome ™ litterless flooring system after use (AviHome LLC, 2018), and meat chickens on common a common litterless system (FIT, 2018).

High litterless systems

High litterless systems are when the slats are elevated sufficiently above the shed floor so that the manure falls through the flooring and dries. The elevation of the slats off the floor allows for more air follow and can improve manure drying (Aviagen, 2016). After several batches, the flooring is removed, and manure is collected, or systems are developed that allow manure to be cleaned from under the slats without removing the floor. AGCO GSI (2013) shows high litterless systems in use, as

well as manure removal (Figure 25). The slats are suspended high enough to allow workers access to remove manure, and flooring does not have to be removed for cleaning or manure removal.

Figure 25. High litterless system showing slat legs (elevated approximately 0.6m) (JHFarming, 2018) and the underside of a high litterless system (elevated approximately 2m) (AGCO GSI, 2013).

General properties

Litterless systems are usually made from PVC plastic. Depending on the manufacturer, the lifetime warranty of these products usually ranges from 10-20 years (Henan Danong agricultural S&T Co. LTD, 2018).

Application in the Australian chicken meat industry

AviHome ™ Litterless system

The Ritz et al. (2015) industry study into the AviHome ™ litterless system found that, although the system did show promise in the areas of ammonia and particulate matter concentration reductions, there were issues with bird welfare and mortality, energy usage, labour, and longevity of the system components. While the industry trial was scheduled to last for 2 years, it was terminated, and the flooring was removed at the end of the first year at request of the poultry growers. Ritz et al. (2015) concluded that significant further research and development would be required before the system could be commercially viable. There was a similar trial conducted in Australia, with limited success; the producer said the litterless system required 3 times more gas and 3 times more ventilation (personal communication).

Other litterless systems

Litterless systems have been used successfully in commercial chicken meat production in Eastern Europe, Russia, Asia and the Americas (Philip, 2013). Manure and bird handling are managed differently in this system and temperature control may be an issue (especially in temperate regions), which could significantly increase heating costs. It should be noted that, conversely, in hotter regions it may also reduce cooling costs. Several studies have found that properly designed litterless systems do not significantly affect production or bird performance (Simpson and Nakaue, 1987, Çavuşoğlu et al., 2018, Karcher et al., 2013, Andrews et al., 1988, Carter et al., 1972, Cooper and Barnett, 1972, Newcombe et al., 1991, Parkhurst, 1974). Manure from this system would be more concentrated than litter-based systems, so it may increase the fertiliser value of the manure.

Practical considerations

Table 66 describes the practical consideration that need to be assessed before the application in the Australian chicken meat industry.

Table 66. Practical considerations of litterless system application.

Practical Considerations		Litterless
Supply	Commercially available in Australia?	There are several Chinese companies that manufacture litterless systems.
Operation	Optimisation of product in an Australian context?	Heating costs and management practises.
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	Bulk purchasing could reduce cost significantly.
Management	Additional management practises needed?	Different management practises- bird harvesting and cleaning would be different to current practises.
Regulation	Regulatory / market barriers	RSPCA and possibly consumers.
Other	Heating costs/ operational costs	Could be a significant ongoing cost
	Management/ labour costs	Machinery can't be used to harvest birds- this would have to be done by hand.
	Laying and transport cost	Capital cost
	Maintenance costs	Product can last for 10-20 years, however, it would require regular maintenance.

Economic considerations

Table 67 outlines the assumptions used to estimate the cost of litterless system. The cost of installation has not been included.

Table 67. Assumptions of Litterless and cost estimate.

	Assumptions	Unit	Litterless system
Shed	Shed length	m	150
	Shed width	m	15
	Shed area	m^2	2250
Slat flooring	Cost per piece	(USD, $)	10 [a]
	Value of USD in AUD	(AUD, $)	1.28 [b]
	Length	m	1
	Width	m	0.60
	Life-time	years	10
Calculation	Pieces needed for shed	pieces	3750
	Cost of litter-less (total cost)	(AUD,$)	$ 48,000.00
	Cost of litter-less (per year)	(AUD,$)	$ 4,800.00
	Cost of litter-less (per batch)	(AUD,$)	$ 857.14

[a] Cost based on Weifang Jiade Machinery Co. Ltd. (2018)

[b] Based on 07/06/2018 currency exchange values

[c] 5.6 batches per year

Alternative litter processing options

Table 68 outlines all other litter processing options that have not yet been defined in this report.

Table 68. Examples of cereal crop residuals materials used for animal litter.

Example	Suitability	Application	Notes
Pelletisation machine	Suitable	Applied commercially	Pelletisation could be used to make poorer quality materials more suitable for chicken meat litter.
On farm straw processing (chopping, crushing)	Suitable	Applied commercially	Chopping machines are used by several producers that grow their own litter.
Wood shaving/ saw dust drier	Suitable	Not applied commercially	Shaving/ sawdust drier machine could be used to dry litter before use. This is a more suitable for a litter supplier, rather than a producer.
Crushing pellets	Suitable	Not applied commercially	Pellets are crushed after manufacturing. This increases the surface area. Commonly used for equine litter. This may be cost prohibitive.

Example of alternative litter processing options: Pelleting machine with straw

Pelletisation could be used to turn materials that are low in quality, into pellets that are more usable litter product for meat chickens (Figure 26). This option may be more suitable for litter suppliers, rather than chicken meat growers and producers. Straw was chosen as an example due to the widespread availability, however, this alternative option could be used with a wide range of materials, including crop stubble, leaves/needles, bark, invasive native scrub, nut hulls, milled almond hulls, cereal crop residuals, bagasse, coir, grass, cotton products, banana fibre and others. Pelletisation could also be applied to mixtures of materials.

Figure 26. Medium palletisation machine that produces ~400-700 kg/hr (Quzhou Surri Import and Export Trading Co. Ltd., 2018), and a large palletisation machine that produces ~800-4000 kg/hr (Zhengzhou Amisy Trading Co. Ltd., 2018).

General properties

There are many Chinese companies that manufacture pelletisation machines and they range in cost and pellet production capacity. Small and medium pelletisation machines are usually free standing and can be powered by electric, petrol or diesel engines. Large pelletisation machines are usually fixed and are electric.

Application in the Australian chicken meat industry

Some commercial pelletisation plants exist in Australia, but these are not generally operated by the chicken meat industry at a smaller scale.

Practical considerations

Table 69 describes the practical considerations that need to be assessed before application in the Australian chicken meat industry.

Table 69. Practical considerations of litterless system application.

Practical Considerations		Notes
Supply	Commercially available in Australia?	There are many Chinese companies that manufacture pelletisation machines
Operation	Optimisation of product in an Australian context?	Optimisation of pelletisation machine operation and biomass material used would be required.
	Could it be available if demand was high?	Yes
	What might it cost with high demand?	Likely to produced pellets at a lower cost than current commercial prices.
Management	Additional management practises needed?	No
Regulation	Regulatory / market barriers	No
Other	Operational and maintenance costs	Product can last for 10-15 years; however, it would require regular maintenance.
	Labour costs	There would be additional labour cost associated with palletisation.
	Transport/ shipping cost	Capital cost.

Economic considerations

Table 70 outlines the assumptions used to estimate the cost of pelletisation machine, however, the cost of transport has not been included.

Table 70. Assumptions of pellet machine and cost estimate.

	Assumptions	Unit	Medium pellet machine	Large pellet machine
Shed	Depth spread [a]	mm	14	14
	Shed length	m	150	150
	Shed width	m	15	15
	Litter required	m^3	123.75	123.75
Straw	Cost	(AUD, $)	$3,114.75	$3,114.75
Pelletisation machine	Cost of pellet machine [b]	(AUD, $)	$ 5,757	$ 15,410
	Cost over 10 years	(AUD, $)	$ 576	$ 1,541
	Cost per batch over 10 years	(AUD, $)	$103	$275
Pelletisation	Average productivity	Kg /Hour	633	1660
	Hours need to produce litter	Hours	32	12
	Average running cost [c]	(AUD, $)	$336	$213
	Labour (pelletisation labour cost only)	$25/hour	$799	$305
Overall costs	Cost per batch [d]	(AUD, $)	$4,352.62	$3,908.37

[a] Straw pellets expand by 308%,

[b] Only cost of pelletisation machine, does not include shipping, exchange or import fees,

[c] based on average watt and 35 cents per kWh (Department of Mining and Energy, 2018),

[d] including cost of straw, per batch 10 year machine cost, running cost and labour.

Conclusions and Recommendations

Fresh litter demand in Australia has increased in line with expanded production across the industry and is expected to continue to do so into the future. This study found that fresh litter costs have increased at a much higher rate than would be expected over the past 17 years, since a similar audit was conducted, based on average costs reported in 2017. It is noted that some fresh litter materials also vary widely in price and availability, and at the time of publication, cereal straw prices in eastern Australia had reached $460 per tonne in response to the severe drought conditions experienced. These trends will continue to prompt the industry to investigate new litter alternatives, or management practises that could reduce litter requirements. The choice of litter materials or litter management strategies is dependent on individual chicken growers' circumstances and the availability and cost of materials, which will vary significantly between regions. The treatment requirements, and value of spent litter also influences the final cost effectiveness of one litter type compared to another. This review has identified many alternative litters and management options that could be used by the Australian chicken meat industry. While bird performance will continue to be the primary threshold criterion, cost and availability will be the ultimate deciding factors in whether these alternatives are adopted by the industry.

It should be noted that the estimated costs presented in the report were not inclusive of all associated costs, and for several alternatives there were limited cost data sources to draw cost estimates from. Consequently, these should be considered indicative, and readers should consider all factors and use local quotes before making financial decisions.

The following general recommendations are provided for industry consideration.

Collection and communication of farm trial data across the industry: Litterpedia

The industry survey found that trials have been conducted quite regularly by individual producers, but the results are not currently communicated to the whole industry. Communication of litter trial results to the whole industry would be beneficial. This could be achieved by establishing a database of litter types and trial results in a more dynamic form (such as a website), where producers could submit information on litter types used.

Development of a litter cost calculator

The industry survey found that litter, delivery, treatment and spreading costs vary significantly between farms and regions. It could be beneficial to develop a simple litter cost calculator to help producers compare the full cost of different litter alternatives. This could take into account:

- litter cost per cubic metre and per square meter (taking into account depth requirement)
- transport cost to farm
- treatment cost (e.g. straw needs to be chopped)
- spreading cost
- management costs (such as tillage requirements)
- sale value of spent litter.

Further research on depth requirements of litter

From both the industry survey and literature review, it was found that the optimal depth of litter can vary significantly between litters and the current RSPCA depth requirement of 50mm is highly prescriptive. There has not been enough research conducted to validate the RSPCA 50mm litter depth requirement for all litter types, which is limiting to the uptake of several litter types that are otherwise promising and may not require the same depth of material as traditional litters. Further research by the industry is needed to determine the optimal depth of traditional and alternative litters, to ensure ideal production and welfare conditions without causing greater cost burdens than are necessary. If this research demonstrates that lower litter depths can be used while maintaining optimum performance, this could be presented to RSPCA as justification for revising the litter depth requirements.

Further research into alternative litter types and management practises, where limited information is available

A range of potential litter materials and management practises were identified in the review and audit that could be suitable for the Australian chicken meat industry but have little information available to enable any rating to be performed. Further research or industry trials would be beneficial to determine if these alternative litters or management practises are suitable for the Australian chicken meat industry. Examples of materials that require further investigation include, canola, grape marc and various nut hulls.

Further research on the optimisation of alternative litters to Australian conditions

Further research is needed to optimise alternative litters to Australian conditions. For example, sand would need more than a one batch trial to optimise system, however, it would be difficult for a commercial business to conduct a long trial.

Provision of extension materials and information in the EMS

In several instances, it was found that litter materials were being applied successfully in one region but were determined ‘unsuitable’ in other regions where they were not commonly used. Several examples were found where management practises were needed to successfully use the alternative litter type (see below). This suggested that litter management extension material would be beneficial, and potentially, this information could be integrated into industry EMS training materials to improve management. Materials, such as video case studies and standard operating procedures, could be suitable and should be considered by the industry.

Specific recommendations for alternative options

Alternative litters options

Recycled wood pallets- Recycling wood pallets could be applied in several regions of Australia, provided that recycling plants apply stringent operating procedures to ensure the material meets the chicken meat industry’s requirements. These operating procedures have been developed in WA and NSW and could be accessed by commercial operations in other regions.

Peat- This material has been deemed suitable in other regions of the world but use in Australia is less likely to occur due to current limited supply and the high cost of imported peat. There are also potential environmental issues, such as GHG emissions, that could inhibit the production of peat in Australia, and therefore limit the future use of this alternative. For these reasons, the material has not been recommended for further investigation at the present time.

Miscanthus grass, switchgrass and other grasses- Currently, miscanthus and switchgrass are not grown commercially in Australia, however, with the success of these litters overseas and the large regions where both plants could be grown commercially in Australia, these grasses could be a viable

litter alternative in Australia. Miscanthus has a high capital cost and no yield in the first year, so the industry would have to invest in long term production of this litter by developing commercial supply agreements to make it viable for crop farmers to plant a perennial crop. To advance this, a more detailed examination of regional agronomic requirements, cost-benefit and business models could be developed to support production and determine the most likely price point for the product, acting as a starting point for negotiations. This would be most beneficial in regions where grower collectives or large regional growers (i.e. with sufficient buying power) exist. WA may be a suitable case study region.

Straw pellets- Currently, this option is price prohibitive because of depth requirements to meet the RSPCA standard, however, with the future introduction of field pellet harvester, cost could be greatly reduced. If there is sufficient industry interest, commercial trials would be required to determine the optimal depth and management conditions of use. Industry would also need to negotiate with the RSPCA over depth requirements.

Sand litter- This option could be applied in the warmer regions of Australia, such as Queensland, though further trials would be required to determine the type of management that is required. The use of sand litter in Queensland would potentially reduce cooling costs, and the reuse of sand litter over several years could control the potential for gizzard stones to affect processing machinery. Sand litter would be less suitable for colder regions of Australia due to its high density and thermal conductivity/heating requirements. There are two major areas that require research- 1) optimisation for Australian conditions and 2) potential processing issues (gizzard stones).

Alternative management options

Reuse- This option could be expanded throughout all regions of Australia, with implementation of suitable risk management practises. Producers that currently reuse litter noted that it takes time to learn how to manage this system well. Consequently, extension activities (videos, fact sheets, standard operating procedures) could improve the success of new growers that wish to trial reuse.

Litterless- The litterless (slatted) systems options could be applied throughout warmer regions of Australia, however, trials and market testing is recommended to see if any problems are likely to emerge as a result of this practise. Implementation in the free-range egg sector provides a positive case study for application in meat chickens. The litterless option is likely to be unsuitable for colder regions of Australia because the high heating requirements in these regions would make it cost prohibitive. As slats are currently used in the egg industry, it should be possible to find suitable suppliers in Australia and the regulatory or welfare barriers should be reduced. If this was considered a worthwhile area to investigate, a further project would be beneficial to consult industry and regulators, including the RSPCA, regarding potential barriers for uptake, and to produce a more detailed cost-benefit analysis. This could then be extended to field trials if the results were favourable.

Caged – While this alternative management option is commonly used overseas, in Australia there are significant RSPCA and consumer concerns with the welfare of layer hens in this system and it is therefore not recommended, despite being technically suitable.

Seasonal use of litter- The option to switch between litters dependent on seasonal availability could be applied in regions where there are multiple litters seasonally available. For example, in Victoria producers could switch between rice hulls (summer crop), wheat straw (winter crop) and sawdust depending on the seasonal availability. It should be noted that different litters require different management practises, which could result in poorer management outcomes. Having suitable standard operating procedures may help to partially overcome this problem.

Alternative litter processing options

Pelletisation- This litter processing option could be used to turn materials that are of low quality into pellets that are more usable litter product for chicken meat production. This option may be more

suitable for litter suppliers, rather than chicken growers. Currently, the cost of pelletisation and the RSPCA depth requirement is likely to inhibit the application of this option to the Australian chicken meat industry, however, commercial supply agreements with pellet manufactures could reduce costs, making it more economically viable. Further research by the industry is needed on depth requirements, characteristic of pelletised material and cost minimisation for Australian conditions.

Straw processing - On farm straw processing (chopping, crushing) could be used to improve the suitability of straw and improve litter management outcomes. The industry survey found the majority of producers have optimised straw litter use by finely chopping and crushing straw themselves before use. For users planning to use straw, it would be beneficial to develop and provide information that shows the ideal processing options via simple videos, fact sheets or standard operating procedures, to improve litter management across the industry.

Cereal Straw- The use of straws could be expanded throughout all of Australia, as the material is widely available at a competitive cost in most years. However, straw requires additional management (tilling) to address the problems with caking. The industry survey found several producers have optimised straw litter use by finely chopping and crushing straw before use and tilling as required. Additionally, several southern Australian producers will add a layer of sawdust over straw to control moisture levels and caking during winter. Using this producer knowledge, extension materials such as video case studies or fact sheets could be developed showing ‘best practise’ management of straw with helpful information and standard operating procedures (SOPs) that can be adopted by growers that have not previously used straw as a litter option.

References

AAB (2015) *Bedding info*, United Kingdom: Alternative Animal Bedding (AAB). Available at: http://alternativeanimalbedding.com/beddinginfo.htm.

Abreu, V. M. N., Abreu, P. D., Paiva, D. P., Coldebella, A., Jaenisch, F. R. F., Cestonaro, T. and Silva, V. S. (2013) 'Evaluation of Soybean Straw as Litter Material in Poultry Production and Substrate in Composting of Broiler Carcasses', *Composting of Broiler Carcasses, Soybean*. Hany El-Shemy: IntechOpen. Available at: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/96714/1/6886.pdf.

Abreu, V. M. N., Abreu, P. G. d., Coldebella, A., Jaenisch, F. R. F. and Silva, V. S. (2011) 'Evaluation of litter material and ventilation systems in poultry production: I. overall performance', *Revista Brasileira de Zootecnia*, 40(6), pp. 1364-1371.

ABS (2016a) *7121.0 Agricultural Commodities, Australia, 2014-2015*, Australia: Australian Bureau of Statistics (ABS).

ABS (2016b) *7215.0 Livestock Products, Australia*, Australia: Australian Bureau of Statistics (ABS). Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7215.0Jun%202016?OpenDocument.

ABS (2017) *7215.0 Livestock Products, Australia*, Australia: Australian Bureau of Statistics (ABS).

ACMF (2011) *The Australian Chicken Meat Industry: An Industry in Profile*, North Sydney, NSW: The Australian Chicken Meat Federation. Available at http://www.chicken.org.au/industryprofile/.

ACMF (2014) *Submission to the Agricultural Competitiveness Taskforce*, Australia: Australian Chicken Meat Federation Inc.White Paper Submission - IP500).

Adapa, P., Tabil, L., Schoenau, G. and Opoku, A. (2010) 'Pelleting characteristics of selected biomass with and without steam explosion pretreatment', *International Journal of Agricultural and Biological Engineering*, 3(3), pp. 62-79.

Adebayo, I. A., Awoniyi, T. A. M. and Akenroye, A. H. (2009) 'Growth performance and meat wholesomeness of broiler chickens reared on different types of litter materials', *Journal of Food, Agriculture & Environment*, 7.3 & 7.4, pp. 5.

AFRMA (2015) *Purr & Simple™ Litter Review*, America: American Fancy Rat and Mouse Association (AFRMA). Available at: http://www.afrma.org/cc_purrsimple.htm.

Ag Products 2018. AG CATTLE AND ANIMAL BEDDING | PRODUCTS. Available at - http://www.ag-products.co.uk/bedding/.

AGCO GSI (2013) *Slatted floor broiler house (explainer video)*, Bukit Minyak: AGCO GSI. Available at: https://www.youtube.com/watch?v=OMo8h7NipFs.

AGRA Marketing Group 2016. By-Products / Almonds. Available at: http://www.agramarketing.com/by-products/almonds.

Aktan, S. and Sagdic, O. (2004) 'Dried rose (Rosa damascena Mill.) dreg: An alternative litter material in broiler production', *South African Journal of Animal Science*, 34(2), pp. 5.

Allison, R. C. and Jordan, H. C. (1973) 'Criteria and evaluation of hardwood bark as a poultry litter', *Forest products journal*.

Andrews, L. and McPherson, B. (1963) 'Comparison of different types of materials for broiler litter', *Poultry Science*, 42(1), pp. 249-254.

Andrews, L. D., Stamps, L., Johnson, Z. and Arbabi, A. R. (1988) 'Influence of floor types on performance of broiler breeder hens', *Poultry Science*, 67(10), pp. 4.

Anval Valves *Bulk Density Chart*, Available at: http://www.anval.net/downloads/bulk%20density%20chart.pdf.

Arbortanics Incorporated (2016) *Giant Japanese Silver Grass (Miscanthus)*, Longmont, CO: Arbortanics Inc. dpa The Tree Farm. The Accessed 02/02/2018. Available at: http://www.thetreefarm.com/japanese-silver-grass-giant.

Atapattu, N. S. B. M. and Wickramasinghe, K. P. (2007) 'The use of refused tea as litter material for broiler chickens', *Poultry Science*, 86(5), pp. 5.

Atencio, J. L., Fernández, J. A., Gernat, A. G. and Murillo, J. G. (2010) 'Effect of pine wood shavings, rice hulls and river bed sand on broiler productivity when used as a litter sources', *International Journal of Poultry Science*, 9, pp. 4.
AUBIOSE (2018) *Horse Bedding*, United Kingdom: AUBIOSE. Available at: http://www.aubiose.co.uk/.
Avdalovic, V., Vucinic, M., Resanovic, R., Avdalovic, J., Maslic-Strizak, D. and Vucicevic, M. (2017) 'Effect of Pelleted and Chopped Wheat Straw on the Footpad Dermatitis in Broilers', *Pakistan Journal of Zoology*, 49(5), pp. 8.
Aviagen 2009. Ross Broiler Management Manual. Available at: https://wp.ufpel.edu.br/avicultura/files/2012/04/Ross_Broiler_Manual_308.pdf: Aviagen.
Aviagen (2016) *A guide to managing broilers in open-sided housing*, Huntsville, Alabama: Aviagen. Available at: http://eu.aviagen.com/assets/Tech_Center/Broiler_Breeder_Tech_Articles/English/AVIAEnvMgtOpenSidedHseBroiler-EN-2016.pdf.
AviHome LLC 2018. AviHome™ Technology. Available at: http://www.avihomellc.com/technology.aspx.
Aydin, C. (2003) 'Physical properties of almond nut and kernel', *Journal of Food Engineering*, 60(3), pp. 315-320.
Azeus (2015) *Energy Crops Pellets - A Revolution for Miscanthus*, Zhengzhou, China: Zhengzhou Azeus Machinery Co.,Ltd. Available at: http://www.biopelletmachine.com/biopellets-making-guidance/energy%20crops%20pellets%20-%20a%20revolution%20for.html
Ballard, L. (1995) *Bedding materials for animal. Patent no. US5429073A*, United States of America: U.S. Patent. Available at: https://patents.google.com/patent/US5429073.
BC Sands *River Sand Natural (Brown)*. Available at - http://www.bcsands.com.au/index.php?main_page=product_info&cPath=74_68&products_id=2313&zenid=cs922i8fav1dmnm04rkv1fb5u7: BC Sands.
Benabdeljelil, K. and Ayachi, A. (1996) 'Evaluation of alternative litter materials for poultry', *Journal of Applied Poultry Research*, 5(3), pp. 7.
Bilgili, S., Hess, J., Blake, J. and Eckman, M. (2000) 'Turning Trash into treasure: Sand as bedding material for rearing broilers', *Highlights of Agricultural Research*, 47(1).
Bilgili, S. F., Hess, J. B., Blake, J. P., Macklin, K. S., Saenmahayak, B., & Sibley, J. L. (2009) 'Influence of bedding material on footpad dermatitis in broiler chickens', *Journal of Applied Poultry Research*, 18(3), pp. 7.
Bilgili, S. F., Montenegro, G. I., Hess, J. B. and Eckman, M. K. (1999) 'Sand as litter for rearing broiler chickens', *Journal of Applied Poultry Research*, 8(3), pp. 7.
Bilings, L. D. (1993) *Absorbent material with wood and peat. U.S. Patent No. 5,271,355*, United States of America: U.S. Patent. Available at: https://patents.google.com/patent/US5271355.
Bouffier, C. G., Riall, B. W. and Downing, C. C. (1996) *Pallet disposal: Current Situation and opportunities for change*, Muscle Shoals, AL (United States)No. CONF-960958-).
Brake, J. D., Boyle, C. R., Chamblee, T. N., Schultz, C. D. and Peebles, E. D. (1992) 'Evaluation of the chemical and physical properties of hardwood bark used as a broiler litter material.' *Poultry Science*, 71(3), pp. 6.
Brake, J. D., Fuller, M. J., Boyle, C. R., Link, D. E., Peebles, E. D., & Latour, M. A. (1993) 'Evaluations of Whole Chopped Kenaf and Kenaf Core Used as a Broiler Litter Material', *Poultry science*, 72(11), pp. 5.
Bramley, A. (1962) *Bedding. Patent no. US3066646*, United States of America: U.S. Patent.
Breeder's Choice (2018) *Breeders Choice Cat Litter*, United States: Breeder's Choice. Available at: http://www.breeders-choice.com.au/.
Burg, P., Vítěz, T., Turan, J. and Burgová, J. (2014) 'Evaluation of grape pomace composting process', *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(5), pp. 875-881.
Burt, C. D. (2015) *Effects of gypsum addition to broiler litter*. PhD, University of Georgia, United States.
Carpenter, G. H. 'Current Litter Practices and Future Needs'. *Proc. Natl. Poult. Waste Manage. Symp.* , Birmingham, Alabama.

Carter, T. A., Allison, R. C., Mills, W. C. and West, J. R. (1979) 'Wood chips for poultry litter', *Poultry Science*, 58, pp. 4.
Carter, T. A., Bressler, G. O. and Gentry, R. F. (1972) 'Wire and litter management systems for broiler breeders', *Poultry Science*, 51(2), pp. 6.
Caslin, B., Finna, J. and Easson, L. 2011. Miscanthus Best Practice Guidelines. Available at: https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/bioenergyscheme/MiscanthusBestPracticeManual190913.pdf: Teagasc.
Chaloupka, G. W., Loyd, R. W., Gordy, J. F. and Greene, L. M. (1967) 'Evaluation of litter materials for broiler production', *Poultry Science*, 46(5), pp. 5.
Chamblee, T. N. and Yeatman, J. B. (2003) 'Evaluation of Rice Hull Ash as Broiler Litter', *Journal of applied poultry research*, 12(4), pp. 4.
Christianson, G. (1981) *Animal litter and method of preparation. U.S. Patent 4,263,873.*, United States of America: U.S. Patent.
Cooper, J. B. and Barnett, B. D. (1972) 'Performance of broiler breeders on slats versus slat-litter floors', *Poultry Science*, 51(4), pp. 3.
Coufal, C. D., Chavez, C., Niemeyer, P. R. and Carey, J. B. (2006) 'Measurement of broiler litter production rates and nutrient content using recycled litter', *Poultry science*, 85(3), pp. 6.
Currey, J. E. and The Cosmin Corporation (1981) *Deodorizing litter for poultry farms. U.S. Patent No. 4306516*, United States of America: U.S. Patent.
Curry, C. W., Bennett, R. H., Hulbert, M. H., Curry, K. J. and Faas, R. W. J. M. G. a. G. (2004) 'Comparative study of sand porosity and a technique for determining porosity of undisturbed marine sediment', 22(4), pp. 231-252.
de Jong, I. and van Narn, J. (2012) *Management Tools to Reduce Footpad Dermatitis in Broilers*, The Netherlands: Aviagen. Available at: http://en.staging.aviagen.com/assets/Tech_Center/Broiler_Breeder_Tech_Articles/English/AviaTech-FoodpadDermatitisSept2012.pdf.
DeBruyn, J. (2015) *Livestock Farm Uses of Switchgrass and Miscanthus*, Ontario: OMAFRA. Available at: https://ontariobiomassproducersgroup.wildapricot.org/Resources/Documents/Ag%20Biomass%20Day%202015/Ag%20Biomass%20Day%202015%20Presentations/7%20-%20Livestock%20Farm%20Uses%20of%20Switchgrass%20and%20Miscanthus.%20Jake%20DeBruyn,%20Ag%20Biomass%20Day%202015.pdf.
Department of Mining and Energy, S. 2018. Calculate appliance running costs. Available at: https://www.sa.gov.au/topics/energy-and-environment/using-saving-energy/calculate-running-costs: Department of Premier and Cabinet - SA.
Dingke, Z. and Fielke, J. (2014) 'Some physical properties of Australian Nonpareil almonds related to bulk storage', *International Journal of Agricultural and Biological Engineering*, 7(5), pp. 116-122.
Direct Pallets® (2018) *Direct BioBedding® – Forest Friendly Animal Bedding*, United States: Direct Pallets®. Available at: http://www.directpallets.com.au/direct-bioproducts/direct-biobedding/.
Dorahy, C. G. and Dorahy, C. M. (2008) *Understanding the Fertiliser Value of Poultry Litter, RIRDC Project No. PRJ-2752*, Australia: RIRDC.
Dowell, J. G. W. (1955) *Poultry litter. U.S. Patent No. 2712811*, United States of America: U.S. Patent.
Dunkley, C. and Ritz, C. (2017) *Giant Miscanthus grass as an alternative bedding in poultry houses*, United States: UGA Extension. Available at: https://secure.caes.uga.edu/extension/publications/files/pdf/B%201470_1.PDF.
Dunlop, M. 'Moistume Holding Capacities of Various Litter Materials'. *PIX 2014 Litter Management Workshop*, Gold Coast, Australia, 28 May: PIX Committee, 25-34.
Ecoland (2018) *Bedding for animals*, Poland: Ecoland. Available at: http://eco-land.pl/en/productsen/bedding-for-animals.html.
El-Deek, A. A., Al-Harthi, M. A., Khalifah, M. M., Elbanoby, M. M. and Alharby, T. (2011) 'Impact of newspaper as bedding material in arid land on broiler performance', *Egypt Poult Sci*, 31, pp. 11.

Embury, I. S. (1987) *Alternative litter materials for poultry*, NSW: NSW Agriculture. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/134446/Alternative-litter-materials-for-poultry.pdf.
EMRC (2018) *Wood Chip and fines*, Australia: EMRC. Available at: http://www.emrc.org.au/waste-services/waste-and-recycling-services/recycling-services-and-products/emrc-recycled-products/wood-chip.aspx.
Engineering, K. 2018. Straw Pellet Machine for Sale and Pellet Plant Manufacturer. Available at - http://www.biomasspelletplant.com/news/Straw-Pellet-Machine.html: KMEC Engineering.
Enueme, J. E. and Waibel, P. E. (1987) 'Research note: Comparison of reed-sedge peat with wood shavings as bedding for turkeys', *Poultry Science*, 66(9), pp. 1508.
ENVIGO (2018) *Key benefits of 7084 Teklad pelleted paper bedding*, United States: ENVIGO. Available at: https://www.envigo.com/products-services/teklad/bedding-and-environmental-enrichment/contact-bedding/7084-pelleted-paper.aspx.
Equisearch (2005) *Bedding For Horses: Material Choices*, United States: Equisearch. Available at: https://www.equisearch.com/articles/bedding-for-horses-18103.
Everett, D. L., Vizzier-Thaxton, Y., McDaniel, C. D. and Kiessume, A. S. (2013) 'The impact of peat moss amendments on the microbial load in used pine shaving poultry litter', *Int. J. Poult. Sci.*, 12(4), pp. 4.
Farhadi, D. (2014) 'Evaluation of the physical and chemical properties of some agricultural wastes as poultry litter material', *Global Journal of Animal Scientific Research*, 2(3), pp. 7.
Fisher, S. (1973) *Animal litter. U.S. Patent No. 3765371*, United States of America: U.S. Patent.
Fisinin, V. and Kavtarashvili, A. (2013) *Evaluation of in-cage broilers cultivation technology considering new realities*, Ukraine: TEXHA. Available at: http://texha.com/en/press-center/articles/evaluation-of-in-cage-broilers-cultivation-technology-considering-new-realities.html.
FIT (2018) *Golden Broiler Floor*, Steinfurt: Farm Innovation Team (FIT). Available at: http://farm-innovation-team.de/golden-broiler-floor-system/.
Flame Engineering Inc 2017. RED DRAGON® POULTRY HOUSE FLAME SANITIZER. Available at - https://flameengineering.com/products/red-dragon-poultry-house-flame-sanitizer: Online.
Février, C. and Willequet, F. (2009) 'Valorisation par l'alimentation animale', in Moletta, R. (ed.) *Le traitement des déchets*. Paris: Éd. Tec & Doc/Lavoisier.
Garcia, M. C. 'Characteristics of broiler litter using different types of materials (straw, wood shavings and rice hulls). A Castilla y Leon (Spain) case study'. *International Symposium on Air Quality and Waste Management for Agriculture, Broomfield, CO. Pub*.
Garcia, R. G., Almeida Paz, I. C. L., Caldara, F. R., Nääs, I. A., Bueno, L. G. F., Freitas, L. W. and Sim, S. (2012a) 'Litter materials and the incidence of carcass lesions in broilers chickens', *Revista Brasileira de Ciência Avícola*, 14(1), pp. 6.
Garcia, R. G., Almeida Paz, I. C. L., Caldara, F. R., Nääs, I. A., Pereira, D. F. and Ferreira, V. M. O. S. (2012b) 'Selecting the most adequate bedding material for broiler production in Brazil', *Revista Brasileira de Ciência Avícola*, 14(2), pp. 7.
Garcês, A., Afonso, S. M. S., Chilundo, A. and Jairoce, C. T. S. (2013) 'Evaluation of different litter materials for broiler production in a hot and humid environment: 1. Litter characteristics and quality', *Journal of Applied Poultry Research*, 22(2), pp. 9.
García-Lomillo, J. and González-SanJosé, M. L. (2017) 'Applications of wine pomace in the food industry: approaches and functions', *Comprehensive Reviews in Food Science and Food Safety*, 16(1), pp. 3-22.
Gençoğlan, S. and Gençoğlan, C. (2017) 'The Effect of the Litter Materials on Broiler Chickens Welfare and Performance', *Turkish Journal of Agriculture-Food Science and Technology*, 5(12), pp. 8.
Gernat, A. (2009) *Use of sand as litter for broilers*. Available at: https://www.wattagnet.com/articles/3911-use-of-sand-as-litter-for-broilers: Watt Ag Net 2018.
Ghaly, R. A., Pyke, J. B., Ghaly, A. E. and Ugursal, V. I. (1999) 'Physical and thermochemical properties of uncontaminated and diesel-contaminated peat', *Energy sources*, 21(5), pp. 9.
Godchaux, W. (1939) *Poultry litter and animal bedding. U.S. Patent No. 2179591*, United States of America: U.S. Patent.

Gonzalez, A. G., Pokrovsky, O. S., Beike, A. K., Reski, R., Di Palma, A., Adamo, P., Giordano, S. and Fernandez, J. A. (2016) 'Metal and proton adsorption capacities of natural and cloned Sphagnum mosses', *Journal of colloid and interface science*, 461, pp. 326-334.
Green Pet Products Inc (2018) *Aspen Supreme™ pellets- Pet and Bird All Natural Litter/Bedding*, Conrad, IA: Green Pet Products Inc. Available at: http://www.greenpetproducts.com/prodaspen.htm.
Grimes, J., Smithi, J. and Williams, C. (2002) 'Some alternative litter materials used for growing broilers and turkeys', *World's Poultry Science Journal*, 58(4), pp. 515-526.
Grimes, J. L. (2004) 'Alternative litter materials for growing poultry', *North Carolina Poultry Industry Newsletter*, 1(11), pp. 4.
Grimes, J. L., Carter, T. A., Gernat, A. E. and Godwin, J. L. (2007) 'A novel bedding material made from cotton waste, gypsum, and old newsprint for rearing turkeys', *Journal of Applied Poultry Research*, 16(4), pp. 6.
Hafeez, A., Suhail, S. M., Durrani, F. R., Jan, D., Ahmad, I., Chand, N. and Rehman, A. (2009) 'Effect of different types of locally available litter materials on the performance of broiler chicks', *Sarhad J Agric*, 4, pp. 6.
Harms, R., Simpson, C., Waldroup, P. and Ammerman, C. 1968. Citrus pulp for poultry litter and its subsequent feeding value for ruminants. Florida Agricultural Experiment Station
Hay, G. P. (1965) *Litter and bedding for poultry. U.S. Patent No. 3217692*, United States of America: U.S. Patent.
HCCMPW (2010) *Alternative bedding materials for beef and sheep housing systems in Wales*, Wales: Hybu Cig Cymru / Meat Promotion Wales.
Henan Danong agricultural S&T Co. LTD (2018) *Poultry Slat Floor*, China: Henan Danong agricultural S&T Co. LTD. Available at: http://www.chicken-cage.com/broiler-ground-system/poultry-slat-floor.html.
Hester, P. Y. C., D. L. and Bryan, T. A. (1997) 'The applicability of particleboard residue as a litter material for male turkeys', *Poultry science*, 76(2), pp. 8.
Heuzé, V. and Tran, G. 2017. Grape Pomace, Available at - https://www.feedipedia.org/node/691: Feedipedia.
Higgins, A. (2017) *Peat moss: Good for plants but bad for the planet*, United States: Financial Review. Available at: https://www.afr.com/business/environmental-services/peat-moss-good-for-plants-but-bad-for-the-planet-20170515-gw52mt.
Islam, A. F. M. F., Heuvel, A., Walkden-Brown, S. W., Cressman, M. D. and Redding, M. R. 'Effect of high level inclusion of adsorbent materials in litter on chicken welfare, performance and litter ammonia production'. *24th Annual Australian Poultry Science Symposium*, Sydney, 17-20 February 2013: Poultry Research Foundation, 183-186.
Jacob, J. (2015) *Litter Material for Small and Backyard Poultry Flocks*, United States: University of Kentucky. Available at: http://articles.extension.org/pages/65873/litter-material-for-small-and-backyard-poultry-flocks.
JHFarming (2018) *Chicken Coop Floor Plastic Slatted Flooring*, China: JHFarming. Available at: http://www.jhfarming.com/broiler-ground-system/plastic-slatted-flooring.html.
Johnston, C. (1990) *U.S. Patent No. 4901671*, United States of America: U.S. Patent.
Jordaan, J. D. (2004) *The influence of bedding material and collecting period on the feeding value of broiler and layer litter. Dissertation*, Bloemfontein: Univeristy of the Free State. Available at: http://nrfnexus.nrf.ac.za/handle/20.500.11892/99834.
Karcher, D. M., Makagon, M. M., Fraley, G. S., Fraley, S. M. and Lilburn, M. S. (2013) 'Influence of raised plastic floors compared with pine shaving litter on environment and Pekin duck condition', *Poultry science*, 92(3), pp. 8.
Keithly, J. H., Taggart, T. and Wilson, D. L. (2003) *U.S. Patent No. 6523496*, United States of America: U.S. Patent.
Keithly, J. H., Taggart, T. and Wilson, D. L. (2005) *U.S. Patent No. 6860232*, United States of America: U.S. Patent.
Kheravii, S. K., Swick, R. A., Choct, M. and Wu, S. B. (2017) 'Potential of pelleted wheat straw as an alternative bedding material for broilers', *Poultry science*, 96(6), pp. 7.

Kliment, K., Vermes, R. N. and Stockel, R. F. (1977) *Water soluble polymers useful in the preparation of novel animal litter*. [Online].
Kosanović, A. R. 2015. Wheat straw pellets increase poultry production by 20%. Available at - https://www.linkedin.com/pulse/wheat-straw-pellets-increase-poultry-production-20-radukin-kosanovi%C4%87: LimkedIn.
Krone UK 2018. Premos 5000. Available at - https://www.krone-uk.com/english/products/pellet-harvester/premos-5000/: Online.
Labosky Jr, P., Holleman, K. A., Dick, J. W. and So, D. T. (1977) 'Utilization of bark residues as poultry litter', *Forest Products Journal*.
Lander, H. L. (1984) *Non-water wettable granular material and method of preparing and using same. U.S. Patent 4471717*, United States of America: U.S. Patent.
Lien, R. J., Conner, D. E. and Bilgili, S. (1990) *Comparison of Recycled Paper Chips to Pine Shavings for Use as Broiler Litter*, Virginia: Poult. Sci. Meeting.
Lipscomb, J. M. and Repinski, S. (2016) *Coated extruded animal litter. U.S. Patent 9266090*, United States of America: U.S. Patent.
Lloyd, P. D. (2002) *Method of applying bedding on the floor of a poultry rearing barn and for recycling or disposing of spent bedding. U.S. Patent 6453846*, United States of America: U.S. Patent.
Malone, G. W., Allen, P. H., Chaloupka, G. W. and Ritter, W. F. (1982) 'Recycled paper products as broiler litter', *Poultry Science*, 61, pp. 5.
Malone, G. W. and Chaloupka, G. W. (1983) 'Influence of litter type and size on broiler performance: 2. Processed newspaper litter particle size and management', *Poultry Science*, 62, pp. 4.
Malone , G. W. and Martin , J. H. J. (1999) 'Evaluation of a clay-based product as an alternative bedding material for broilers', *Poultry Science*, 78.
Malone, G. W., Tilmon, H. D. and Taylor, R. W. (1990) 'Evaluation of kenaf core for broiler litter', *Poultry Science*, 69, pp. 4.
Martinez, D. F. and Gernat, A. G. (1995) 'The effect of chopped computer and bond paper mixed with wood shavings as a litter material on broiler performance', *Poultry Science*, 74, pp. 5.
McGahan, E., Bielefeld, N., Wiedemann, S., Keane, O. and Consulting, F. (2014) *National Environmental Management System for the Meat Chicken Industry: A Report for the Rural Industries Research and Development Corporation. Version 2. Publication No. 14/100. Project No PRJ-005765.* RIRDC.
Miles, D. M., Rowe, D. E. and Cathcart, T. C. (2011) 'Litter ammonia generation: Moisture content and organic versus inorganic bedding materials', *Poultry Science*, 90(6), pp. 8.
Monira, K. N., Islam, M. A., Alam, M. J. and Wahid, M. A. (2003) 'Effect of litter materials on broiler performance and evaluation of manureal value of used litter in late autumn', *Asian-australasian journal of animal sciences*, 16(4), pp. 3.
Moore , J. (2014) *The good bedding guide*, Available at: http://www.countrysmallholding.com/poultry/the-good-bedding-guide-1-3695353: Country Smallholding.
Mormino, K. S. (2018) *Chicken Coop Litter: Sand, the Litter Superstar*: http://www.the-chicken-chick.com/chicken-coop-bedding-sand-litter/ 2018).
Morrison, D. G. (1989) *Processed peat poultry litter for confined enclosures. U.S. Patent 4827871*, United States of America: U.S. Patent.
Mountain Meadows 2018. Critter Country. Available at - http://www.mtnmeadowspet.com/critter_country.html.
Moyle, J. R., Brooks, L. A., McCrea, B. A. and Brown, W. R. (2016) 'On-farm assessment of switchgrass bedding', *The Journal of Applied Poultry Research*, 25(2), pp. 5.
Musa, W. I., Sa`idu, L., Kaltungo, B. Y., Abubakar, U. B. and Wakawa, A. M. (2012) 'Poultry Litter Selection, Management and Utilization in Nigeria', *Asian Journal of Poultry Science*, 6, pp. 12.
Navneet, K., Nagra, S., Daljeet, K. and Hanah, S. (2015) 'Paddy straw as an alternate bedding material for broiler chicks'.
Neubauer, H. A. (1976) *U.S. Patent No. 3,980,050*.

Newcombe, M., Fitzsimmons, R. C. and Decolongon, J. (1991) 'Effect of floor type and energy source on growth and productivity of broiler breeders', *Poultry Science*, 70 (11), pp. 7.
NSW Agriculture (2004) *Agfact A5.1.9. Alternative litter materials for poultry* Australia: NSW Department of Primary Industries (DPI). Available at: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/134446/Alternative-litter-materials-for-poultry.pdf.
Nudgee Road Landscape Supplies (2018) *Peat Moss 220L*. Available at - http://nudgeeroadlandscapes.com.au/buyonline/index.php?main_page=product_info&products_id=330: Nudgee Road Landscape Supplies 2018).
Oxbow 2018. Bene Terra Eco-Straw. Available at - http://www.oxbowanimalhealth.com/our-products/litter-bedding/bene-terra-eco-straw: Online.
OZ Gardener (2013) *The Perils of Peat Moss*. Available at - http://thegardenofoz.org/peat.asp: OZ Gardener 2018.
Palmer Jr, W. M. (1996) *U.S. Patent No. 5542374*, United States of America: U.S. Patent.
Parkhurst, C. R. (1974) 'Comparison of broiler breeders housed on full and partial slat floors', *Poultry Science*, 53(3), pp. 4.
Parsons, A. H. and Baker, S. L. (1985) 'Softwood chipping fines: Efficacy as poultry litter', *Poultry Science*, 64, pp. 4.
Pennell, K. (2016) *Specific Surface Area*.
Pet Care Systems Inc 2018. Products. Available at - https://www.swheatscoop.com/products/.
Pet Circle 2016. Oz-Pet Pellet Litter. Available at - https://www.petcircle.com.au/product/oz-pet-animal-litter/ozp7458?iv_=__iv_p_1_a_194017531_g_9922078651_w_pla-258242668235_h_9069291_ii__d_c_v__n_g_c_49757910931_k__m__l__t__e__r_1o4_x_pla_y_9484867_f_online_o_OZP7458_z_AU_i_en_j_258242668235_s__vi__&gclid=EAIaIQobChMI7dexqqjE1QIVTH29Ch2syQlnEAYYBCABEgJpUPD_BwE.
Philip, R. (2013) 'Cheong Bee see success in e-systems', *Asian Poultry Magazine*.
Plant Biotech Pty. Ltd. 2018. Miscanthus GiganteusThe Best Biofuel Plant for Biomass Extraction. Available at - https://www.miscanthus.com.au/.
Playsted, C., Wiedemann, S. and McGahan, E. (2011) *Biochar Manufacture from Poultry Litter Final Report*, Australia: Rural Industries Research and Development Corporation (RIRDC).
Porschitz, H. R. and Schwarz, B. 'Wood shavings as insulating material for prefabricated low energy homes', *World Conference on Timber Engineering*, Whistler Resort, British Columbia, Canada.
PW Reporters (2012) 'New poultry bedding from miscanthus', *Farmers Weekly*.
Redding, M. R. (2013) 'Bentonite can decrease ammonia volatilisation losses from poultry litter: laboratory studies', *Animal Production Science*, 53(10), pp. 4.
Reed, M. J. and McCartney, M. G. (1970) 'Physical properties of selected litter materials and performance of broiler chickens', *Physical properties of selected litter materials and performance of broiler chickens.* (75).
Reinhart, D. R. 2004. Estimation of the Moisture Content in Typical MSW. Available at - http://msw.cecs.ucf.edu/Exercise-EstimationoftheMoistureContentinTypicalMSW.pdf: University of Central Florida.
Renergy UK Ltd 2018 Straw Pellets. Available at - http://www.renergyuk.com/home/: Online.
Ritz, C., Czarick, M. and Fairchild, B. (2015) *Final Report: Evaluation of the Use of the AviHome Plenum Flooring System in Commercial Broiler Production in Georgia*: University of Georgia.
Ritz, C. W., Fairchild, B. D. and Lacy, M. P. (2017) *Litter Quality and Broiler Performance*, Available at - http://extension.uga.edu/publications/detail.html?number=B1267&title=Litter%20Quality%20and%20Broiler%20Performance: University of Georgia.
RSPCA (2013) *Meat Chickens: RSPCA Approved Farming Scheme Standards*, Deakin West, ACT.
Runge, G. A., Blackall, P. J. and Casey, K. D. (2007) *Chicken Litter - Issues Associated with Sourcing and Use*, RIRDC.
Samson, R., Deen, B. and Nott, D. 2017. Using Switchgrass and Miscanthus as sustainable livestock and poultry bedding. Available at

- http://www.ontariobiomass.com/resources/Documents/KTT%20Projects/KTT%20Documents%20and%20Videos/SG%20MISCBeddingFINAL.pdf: Ontario Biomass Producers Co-operative INC.
Sansom, G. 'Alternative litter sources and management', *Poultry Information Exchange (PIX)*, Gold Coast, QLD.
Sarica, M. and Cam, M. A. (2000) 'Potential of hazelnut husks as a broiler litter material', *British poultry science*, 41(5), pp. 3.
Schulein, B. M. and Schulein Jr, B. M. (1969) *Animal litter preparation. U.S. Patent 3425397*, United States of America: U.S. Patent.
Sharma, G., Khan, A., Singh, S. and Anand, A. K. (2015) 'Efficacy of pine leaves as an alternative bedding material for broiler chicks during summer season. Veterinary world, 8(10), 1219.', *Vetrinary World*, 8(10), pp. 1.
Shepherd, E., Fairchild, B. and Ritz, C. (2017) 'Alternative bedding materials and litter depth impact litter moisture and footpad dermatitis', *Journal of Applied Poultry Research*, 26(4), pp. 518-528.
Simpson, G. and Nakaue, H. (1987) 'Performance and carcass quality of broilers reared on wire flooring, plastic inserts, wood slats, or plastic-coated expanded metal flooring each with or without padded roosts', *Poultry Science*, 66(10), pp. 1624-1628.
Singh, C. and Sharma, R. (2000) 'Utilization of different litter materials for raising commercial broilers in hilly area', *Mortality*, 4(5), pp. 5.
Skewes, P. A., Hughes, B. L., Allen, W. H. and Dawson, P. L. (1998) 'Recycled rubber tires as an alternative material for poultry house litter', *Poultry Science* 77 (Suppl.1): 146
Slobodzian–Ksenicz, O. and Kuczynski, T. (2002) 'Effect of litter type on ammonia emission in turkey housing', *Agricultural Engineering International: CIGR Journal*.
Snyder, J., Rowoth, O., Scholes, J. and Lee, C. 1958. Pages 79–83 in Profitable Poultry Management. Beacon Milling Co., Cayuga, NY.
Stasiak, M., Molenda, M., Bańda, M., Wiącek, J., Parafiniuk, P. and Gondek, E. (2017) 'Mechanical and combustion properties of sawdust—Straw pellets blended in different proportions', *Fuel Processing Technology*, 156, pp. 366-375.
Strawcomfort 2016. Superior Straw Pellets. Available at - http://www.strawcomfort.lt/superior-straw-pellets: AT Energy.
Stuart, G. A. (1987) *Animal litter and related processes. U.S. Patent 4685420*, United States of America: U.S. Patent.
Sudin, N. (2014) *Evaluating Biological Alternative Material for Poultry Bedding.* Bachelor of Chemical Engineering (Biotechnology), University Malaysia Pahang.
Sugarman, N. (1955) *Animal bedding. U.S. Patent 2708418*, United States of America: U.S. Patent.
Swain, B. K. and Sundaram, R. N. S. (2000) 'Effect of different types of litter material for rearing broilers', *British poultry science*, 41(3), pp. 2.
TDA & EPA NSW (2012) *Specification for the Supply of Recycled Urban Wood for Broiler Chicken Bedding 2012*, Available at - http://www.timberstewardship.org.au/images/pdf_documents/final_uwpb_spec_2012_12_08.pdf.
Thacker, C. E. (1986) *Animal litter. U.S. Patent No. 4607594*, United States of America: U.S. Patent.
The Andersons (2018) *Pel-o'Cobs® Pelleted, absorbent bedding*, Ohio: The Andersons Lab Bedding Products. Available at: https://andersonslabbedding.com/cob-products/pel-ocobs/.
Thompson, C. 2015. Giant miscanthus grass an alternative for bedding in poultry houses. Available at - http://www.caes.uga.edu/newswire/story.html?storyid=5643: University of Georgia.
Thornberry, F., Arnold, J. and Currie, C. 'Comparative Evaluation of Processed Pine Bark Shavings for Poultry Litter'. *POULTRY SCIENCE*: Oxford University Press.
Tucci, F. J. (1977) *Artificial bedding material for animals*.
Villagra, A., Olivas, I., Benitez, V. and Lainez, M. (2011) 'Evaluation of sludge from paper recycling as bedding material for broilers', *Poultry science*, 90(5), pp. 5.
Villagrá, A., Olivas, I., Althaus, R. L., Gómez, E. A., Lainez, M. and Torres, A. G. (2014) 'Behavior of broiler chickens in four different substrates: a choice test', *Revista Brasileira de Ciência Avícola*, 16(1), pp. 9.

Voyles, R. and Honeyman, M. S. (2006) 'Absorbency of alternative livestock bedding sources'.
Weifang Jiade Machinery Co. Ltd. 2018. Poultry Plastic Flooring, Slat Floor for Chicken House. Available at - https://www.alibaba.com/product-detail/poultry-plastic-flooring-slat-floor-for_60704453392.html?spm=a2700.7724857.main07.1.4b79450fuAtjz9&s=p: Alibaba.
Wektor 2013. Pellets Ø 22mm 50% tree bark + 50% sawdust - test 1 - 50% kora + 50% trocina. Available at - https://www.youtube.com/watch?v=BSWyhjJGrFs: YouTube.
Whittaker, C. and Shield, I. (2017) 'Factors affecting wood, energy grass and straw pellet durability–A review', *Renewable and Sustainable Energy Reviews*, 71, pp. 1-11.
Willis, W. L., Murray, C. and Talbott, C. (1997) 'Evaluation of leaves as a litter material', *Poultry Science*, 76(8), pp. 3.
Wyatt, C. L. and Goodman, T. N. (1992) 'Research Note: The utilization of recycled sheetrock (refined gypsum) as a litter material for broiler houses', *Poultry Science*, 71, pp. 5.
Ye, Z., Harrison, R., Cheng, V. and Bekhit, A. (2015) 'Wine making by-products', *Valorization of wine making by-products*: CRC Press Boca Raton, pp. 73-115.
Yildiz, A., YILDIZ, K. and APAYDIN, B. (2014) 'The effect of vermiculite as litter material on some health and stress parameters in broilers', *Kafkas Universitesi Veteriner Fakultesi Dergisi*, 20(1), pp. 6.
Çavuşoğlu, E., Petek, M., Abdourhamane, İ. M., Akkoc, A. and Topal, E. (2018) 'Effects of different floor housing systems on the welfare of fast-growing broilers with an extended fattening period', *Archiv fuer Tierzucht*, 61(1), pp. 5.

Appendix 1

Survey: Litter suppliers

[1] Good ..... My name is ..... from Integrity Ag Services. We're a small rural consulting firm working on behalf of AgriFutures Australia – Chicken Meat Program on a research project on identifying new or alternative litter sources for the chicken meat industry to address supply concerns. Your phone number was provided to us by ..... as someone who might be able to provide us with some feedback from their experience of using poultry litter. Who would the best person be to speak to about this?

[if current interviewee has major role, **continue** at **2**, below]
[if person with major role is not available, arrange **call back**]
[if another person has major role and is available, **repeat 1]**

[2] We're trying to get some information together on chicken litter sources and use practises and were wondering if you could provide us some of this information? Participation in this survey is voluntary and the questions take about 15 minutes. Your responses will be strictly confidential and all personal and business information will at all times be safeguarded. If at the end of the interview you would like more information about the project, we can email or post it to you. Is now a good time to run through these or should I call back later?

[if agreed, continue at **3**, below]
[if agreed, not available, **thank and arrange call back**]
[if refused, thank and terminate]

Thanks for agreeing to take part. The first few questions are about your sources of poultry litter and volume supplied to chicken meat farmers.

[3] How many chicken meat producers do you supply?

[4] Could you please tell me what type of litter/s you supply and the annual volume that is supplied of each?

[5] If you don't mind me asking, what is the range in price of fresh litter sold to chicken producers? (by type)

[min, max. average, seasonal effects]

[6] I'll read out a list of poultry litter types. For each one can you please rank these from 1 to 5 -with 1 being most preferred by chicken meat farmers)?

Shavings Sawdust Straw Wood chip Other

[7] Are different litters ever mixed?

Why (supply problems, expense?)
if so, what blends have you used?

[8] Do you spread litter in sheds?

If so, what is the typical spreading depth of litter supplied to sheds?
Does depth vary with different litters?

[9] If you source shavings/sawdust:

Have you noticed problems sourcing enough dry material?
(if relevant) Why is it sometimes wet?

[10] Do you supply litter to other industries?

If so, how much?

<u>The next few questions are about the litter shortages.</u>

[11] Have you experienced difficulties with supplying sufficient volumes of litter at the right price?

If yes:

a. Would you say this is strictly a supply problem (not enough material?) OR
b. Is it about the volume of material at the right price point?

[12] Have you investigated/supplied alternative litter sources?

If yes:

a. What were they?

b. Were chicken meat producers receptive to new litter types?

The next few questions are about spent litter use.

[13] Do you handle spent litter?

[14] Do you know of any producers reusing litter within the shed (multi-batch?)

[15] What markets are you sending spent litter to? (i.e. horticulture, grain, dairy, feedstock for composting etc)?

[16] The price of spent litter around the country varies.

a. In your market, what is the typical range in sale values for spent litter?
b. What would you say the average value was?

[17] What is the maximum distance litter is being transported?

End

That's the last question. Thank you very much for your help with this. If there is anything in your answers that we need to check with you later on, would you mind if we rang back at a time that was convenient for you?

[if no, go to **18**, below]

[if yes, ask for a time of day, and day of the week that is convenient for them, and who to ask for. Continue at **18**, below]

[18] The findings from this project will be published by the Rural Industries AgriFutures Australia – Chicken Meat Program, who are funding the project. If you would like to receive a summary of the findings from this project, you can leave your postal or email address with me, and it will be sent to you next year.

[record address for summary of findings if required]

Thanks again for your help.

Survey: Chicken meat farm managers/ company representatives

[1] Introduction
[1] Good ..... My name is ..... from Integrity Ag Services. We're a small rural consulting firm working on behalf of AgriFutures Australia – Chicken Meat Program on a research project on alternative litter sources for the chicken meat industry. Your phone number was provided to us by ..... as someone who might be able to provide us with some feedback from their experience of using poultry litter. Who would the best person be to speak to about this?
[if current interviewee has major role, **continue** at **2**, below]
[if person with major role is not available, arrange **call back**]
[if another person has major role and is available, **repeat 1**, above, then continue at **2**, below]
[2] We're trying to get some information together on chicken litter sources and use practises and were wondering if you could provide us some of this information? Participation in this survey is voluntary and the questions take about 15 minutes. Your responses will be strictly confidential and all personal and business information will be safeguarded. If at the end of the interview you would like more information about the project, we can email or post it to you. Is now a good time to run through these or should I call back later?
[if agreed, continue at **3**, below]
[if agreed, not available, **thank and arrange call back**]
[if refused, thank and terminate]
Thanks for agreeing to take part. The first few questions are about general farm conditions.
[3] What is the total bird capacity of farms you manage?
[bird places]
[4] How many batches are produced per year?
[batches/ year]
[5] What is your bird stocking density?
[chickens/m2 OR just ask shed area?]
The next few questions are about the litter use and management.
[6] What litter types do you use?

a. Estimate % of each:
    i. Shavings
    ii. Sawdust
    iii. Straw
    iv. Wood chip
    v. Other

b. Are there any seasonal effects on supply of litter types?

[7] I'll read out a list of poultry litter types. For each one can you please rank these from 1 to 5 -with 1 being most preferred by chicken meat farmers)?

- Shavings
- Sawdust
- Straw
- Wood chip
- Other

The next few questions are on alternative litter and management practises.
[8] Do you think you will change litter <u>type</u> used in the future?
[9] We have investigated the following alternative litters types that have been used overseas and/or trials and are looking for feedback on their use in Australia – could you rank the suitability of the following alternatives from 1 to 5 -with 1 being most preferred by chicken meat farmers?

- Straw pellets
- Sand
- Peat
- Paper pellets

- Nut hulls
- Mixes
- Stubble/ bagasse- cereals, beans
- Husks- oat
- Recycled wood material- from pallet or building materials
- Are there alternative litters listed that you are uncertain or have no idea about?
- Do you know of any others?

We have a few questions regarding general litter management:

[10] Do you mind telling the average thickness of litter spread for each litter use on your farms?

Do you have minimum litter depth requirements – RSPCA for example?

[11] Are different litters ever mixed?

If so, what blends have you used?

[12] Who supplies fresh litter to the farms?

[13] Do you mind telling me a general range of litter costs for your farms?

[survey participants might be sensitive with this information]

[range: low, average, high if possible]

Do these prices include transport costs?

Are transport costs a significant factor of total litter costs?

Does price vary with season?

[14] Do you have any management practises to reduce costs associated with litter?

[15] Is litter managed as Single use, Partial reuse or Multi-use?

If multi use, how many batches before being changed?

If litter is reused how is it disinfected/ sanitised?

Composted/ pasteurised?

[16] Are you looking into alternative management practises, such as reuse if not practised now?

What are the barriers to litter reuse? (Council regulation, licensing constraints, potential odour problems, no composting area available)

The last few questions are about the litter problems and spent litter.

[17] Out of the following options, can you rank the most significant problems with current litter or litter suppliers from 1 to 5 -with 1 being most significant problem for chicken meat farmers??

a. Cost
b. Quality
c. Wet litter (and how did you manage this)
d. Clumping
e. Bird health issues
f. Supply issues (problems sourcing enough)
g. Reuse issues
h. Are there other management/cost issues associated with particular types of litter? (for example, the need for tillage with straw litter, or dust, or ammonia etc)
i. Odour

[18] [if identified above] Further questions about problems sourcing enough litter.

a. What were the management strategies used to cope with litter storages?

b. Did you find litter suppliers or new litter products?

[19] Regarding spent litter: how is this disposed of/ its end use? Composting, fertiliser, etc.

[20] Costs/revenue with spent litter disposal?

End

That's the last question. Thank you very much for your help with this. If there is anything in your answers that we need to check with you later on, would you mind if we rang back at a time that was convenient for you?
[if no, go to **21**, below]
[if yes, ask for a time of day, and day of the week that is convenient for them, and who to ask for.
Continue at **21**, below]

[21] The findings from this project will be published by the Rural Industries AgriFutures Australia – Chicken Meat Program, who are funding the project. If you would like to receive a summary of the findings from this project, you can leave your postal or email address with me, and it will be sent to you next year.
[record address for summary of findings if required]
Thanks again for your help.

Appendix 2

Properties of common litter materials

Table 71. Properties of litter materials commonly used in Australian chicken meat farms.

Litter	General properties and description	Moisture exchange	Bird health and performance	Spent litter utilisations	Practical and Economic considerations	Positives	Notes	References
Wood shaving	Lightweight Medium particle size Soft and compressible Low thermal conductivity	Highly absorbent, yet can dry rapidly	Excellent	Useful as a fertiliser in Australia	Regional availability. Supply has been effected by wood industry mills	Best litter material	Preferred litter material but becoming limited in supply and expensive in some areas	Ritz et al (2017), NSW Agriculture (2004), Atencio et al (2010), Benabdeljelil and Ayachi (1996), Grimes et al. (2007), Villagra et al. (2011), Villagrá et al (2014)
Sawdust	Lightweight Small particle size Soft and compressible Low thermal conductivity	Highly absorbent, yet can dry rapidly	Excellent	Useful as a fertiliser in Australia	Regional availability	A good litter material when available	Often high in moisture and susceptible to dangerous mould growth if stored improperly prior to use.	Singh and Sharma (2000) Ritz et al (2017), NSW Agriculture (2004), Hafeez et al (2009), Benabdeljelil and Ayachi (1996)
Rice hulls	Lightweight Medium particle size Low thermal conductivity	Large surface area - dries rapidly	Excellent	Useful as a fertiliser in Australia	Regional availability. Dependent on rice crop yields.	A good litter material when available	A good litter material where available at a competitive price.	Ritz et al (2017), Singh and Sharma (2000), NSW Agriculture (2004), Swain and Sundaram (2000), Atencio et al (2010), Benabdeljelil and Ayachi (1996), Villagrá et al (2014)

Straw- chopped	Lightweight Medium particle size Soft and compressible Low thermal conductivity	Excellent (provided caking issues are sufficiently managed)	Useful as a fertiliser in Australia	Regional availability	Large supply in most regions. Good litter when managed properly.	Caking problems Bird contamination problems Susceptible to mould growth.	Ritz et al (2017), Singh and Sharma (2000), NSW Agriculture (2004), Hafeez et al (2009), Benabdeljelil and Ayachi (1996), Villagrá et al (2014), Avdalovic et al (2017)

Table 72. Commonly used litter materials in other regions.

Region	Commonly used litter materials	Reference
USA	Pine chaff	Grimes et al.(2002)
Southeast United States	Pine shavings Pistachio stalks	Carpenter (1992)
Northern Europe	Wood shavings Chopped wheat straw Peat Lignocellulose Rapeseed straw Maize silage'	de Jong and van Narn (2012)
Scandinavian countries	Peat Peat and wood shaving	de Jong and van Narn (2012)
Spain	Long rye straw Wheat straws Barley straws Pine shavings	Gençoğlan and Gençoğlan (2017)
Mediterranean	Rice stalks	Garcia et al.(2007)
Pakistan	Sawdust	Hafeez et al (2009)
Southeast Asian	Sawdust Rice husk Grain stalk	Lien et al. (1990)

Appendix 3

Alternative litter sources assessed

Table 73. Inorganic Materials.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Aust.	Overseas	Aust.	Overseas		
Sand	Yes	Yes	Mixed	Positive	Possible concerns: Management. Commonly used overseas. In USA can be used for 2-5 years, multi batch. Organic matter can be treated with flames for reuse. More difficult to maintain suitable floor temperatures in colder regions. More difficult to maintain temperature during cold weather.	Ritz et al (2017), Jacob (2015), Atencio et al (2010), Hafeez et al (2009), Bilgili et al (2009), Adebayo et al. (2009), Swain and Sundaram (2000), Atencio et al (2010), Bilgili et al (1999), Garcês et al (2013), Villagrá et al (2014), Grimes et al (2002), Grimes (2004)
Gypsum (litter amendment)	No	Yes	n/a	Negative	Possible concerns: Human health Gypsum was used as a litter amendment can decrease in NH3 nutrient loss. When used as a base and top-dressed with wood shavings it functioned well but poses major potential health risks to workers (dust problems).	Wyatt and Goodman (1992), Burt (2015)
Bentonite clay (litter amendment)	Yes	Yes	Negative	Negative	Possible concerns: Bird health, Human health Can have significant clumping and dust issues. Inclusion of 33% and 50% bentonite to pine shavings increased mortality of chickens during brooding. Did not adversely affect chicken live weight, footpad dermatitis, hock burn, breast blister and breast feathering of chickens up to day 42. Significantly reduced NH3 in litter up to day 28.	Redding (2013), Islam et al. (2013)

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Aust.	Overseas	Aust.	Overseas		
Zeolite (litter amendment)	Yes	Yes	Positive	Positive	Possible concerns: Human health Zeolite was used as a litter amendment can decrease in NH3 nutrient loss. Inclusion of 33% and 50% zeolite to pine shavings did not adversely affect mortality, chicken live weight, footpad dermatitis, hock burn, breast blister and breast feathering of chickens up to day 42. Significantly reduced NH3 in litter up to day 28. While there were human health concerns with dust, chickens raised on the zeolite were unaffected.	Islam et al. (2013)
Vermiculite	No	Yes	n/a	Mixed	Possible concerns: Cost, availability and bird health The foot health was positively affected by the use of Vermiculite as litter material (Yildiz et al, 2014). Miles et al (2011) found that vermiculite has a high-water absorption capacity, however because of high NH_3 generation (in comparison to wood shaving and rice hulls), it is not recommended for further study as broiler bedding material.	Yildiz et al (2014) Miles et al (2011)
Recycled rubber tyre	No	Yes	n/a	Negative	Possible concerns: Bird health Mortality and litter caking tended to be higher with the tyre products.	Skewes et al. (1998), Grimes (2004)
Recycled sheetrock	No	Yes	n/a	Negative	Possible concerns: Human health and availability Product showed no significant influence on feed conversion, chick mortality, condemnations, or incidence of leg abnormalities. Possible dust problems.	Wyatt and Goodman, (1992), Grimes (2004)

Table 74. Mined organic materials.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Aust.	Overseas	Aust.	Overseas		
Clay	No	Yes	n/a	Negative	Possible concerns: Bird health, availability and cost Significant clumping problems not advised.	Reed and McCartney (1970), Andrews and McPherson (1963), Malone and Martin (1999), Embury (1987), Grimes (2004), Reed and McCartney (1970)
Expanded clay	No	No	n/a	n/a	Possible concerns: Limited information Type of animal litter material.	Christianson (1981)
Peat	No	Yes	n/a	Positive	Possible concerns: Availability and cost It is commonly used in Northern European/ Scandinavian countries that mine peat commercially. It is managed in similar way to sawdust, however it is used at a much lower depth because it expands greatly with use. Currently peat is not mined in Australia.	Chaloupka et al. (1967); Enueme and Waibel (1987), Snyder et al.(1958), Grimes (2004)

Table 75. Wood products.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Aust.	Overseas	Aust.	Overseas		
Pine leaves/needles/ straw	No	Yes	n/a	Negative	Possible concerns: Bird health May cause injuries to breast and feet.	Singh and Sharma (2000), Sharma et al (2015), Singh and Sharma (2000), Embury (1987), Reed and McCartney (1970)
Pine-bark	No	Yes	n/a	Neutral	Possible concerns: Bird health High footpad dermatitis. Similar to chips or shavings in moisture absorption capacity. Medium-sized particles preferred.	Bilgili et al (2009), Embury (1987), Reed and McCartney (1970), Labosky Jr et al. (1977), Allison et al (1973), Thornberry et al (1970), Brake et al (1992)
Pine-chipped	No	Yes	n/a	Negative	Possible concerns: Bird health High footpad dermatitis. Used successfully but may cause increased incidence of breast blisters if allowed to become too wet.	Bilgili et al (2009), Parsons and Baker (1985), Carter et al (1979), Embury (1987), Reed and McCartney (1970)
Invasive native scrub (INS) chips or shavings – cypress	No	No	n/a	n/a	Possible concerns: Limited information and economic feasibility	
Ground door filler	No	Yes	n/a	Positive	Possible concerns: Bird health, availability and cost Ground door filler was a wood fibre-based material used in insulating metal doors. Low rate of footpad dermatitis.	Bilgili et al (2009), Jacob (2015)
Recycled wood pallets	Yes	Yes	Positive	Positive	Possible concerns: Oz-Pet Cat & Pet Litter. Recycled plantation waste wood with no additives. Also used for horse bedding.	Pet Circle (Pet Circle, 2016)
Particleboard Residue	No	Yes	n/a	Negative	Possible concerns: Bird health, availability and cost High possibility of contaminates from glues, increased caking and increased the incidence of foot pad dermatitis	Hester et al (1997)

Table 76. Paper materials.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Australia	Overseas	Australia	Overseas		
Paper-sludge (dried before birds were placed)	No	Yes	n/a	Negative	Possible concerns: Bird health and availability Initial moisture content of the sludge was high. Decreased strongly after 7 d of drying, reaching lower values than those of wood shavings. Hock burn was higher than wood shaving control. Potential caking issues	Villagrá et al. (2011)
Paper-pellets	No	No	n/a	n/a	Possible concerns: Limited information, bird health and cost Sustainable. Commonly used as cat litter in Australia. Would have similar properties to paper and paper sludge. Potential caking issues	Breeders choice (2018)
Paper (shredded)	Yes	Yes	Positive	Positive	Possible concerns: Bird health Various forms of processed paper have proven to be good litter material in research and commercial situations. Tendency to cake with increased particle size. Top dressing paper base with shavings may minimize this problem. Careful management is essential.	Jacob (2015), El-Deek et al (2011), Garcês et al (2013), Martinez and Gernat (1995), Malone and Chaloupka (1983), Malone et al (1982), Lien et al (1992), Burke et al (1993), Embury (1987), Grimes et al (2002), Grimes (2004), Sansom (1988)
Paper sludge ash (Lime ash) Litter amendment	No	No	n/a	n/a	Possible concerns: Limited information, bird health and cost Lime ash is short fibres and lime slurry from paper recycling that has been combusted. It resembles sand and has been sold in the UK as a bedding desiccant/ drying agent.	HCCMPW (2010)
Paper crumb	No	No	n/a	n/a	Possible concerns: Limited information, bird health and cost Paper crumb is the short fibres are removed in a sludge type material and is a by-product from the paper industry.	HCCMPW (2010)

Table 77. Cereal crop residuals.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Australia	Overseas	Australia	Overseas		
Straw pellets	No	Yes	n/a	Positive	Possible concerns: Cost and availability Commonly used in Europe. Also used for horse bedding.	Avdalovic et al (2017), Kheravii (2017), Mountain Meadows (2018), Oxbow (2018), Ecoland (2018)
Crushed straw pellets	No	No	n/a	n/a	Possible concerns: Cost and availability Used for small animal bedding. Crushed straw pellets have a larger specific surface area than straw pellets.	Ecoland (2018)
Rice straw	No	Yes	n/a	Mixed	Possible concerns: Bird health and availability. Rice Straw has the unique property of not absorbing water.	Navneet et al (2015)
Rye straw	No	Yes	n/a	Positive	Possible concerns: Availability Commonly used in Europe chicken meat production.	Slobodzian–Ksenicz, and Kuczynski (2002)
Stubble-canola, bean,	No	No	n/a	n/a	Possible concerns: Limited information Likely to have similar properties to straw. Would need to be trialled and optimised for Australian conditions.	
Soybean straw	No	Yes	n/a	Positive	Possible concerns: Bird health and availability. Abreu et al. (2013) found soybean straw can be used as litter for rearing up to four flocks of broilers, however it increases the incidence of footpad lesions relative to rice hulls.	Abreu et al. (2013)

Table 78. Crop and nut hulls.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Australia	Overseas	Australia	Overseas		
Hazelnut husks	No	Yes	n/a	Positive	Possible concerns: Bird performance, availability and cost.	Sarica and Cam (2000)
Nut husks (general)	No	No	n/a	n/a	Possible concerns: Limited information Probably similar to hazelnut husks. Further research would be needed.	
Nut pellets (walnuts, walnut shells, almond shells)	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic cat/ small animal litter.	AFRMA (2015)
Almonds husks	Yes	Yes	Negative	Positive	Possible concerns: Limited information There was an Australian trial with almonds. The negative outcomes were likely due to poor management.	
Milled Almond hulls	No	No	n/a	n/a	Possible concerns: Limited information Milled Almond hulls are inexpensive however they are quite dusty.	
Corn cobs (crushed)	No	Yes	n/a	Negative	Possible concerns: Bird health, availability and cost. May be associated with increased breast blisters. NeedS to be processed/cut. less compacted than wood shavings. g	Ritz et al (2009), Jacob (2015), Garcês et al (2013), Embury (1987), Reed and McCartney (1970)
Corn cob pellets	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic cat/ small animal litter.	The Andersons (2018)
Crushed husks	No	Yes	n/a	Positive	Possible concerns: Limited information Probably similar to hazelnut husks. Further research would be needed. 6% – 8% moisture content resulting in 20% more efficiency than sawdust	Ag Products (2018)
Peanut hulls	Yes	Yes	Positive	Positive	Possible concerns: Supply highly regional and bird health Increased risk of Aspergillus if not managed properly. Caking can be an issue.	Lien et al. (1998), Embury (1987), Grimes et al (2002), Reed and McCartney (1970), Sansom (1988)

Oat hulls	Yes	Yes	Negative	Negative	Possible concerns: Bird health and limited information This has been trialled in Australia and had poor bird health outcomes. Product was the cause of severe eye irritation in birds and made handling them difficult.	Monira et al (2003)
Sun flower husks	No	Yes	n/a	Positive	Possible concerns: Sunflower husks, which are a by-product of the oilseed industry.	Embury (1987)

Table 79. Other crop residuals.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	Reference
	Australia	Overseas	Australia	Overseas		
Sorghum bagasse	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Expected to have similar properties to sugar cane bagasse.	
Sugar cane bagasse	No	Yes	n/a	Negative	Possible concerns: Bird health and availability and cost Birds presented more scratches, bruises and footpad lesions than wood shaving or rice hulls. Higher levels of Dermatitis than wood shaving or rice hulls. Higher compaction than wood shaving or rice hulls. Can be used in ethanol production. Production is seasonal.	Garcia et al (2012b, 2012a),Farhadi (2014), Grimes (2004), Sansom (1988)
Coir (coconut fibre)	No	Yes	n/a	Negative	Possible concerns: Limited information, bird health, availability and cost Many sources heavily contaminated with pathogenic fungi. Higher water content than rice hulls or saw dust.	Swain and Sundaram (2000), Garcês et al (2013)
Grass- general	No	Yes	n/a	Mixed	Possible concerns: Minor bird health issues. Higher compaction than wood shaving or rice hulls. Higher levels of Dermatitis than wood shaving or rice hulls. Several trials, mixed results based on management practises.	Garcia et al (2012b, 2012a), Adebayo et al. (2009), Garcês et al (2013), Moyle et al (2016)
Grass- miscanthus	No	Yes	n/a	Positive	Possible concerns: Availability Used overseas for dairy, poultry and equine bedding. Also used as a biofuel.	Samson et al.(2017)
Grass- switchgrass	No	Yes	n/a	Positive	Possible concerns: Availability Used overseas for dairy, poultry and equine bedding. Also used as a biofuel.	Samson et al.(2017)
Cocoa bean	No	Yes	n/a	Positive	Possible concerns: Availability and cost Local production of Cocoa beans is small.	

Lemongrass straw	No	No	n/a	n/a	Possible concerns: Availability and cost Hasn't been applied on a commercial scale	Dunlop (2014)
Hemp fibre	No	No	n/a	n/a	Possible concerns: Availability and cost Used as pet litter and equine bedding. Not commercially available. Queensland is in the process of legalising hemp farming, so this might become an option in future.	Moore (2014) AUBIOSE (2018))
Kenaf core	No	Yes	n/a	Negative	Possible concerns: Bird health, availability and cost Higher moister content than pine sawdust, but has similar bird health outcomes. Caking can be significant.	Malone et al (1990), Brake et al (1993)
Composited leaves	No	Yes	n/a	Unknown	Possible concerns: Availability and cost Composted hardwood leaves. Low placement densities were and low litter moister conditions used in study. Bird health effects cannot be extrapolated from data.	Willis et al (1997)
Fibre remaining after tea tree oil distillation	No	Yes	n/a	Positive	Possible concerns: Availability and cost. Fibre remaining after tea tree oil distillation, reasonable performance.	
Rape Straw	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Rape straw is reported to have poor absorbency due to its high oil content and stalky structure. It can be difficult to dry for use as a livestock bedding material and bales can be volatile and ignite easily when stored.	HCCMPW (2010)
Canary Reed Grass	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Canary Reed Grass is grown for biomass fuels in Europe. It has similar properties to cereal straws.	HCCMPW (2010)
Bracken ferns	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Bracken ferns have been used for livestock bedding in Europe. Bracken spores have carcinogenic properties and the material should therefore be handled with care.	HCCMPW (2010)
Pea Haulm/ Straw	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Pea Haulm is reported to have poor absorbency; however no definitive figures are available on this material.	HCCMPW (2010)

Rushes/ Reeds	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Rushes have been used for livestock bedding in Europe. Rushes grow in wet boggy areas and can only be harvested in dry conditions. They can be baled using conventional machinery when ground conditions are dry. Dried rushes are less absorbent than straw.	HCCMPW (2010)
Pelleted aspen bark	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic cat/ small animal litter.	Green Pet Products (2018) AFRMA (2015)

Table 80. Miscellaneous organic material.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	References
	Australia	Overseas	Australia	Overseas		
Rice hull ash	No	Yes	n/a	Positive	Possible concerns: Availability and cost. 100% rice hull ash, good performance.	Chamblee and Yeatman (2003)
Cotton-gin trash	No	Yes	n/a	Negative	Possible concerns: Bird Health. High footpad dermatitis and possible pesticide contaminates.	Bilgili et al (2009)
Coffee chaff	No	Yes	n/a	Positive	Possible concerns: Availability and cost. Small-scale non-commercial.	-
Dried rose dreg	No	Yes	n/a	Positive	Possible concerns: Availability and cost. By-product of roses. No large-scale production in Australia.	Aktan and Sagdic (2004)
Citrus pulp	No	Yes	n/a	Positive	Possible concerns: Availability and cost. By-product of juicing. Has not been trialled commercially.	Harms et al. (1968)
Reused Tea	No	Yes	n/a	Positive	Possible concerns: Availability and cost. By-product of tea manufacturing, unknown if there is an Australian supplier. Has not been trialled commercially.	Atapattu and Wickramasinghe (2007)
Banana fibre	No	Yes	n/a	Positive	Possible concerns: Availability	Sudin (2014)
Oil palm frond fibre	No	Yes	n/a	Positive	Possible concerns: Availability and cost.	Sudin (2014)
Composted municipal garbage	No	Yes	n/a	Negative	Possible concerns: Bird health. An aerobically digested composted municipal garbage. High mercury, lead, chromium, and nickel in CMG litter.	El-Deek et al (2011)

Table 81. Mixed or layered materials.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	References
	Australia	Overseas	Australia	Overseas		
Sugar cane + wood shavings	No	Yes	n/a	Negative	Possible concerns: Availability (of sugar cane). 50% sugar cane bagasse plus 50% wood shavings. Higher compaction than wood shaving or rice hulls. Higher levels of Dermatitis than wood shaving or rice hulls.	Garcia et al (2012b, 2012a)
Sugar cane + rice husks	No	Yes	n/a	Negative	Possible concerns: Availability (of sugar cane). 50% sugar cane bagasse plus 50% rice husks. Higher levels of Dermatitis than wood shaving or rice hulls. Higher compaction than wood shaving or rice hulls.	Garcia et al (2012b, 2012a)
Paper +wood shaving s	Yes	Yes	Mixed	Unknown	Possible concerns: Bird health and management. 50:50 mix, Highly arid climate trial. Higher growth performance than paper and wood shaving alone. Bird health was not specifically discussed in research paper.	El-Deek et al (2011)
Paper + barley straw	No	Yes	n/a	Unknown	Possible concerns: Bird health and management. 50:50 mix, Highly arid climate. Higher growth performance than paper and wood shaving alone. Bird health was not specifically discussed in research paper.	El-Deek et al (2011)
Reused Paper +wood shavings	No	Yes	n/a	Positive	Possible concerns: Bird health. Birds consumed the higher amount of feed than single use litter. Reused of bedding materials had insignificant effect on final body weight.	Coufal et al (2006)
Rice hull ash + pine shaving	No	Yes	n/a	Positive	Possible concerns: Availability and cost. Pine shaving / rice hull ash ratios: 50/50, 70/30 and 30/70.	Chamblee and Yeatman (2003)
Reused Paper + barley straw	No	Yes	n/a	Positive	Possible concerns: Bird health. Birds consumed the higher amount of feed than single use litter. Reused bedding materials had insignificant effect on final body weight.	El-Deek et al (2011), Martinez and Gernat (1995)
Dried rose dreg + pine shaving	No	Yes	n/a	Positive	Possible concerns: Availability and cost. 50:50 mix of dried rose dreg and pine shaving. By-product of roses. No large-scale production in Australia.	Aktan and Sagdic (2004)

aGroChips	No	Yes	n/a	Positive	Possible concerns: Availability and cost. Material is made from: cotton waste + gypsum + newspaper blend. Potential pesticide contamination problems. Small trial conducted: no difference between control (pine shaving) and aGroChips performance. aGroChips had more caking than pine shavings.	Grimes et al (2007)
Short fibres from recycled waste paper with the dust from coal-fired dolomitic lime kilns	No	No	n/a	n/a	Possible concerns: Limited information, bird health, availability and cost. Used in USA dairy industry. Short fibres from recycled waste paper are combined with the dust from coal-fired dolomitic lime kilns.	AAB (2015)a
Straw and wood shaving /sawdust	No	Yes	n/a	Positive	Possible concerns: Availability	Benabdeljelil and Ayachi (1996)
Wood shaving on rice hulls	No	Yes	n/a	Positive	Possible concerns: Availability	Benabdeljelil and Ayachi (1996)
Aspen wood particles and ground wheat pellets	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic cat/ small animal litter.	Pet Care Systems Inc (2018)
Recycled paper and aspen hardwood sawdust pellets	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic cat/ small animal litter.	ENVIGO (2018)
Wood shavings-vermiculite	No	Yes	n/a	Positive	Possible concerns: Cost, availability and bird health The foot health was positively affected by the use of wood shavings and vermiculite as litter material (Yildiz et al, 2014). Miles et al (2011) found that vermiculite has a high-water absorption capacity, however because of high NH_3 generation (in comparison to wood shaving and rice hulls), it is not recommended for further study as broiler litter material.	Yildiz et al (2014)
Wheat and rapeseed straw	No	No	n/a	n/a	Possible concerns: Limited information Used as a domestic small animal litter.	Ecoland (2018)
Pine sawdust—straw pellets	No	No	n/a	n/a	Possible concerns: Limited information Used as biomass for heat and energy production.	Stasiak et al (2017)
Sawdust and bark pellets	No	No	n/a	n/a	Possible concerns: Limited information	Wektor (2013)

Table 82. Undefined alternative litter options.

Alternative litter materials	Trialled in:		Trial outcome:		Notes	References
	Australia	Overseas	Australia	Overseas		
Papermill effluent + bark mix	No	No	n/a	n/a	Possible concerns: Limited information, possible bird health and availability. Patent: US 3980050 A. Description: Composite the fibrous material effluent from a paper mill with bark particles.	Neubauer (1976)
Clay + cedar mix	No	No	n/a	n/a	Possible concerns: Limited information, possible bird health, availability and cost. Patent: US 5542374 A	Palmer (1996)
Wood + peat pellets	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 5271355 A. Description: Wood and peat in the volume ratio range 1:0.01 to 1:100.	Bilings (1993)
Dried citrus peel	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 6523496 B1 and WO 2003059046 A1. Description: The citrus peel by-product or waste is in a dried state.	Keithly et al (2003), Keithly et al (2005)
Bagasse	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 2179591 A Description: Poultry litter and animal bedding	Godchaux,(1939)
Foamed polymer	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 4901671 A. Description: Synthetic chicken litter of foamed polymer is coated with a tough polymeric coating which cannot be picked off by chickens.	Johnston (1990)
Foamed polymer-general animal bedding	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 3033346, US 4,038,944, US 4009684 A, US 4471717 A and US 3765371 A	Tucci (1977), Lander (1984), Fisher (1973), Bramley (1962), Kliment et al (1977)
Thermoplastic polymer and starch.	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 5429073 A. Description: A degradable, reusable, partially synthetic and partially non-synthetic bedding material for animals includes a plurality of flexible monofilaments formed from a blend of a thermoplastic polymer and starch.	Ballard (1995)

Chlorophyll-containing agent and a vermiculite or perlite mix	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 3425397 A Description: A chlorophyll-containing agent, such as alfalfa and like plants, and a lightweight, highly absorptive material, such as vermiculite and perlite	Schulein (1969)
Paper	No	No	n/a	n/a	Possible concerns: Limited information Patent: US 2708418 A Description: Animal bedding	Sugarman (1955)
Cellulosic material or clay and volcanic rock mix	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 4607594 A Description: A absorbent particles (e.g. cellulosic material or clay) and inert adsorptive granules (e.g. volcanic rock)	Thacker (1986)
A porous, inert solid substrate and a dry particulate polymer compound.	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 4685420 A Description: A animal litter comprising a porous, inert solid substrate and a dry particulate polymer.	Stuart (1987)
Coated extruded animal litter	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost Patent: US 9266090 B2 Description: A litter and litter making method producing cat litter from a carbohydrate starch-containing cereal grain, e.g., corn, based admixture extruded from a single screw or twin screw extruder forming pellets having a clumping agent formed during extrusion composed at least in part of carbohydrate polymer binder.	Lipscomb and Repinski (2016)
Amorphous silica	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost Patent: US 3217692 A Description: This invention relates to the use of amorphous silica as a litter material in the raising of chickens and turkeys in the broiler industry. In addition to the above objects, a principal object of this invention is to improve the raising of young poultry by the use of a particulate litter and bedding material which is fireproof, dustless, and which is absorbent of liquids and gases.	Hay (1965)
Deodorizing litter for poultry farms	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost Patent: US 4306516 A Description: The litter is a mixture comprised of from about 80 to about 95 percent by weight ferrous sulfate heptahydrate; from about 0.1 to about 3.5 percent by weight iron oxide and may contain from about 0.2 to about 1.5 percent calcium carbonate.	Currey (1981)
Peat and peat mix with wood shavings	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 4827871 A Description: Processed peat poultry litter for confined enclosures	Morrison (1989)

Tobacco stalk	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 2712811 A Description: Poultry litter	Dowell (1955)
Lightweight expanded polystyrene chips.	No	No	n/a	n/a	Possible concerns: Limited information, availability and cost. Patent: US 6453846 B2 Description: Lightweight expanded polystyrene chips. After use, the dirty chips may be cleaned to remove waste manure and the cleaned chips may be reused again as bedding. Alternatively, the dirty chips and waste manure may be burned to generate electricity.	Lloyd (2002)

Appendix 4

Alternative management practises

Table 83. Alternative litter material: Organic materials- paper.

Alternative management practises	Trialled in:		Trial outcome:		Notes	Reference
	Australia	Overseas	Australia	Overseas		
Reuse-partial (50:50)	Yes	Yes	Positive	Positive	Possible concerns: bird health, gas emissions	
Reuse- full	No	Yes	n/a	Positive	Possible concerns: bird health, gas emissions Commonly used overseas	Embury (1987)
Layering	Yes	Yes	Positive	Positive	Possible concerns: Inconsistent results dependent on litter types layered, depth and management	
Mixing	Yes	Yes	Positive	Positive	Possible concerns: Inconsistent results dependent on litter types layered, depth and management	
Concrete floors	Yes	Yes	Positive	Positive	Possible concerns: Cost	Abreu et al (2011)
Growing your own litter- straw or grass system	Yes	Yes	Positive	Positive	Possible concerns: Land requirements	
Seasonal use of different litters	Yes	Yes	Positive	Positive	Possible concerns:	
Sustainable tree buffer system	No	Yes	n/a	Positive	Possible concerns: Land requirements	

Sectioning shed	Yes	Yes	Mixed	Mixed	Possible concerns:	
Litterless	Yes	Yes	Positive	Positive	Possible concerns: Operational costs Used in Eastern Europe, Russia, Asia and USA.	Philip, R. (2013)
Caged	No	Yes	n/a	Positive	Possible concerns: Operational costs, capital cost, consumer concerns Used in Eastern Europe, Russia, Asia and USA. Usually multi-storied litter less cage systems.	Fisinin V. and Kavtarashvili A. (2013)

Appendix 5

Alternative processing options

Table 84. Alternative processing options.

Alternative management practises	Trialled in:		Trial outcome:		Notes
	Australia	Overseas	Australia	Overseas	
Pelletisation machine	No	No	No	Yes	Possible concerns: Cost Pelletisation machine could be used to process poor litters into a higher quality litter material.
On farm straw processing (chopping, crushing)	Yes	Yes	Positive	Positive	Possible concerns: Cost This is used by several producers that grow their own litter.
Wood shaving/ saw dust drier	Yes	Yes	Positive	Positive	Possible concerns: Cost Shaving/ sawdust drier machine could be used to dry litter before use.
Crushing pellets	No	No	No	Yes	Possible concerns: Cost Pellets are crushed after manufacturing. This increases the surface area. Commonly used for equine litter.

Appendix 6

Summary of matrix rating

Category	Litter options	Bird performance	Management/ Ease of handling	Water absorption and drying rate	Caking	Gas emissions	Environmental impacts	Spent litter-end-of-life	Thermal insulation.	Depth	Cost per m^2	Cost-operational	Abundance	Application
	Commonly used litters in Australia													
Wood products	Wood shaving	4	4	4	4	4	4	4	4	3	2	4	3	4
Wood products	Sawdust	4	4	4	4	4	4	4	4	3	3	4	3	4
Crop and nut hulls	Rice hulls	4	4	4	4	4	4	4	4	3	3	4	3	4
Cereal crop residuals	Straw- chopped	3	3	3	3	3	3	4	3	3	4	3	4	4
Crop and nut hulls	Peanut hulls	3	3	3	3	3	4	4	3	3	3	3	3	3
	Alternative litters													
Inorganic materials	Sand	3	3	3	3	3	4	3	2	3	4	4	4	2
	Gypsum	3	1	2	2	0	4	3	0	0	2	2	3	1
	Bentonite clay	2	1	2	2	0	3	3	0	0	2	2	3	1
	Zeolite	3	2	2	3	0	3	4	0	0	1	2	3	1
	Vermiculite	2	2	2	3	2	3	4	0	0	2	2	2	1
	Recycled rubber tyre	1	2	0	0	0	3	1	0	0	0	0	3	0
	Recycled sheetrock	3	2	4	3	0	3	3	0	0	3	2	3	1
Mined organic materials	Clay	2	1	2	2	0	0	3	0	0	2	2	3	2
	Peat	4	4	4	4	4	2	4	3	4	1	3	2	2
Wood products	Pine leaves/needles/ straw	3	2	3	2	0	3	4	3	3	3	3	3	1
	Pine-bark	3	2	3	2	0	3	4	3	3	3	3	3	1
	Pine-chipped	2	2	3	2	0	3	4	3	3	3	3	3	1
	Invasive native scrub (INS) chips or shavings – cypress	0	0	0	0	0	4	0	0	0	3	3	4	0
	Ground door filler	0	0	0	0	0	0	0	0	0	0	0	0	0
	Particleboard Residue	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recycled wood pallets (with stringent protocols)	4	4	4	4	4	4	4	4	3	4	4	3	4
Paper materials	Paper-dried sludge (short fibres from paper recycling)	2	3	2	2	0	4	4	3	0	0	0	0	0
	Paper- pellets	0	0	2	2	0	3	3	0	0	0	0	0	0
	Paper- shredded	3	2	3	2	3	3	3	3	3	4	2	2	2
	Paper sludge ash (short fibres and lime slurry from paper recycling)	0	0	0	0	0	0	0	0	0	0	0	0	0
Cereal crop residuals	Straw pellets	4	4	4	3	3	3	3	3	4	4	3	3	2

Category	Litter options	Bird performance	Management/ Ease of handling	Water absorption and drying rate	Caking	Gas emissions	Environmental impacts	Spent litter-end-of-life	Thermal insulation.	Depth	Cost per m^2	Cost-operational	Abundance	Application
	Soybean straw	3	3	3	2	3	3	4	3	3	4	3	2	3
	Rice straw	3	3	3	2	3	3	4	3	3	4	3	3	3
	Rye straw	3	3	3	2	3	3	4	3	3	4	3	1	3
	Stubble- canola, bean, etc	0	0	0	0	0	0	0	0	0	0	0	0	0
Crop and nut hulls	Hazelnut husks	3	0	0	2	0	0	3	0	0	0	0	0	1
	Nut husks (general)	3	3	3	2	0	4	3	3	3	3	3	3	1
	Almonds husks	3	3	3	2	0	4	3	3	3	3	3	3	1
	Corn cobs (crushed)	3	3	3	3	3	3	3	3	3	2	3	2	1
	Crushed husks	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oat hulls	2	2	3	0	0	3	3	3	3	3	3	2	1
	Sun flower husks	3	3	3	3	0	0	3	3	2	2	3	2	1
	Milled almond hulls	0	0	0	0	0	0	0	0	0	0	0	0	0
Other crop residuals	Sorghum bagasse (straw)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sugar cane bagasse	0	0	0	0	0	0	0	0	0	0	0	0	0
	Coir (coconut)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grass- general	3	3	3	3	3	3	3	3	3	3	3	3	3
	Grass- miscanthus	4	4	4	3	3	3	3	4	3	3	3	1	3
	Grass- switchgrass	4	4	4	3	3	3	3	4	3	3	3	1	3
	Cocoa bean	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lemongrass straw	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hemp fibre	0	0	0	0	0	0	0	0	0	0	0	0	0
	Kenaf core (Hibiscus cannabinus)	3	3	0	3	0	3	3	0	0	0	0	0	0
	Composted leaves	3	3	0	3	0	3	3	3	3	3	4	4	0
	Fibre remaining after tea tree oil distillation	3	0	0	0	0	0	0	0	0	0	0	0	0
	Rape (canola) straw	3	3	3	2	3	3	3	3	3	3	3	3	2
	Canary Reed Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bracken ferns	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pea Haulm (crop residue)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rushes	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous organic material	Rice hull ash	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cotton-gin trash	0	0	0	0	0	0	0	0	0	0	0	0	0
	Coffee chaff	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dried rose dreg	0	0	0	0	0	0	0	0	0	0	0	0	0

Category	Litter options	Bird performance	Management/ Ease of handling	Water absorption and drying rate	Caking	Gas emissions	Environmental impacts	Spent litter-end-of-life	Thermal insulation.	Depth	Cost per m^2	Cost-operational	Abundance	Application
	Citrus pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
	Reused Tea	0	0	0	0	0	0	0	0	0	0	0	0	0
	Composted municipal garbage	2	0	0	0	0	2	2	0	0	0	0	3	2
	Pomace/ marc	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed or layered materials	Sugar cane + wood shavings	2	2	3	2	0	3	3	3	3	3	3	3	1
	Sugar cane + rice husks	2	2	3	2	0	3	3	3	3	3	3	3	1
	Paper +wood shavings	0	2	2	2	0	3	3	3	3	3	3	3	1
	Paper + barley straw	0	2	2	2	0	3	3	3	3	3	3	3	1
	Reused Paper +wood shavings	3	2	2	2	0	3	3	3	3	3	3	3	1
	Rice hull ash + pine shaving	3	0	0	0	0	3	3	3	3	0	0	0	0
	Reused Paper + barley straw	3	2	2	2	0	3	3	3	3	3	3	3	1
	Dried rose dreg + pine shaving	3	2	2	2	0	3	3	3	3	3	3	3	1
	aGroChips (cotton waste, gypsum and newspaper mix)	3	3	3	0	0	0	0	3	3	3	3	3	1
	short fibres from recycled waste paper with the dust from coal-fired dolomitic lime kilns	0	0	0	0	0	0	0	0	0	0	0	0	0
	Straw and wood shaving /sawdust	3	3	3	3	3	3	3	3	3	2	3	2	3
	Wood shaving on rice hulls	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pine sawdust—straw pellets	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown	Papermill effluent + bark mix	0	0	0	0	0	0	0	0	0	0	0	0	0
	Clay + cedar mix	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wood + peat pellets	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dried citrus peel	0	0	0	0	0	0	0	0	0	0	0	0	0
	Foamed polymer	0	0	0	0	0	0	0	0	0	0	0	0	0
	Foamed polymer- general animal bedding	0	0	0	0	0	0	0	0	0	0	0	0	0
	Thermoplastic polymer and starch.	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chlorophyll-containing agent and a vermiculite or perlite mix	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cellulosic material or clay and volcanic rock mix	0	0	0	0	0	0	0	0	0	0	0	0	0
	A porous, inert solid substrate and a dry particulate polymer compound.	0	0	0	0	0	0	0	0	0	0	0	0	0
	Coated extruded animal litter	0	0	0	0	0	0	0	0	0	0	0	0	0
	Amorphous silica	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deodorizing litter for poultry farms	0	0	0	0	0	0	0	0	0	0	0	0	0
	Peat and peat mix with wood shavings	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tobacco stalk	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lightweight expanded polystyrene chips.	0	0	0	0	0	0	0	0	0	0	0	0	0

Category	Litter options	Bird performance	Management/ Ease of handling	Water absorption and drying rate	Caking	Gas emissions	Environmental impacts	Spent litter-end-of-life	Thermal insulation.	Depth	Cost per m^2	Cost-operational	Abundance	Application
Alternative management system														
	Reuse-partial (50:50)	4	3	3	3	3	4	4	3	4	4	4	4	4
	Reuse- full	4	3	3	3	3	4	4	3	4	4	4	4	4
	Layering	1	1	1	1	1	3	3	3	3	3	3	3	2
	Mixing	1	1	1	1	1	3	3	3	3	3	3	3	2
	Concrete floors	3	4	3	3	3	3	3	3	3	2	2	3	2
	Sustainable grass system (miscanthus or switchgrass)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sustainable tree buffer system (softwood)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Seasonal use of different litters	3	3	3	3	3	3	3	3	3	3	3	3	3
	Sectioning shed	0	3	3	3	3	3	3	3	3	3	3	3	3
	Litterless (slats)	3	4	4	4	2	4	4	3	4	3	4	4	3
	Caged (with manure belts)	3	4	4	4	4	4	4	3	4	3	4	4	3
Alternative litter processing options														
	pelletisation machine	4	3	4	4	3	3	4	4	4	2	4	4	3
	Chopping machine: for straw	4	3	3	3	3	3	3	3	3	3	4	4	3
	Wood shaving/ saw dust drier	0	0	0	0	0	0	0	0	0	0	2	3	0
	Crushing pellets	4	4	4	3	3	3	3	3	4	4	3	3	2

Table 85. Alternative litter processing options practise- overall rating that were rated zero.

Alternative litter material	Overall feasibility rating	Overall feasibility rating percent
Ground door filler	0	0%
Particleboard Residue	0	0%
Paper sludge ash (short fibres & lime slurry from paper recycling)	0	0%
Stubble- canola, bean, etc	0	0%
Crushed husks	0	0%
Milled almond hulls	0	0%
Sorghum bagasse (straw)	0	0%
Sugar cane bagasse	0	0%
Coir (coconut)	0	0%
Cocoa bean	0	0%
Lemongrass straw	0	0%
Hemp fibre	0	0%
Canary Reed Grass	0	0%
Bracken ferns	0	0%
Pea Haulm (crop residue)	0	0%
Rushes	0	0%
Rice hull ash	0	0%
Cotton-gin trash	0	0%
Coffee chaff	0	0%
Dried rose dreg	0	0%
Citrus pulp	0	0%
Reused Tea	0	0%
Pomace/ marc	0	0%
Short fibres from recycled waste paper with the dust from coal-fired dolomitic lime kilns	0	0%
Wood shaving on rice hulls	0	0%
Pine sawdust—straw pellets	0	0%
Papermill effluent + bark mix	0	0%
Clay + cedar mix	0	0%
Wood + peat pellets	0	0%
Dried citrus peel	0	0%
Foamed polymer	0	0%
Foamed polymer- general animal bedding	0	0%
Thermoplastic polymer and starch.	0	0%
Chlorophyll-containing agent and a vermiculite or perlite mix	0	0%
Cellulosic material or clay and volcanic rock mix	0	0%
A porous, inert solid substrate and a dry particulate polymer compound.	0	0%
Coated extruded animal litter	0	0%
Amorphous silica	0	0%
Deodorizing litter for poultry farms	0	0%

Peat and peat mix with wood shavings	0	0%
Tobacco stalk	0	0%
Lightweight expanded polystyrene chips.	0	0%
Sustainable grass (miscanthus or switchgrass) or tree buffer (softwood) system	0	0%

AgriFutures™
Chicken Meat

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