Final report

Investigating animal health and diseases in Australian lamb feedlots

Project code: P.PSH.1321
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Date published: May 2023

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

This is an MLA Donor Company project funded in part by Animal Health Australia (AHA). Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Specialist lamb finishing systems (feedlots) are increasingly being utilised by Australian lamb producers to combat the seasonal fluctuations of nutrient supply in extensive pasture-based systems. Health concerns in lot fed lambs is an area where limited research has been previously conducted. Beyond the limited inconsistent information on major health concerns in Australia, the occurrence of common diseases is largely unknown and additionally any associations or interactions between diseases have not been investigated. The purpose of this project was to:

1. Conduct a literature review to determine the most significant health concerns in feedlots specific to Australia and worldwide and establish gaps in the literature.
2. Conduct prospective cohort monitoring to determine the incidence of health conditions within feedlots and to determine risk factors associated with these conditions.
3. Develop an appropriate resource to aid producers in managing health issues in Australian feedlot systems.

Mortality rates varied widely across the 21 cohorts surveyed with the average mortality rate per day being 0.18%. Acidosis, urolithiasis, pulpy kidney, salmonella and pneumonia had the highest incidence within the surveyed animals. Time of year, low space (<2.1m$^{2/}$/lamb) allocation and rainfall in the previous 24 hours have been identified as two key risk factors. Antibiotic usage was not common practice in the cohorts investigated; however, multidrug antibiotic resistance was found within one pneumonic lung sample, which highlights the need for further research into more effective preventive measures when it comes to bacterial infections.

Executive summary

Background
Specialist lamb finishing systems (feedlots) are increasingly being utilised by Australian lamb producers to combat the seasonal fluctuations of nutrient supply in extensive pasture-based systems. The practice involves removing lambs from pastures and crops and feeding groups of them in confined pens in accordance with regulated standard and guidelines. For more comprehensive information regarding the standards that feedlots need to abide by, please see www.mla.com.au/contentassets/769ad90825574c27bb1b3873f03e3ed0/l.lsm.0022_-_national_procedures_and_guidelines_for_intensive_sheep_and_lamb_feeding_systems.pdf.
Lot feeding energy dense diets is a practical method to realise the potential of high growth genotype lambs. By meeting market specifications at younger ages, total nutrient intake decreases and feed resources can be prioritised elsewhere, improving overall production efficiency. Lot feeding lambs has increased in popularity due to consistently high lamb prices making the practice profitable despite considerable sources of production loss remaining unresolved.

The practice of lot feeding lambs inherently occurs after lambs are weaned from their dams, which is a known period of stress in lambs (Freitas-de-Melo et al., 2022). Furthermore, dietary changes, transport and mixing of lambs of different age groups and origins, as is often the case when feed lotting, exacerbates this stress in the initial days of induction into a feedlot (Navarro et al., 2020). Under these circumstances, certain infectious agents such as species of coccidia or respiratory tract pathogens, which may be present in healthy animals may cause disease in these stressed lambs.

Nutrient intake is the primary driver of lamb growth rate and feed efficiency, consequently, any cause of reduced intake threatens to decrease production and profitability. Many common diseases in lamb feedlots initially result in decreased intake and frequently result in removal of lambs from the feedlot environment and in extreme cases mortality.

The incidence of certain diseases in lamb feedlots is largely unknown, due primarily to a lack of diagnostics and reporting at a farm level. Previous surveys conducted with lamb feedlot operators have identified acidosis and shy feeding as the major contributors to production loss; however, without accurate diagnostics many producers are possibly attributing unknown deaths to common causes.

Objectives
The aims of this project were to

- Conduct a literature review to determine the most significant health concerns in feedlots and establish gaps in the literature
- Conduct prospective cohort monitoring to determine the incidence of health conditions within feedlots and to determine risk factors associated with these conditions.
- Develop an appropriate resource to aid producers in managing health issues in Australian feedlot systems.

The results from prospective cohort monitoring and the producer resource are presented in this report.

Further to this, an honours student joined the project team at the end of 2022 to further examine the risks of shy feeding in Australian lamb feedlots and to conduct an economic analysis to determine the cost of shy feeding to the lamb feedlot industry. The results of these analyses are presented in this report.

Methodology

This project consisted of three separate, but linked, phases:

- A review of existing literature and industry information
- Feedlot selection and collection of historical information with subsequent cohort study on 10 feedlots to determine the incidence of disease and risk factors associated with the most common diseases using Bayesian networks
- The development of extension materials to communicate the outcomes of the project and guide producers on effective health management of lambs under feedlot conditions.

Results

Mortality rates varied widely across the 21 cohorts surveyed with the average mortality rate per day being 0.18%. Acidosis, urolithiasis, pulpy kidney, salmonella and pneumonia contributing to the highest incidence within this project. Time of year and low space allocation ($<2.1m^{2/}$/lamb) have been identified as two key risk factors. Antibiotic usage was not common practice; however, multidrug antibiotic resistance was found within one pneumonic lung sample which highlights the need for further research into more effective preventive measures when it comes to bacterial infections.

Benefits to industry

This project has provided:

- Industry data on lamb mortality within feedlots to inform industry benchmarks.
- Insights into the causes of feedlot related lamb mortality.
- Improved understanding of risk factors for disease related lamb mortality to inform industry best-practice management recommendations for lot fed lambs.
- Improved understanding of how veterinarians can aid livestock producers with their sheep management through their diagnostic expertise.

Findings from this study will inform guidelines for improved lamb survival within feedlots.

Future research and recommendations

Further research is recommended into pneumonia and pleurisy including:

- Examination of data from pedigree-recorded flocks in Australia with a high incidence of severe pneumonia and pleurisy to enable more accurate estimates of genetic parameters, and subsequent correlations with production and disease traits;
- Investigating antibiotic use as a treatment for pneumonia in feedlots and the efficacy of these treatments with a strong focus on resistance issues with antibiotic use;
- Development of a multi-valent vaccine against organisms known to cause pneumonia in lambs.

Further research into effective salmonella prevention strategies is pertinent given the high incidence of the disease identified in this study and the serious risk of antibiotic resistance development without judicial use.

With urolithiasis, investigating the role of dietary magnesium levels in feedlot rations as a cause of urolith formation is a current knowledge gap as well as investigating the role of ammonium chloride in reduced growth rates in lot fed lambs.

Furthermore, the conflicting results between studies regarding shy feeding in feed lot settings highlight the need for further research to develop practical and reliable methods for the early identification of the most vulnerable animals in feedlots.

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1. Background

Lamb meat production is an important industry in Australia and the country is the second largest producer of lamb and mutton in the world. Seasonal variations combined with market pressure to finish lambs at specific weight and age brackets, presents a challenge to the industry. One way of approaching this challenge is to finish lambs on (usually) grain-based diets for several weeks before they are sent to slaughter in a lot fed (feedlot) situation. Lamb feedlots can be broken into three size categories as defined by Giason and Wallace (2006):

- Large feedlots - finishing over 15, 000 lambs each year
- Medium feedlots - finishing between 4,000 and 15,000 lambs each year
- Smaller opportunistic on farm feedlots - finishing less than 4,000 lambs each year

In November 2020, Meat & Livestock Australia published the report "Current State of R&D in the Australian Lamb Feedlotting Sector – A brief report" as a component report of "L.LSM.0022 - Sheep Feedlotting and Containment Management Guidelines Update". This report identified that the Australian lamb finishing industry has "developed on a 'trial and error' basis, in combination with anecdotal information supported by a small amount of fragmented research".

This project seeks to better understand the incidence of animal health issues specific to lamb feedlotting in Australia. This has been done by:

1. Conducting a literature review to determine gaps in the literature
2. Using animal health and performance information from established feedlots, performing post mortem examinations on a cohort of lambs which die in these feedlots and gathering abattoir surveillance data in relation to lambs which come from the selected feedlots.

This has allowed for the identification of the most significant animal health issues and provides insight as to how these are prevented and managed. Current R & D does not delve into the incidence of disease in lamb feedlots and so this project has aimed to fill this knowledge gap.

2. Objectives

Objective	Objectives met
Develop a report / literature review on animal health issues in lot feeding, including at lamb feedlots, live export terminals and overseas	Completed as part of the first Milestone.
Identify and quantify the most common animal health issues in a minimum of 10 lamb feedlots in Australia.	All 10 feedlots have full data sets that have been prepared in this report.
Identify and quantify the extent of antibiotic use in a minimum of 2 cohorts in 10 lamb feedlots in Australia	All feedlot producers involved have been questioned on their extent of antibiotic use and have provided data on their use (Table 1). Where possible bacterial samples collected were tested for antibiotic resistance (Table 2)
Provide guidelines to lamb lot feeders to improve management and animal health outcomes for lambs in feedlots as per the communication and adoption plan developed as part of milestone 2.	The guidelines and post mortem guide are displayed as resources generated from this project
Workshop at 2021 Australian Sheep Vets Conference to discuss preliminary results from the pilot study and gather feedback from Australian vets on the extension plan	Work from this project was accepted and discussed at both the 2021 and 2022 Australian Sheep Vets conferences.
Development of an appropriate resource/extension tool for Australian feed lotters to use.	See project resources for more information
Peer review of the findings and recommendations and extension of findings to scientific community through at least one scientifically-reviewed article	The project team plans to submit a paper to an appropriate journal for peer review by the end of June 2023.
Presentation at Australian Sheep Vets Conference and International Sheep Vets conference in 2023	An abstract was submitted and accepted. This presentation occurred on the 8th March 2023

3. Milestone Description

This report represents the final milestone and includes:

- Submission of the final report addressing MLA feedback on the previous milestone including:
  - Details of the most common animal health issues in lamb feedlots in Australia
  - Details of the extent of antibiotic use in lamb feedlots in Australia.
  - Final guidelines for lamb feed lot producers to improve management and animal health outcomes
- Development of an appropriate resource as per the communications plan in alignment with MLA's communication team

4. Success in meeting milestone

Details of the most common animal health issues have been compiled on all 10 feedlots.
The extent of antibiotic use has been determined and described for each feedlot (Table 1) a resource aiding producers to determine the most common causes of death and manage the risk has been created as a resource generated from this project. Further to this a veterinary lamb post mortem protocol has been developed for use by veterinarians examining lambs in feedlots based on the forms used by the project veterinary team (10.2). Delivery of outcomes has been detailed in the final communications and adoption plan (10.4)

5. Methodology

This project consisted of three phases:

- A review of existing literature and industry information
- Feedlot selection and collection of historical information with subsequent cohort study on 10 feedlots
- The development of extension materials to communicate the outcomes of the project and guide producers on effective health management of lambs under feedlot conditions.

The methodology for each phase of the project is outlined in this section.

5.1 Literature Review

A search of peer-reviewed scientific literature was conducted between 7th and 14th December 2021 using the library search engines Cab Abstracts, PubMed and Google Scholar, which yielded literature published between 1943 and January 2021. The search terms included:

'(enterotoxaemia OR "pulpy kidney"), (acidosis OR "grain poisoning" OR "grain overload" OR "rumen impaction"), (pleurisy OR pleura OR pneumonia OR "ovine respiratory complex" OR pasteurellosis), (coccidia OR coccidiosis), ("pink eye" OR conjunctivitis), ("fly strike" OR myiasis), (lice OR louse), (“shy feed*” OR inappetence), (urolith* OR “water belly”), (“internal parasite*” OR “gastrointestinal nematode” OR worm* OR endoparasite), (salmonell*), (yersini*OR diarrhoea OR scour)

was used with the following three search terms linked with the Boolean link (AND):

(feedlot OR “lot fed” OR fattening);

AND

‘(“ovis aries” OR sheep OR lamb)’;

AND

‘(mortality OR cull OR death OR dead OR condemn*) OR (trim* OR loss OR weigh* OR grow*) OR (health OR immunodefic*OR stress OR illthrift)’

The above search yielded 409 results.

Original articles and reviews from journals, conference proceedings, books or book chapters, published in English that were publicly available, or available in hardcopy or electronically from Charles Sturt University library were considered. The articles were extracted from the search engines, imported into Endnote, and duplicates were subsequently removed. All titles and/or abstracts of the articles were screened with the inclusion criteria being those studies focusing on health and epidemiological factors associated with one or several conditions of interest in relation to lot feeding. When a title and/or abstract could not be rejected with certainty, the full text of the article was retrieved for further appraisal. Full-text articles were retrieved that met or could potentially meet the inclusion criteria and appraisal.

5.2 Prospective cohort study

Animal ethics approval was sought and approved (Protocol number: A21480) by Charles Sturt University Animal Ethics Committee.

A total of 10 producers were selected in line with the project contract. This selection was based on producers who indicated they would like to be involved in further research after completing a CSU designed cross-sectional survey (P.PSH.1212), as well as producers within the project teams existing working network. Selection criteria included:

- Location – within southern Australia (including New South Whales and Victoria)
- Animal capacity- diversity of small (<4000 head), medium (4000-15000 head) and large (>15000feedlots between the two states
- the ability of producers to keep accurate records
- the ability of producers to weigh lambs at entry and exit into the feedlot.

Due to wet weather conditions in 2022, four of the selected producers didn’t lot feed or are starting to do so much later into 2023 which meant a further four feedlots were selected in November 2022 to make up for this loss (Table 1).

The producers selected were asked to provide previous histories and information regarding backgrounding, feedlot design, capacity and shy feeder management. Further to this, the selected producers were asked to record health data on two cohorts of lambs that enter and exit the feedlot in a project designed diary. This included information on any deaths, disease occurrences, treatments or interventions that occur in these two cohorts. When lambs died, producers were asked to record the date of the death, the sex of the lamb, body condition score and the suspected cause of death if it was obvious. A cohort of lambs was defined as a group of lambs that entered and exited the feedlot at the same time. The monitoring of these cohorts was done as per usual management practice for each feedlot.

Concurrently, the project veterinarians conducted disease investigations on up to three occasions on each cohort. If there were two cohorts being run simultaneously then only three visits occurred. If there was only one cohort being run at a time, then six visits in total could occur.
Each veterinary visit involved post mortem exams on any lambs that had died in the preceding 24 hours and diagnostic sample collection for each lamb. Although lambs could have multiple conditions diagnosed concurrently the final diagnosis was defined as the condition that would have ultimately led to death rather than an underlying cause. For example, if a lamb was found to have acidosis and mild pneumonia the death was recorded as an acidosis-related death as this would have caused the death ultimately even if the pneumonia was a contributing factor.

The project veterinarians followed the same post mortem protocol for congruence of clinical findings. Further to this, the veterinarians involved in this project met monthly to discuss their findings. The veterinary post mortem protocol has been redeveloped as a resource as one of the outputs of this project.

Health data was sought from abattoirs when lambs from each cohort were sent to slaughter at plants that participate in the National Sheep Health Monitoring Project (NSHMP).

Using results from prospective monitoring, the five most significant animal health problems have been identified and an industry report that articulates their extent, causes and recommendations for management and recommendations for any future research will be produced.

The death rate i.e. the total mortality rate for all diseases– rather than one specific disease – in a population was calculated for each feedlot.

Incidence of disease related death has been calculated as deaths due to each disease per 1000 lambs. As lambs within each cohort were monitored for varying numbers of days the denominator for the calculation was “lamb years” which is calculated by multiplying the number of lambs which entered each cohort by the numbers of days monitored as a fraction of the number of days in the year. The mean values have been calculated for each disease with a 95% CI.

Risk factor analysis used Bayesian Networks (BN). BN, based on Bayes’ Theorem, are graphical tools used to model complex relationships between variables operating under uncertainty and were therefore considered appropriate to analyse mortality data from the most common conditions to identify potential risk factors associated with disease related deaths ((Henrion, 1988, Kjaerulff and Madsen, 2008, Pearl, 1988). The commercial BN software Netica (Norsys) was used to both create four predictive Bayesian net models using the following as target nodes:

- “died from acidosis”
- “died from salmonella”
- “died with pneumonia”
- “died from pulpy kidney”

For each condition a sensitivity analysis was conducted to quantify the strength of the association of the target node with conditions present at the time of death including:

- Rainfall in the past 24 hours
- Time of year (month)
- Body condition score of lambs
- The location (Feedlot ID, feedlot size and state)

- Vaccination status
- Backgrounding status (number of days backgrounded prior to feedlot entry)
- Lamb factors (sex, breed)
- Feedlot factors (m^2/lamb, homebred or purchased, mixing of animals)

The percentage values from the sensitivity analysis are analogous to the adjusted R^2 (the goodness-of-fit measure from a regression analysis), thus providing an indication of the explanatory strength of one variable for another.

5.3 Shy feeder analyses

As part of a veterinary honours student project, four producers that were involved in the project over the summer of 2022/2023 were asked 24 open ended questions specific to shy feeding. Phone interviews were conducted over two days, taking approximately 20 minutes each. This additional data collection was approved by the Charles Sturt University Human Ethics Committee (Protocol number: H23491).

Producers were asked questions pertaining to the annual prevalence of shy feeding in the feedlot; the percentage of deaths observed in shy feeders; frequency of weighing and drafting; how and when shy feeders are identified and drafted; how shy feeders are managed; additional time on feed for shy feeders; average weight of shy feeders when they are first identified and drafted; frequency of weighing; and additional costs associated with shy feeder management. Data from the shy feeder questions was collated and combined with the data from the backgrounding information in Excel (Microsoft, 2023) and checked for data entry errors.

5.3.1 Shy feeder risk factor analysis

As with the cohort monitoring data, the commercial BN software Netica (Norsys) was used to both create a predictive Bayesian net model using “estimated shy feeder percentage” as the target node, and to conduct a sensitivity analysis to quantify the strength of the association of the target node with management practices employed by the surveyed producers.

5.3.2 Shy feeder economic modelling

A model was developed to determine the cost of shy feeding to an individual lamb feedlot enterprise using data collected in this project and previously published data. The majority of feedlots are opportunistic or only operate to manage poor seasonal conditions (Keogh et al 2021). Therefore, costs associated with shy feeding were calculated on a per head and per flock basis, rather than at an industry level. The main costs associated with shy feeding were additional feed costs and downgrading to mutton pricing. The model was designed in Excel (Microsoft, 2023).

Costs associated with shy feeding were determined at 2%, 3.5%, 5%, 8%, 10%, 15% and 20% prevalence to cover the ranges reported in the literature (Jolly & Wallace, 2007; Keogh et al., 2021; Savage et al., 2008). The economic costs associated with shy feeding were modelled for a 1500 head feedlot (Keogh et al., 2021). Mean data from the project was used for mortality rate and days on feed at which mortality occurred (Table 2).

A ration was formulated to achieve an energy density of 12.5 MJ ME/kg DM, and a minimum protein content of 16% (16.5%) (CSIRO, 2007). The ration consisted of 66% barley, 26% lupins and 8% oaten hay. For simplicity, the ration was assumed to be fed ad libitum as a total mixed ration. For normal lambs, feeding intake was determined using mean data for sale and induction weight, and days on feed (Table 4). Base growth rates and feed conversion were based on CSIRO (2007). The standard reference weight (SRW) was chosen to achieve an ADG consistent with the project mean.

Shy feeder feed intake was modelled in two distinct periods, a weight loss period, and a weight gain period. Producer reported weights at induction, and at shy feeder identification/drafting were used to calculate weight loss for this period and associated feed intake (Table 4) (CSIRO, 2007). For the weight gain period, the first model assumed that all shy feeders consumed maximum intake from drafting to sale, and all lambs received heavy lamb pricing. In the second model, maximum intake was assumed for the top 50% of shy feeders and the bottom 50% of shy feeders were assigned a lower ADG. The ADG for the bottom 50% of shy feeders was calculated using producer reported values, with total days on feed adjusted to reflect the mean project weight gain (Table 4). It was assumed that the bottom 50% of shy feeders received mutton pricing. The division of shy feeders into two groups was in response to survey data. Half (n=2) of the producers surveyed reported that the bottom 50% of shy feeders took an extended period to finish, despite drafting and separate feeding.

Prices for lupins and barley were calculated based on igrain listings from the 21st of April 2023. igrain is an online trading platform that enables buyers to purchase grain directly from growers across NSW, SA and Vic (igrain, 2023). As the majority of lamb feedlots complement a cropping enterprise (Keogh et al. 2021), it was assumed that grain was available on farm and there was no cost associated with grain and fodder transport. Oaten hay prices were calculated using Feed Central, an online fodder trading platform (Feed central, 2023). A sensitivity analysis was performed for both models, assessing the cost of shy feeding with average ration costs 20% lower and 20% higher than April 2023 prices. All feed costs are listed in Table 2.

Sheep prices utilised for the model were all based on 5-year averages from 31/12/2018 – 31/12/2022 (Table 1). Animal health, transport and selling costs were based on NSW DPI livestock gross margins (NSW DPI, 2022). It was assumed that lambs were bred on farm and therefore there were no transport costs associated with transport to the farm. The additional labour costs associated with shy feeding were not included in the modelling.

Table 1: Mortality data, feed costs and lamb/sheep meat prices inputs for economic model

Input	Value	source
Mortality rate	2.89%	Project data
Mean days on feed - mortalities	27.7	Project data
Barley (BAR 1, BAR 2, feed barley) $/T DM*	$ 366.96	(igrain, 2023)
Lupins $/T DM*	$ 501.30	(igrain, 2023)
Oaten Hay $/T DM*	$ 279.00	(Feed central, 2023)
Feed cost $/T DM (21 April 2023)	$397.54	(CSIRO, 2007)
Feed cost $/T DM + 20%	$ 477.04	(CSIRO, 2007)
feed cost $/T DM - 20%	$ 318.03	(CSIRO, 2007)

NEW national mutton indicator ($/kg cwt)**	$ 5.43	(MLA market information, 2023)
NEW national restocker lamb indicator ($/kg cwt)**	$ 7.63	(MLA market information, 2023)
NEW national heavy lamb indicator ($/kg cwt)**	$ 7.48	(MLA market information, 2023)
Yield (%)	47.0%	(Ritchie, 2019)

*All feed costs as of 21/04/2023
**5 year average 31/12/2018 - 31/12/2022

5.4 Producer resource development

The outcomes of the literature review and cohort study indicated a strong case to develop a producer guide detailing a basic post mortem examination and a list of common disease occurrences as well as prevention and treatment strategies.

The literature review highlighted gaps in information. The cohort studies provided robust information on the incidence of diseases under feedlot conditions.

The resources are detailed in this milestone. A final producer Feedlot Health Guide and veterinary post mortem guide have been developed.

6. Results

6.1 Literature review

After screening the 409 initial articles using the inclusion criteria, a total of 101 articles were included in the review and the sections below present the results for each of the health conditions identified, focusing on aetiology, occurrence in Australia, diagnosis, treatment and prevention options.

Enterotoxaemia (pulpy kidney)
Enterotoxaemia is a septicaemia of sheep caused by the anaerobic, gram-positive, bacteria *Clostridium perfringens* and the liberation of its fatal type D exotoxins (Wise, 1957). *C. perfringens* is a commensal organism of the intestine of sheep. The organism is also found in soil, water, air, and food (Ahsani et al., 2011). Sheep acquire the organism early in life via ingestion (West et al., 2017). The organism multiplies slowly under normal conditions and toxin levels do not build up in this instance (ElSify et al., 2016). However sudden changes in diet, particularly an increased plane of nutrition (as may often be the case with entry into feedlots), results in fermentable carbohydrate entering the small intestine, providing a substrate in which the organism may readily proliferate (Uzal and Songer, 2008). This often occurs when lambs which enter feedlots have not been adequately adapted to grains or concentrated rations (Bullen, 1963). Possible other causes of toxin build up in the gut may include heavy tapeworm burdens and bowel stasis caused by insufficient roughage in the diet (West et al., 2017) but convincing evidence of this has not been published.

The non-toxic prototoxin produced by *C. perfringens type D i*s converted into epsilon toxin by proteolytic enzymes in the sheep intestine or from *C. perfringens* itself. The epsilon toxin causes increased vascular permeability in the intestine, whereby it can escape into the blood stream and bind with high affinity to brain vascular endothelial cells, disrupting the blood brain barrier and causing brain oedema, haemorrhage and necrosis (Uzal and Songer, 2008). Vascular endothelial tissue of other organs (namely the heart and lungs) also occurs, leading to protein rich effusion in the pericardium, brain and lungs. It is also hypothesised that the condition leads to rapid autolysis of the kidney, hence the name 'pulpy kidney'; however this has not been proven and no information is available in the literature comparing the speed of autolysis in animals with enterotoxaemia compared to other conditions (Uzal et al., 2004).

Historically the disease occurs commonly in well grown lambs between 3 and 10 weeks of age (West et al., 2017). However due to the widespread practice of vaccinating ewes prior to lambing (58% of producers nationally (AWI, 2017)), more cases are now reported in weaned unvaccinated lambs following waning of passive maternal antibodies (West et al., 2017). This is commonly encountered with either young sheep grazing lush pasture or in feedlot situations. The disease is consistently fatal; however, highly effective, and cheap vaccines (30 cents per dose plus labour) exist against the major clostridial diseases (Lane et al., 2015, Allworth, 2021).

The prevalence of clostridial diseases may be over-estimated, due to Australian producers attributing sudden deaths to enterotoxaemia (Lane et al., 2015). However, sudden death resulting in rapid carcase autolysis may be caused by many diseases.

There is no current information on the prevalence or incidence of enterotoxaemia in Australian flocks or feedlot situations. In other countries prevalence rates have been recorded as ranging between 0.14%to 38% (Goekce et al., 2007, Greco et al., 2005, Nasr et al., 2014, Nawaz et al., 2021, Tooloei and Masodei, 2008). In an extensive prevalence study conducted in Iran, the prevalence rate of enterotoxaemia in sheep was 0.14% with a case fatality rate ranging between 0% and 80% (Tooloei and Masodei, 2008). It was noted in this publication that sheep examined had been vaccinated against clostridial diseases according to manufacturer guidelines, however antibody titre levels were not evaluated in these animals to determine if they had appropriate antibody protection. In general, up to 10% of a flock may be affected and the case fatality rate is usually 100% (Pawaiya et al., 2020). Thus, the disease is characterised by sudden death. If clinical signs are seen, these will include anorexia, dullness, convulsions and frothing at the mouth which will progress to death within a few hours (West et al., 2017).

History, clinical signs, and gross post mortem examination findings are useful in establishing a presumptive diagnosis of clostridial enterotoxaemia, but confirmation requires laboratory testing (West et al., 2017). Histological examination of the brain of deceased lambs, coupled with epsilon toxin detection in the intestinal contents, are needed for a definitive diagnosis of enterotoxaemia (Uzal et al., 2004). Other post mortem changes such as excess, straw coloured pericardial fluid with or without the presence of fibrin, as well as pulmonary oedema and glucosuria are relatively consistent changes with this disease that should help in establishing a presumptive diagnosis (Uzal et al., 2004).

There is no effective treatment for the disease in the flock situation (Pawaiya et al., 2020). Prevention involves avoidance of sudden changes in feed, and vaccination. It is recommended that sheep receive two doses of toxoid vaccine, about 4 – 6 weeks apart followed by subsequent annual booster (Uzal et al., 2016). Anecdotally, it appears that this vaccination protocol is relatively ineffective in protecting fast growing lambs within intensive finishing system in Australia and a protocol of vaccinating lambs more frequently at 3-6 monthly intervals has been suggested (Allworth, 2021).

Acute lactic acidosis (acidosis, acute ruminal acidosis, grain overload, grain poisoning, rumen impaction)

Acute lactic acidosis (ALA) is defined as "a fermentation disorder in the rumen characterized by a lower than normal ruminal pH (≤ 5.0), reflecting an imbalance between microbial production, microbial utilization, and ruminal absorption of volatile fatty acids" (Hernández et al., 2014).

ALA has long been a major issue when introducing ruminants to grain-based diets, as they to adapt to converting the highly soluble grain carbohydrates to useable energy sources and presents a significant animal welfare concern for sheep in the feedlot industry (Fanning et al., 2018). Lamb feedlot operators are aware that there is an inherent risk associated with the utilisation of energy dense grains. Despite a thorough understanding of the disease mechanism and methods for the safe introduction of grain-based diets to ruminants, under commercial conditions, acidosis remains a common occurrence (Bowen et al., 2006).

Ruminants have a complex population of ruminal microorganisms. The natural diet of a ruminant such as a sheep, is forage from grazing. This contains abundant cellulose but little soluble carbohydrate. When grains are ingested, fermentation of carbohydrates releases organic acids which dissociate and decrease ruminal pH (Allen, 1997). Ruminal fluid pH should be maintained at 6.0 to 8.0 under normal circumstances (Fanning et al., 2018). This is achieved by a combination of mechanisms including:

- Neutralisation of the acid as its produced with salivary buffers (bicarbonate and phosphate) (Allen, 1997)
- Rumen or caecal epithelial absorption of acids (Radostits et al., 2007).
- Removal of some ruminal acids with digesta as it flows from the rumen to the reticulum (Aschenbach et al., 2011).

The effectiveness of these methods is related to the rate and type of acid production compared to the rate of acid removal and buffering (Fanning et al., 2018). When highly soluble carbohydrates such as grain are ingested, ruminal microbes adapted to soluble carbohydrates and lower pH proliferate and produce lactic acid (Allen, 1997). This lactic acid is fermented to produce volatile fatty acids (VFAs) by other, mainly gram-negative bacteria (Abbott, 2018). These VFAs can then be absorbed from the rumen and caecum to maintain ruminal fluid pH between 6.0 and 8.0 (Fanning et al., 2018). If a sheep diet is changed to highly soluble carbohydrates (such as grains) too suddenly, (increasing grain feeding by more than 25g/head/day over a period shorter than 21 days (AgricultureVictoria, 2020)) there is insufficient time for lactic acid utilising bacteria to proliferate, causing ruminal fluid pH to reduce. The ruminal epithelial papillae respond by increasing their total surface area to maximise absorption of the VFAs produced (Fanning et al., 2018). If these mechanisms are overwhelmed and the ruminal pH drops to 5.0 or below there is complete rumen stasis, anorexia and destruction of cellulolytic bacteria and protozoa (Abbott, 2018). At this stage fluid is drawn into the rumen from the circulatory system due to the high rumen osmolality leading to rumen distension, haemoconcentration and severe dehydration (Abbott, 2018). In experimental lactic acidosis induced by sucrose in sheep; feed intake does not resume until rumen pH has returned to 6.0 or higher and lactic acid is no longer detectable in the rumen (Minuti et al., 2014). Renal blood flow and glomerular filtration rate are also decreased, resulting in anuria (Minuti et al., 2014).

The high concentration of lactic acid in the rumen causes chemical rumenitis, which can lead to secondary mycotic (fungal) rumenitis in those that survive; this occurs approximately 4 to 6 days later (Radostits et al., 2007). The low pH of the rumen favours the growth of certain bacteria (*Mucor, Rhizopus*, and *Absidia* spp.) which invade the ruminal vessels, causing thrombosis and infarction. Widespread necrosis and gangrene of the ruminal wall can lead to the development of an acute peritonitis. The damage to organ linings causing complete gut stasis; coupled with the toxaemia from the necrosis is usually sufficient to cause death. All these events can occur within 24 hours after engorgement of a lethal dose of carbohydrate; with toxic doses the course of events may take 24 to 48 hours (Radostits et al., 2007). If sheep survive, complications may still arise including:

- Hepatic abscessation due to a combination of rumenitis caused by lactic acidosis and allowing *Fusobacterium necrophorum* and *Trueperella* (formerly *Arcanobacterium* or *Corynebacterium*) *pyogenes* to enter directly into ruminal vessels and spread to the liver, which may have also undergone injury from the lactic acidosis (Radostits et al., 2007).
- Laminitis due to translocation of the vasoactive substance lipopolysaccharide (LPS) from the gastrointestinal tract to the bloodstream which causes an inflammatory response (Nocek, 1997) resulting in injury to the microvasculature of the corium of the hoof leasing to cell swelling and the insidious rotation of the distal phalanx (pedal bone) that can result in permanent anatomic change (Radostits et al., 2007).

In the 2006 survey of lamb finishers conducted by Giason and Wallace, most small and medium lot feeders surveyed reported acidosis combined with shy feeders to account for less than 2% of the health concerns in lambs and in large feedlots between 2-5% (Giason and Wallace, 2006). However, the question asked in this survey, “What is your average percentage of shy feeders/acidosis?” should have been separated as shy feeders and acidosis are not the same condition although they can be enhanced by each other.

In outbreaks the severity of the condition in individual animals ranges from recumbency and death in the worst affected, to staggering in the severely affected and flock separation in milder cases. Depression, dehydration, weakness, abdominal distension, and anorexia are typical findings (Hernández et al., 2014, Jaramillo-López et al., 2017).

A mucopurulent discharge is common because animals fail to lick their nares (Radostits et al., 2007). Diarrhoea is almost always present (Hernández et al., 2014, Jaramillo-López et al., 2017, Radostits et al., 2007). Faeces are light coloured with an obvious sweet to sour odour (West et al., 2017) and ruminal pH will generally be below 5.

Acute laminitis may be present with sheep showing signs of pain on all feet, including walking slowly and reluctance to walk (Jaramillo-López et al., 2017). Evidence of chronic laminitis may develop several weeks after the acidosis event (Radostits et al., 2007).

Recumbency usually follows after about 48 hours but may occur earlier with a rapid onset of recumbency suggesting an unfavourable prognosis (Radostits et al., 2007). Mycotic rumenitis is common in animals with a rapid progression and is characterized by a fluid-filled atonic rumen, dehydration in spite of fluid therapy, diarrhoea, anorexia, weakness leading to recumbency, and death in 2 to 3 days caused by acute diffuse peritonitis (Jaramillo-López et al., 2017).

On post mortem examination the rumen of affected animals will be distended and filled with undigested grain with an acidic sweet smell (West et al., 2017). The carcase will be dehydrated and congested (West et al., 2017). If the post mortem examination takes place less than an hour after death, measuring ruminal pH may be of value in confirming the diagnosis with a pH between 4.0 and 5.0, but after 1 hour the pH of the rumen contents begins to increase and its measurement may not be reliable (Bello et al., 2010). The rumen wall is often reddened globally or in patches, and the papillae strips off easily (Radostits et al., 2007). In cases that have persisted for 3 to 4 days the wall of the reticulum and rumen may be gangrenous (West et al., 2017).

For most cases of ALA the prognosis is poor, especially when signs of shock have already developed. Under Australian feedlot conditions the treatment of ALA is unrewarding and veterinary effort is better placed in advice regarding prevention.

Pneumonia and pleurisy

Pneumonia is a disease of the lower respiratory tract of sheep (Abbott, 2018). Historically the condition appeared to be of low significance in causing mortality and production losses in Australian sheep flocks (Abbott, 2018). However, abattoir surveys suggest that the condition is more prolific than previously thought (Meyer, 2013, Lloyd et al., 2016, Lloyd et al., 2022). Further research is needed to better understand the effects of the condition on live animals. Pneumonia in sheep can be caused by a range of agents including parasites, viruses and bacteria (Caswell and Williams, 2007, West et al., 2017). These agents cause a range of clinical signs and physical changes to the lungs (Abbott, 2018).

Difficulty breathing, fever, anorexia, weakness, nasal discharge and coughing are the classical clinical signs of pneumonia (Alley, 2002, Bell, 2008). According to the presentation of these signs, three main clinical forms can be discerned; peracute, acute and chronic. Sudden deaths are the most frequent expression of peracute disease. By contrast, in chronic forms lambs won't necessarily show respiratory related clinical signs but often have a poor body condition and reduced average daily liveweight gain.

Pleurisy is the inflammation of the membrane that covers the outer surface of the lungs and the inside of the ribcage (Radostits et al., 2007). This condition often develops secondary to pneumonia (Lloyd et al., 2016). Animals that recover from acute pneumonia and pleurisy will have scar tissue of varying severity that can fuse the pleura of the ribcage and lungs to stick to each other. At processing, parts of or the whole rib cage may have to be removed to cleanly eviscerate the carcase (Lloyd et al., 2016). Frenched racks are one of the most valuable cuts from a lamb carcase; therefore, rib removal represents a significant financial loss to the processing sector as well as to producers being paid 'over the hook' (Lloyd et al., 2016).

The terms used to classify pneumonia in sheep are confusing, owing to the range of descriptors and terms used to encompass the condition in various countries. Enzootic pneumonia is commonly used as a term to encapsulate the whole spectrum of lower respiratory tract infections (West et al., 2017), but is also used to describe only the most severe, acute and exudative forms of pneumonia often associated with the bacteria *Manheimia haemolytica* (Hore, 1976). Ovine respiratory complex (ORC) (Gonzalez et al., 2016) and pasteurellosis, have been used as terms synonymous with pneumonia (West et al., 2017). However, pasteurellosis is also used to describe pneumonia caused by *M. haemolytica* (Radostits et al., 2007) owing to the bacteria previously being termed *Pasteurella haemolytica* type B (Abbott, 2018).

In New Zealand it is generally recognised that two clinical forms of pneumonia in sheep are seen; chronic non-progressive pneumonia (CNP) of lambs or hoggets between 3-10 months of age and acute fibrinous pneumonia in sheep of all ages (West et al., 2017). CNP is a subclinical infection associated with the bacterium *Mycoplasma ovipneumoniae*, which is enzootic in lambs of slaughter age in New Zealand (Alley and Clarke, 1979, Alley et al., 1999). It has recently been found that this is also the case in Australia (Lloyd et al., 2022).

CNP is complex, involving the interaction of a range of different micro-organisms and environmental factors and the sheep's physical and immune mediated responses to these organisms and environmental factors (West et al., 2017). In general, viral lung infections predispose to secondary bacterial infections, most notably *Mycoplasma ovipneumoniae* (Lloyd et al., 2016), *Mannheimia* *haemolytica*, *Pasteurella multocida* or *Histophilus somni* (Caswell and Williams, 2007). *M. haemolytica* is a commensal organism found in the upper respiratory tracts of healthy sheep. It is thought that infections with certain viruses (parainfluenza virus type 3 and bovine herpes virus type 1) damage respiratory clearance mechanisms and lung tissue, which facilitates the translocation of bacteria from the upper respiratory tract and the establishment of infection in compromised lungs (Radi et al., 2010). However, it is unclear if all viruses involved in pneumonia act in this way and so further studies are needed to determine the role of respiratory virus infections in sheep (Navarro et al., 2019a).

In New Zealand, experimentally induced pneumonia in sheep resulted in extensive lesions in the lungs. Viruses and bacteria inoculated sequentially as well as mycoplasmas and bacteria inoculated together both resulted in pneumonia, suggesting they act synergistically (Davies et al., 1977, Davies et al., 1982, Sharp et al., 1978). However not all infections under these experimental conditions led to the development of pneumonia, emphasizing the complexity of the disease. It is only when the immunological defences of the lungs are overwhelmed and the microorganisms proliferate that pneumonia is seen (Navarro et al., 2019a). The nature of the lung lesions is determined by the organisms that proliferate (Davies et al., 1982). When only a small amount of the infectious organism was present, purulent lesions in the lung developed, which quickly resolved as the sheep's immune system overcame the infection (Davies et al., 1982). At higher doses, lung tissue necrosis occurred and bacteria were able to escape from the lesions, leading to death in the lambs due to septicaemia. If the infection was instead confined to the rib cage and lungs, an acute necrotizing pneumonia and pleurisy occurred. The pleurisy did not fully resolve in these, leaving scar tissue in the lungs and pleura (Davies et al., 1982).

Environmental, management and host factors play a role in the pathogenesis of pneumonia in lambs as well as concurrent infections (Navarro et al., 2019a). Exposure to extreme weather conditions is a known risk factor for pneumonia (McRae et al., 2016). Dry, dusty environments and management practices such as weaning, mustering, and shearing are known risk factors (Abbott, 2018, Goodwin-Ray, 2006, West et al., 2017).

Concurrent infections with certain diseases such as coccidiosis (Gonzalez et al., 2013, Wright and Coop, 2007), Orf (Haig et al., 1997) and Border disease (Gonzalez et al., 2014) are (Mukasa-Mugerwa et al., 2000) survey carried out by González et al., lambs with coccidiosis had 1.84 times more risk of suffering from pneumonia than those without it (Gonzalez et al., 2013).

Epidemiological data for pneumonia suggest the risk factors vary across regions and even within a flock (Navarro et al., 2019a). Studies have reported significant breed differences in the morbidity and mortality rates in sheep with pneumonic lesions (Mukasa-Mugerwa et al., 2000). However, these studies have not taken place in Australia. In general, heritability has shown to be low for pneumonia and pleurisy in sheep. McRae et al. (2016) estimated these values in 0.07 ± 0.02 and 0.02 ± 0.01, respectively (McRae et al., 2016), while Baird et al., 2012 found the heritability of the consolidated pneumonic lesion score in pedigree-recorded lambs was estimated in 0.12 ± 0.06, taking into account breed differences as well as within breed variation (Baird et al., 2012).

Risk factors such as breed, sex, adverse weather events, stress and age have all been implicated in the development of respiratory disease in sheep (Goodwin-Ray, 2006, Mukasa-Mugerwa et al., 2000, Nash et al., 1997, Navarro et al., 2019a). Mukasa-Mugerwa et al. (2000) found that Ethiopian indigenous sheep had a 1.32 times higher risk of developing respiratory illness compared to their non-indigenous counterparts (Mukasa-Mugerwa et al., 2000) while an American study found that male sheep had a 1.9 higher risk compared to female lambs in Illinois (Nash et al., 1997). Adverse weather conditions and stress (caused by poor nutrition, transport, mixing of lambs from multiple properties) can act as trigger factors that allow infectious microorganisms to cause pneumonia (Goodwin et al., 2004). Age plays a role in infections as well and although acute pneumonic outbreaks can occur in any age group, most cases affect lambs younger than 12 months old (Navarro et al., 2019a).

In a study conducted in New Zealand, the prevalence of lung abnormalities in lambs was as high as 80%, and severe lung lesions were associated with a reduction in daily weight gain by 5% to 10% during the last month of the finishing period (Goodwin et al., 2004). While in a Spanish feedlot study 78.5% of 5,394 lambs examined post-mortem, had died as the result of respiratory problems (Gonzalez et al., 2016). Australian pneumonia and pleurisy prevalence in lamb feedlots are unknown, with the only sheep prevalence studies available being based on abattoir surveillance. Preliminary data from a South Australian case study suggested that animal level prevalence is commonly <20%, with nearly half of sheep producers having affected flocks (Meyer, 2013). Lloyd et al. (2022), found that on examination of 1095 sets of lungs from 253 abattoir lots, 64.4% of the samples tested positive for *M. ovipneumonia*, 39.8% were positive for *Mannheimia haemolytica* and 15.3% were positive for *Pasteurella multocida*, 2.4 % for ovine Respiratory Syncytial Virus and 2.0% for ovine Parainfluenza Virus 3, signifying *M. ovipneumoniae* as the main pathogen causing pleurisy and pneumonia in Australian sheep. Further research and extension are warranted to help producers manage these infections in sheep. In a previous study by Lloyd et al (2016) region and age, but not breed, were significant risk factors for pleurisy. It was found that older lambs that had been weaned were more at risk of pleurisy than younger lambs (pre-weaning) with weaning being suggested as the stressor which attributes this difference. Regions with seasonal weather extremes were found to have a higher prevalence of pleurisy in this study (Lloyd et al., 2016).

Production losses are a known effect of pneumonic lesions. Goodwin et al reported that when over 20% of lung surface area was affected by pneumonic lesions, lamb bodyweight gain decreased from 135 to 65g per day (Goodwin et al., 2004). Alley and colleagues found that for every 10% of the lung surface area affected, a reduction of almost 1kg per month could be expected in lamb bodyweight gain (Alley and Clarke, 1979). In a study conducted in England, lambs weaned at 45 days of age and thereafter fattened intensively to a bodyweight of 33 kg (to be reached at an approximate age of 14 weeks), reported differences of up to 14 days longer needed for lambs to reach bodyweight for slaughter in animals with lung lesions and up to 33 days in animals with pleural adhesions (Green et al., 1995).

Clinical diagnosis of pneumonia is difficult, with accurate diagnosis requiring post-mortem examination of the lungs. For peracute and acute forms of the disease, post-mortem lesions are usually extensive and include fibrinous exudates, cranioventral, dark red consolidation, and congestion and haemorrhage of lung tissue (Lacasta et al., 2019). With the chronic form of disease, pneumonic lesions have a low congestive pattern (Navarro et al., 2019b). Fresh tissue samples are needed to culture organisms such as *Myclopasma ovipneumoniae*, *Pasteurella mutocida* and *Manheimia haemolytica* (Chakraborty et al., 2014, Lloyd et al., 2016)

In the face of a pneumonia outbreak antibiotics can be useful (Scott, 2011). However anecdotally it would appear that a high proportion of lambs will not fully recover from lung lesions before slaughter, even though controlled efficacy trials of various antimicrobials indicate that resolution of lung lesions entirely with antibiotics is possible (Politis et al., 2019). This suggests there is an issue with treatment efficacy in real world commercial situations. In the United States, a survey carried out in calves, found that 72% of *Mannheimia haemolytica* and 50% of *Pasteurella multocida* isolates were resistant to more than one antibiotic (Klima et al., 2014). It is important that Australian research determines whether antibiotic resistance is occurring in pneumonic bacteria in lambs.

There is no commercially available vaccination for use in sheep, therefore prevention relies on minimising predisposing factors, and specifically by avoiding unnecessary stressors to lambs or hoggets (Abbott, 2018, Goodwin-Ray, 2006, West et al., 2017). Appropriate control of immune system dampening diseases such as coccidiosis and orf should be implemented (Gonzalez et al., 2016, Nandi et al., 2011) and management practices such as mustering or yarding in hot dry environments should be avoided or the risk minimised by dampening the ground before yarding (West et al., 2017). Furthermore, development of a sheep vaccine against several of the organisms known to cause pneumonia in lambs so that ewes could be vaccinated prior to lambing would be prudent (Thonney et al., 2008).

Given the above information, lambs entering feedlots are likely to be at risk to pneumonia, given the impact of stress and age, and the possibility of favourable environmental conditions, including dust and adverse weather conditions. Pneumonia has been reported to be a major cause of mortality in feedlot lambs in other countries, and results in reductions in growth and feed efficiency, with reductions increasing with severity of disease (Thonney et al., 2008, Gonzalez et al., 2016).

Coccidiosis (Eimeriosis)

Coccidiosis or eimeriosis in sheep is for the most part, a disease of intensive management (Ridler, 2008) caused by the protozoan parasite, *Eimeria* spp, which develops in the small and large intestine of sheep.

There are 11 species of coccidia in sheep but only two, *Eimeria crandallis* and *Eimeria ovinoidalis*, are considered pathogenic (Gregory and Catchpole, 1987, Gregory and Catchpole, 1990). Although often asymptomatic in sheep, coccidiosis can be a serious enteric disease (Chartier and Paraud, 2012). *Eimeria* species can invade and destroy intestinal cells of the hosts, causing anaemia, electrolyte imbalances and poor absorption of nutrients. The most common clinical sign of infection is diarrhoea, and affected sheep show signs of ill thrift, poor weight gain and weakness (Khodakaram-Tafti and Hashemnia, 2017). The disease is spread via the faecal-oral route with sheep of all ages being susceptible. However, outbreaks are usually seen in two key situations: in young animals 1 to 3 months of age or in situations of high stocking density as is seen in barn housing or feedlot situations (Taylor et al., 2011) or via contaminated water sources (Wright and Coop, 2007).

In a recent Spanish study, coccidiosis was the main cause of morbidity in the feedlots studied, and incidence peaked at the end of the first week of entry to a feedlot (Gonzalez et al., 2016). In this study 39% of lambs diagnosed with coccidiosis were showing signs of coccidiosis on arrival in the feedlot (Gonzalez et al., 2016) which is in keeping with the shorter than expected appearance of clinical disease.

A high faecal oocyst count is not necessarily diagnostic for coccidiosis (Ridler, 2008). Traditional methods of identification are arduous and involve differentiation by either oocyte morphology, pre-patent period, site of infection or minimum sporulation time (Yang et al., 2014a). In more recent times PCR has been used as a diagnostic aid with varying levels of sensitivity and specificity. In a 2014 study, cross breed lambs under extensive conditions from 4 states in Australia had their faeces sampled at 3 time points (weaning, post weaning and pre-slaughter) to determine the prevalence of Eimeria species and to validate a quantitative PCR assay method. The following species were identified: *Eimeria crandallis, Eimeria ahsata, Eimeria ovinoidalis, Eimeria weybridgensis* and *Eimeria cylindrica*. Of these, *E. crandallis* and *E. ovinoidalis*, the most pathogenic species in sheep were responsible for 59% of the infections typed (Yang et al., 2014b). In this study the overall prevalence of *Eimeria* from 8 farms across 4 states over 3 sampling periods (weaning, postweaning and pre-slaughter) was 18.1% (n=3412) (Yang et al., 2014b). The prevalence varied widely between states and sampling points, ranging from 5.8% to 70%. Differences in prevalence were attributed to a wide range of factors, including environment, socking density and potential for contamination of feed/ water (Yang et al., 2014b). However, this prevalence does not differentiate between pathogenic and non-pathogenic strains of *Eimeria* or determine possible production losses associated with the infestations on individual properties and lambs in this study were not elucidated as being clinically affected by *Eimeria* spp. Therefore, further research is required to determine the extent of economic loss associated with *Eimeria* spp in sheep in Australia.

Bacterial enteritis

Yersinia enterocolitica, *Campylobacter jejuni* and *Salmonella enterica* are all pathogenic bacterial enteric infections which are known to occur in lambs and cause production losses and fatalities any time up to pre-slaughter (Yang et al., 2014a, Yang et al., 2016). Two recent studies on the prevalence of these organisms in lambs in southern Australia (using qPCR on lamb faecal samples at weaning, post weaning and pre-slaughter) found an overall prevalence of 13.3% for *Campylobacter* spp and a 5% prevalence for *Salmonella* spp in studied lambs flocks (Yang et al., 2014a) and 14.8 % of lambs shed *Y. enterocolitica* on at least one out of three sampling occasions (Yang et al., 2016). In the former study, *Campylobacter* spp. had the highest median bacterial concentration in faeces at weaning and post-weaning, whereas *S. enterica* had the highest median bacterial concentration at pre-slaughter (Yang et al., 2014a). All lambs in these Australian studies were grown on pasture-based systems.

Urolithiasis

Urolithiasis occurs in all sheep but is of greatest economic importance in feedlot sheep worldwide (Radostits et al., 2007). The condition results from the obstruction of the urethra or ureter (rarely) of mostly male sheep by uroliths (urinary calculi) (Radostits et al., 2007). While uroliths are deemed to form equally in males and females, females are able to pass them without blockages, while blockages occur in wethers and rams as a result of them having a long, narrow and tortuous urethra as well as a narrow urethral process (Videla and Amstel, 2016, Radostits et al., 2007).

Uroliths (calculi) form as a result of mineral precipitates in the urine, with the addition of mucoprotein, which acts as a cementing agent (Radostits et al., 2007). Calculi may be found in the pelvis of kidney or in the bladder of apparently healthy animals (Bramlet, 1954). However, when a urolith or multiple uroliths (Hay, 1990) become lodged in the urinary tract, blockages may occur. This stops or suppresses the passage of urine and symptoms occur (Bramlet, 1954). When a calculus causes a complete obstruction of the urethra or urethral process, urine retention occurs in the bladder and, without relief of the obstruction, the bladder or urethra will eventually rupture, allowing urine to escape into the abdominal cavity or the subcutaneous tissue of the prepuce (depending on the site of the rupture) (Videla and Amstel, 2016).

Diet plays an important role in urolithiasis with high concentrate or pelleted diets predisposing to this condition (Videla and Amstel, 2016, Hoar et al., 1970). Grain based diets are typically relatively high in phosphorus (P) and low in calcium (Ca) while pelleting of diets decreases saliva, which results in increased urinary P and possibly increases the urinary mucoprotein content (Bramlet, 1954, Stewart et al., 1991, Hay, 1990). Diet also influences the mineral content of the urine (Hay, 1990). There are different mineral concentrations of calculi, so while urolithiasis describes the end disease process of an animal having a urinary blockage as a result of any type of calculus; the different types of calculi may have resulted from different dietary imbalances / influences. Struvite crystals / calculi (magnesium ammonium phosphate) are most common (Dunn, 1977, Hay, 1990). However, calcium phosphate (calcium apatite) or calcium oxalate calculi may also occur (Hay, 1990, Stanton and LeValley, 2014). Urinary P levels are very important in determining the presence of calculi. Urinary P levels are:

- Increased by high dietary P levels (Bushman et al., 1968; Ferreira et al., 2018)

- Decreased by high dietary Ca levels (Bushman et al., 1968; Ferreira et al., 2018)
- Decreased by addition of 1% ammonium chloride (presumed to be due to its effects on decreasing urine pH and increasing Ca in urine and urine volume) (Ferreira et al., 2018).

The single most important dietary factor associated with preventing urinary calculi appears to be to maintain Ca: P ratios in the diet at least 2:1 (Hoar et al., 1970; Stanton & LeValley, 2014). In addition, total phosphorous should not exceed 0.6% of total ration (Hay, 1990). High P diets result in urinary calculi, and decreased growth rates (Hoar et al., 1970). Addition of calcium decreases the risk of urolithiasis, and negates the growth rate effect of high P, provided P levels are not excessive (i.e. <0.6%). High dietary P levels have been associated with increased levels of calculi (and urolithiasis) despite adequate Ca: P ratios, although in most experiments it appears that increasing Ca levels in the diet negates most if not all the impact of the high P diet (Hoar et al., 1970, Bushman et al., 1965, Bushman et al., 1968, Emerick and Embry, 1963).

Both urine output and urine pH are important factors. Increased urine output dilutes the P in the urine and decreases likelihood of calculi forming (Hoar et al., 1970). Increasing salt in the diet increases urine output (via increased water intake). Salt supplementation at a concentration of 1% to 3% salt has been recommended, although higher salt concentrations (e.g. 3%) have a negative effect on weight gain.

Increased dietary magnesium (Mg) also increases urine output (Hay, 1990). However, the role of dietary Mg in urolithiasis is not clear. Logically, given the main calculi in feedlot lambs are struvite which contain magnesium, it would seem obvious that higher dietary Mg levels would be associated with increased calculi formation. However, increased Mg also increases urine output which would help decrease risk. Further, in some studies with calculus formation associated with high dietary P levels, increasing dietary Mg levels did not increase risk of calculi (Cuddeford, 1987, Robbins et al., 1965), while one study in goats did find an increase in struvite calculus formation with increasing Mg intake (Wang et al., 2009).

Access to clean fresh drinking water with low mineral content is considered important to minimise risk with urolithiasis (Stanton and LeValley, 2014).

Decreasing urine pH is considered very effective in reducing risk associated with struvite calculi, but not necessarily with calcium phosphate or calcium oxalate calculi. Ammonium chloride at 0.5% to 1% is considered the best means of decreasing urine pH in feedlot lambs (Mavangira et al., 2010, Stewart et al., 1991). Diets with a 1% concentration of ammonium chloride have been associated with decreased growth rates in lambs. Low DCAD (Dietary Cation-Anion Difference) diets are likely to decrease urine pH and urine P levels but have not been associated with decreased urolithiasis (Luebbe et al., 2009) and they are likely to result in lower growth rates.

Clinical signs of partial obstruction include anorexia, twitching of the penis, straining abdomen, lambs not able to sit still while excreting small amounts of urine that may be blood tinged (Radostits et al., 2007)
With complete obstruction, lambs will have severe depression and anorexia. There will be apparent temporary improvement in the animal's condition (once the bladder bursts) (Abbott, 2018). The abdomen will then become distended due to urine in the abdominal cavity and/or there will be swelling of the subcutaneous tissue of prepuce (due to a burst urethra). Death will follow within 48 to 72 hours (Radostits et al., 2007).

Diagnosis is based on clinical findings and knowing the diet sheep are on and can be confirmed by post mortem examination. The urethra or urethral process may be obstructed by one or more uroliths or a fine sandy material (Radostits et al., 2007). If urethral rupture has occurred the urethra will be eroded at the site of rupture and cellulitis and urine accumulation will be evident within the abdominal wall (Radostits et al., 2007). If bladder rupture has occurred urine will be present within the peritoneal cavity with signs of peritonitis (Radostits et al., 2007).

Treatment is via surgical intervention and is not a viable option in lot fed situations and so prevention forms the main stay of control. When formulating a pelleted feedlot ration for lambs to minimise the risk of urolithiasis the following points must be taken into consideration for the total ration fed (including both concentrate pellets and additional hay):

- The Ca: P ratio should be 2:1 or greater
- The P level is recommended to be less than 0.6% i.e., 6 mg/kg, as increased P levels have been shown to increase risk of uroliths even when the Ca: P ratio is 2:1. This is discussed further below. (Stanton and LeValley, 2014)
- Add 1% salt to increase water consumption and urine output (Stanton and LeValley, 2014)
- Consider the addition of ammonium chloride at a maximum of 1%, although given the possible decrease in growth rates it is reasonable to reserve the inclusion of ammonium chloride until any problems are detected. (Mavangira et al., 2010, Stewart et al., 1991)
- Provide access to clean drinking water with low mineral content. (Stanton and LeValley, 2014)

Shy feeders (inappetence)

Lambs described as non-adapters or shy feeders remain the greatest frustration for lamb feedlot operators and the greatest mystery for researchers and consultants (Keogh et al., 2021).

The known factors that contribute to shy feeding include neophobia (fear of a new environment or feed source) and disease (Rice et al., 2016). There is some evidence that shy feeding is more prevalent in feedlots with higher levels of competition for feed (Hodge et al., 1991, McDonald, 1986) and that prevalence doesn't appear to be associated with individual characteristics (Rice et al., 2016). Duddy et al. (2016) and Davis (2003) both suggested it was usual to budget on at least 5% of lambs being shy feeders (Davis, 2003, Duddy, 2016). Giason &. Wallace (2006) reported that between 0 and 5% of lambs entering feedlots were shy feeders in their survey (Giason and Wallace, 2006) while Keogh et al. (2021) identified a median 3.5% based on their survey results (Keogh TP, 2021).

In a 2016 study (Rice et al., 2016), individual shy feeders were characterised as those that spent less than thirty minutes at a feeding trough in a twenty-four-hour period and most of these animals lost weight in the first week of entry to the feedlot. This study also found there was no difference between shy feeder and feeder weights on entry to the feedlot or a significant difference when temperament tested, indicating that these two measures are not useful in discerning shy feeders from feeders. However, another study in feedlot sheep showed that reactivity to social isolation, novelty and human contact in temperament tests were negatively associated with performance in terms of growth rate (Pajor et al., 2008).

Several studies have investigated the link between animal density and feedlot weight gain. da Cunha Leme et al. (2013) found that animals housed in groups of two achieved greater growth rates than animals housed in groups of 10. But found an increased incidence of aggressive behaviour between lambs as the number of lambs in the stalls increased. Kondo et al. (1989) similarly found behavioural changes in cattle subject to varied stocking densities. To a point, animal density can facilitate social learning, leading to allelomimetic feeding patterns and ultimately increase the degree of activity and competition around feeding areas where trough space is limited (Rice et al., 2016b). Although high levels of competition may increase the proportion of shy feeders, low levels of competition have been shown to increase the variation in feed consumption between individuals (Bowman & Sowell, 1997). The majority of feedlots surveyed by Giason and Wallace (2006) maintained a pen density between 2 to 5m per head. Keogh et al. (2021a) reported a median stocking density of 5m2, with 200-300 the most common mob size. Based on these findings, the incidence of antagonist behaviour between lambs would likely increase with increased stocking density and larger mob sizes. Given the study by da Cunha Leme et al. (2013) does not utilise a mob size amenable to commercial feedlotting, further research is required to better understand the implication of these findings for the commercial feedlot. Further research is warranted to determine the ideal mob size for lamb feedlots in order maximise social learning and allelomimetic feeding patterns, while balancing shy feeder risk.

Producers surveyed by Keogh et al. (2021a) noted that 'shy feeding' was an important animal health issue and reported that acidosis was the leading cause of feedlot mortality. This suggests that the successful adaptation of lambs from forage to concentrate based diets is an area requiring further research. Reported prevalences are inconsistent, but can be up to 20% for some feedlots (Giason & Wallace, 2006; Jolly & Wallace, 2007; Keogh et al., 2021). The most recent "priority list of endemic diseases for the red meat industry" did not include shy feeding (Shephard et al., 2022), and no literature has been published in regards to financial implications of shy feeding from an enterprise or an industry perspective.

Conclusion

Health concerns in lot fed lambs is an area where limited research has been conducted.
This review identifies gaps in the literature where further research would be pertinent
Incidence data pertaining to pulpy kidney, pneumonia, clinical coccidiosis infections, bacterial enteritis, urolithiasis, and shy feeding in feedlot settings in Australia is lacking and gleaning this information will be pertinent for improvement of both welfare and productivity in lot fed lambs in Australia.

Further key research areas in the realm of pneumonia and pleurisy include:

- Determination of the predisposing factors
- Examination of data from pedigree-recorded flocks in Australia with a high incidence of severe pneumonia and pleurisy to enable more accurate estimates of genetic parameters, and subsequent correlations with production and disease traits.
- Investigating antibiotic use as a treatment for pneumonia in feedlots and the efficacy of these treatments and possible resistance issues with their use and research into the
- Development of a multi-valent vaccine against organisms known to cause pneumonia in lambs.

With urolithiasis, investigating the role of dietary magnesium levels in feedlot rations as a cause of urolith formation is a current knowledge gap as well as investigating the role of ammonium chloride in reduced growth rates in lot fed lambs.

Furthermore, the conflicting results between studies regarding shy feeding in feed lot settings highlight the need for further research to develop practical and reliable methods for the early identification of the most vulnerable animals in feedlots

6.2 Cohort Study

6.2.1 Feedlots selected

Table 2: Description of feedlots selected

Feedlot ID	State	Feedlot Size	Cohort monitoring	Minimum lamb entry weight (Kg)	Age at entry Months	Source of lambs	No days backgrounded prior to entry	Average days on feed	Lambs/year (n)	Liveweight target (Kg)	Blanket antibiotic treatments	Clostridial vaccination status
1	SA	Large	Yes	35	4-6	Direct from farms	10	55-60	20,000	55-62	No	Unknown
2	SA	Large	Yes	NA	Buy on price	Direct from farms	7	55-60	24,000	55-62	No	Unknown
3	SA	Small	Yes	NA	9-12	Home-bred	21	NA	1,200	NA- breeding ewes in containment	No	Complete
4	SA	Small	No- opportunistic practice and due to other commitments producer	NA	NA	Sale-yards/ home-bred	NA	NA	800	45-60	No	NA

			did not purchase lambs for lot feeding in 2022									
5	SA	Medium	No- unable to organise visits or collection of data due to staffing shortages during COVID	NA	NA	NA	NA	NA	10,000	45-55	No	NA
6	NSW	Large	Yes	36	NA	NA	NA	>90	180,000	55-60	No	Unknown
7	NSW	Medium	No- unable to organise visits or collection of data due to staffing shortages during COVID	NA	NA	NA	NA	NA	17,000	45-55	No	NA
8	NSW	Small	Yes	NA	NA	Home-bred	21	55-60	4,000	55-60	No	Incomplete (only vaccinated at marking not at weaning)
9	NSW	Medium	No- due to wet Spring	NA	NA	NA	NA	NA	12,000	45-60	No	NA

			in 2022, containment feeding to only occur late summer in 2023 making data capture unattainable within the project timeline									
10	NSW	Small	Yes	NA	NA	Farm direct	14	55-60	<1000	45-60	Yes- issues with a previous cohort from same property with pneumonia. Blanket treated incoming lambs with long acting oxytetracycline.	Unknown
11	SA	Medium	Yes	38	Buy on price	Sale-yards	25	>90	9,000	60-63	No	Incomplete (booster not given)
12	SA	Small	Yes	38	Buy on price	Sale-yards	14	55-60	3,000	55-60	No	Unknown

13	SA	Small	Yes	35	Buy on price	Home-bred	14	55-60	3,000	47-55	No	Unknown
14	NSW	Medium	Yes	30	6-7 months	Home-bred	NA	60-90	10,000	45-55	Yes- Lasalocid	Unknown

6.2.2 Antibiotic Use

6.2.2.1 In feed antibiotics

There are three antibiotics available in Australia as in-feed antibiotics; the antibiotic virginiamycin and the ionophores lasalocid and monensin (AVA, 2021). Virginiamycin is highly important in human medicine for treatment of resistant bacterial infections, whereas ionophores are not used in human medicine and are therefore of low importance for humans. Ionophore use does however have the potential to reduce market access and eligibility to European Union markets. All three antibiotics can be added to grain and grain-based pellets or included in pre-mixes. All these products are useful when rapid grain induction is needed, but in most situations they are unnecessary once sheep have adapted to their grain diets especially if in-feed buffers are used instead.

The most effective ways to reduce the use of antibiotics in animal production is to remove them from animal feeds(AVA, 2021) as in feed antibiotics blanket treat multiple animals without them necessarily being efficacious in every animal which increases the risk of antibiotic resistance development.

In-feed antibiotic use has been determined as uncommon practice within these 10 feedlots. Virginiamycin was not used by any of the feedlots enrolled. One feedlot did use in-feed Lasalocid. This antibiotic is used as a coccidia preventative and is of low human importance as a non-human antibiotic.

6.2.2.2 Injectable antibiotic use

The injectable antibiotic oxytetracycline (concentration: 200mg/ml) was used to blanket (i.e. whole mob) treat lambs entering one feedlot at a dose of 10 ml/kg due to producer past experience of mass pneumonia related deaths from previous cohorts from the same property.

With pneumonia outbreaks, when only the clinical animals (lambs showing signs of pneumonia) are treated, new cases may develop for some time. Therefore, there is an argument for whole mob treatment, unless the mob can be easily accessed for ongoing surveillance and treatment. As there were all animals were treated in this cohort it was not possible to determine whether this was a useful course of action. There were still lambs that died from pneumonia within this cohort (3 cases out of 470 lambs). Antibiotic resistance is a major concern and is highlighted in Table 2 with a lamb from a separate cohort having bacteria that are multi-antibiotic resistant including to oxytetracycline. This case further highlights the need for further research and development into effective pneumonia treatments and preventatives such as vaccines with particular focus on mycoplasma species.

6.2.2.3 Antibiotic resistance testing

All bacterial related deaths within this project (salmonellas, bacterial pneumonia) were cultured and where possible, antibiotic susceptibility testing was performed to look for signs of antibiotic resistance. There are concerns about antibiotic resistance in salmonellas and compared with intensive animal industries, there is little information on antimicrobial susceptibility and resistance in bacteria associated with sheep gastrointestinal bacterial diseases. Results are displayed in table 3 below. A good result is to have bacterial samples that are susceptible (S) to all antibiotics tested. A moderately concerning result is when the bacteria cultured is intermediate (I) to some or

all of the antibiotics tested and a very concerning result is when the bacteria cultured is resistant (R) to some or all of the antibiotics tested.
The salmonella samples tested for antibiotic resistance showed no signs of antibiotic resistance. However, one pneumonia sample (11.2) had bacteria cultured that had muti-antibiotic resistance which is concerning and highlights the need for more effective management of pneumonia in Australian sheep production systems.

Table 3. Bacterial culture and antibiotic sensitivity results.

Lamb ID	Cause of death	Bacteria cultures	SXT	P	AMX	OXY	CTET
2.7	Salmonella	*Salmonella species* +++	S	S	S	S	S
2.8	Salmonella	*Salmonella species* +++	S	S	S	S	S
2.9	Salmonella	*Salmonella species* +++	S	S	S	S	S
11.2	Acidosis (pneumonia secondary cause)	*Pasteurella multocida* ++	S	S	S	S	S
		Mannheimia haemolytica ++	S	S	S	S	I
		Bibersteinia trehalosi ++ (used to be *Pasteurella trehalosi)*	S	R	R	I	R

SXT - Sulpha/Trimethoprim; P - Penicillin G; AMX – Amoxicillin; OXY – Oxytetracycline; CTET - Chlortetracycline

6.2.2.4 Mortality Rate

A total of 305 (2.5%) lamb mortality events have been recorded out of a pool of 11959 lambs that were monitored within 21 cohorts (table 4).
Table 4: cumulative mortality rates for each cohort of lambs observed.

Cohort	Days Observed (n)	Number Of Deaths (n)	Total Lambs In (n)	Cumulative Mortality	Mortality/Day
2c	7	23	306	7.52%	1.07%
1a	12	11	170	6.47%	0.54%
2a	14	11	187	5.88%	0.42%
2d	18	20	315	6.35%	0.35%
2e	61	29	300	9.67%	0.16%
1b	64	74	1203	6.15%	0.10%
2b	21	3	202	1.49%	0.07%
8a	40	3	183	1.64%	0.04%
1c	63	21	982	2.14%	0.03%
10a	67	7	470	1.49%	0.02%
8b	40	2	228	0.88%	0.02%

10b	68	6	450	1.33%	0.02%
3a	13	3	1185	0.25%	0.02%
14a	Na	1	82	1.22%	Na
14b	Na	3	414	0.72%	Na
11a	111	72	4000	1.80%	0.02%
12	23	12	310	3.87%	0.17%
13	1	1	374	0.27%	0.27%
8e	40	1	169	0.59%	0.01%
8c	40	1	214	0.47%	0.01%
8d	40	1	215	0.47%	0.01%
	Total	**305**	**11959**		
			Mean	2.89%	0.18%
			Sd*	3.02%	0.28%
			Alpha	0.05	0.05
			Sample Size	21	19
			95% CI	1.29%	0.13%

The mean cumulative mortality was 2.89% (n=21, 95% CI 1.6%, 4.18%).
* The standard deviation (Sd) is high relative to the mean most likely because of significant variability in mortality rates across cohorts. Some cohorts experienced higher mortality rates due to isolated disease outbreaks (e.g. salmonella and water belly) inflating the Sd.

6.2.2.5 Causes of death

A total of 305 mortalities were recorded with the diagnoses shown in table 5.

Table 5: Causes of mortality as attributed by producers and veterinarians as a percentage of the total number of cases observed to have died.

Cause of death	Cause of lamb mortality (attributed by producers) % (n) n=267	Cause of lamb mortality (attributed by vets) % (n) n=38	Cause of lamb mortality (total) % (n) n=305
water belly	35.6 (95)	0 (0)	31.1 (95)
acidosis	25.8 (69)	15.8 (6)	24.6 (75)
unknown	22.1 (59)	2.6 (1)	19.7 (60)
pneumonia	7.1 (19)	13.2 (5)	7.9 (24)
pulpy kidney	4.1 (11)	15.8 (6)	5.6 (17)
salmonella	0 (0)	23.7 (9)	3.0 (9)
shy feeder	2.2 (6)	0 (0)	2.0 (6)
pem	0.4 (1)	10.5 (4)	1.6 (5)
rectal prolapse	1.5 (4)	0 (0)	1.3 (4)
heliotrope toxicity	0 (0)	7.9 (3)	1.0 (3)
flystrike	0.4 (1)	0 (0)	0.3 (1)
misadventure	0.4 (1)	0 (0)	0.3 (1)
vaginal prolapse	0.4 (1)	0 (0)	0.3 (1)

black head	0 (0)	2.6 (1)	0.3 (1)
hypocalcaemia	0 (0)	2.6 (1)	0.3 (1)
kidney infection	0 (0)	2.6 (1)	0.3 (1)
chest infection	0 (0)	2.6 (1)	0.3 (1)

* There were two veterinary examined cases with pneumonia on post mortem examination, however as there was other significant disease concurrently (pulpy kidney and salmonella respectively), pneumonia was not considered the primary cause of death in these cases.

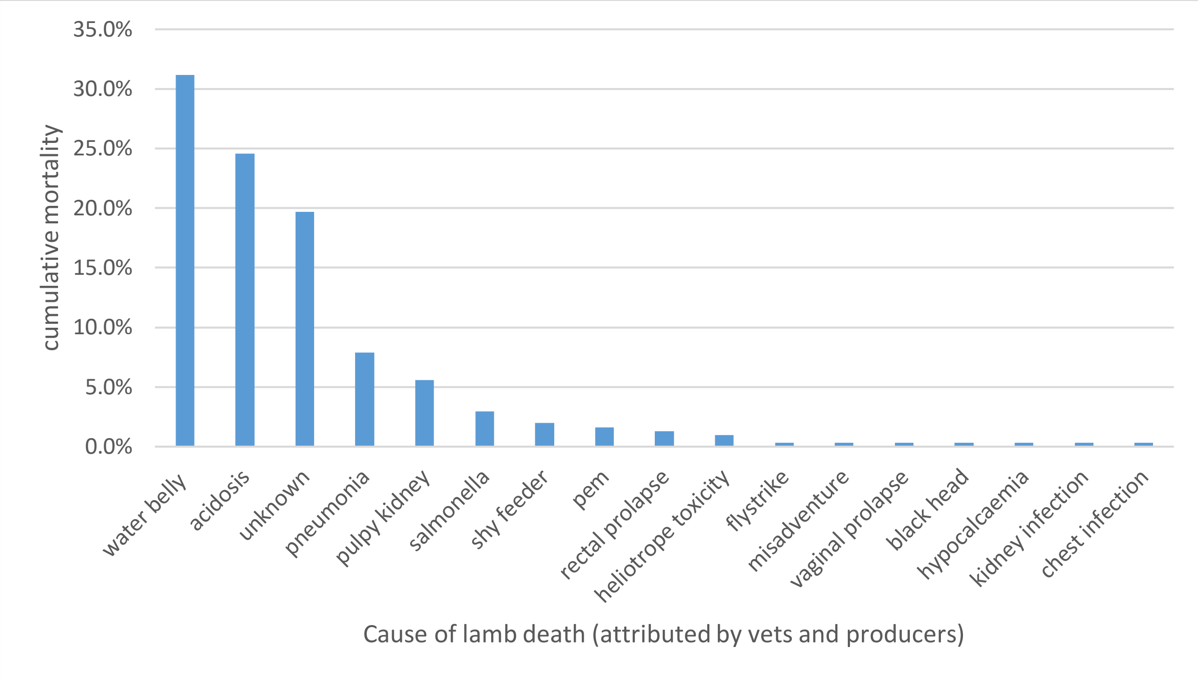

Figure 1: The % of deaths attributed by each condition attributed by both vets and producers

Out of the 305 mortalities recorded, 38 cases had post mortem examinations (12.5% of cases) which yielded a diagnosis in all but one case which was too decomposed for analysis. Whereas in the case of producer diagnosed causes of death 22.1% of cases did not have a diagnosis which is in keeping with the fact that most causes of death cannot be diagnosed without post mortem examination and further testing. This highlights the strong need for veterinary assistance during disease outbreaks. Producers involved found they were confident in diagnosing water belly and acidosis as a cause of death however without post mortem examination and testing found conditions such as polioencephalomalacia (PEM), salmonella, plant toxicities and hypocalcaemia impossible to diagnose.

Lamb mortalities occurred from between 1 day to 110 days in their feed pens with a mean number of days being 27.7 (95% CI 12, 67). Water belly cases occurred on average 30 days post feedlot induction (95% CI 27, 33). Acidosis cases occurred on average 20 days post feedlot induction (95% CI 14,26). Pneumonia cases occurred on average 54 post feedlot induction (95% CI 43, 65). Pulpy kidney cases occurred on average 42 days post feedlot induction (95% CI 31, 53). Salmonella cases occurred on average 9 days post feedlot induction (95% CI 8, 10).

The mean body condition score of the lambs that died was 2.41 (95% CI 1, 4). The majority of mortalities occurred in males (80.7%), which was skewed by the high proportion of water belly cases present on one feedlot which is a disease that is far more likely to occur in male lambs (n=95). When the water belly cases were excluded, 35% of the mortalities were male and 65% were female. A total tally of the number of males and females within each pen at the start of monitoring was not recorded and so the proportional mortality in relation to lamb sex could not be determined.

Incidence of disease related mortality has been represented as deaths per 1000 lambs (Table 6).

Acidosis had the highest incidence ranging from 4 to 77 cases per 1000 lambs within the cohorts that were diagnosed, with at least one case of acidosis with a mean average of 8 cases per 1000 lambs between all cohorts examined (n=16, 95%CI 0, 17). Water belly only occurred in 2 cohorts of lambs however had a high incidence in these cohorts (21-62 cases per 1000 lambs).

Table 6 : Incidence of disease related mortality per 1,000 lambs

cohort	acidosis	black head	heliotrope toxicity	hypocalcaemia	polio-encephalo-malacia	pneumonia	pulpy kidney	pyelonephristis	pyothorax	salmonella	unknown	waterbelly
10a	9	0	0	0	0	6	0	0	0	0	0	0
10b	4	0	0	0	0	0	7	0	0	0	2	0
2a	5	0	0	0	0	5	0	0	0	0	48	0
2e	77	0	0	0	0	0	0	0	0	0	20	0
8a	11	0	0	0	0	0	0	0	5	0	0	0
8b	4	0	0	0	4	0	0	0	0	0	0	0
8c	5	0	0	0	0	0	0	0	0	0	0	0
8d	5	0	0	0	0	0	0	0	0	0	0	0
8e	6	0	0	0	0	0	0	0	0	0	0	0
1a	0	6	0	6	0	0	6	6	0	35	6	0
2b	0	0	15	0	0	0	0	0	0	0	0	0
3a	0	0	0	0	3	0	0	0	0	0	0	0
2d	0	0	0	0	0	0	13	0	0	0	51	0
2c	0	0	0	0	0	0	0	0	0	10	65	0
1b	0	0	0	0	0	0	0	0	0	0	0	62
1c	0	0	0	0	0	0	0	0	0	0	0	21
mean	8	0	1	0	0	1	2	0	0	3	12	5
sd	18	1	4	1	1	2	4	1	1	9	21	15
Alpha	0	0	0	0	0	0	0	0	0	0	0	0
Sample Size	16	16	16	16	16	16	16	16	16	16	16	16
95%CI	9	1	2	1	1	1	2	1	1	4	10	8

6.2.2.6 Risk factors

Risk factors for acidosis, pulpy kidney, salmonella occurrence and dying with pneumonia have been analysed (Table 7).
Figure 2 provides a representation of the BN models developed.

Table 7 Bayesian network sensitivity analysis output identifying factors for disease related deaths, expressed as a percent, for all output factors

Node	% A[a] Acidosis	%B Pulpy Kidney	%C Salmonella	%D Pneumonia
Died from Acidosis (A), pulpy Kidney (B) Salmonella (C), Pneumonia (D)	100	100	100	100
Month	59.6	51.2	50.9	47.6
Pen area (m^2/Lamb)	58	45	24.2	45.7
Lamb BCS	41.4	30.5	27.9	45.1
Days of backgrounding	45.2	27.7	29.9	25.7
Lambs being mixed before entry	23.9	15	4.18	16.6
Rainfall in the previous 24 hours	27	15.2	31.7	15.7

[a] Describes the degree of sensitivity of one node to another.
[b] Lambs dying from acidosis, pulpy kidney, salmonella and pneumonia are 100% explained by themselves.

For all conditions above (acidosis, pulpy kidney, salmonella and pneumonia respectively) the time of year had the highest influence on death from these conditions (Figure 2) (between 47.6-59.6% mutual information).
Pneumonia tended to occur in Summer and early Autumn (in keeping with the name ‘summer pneumonia’).
Pulpy kidney appeared to occur more commonly over summer however December was over represented by an outbreak of pulpy kidney in one cohort with improper vaccination technique. Grain feeding inherently predisposes all sheep to pulpy kidney and so proper vaccination administration is essential on entry and 4 to 6 weeks after entry into the feedlot especially when the vaccine status pre feedlot entry is unknown.
Late summer to early Spring had the highest risk for acidosis occurrence. Low rainfall over this time period also predisposed lambs to acidosis (lambs were 3 times more likely to die of acidosis if there had been no rainfall in the preceding 24 hours), potentially due to the effects of high ambient temperatures with little summer rainfall leading to periods of inanition in lambs followed by periods of excessive grain intake due to hunger. Unfortunately records of daily temperatures were beyond the scope of this study and so conducting further work on the effects of shade provision and cooling methods such as sprinklers over periods of high ambient temperatures would be useful.

Rainfall in the preceding 24 hours was a useful predictor for death due to acidosis (27% mutual information) and salmonella (32% mutual information). The rainfall was categorised as none (0mm in last 24 hours), low rainfall (<20 mm in last 24 hours), moderate rainfall (20-39 mm in last 24 hours), high rainfall (>40mm in last 24 hours). Lambs were 3 times more likely to die from salmonella if there had been heavy rainfall in the preceding 24 hours. This is likely due to water pooling where drainage of pens was poor.

Autumn and Spring had the highest risk of salmonella related death occurrence as did high rainfall (above >40mm in the previous 24 hours) which is likely linked to poor drainage and water pooling within pens. Furthermore, lambs had a 20% increased risk of death due to salmonella when in a smaller pen size (2.01 m^2 compared to >5.31m^2/lamb). This is not surprising given the infectious nature of this disease, with crowded environments predisposing lambs to infection.

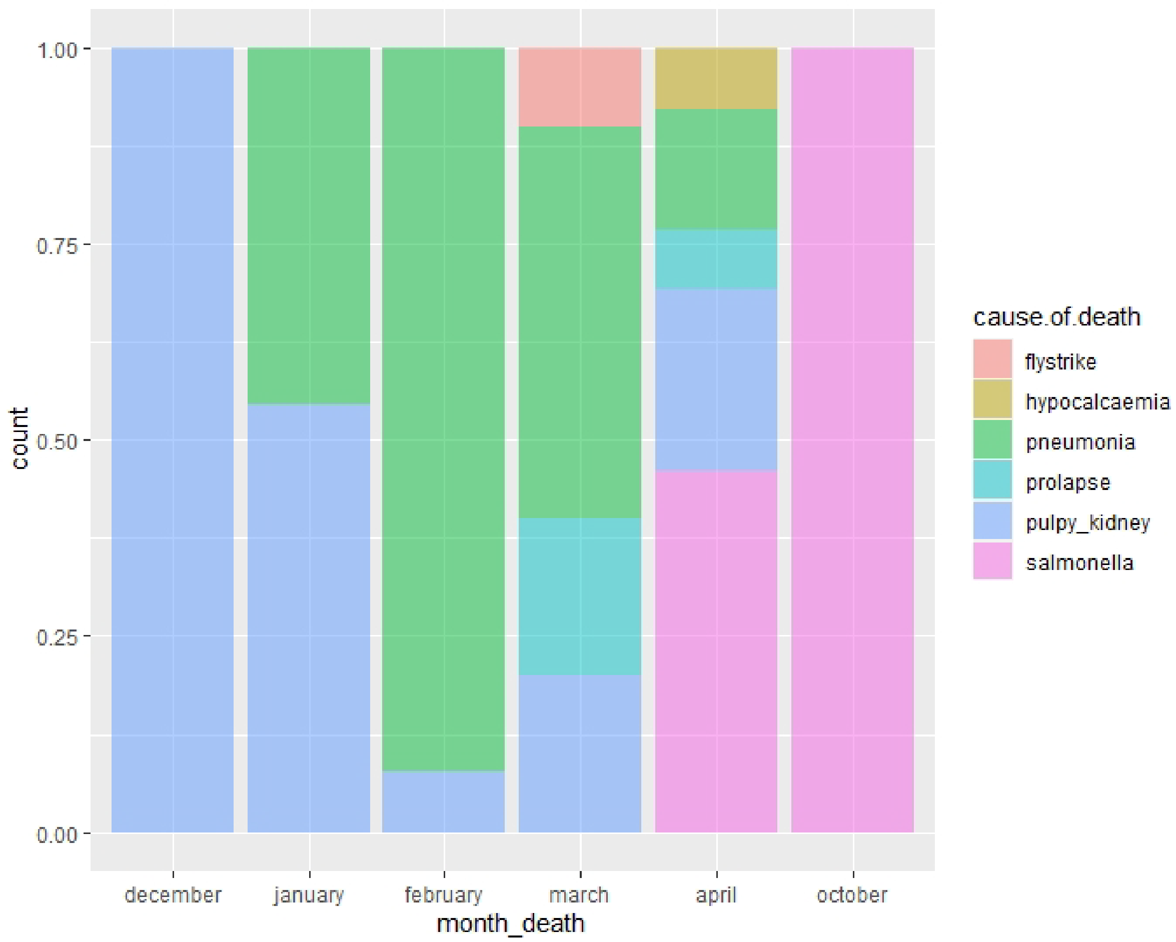

Figure 2 The proportional mortality of lambs that died from certain conditions in relation to the month of death occurrence.

The optimum stocking density for outdoor intensive feeding systems is yet to be determined. Current recommendations suggest 3 – 5 m^2 per head with a minimum space allocation depending on the number of lambs present in the pen (Table 8).

Table 8 showing the minimum area (m^2/lamb) for the numbers of lambs present within a pen

Number of lambs*	Area/lamb (m^2)
<8	0.9
8-15	0.8
16 – 30	0.6
>30	0.5

* The above guide is intended for an average liveweight of 40-55kg. If heavier sheep are to be fed a greater area per head should be provided.

A lower pen area allocation per lamb (<2.01m^2/lamb) increased the risk of lambs dying from acidosis by 9-fold. Similarly, lambs were at a 3-fold higher risk of death due to pulpy kidney with small space allocation per lamb. This is possibly due to stress related effects of crowding in lambs.

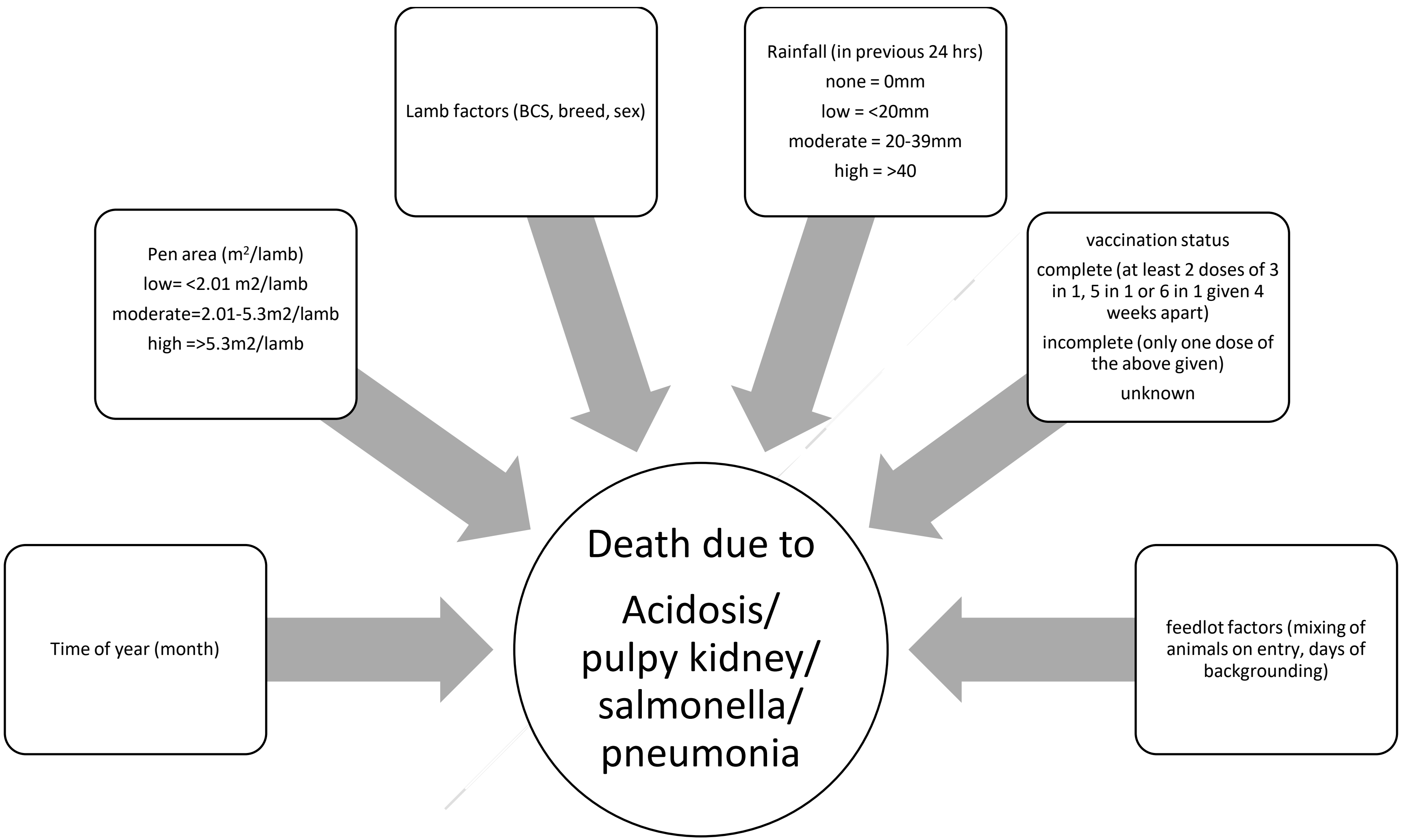

Figure 3: Bayesian Network conceptual model which represents the interrelationships between the deaths due to each condition and the risk factors present at the time of lamb death.

6.3 Shy Feeder analyses

6.3.1 Shy feeder risk factor analysis

The target node "estimated shy feeder percentage" was categorised into 3 categories: low (<2.5%), medium (2.5-5.0%) and high (>5.0%). Using the sensitivity analysis, average days to full ration, average mob size during induction, shearing prior to induction, mob size during finishing, minimum entry weight and fibre provision had the greatest strength of association with the target node (**Table 9**).

Having a shorter time period to get lambs to their full ration predisposed lambs to shy feeding. Feedlots that fed lambs to get to their full ration after 1 week or less were 8.1 times more likely to have a high shy feeding rate. A high shy feeder percentage was 3 times more likely to occur in mob sizes of over 350 animals at induction compared to mob sizes of 250 to 350 animals. Mob sizes under 250 animals were protective against shy feeder occurrence, and this was also the case for larger mob sizes at finishing. Shearing prior to induction predisposed lambs to shy feeding and feedlots where lambs entered at a lighter weight (30 to 35 kg compared to >35kg) were 4.6 times more likely to have a high shy feeder rate.

Table 9: Bayesian network sensitivity analysis output identifying 5 most important factors for shy feeder occurrence, expressed as a percent

Node	Percentage (%)[a]
Estimated shy feeder percentage b	100
Average days to full ration	62.5
Average mob size during induction	49.4
Shorn prior to induction	48.8
Mob size during finishing	46.1
Minimum entry weight	44.3

[a] describes the degree of sensitivity of one node to another

[b] estimated shy feeder percentage was 100% explained by itself and the average days to get to the full ration has the highest influence on shy feeder occurrence with 62.5% mutual information.

Average days to full ration had the greatest strength of association to shy feeder percentage (**Table 3**), with feedlots that utilised induction periods of 7 days or less, 8 times more likely to experience high rates of shy feeding. The transition from a forage diet to a high grain diet has been established as critical period for ruminal acidosis occurrence (Nagaraja et al., 2014). In cattle, Bevans et al. (2005) found that rapid adaptation to grain resulted in a greater variance in hourly rumen pH. However, adaptation was not found to impact dry matter intake. McDonald et al. (1990) observed a lower rate of shy feeding in a pre-embarkation feedlot where a combination of hay and pellets were offered, rather than pellets alone. Barnes et al. (2008) suggests that the provision of a solely pelleted ration may result in an unstable pattern of fermentation, leading to bouts of rumen pH depression and a subsequent reduction in feed intake. Increased rates of shy feeding observed in feedlots with shorter induction periods may be mediated through bouts of ruminal acidosis, however, further work is necessary to better define the interaction between ruminal acidosis and shy feeding/feed intake.

Feedlots with mob sizes of 350 or more were three times more likely to have a high percentage of shy feeders compared to feedlots with induction pen mob sizes of 250-350 head. Mob sizes less than

250 were found to be protective. Mob size at finishing followed a similar trend, granted that the majority producers surveyed used the same mob size throughout induction and finishing. da Cunha Leme et al. (2013) found an increased incidence of aggressive behaviour between lambs as the number of lambs in the stalls increased. Kondo et al. (1989) similarly found behavioural changes in cattle subject to varied stocking densities. On this basis, it is likely that antagonistic behaviour is more likely in the larger pens. Social dominance was not found to inhibit sheep from eating (Norris et al. 1990). Further research is required to assess whether increased shy feeding is seen in association with antagonistic behaviour, or mediated through another mechanism.

The finding that shearing was associated with high rates of shy feeding is contrary to prevailing literature. The removal of the fleece is said to evoke an increase in feed intake to meet energy requirements associated with increased heat production (Mclean et al., 2015). In a feedlot context, Aguilar et al. (2020) assessed the feed intake and behaviour of wethers in pre-embarkation and was unable to observe an increase in feed intake in shorn wethers compared to unshorn controls. In this study, accumulative stress associated with shearing and transport was not observed to impact feeding or behaviour states. Two of the producers in the shy feeder project fed shedding sheep in their feedlots; the effect of breed on shy feeding has not been elucidated. Fasting for periods of 48 hours prior to induction has been associated with an increased prevalence of shy feeding in pre-embarkation feedlots (McDonald et al. 1990). Fasting may play a role in the increased percentage of shy feeders observed in association with shearing prior to induction. Particularly sheep that are purchased, transported and shorn prior to induction. Survey questions did not include the extent of time on feed prior to induction. Further research in this area would be of value.

Lambs entered at a lighter weight (30 to 35 kg compared to >35kg) were 4.6 times more likely to have a high shy feeder rate. The mean entry weight was reported in Keogh et al. (2021) was 36 kg (IQR 33–39 kg). Where feedlots are targeting heavy trade or export lamb markets, lambs at a minimum weight from 25-35 kg are increased greater production costs and associated financial risk (Duddy et al., 2016), a minimum induction weight of 35 kg is recommended on this basis. Further research is required in order to better define the relationship between shy feeding and minimum entry weight.

The results of this bayesian network analysis suggest that through simple management changes, producers are able to manage shy feeding risk in the feedlot. Increasing the grain induction period beyond 7 days, utilising induction mob sizes of less than 350 head and purchasing lambs to achieve a minimum entry weight of 35 kilos, all represent low cost interventions to manage the risk of shy feeding in a feedlot.

6.3.2 Shy feeder economic modelling

Consuming maximum intake from day 36 onwards, the top 50% of shy feeders reached finishing weight at 110 days (**Table 10**). This corresponded well with the producer reported mean of 112 days. One producer reported that the bottom 50% of shy feeders took up to 217 days on feed to reach sale weight. This producer targeted 23.5 kilos of weight gain from induction to finishing. Days on feed for the bottom 50% of shy feeders was adjusted to 197 days to reflect the project average weight gain (**Table 10**).

A 1500 feedlot with 0% shy feeders, 5 year average lamb and sheep meat prices, and April 2023 feed prices produced a gross margin of $13717 or $9.14 per head. Where all shy feeders were assumed to achieve maximum intake during the weight gain period, feedlot gross margin was reduced to $13236 with 3.5% shy feeding (Keogh et al. 2021), representing a cost of $482 per feedlot or 32 c/head

(Table 11). Where the top 50% of shy feeders achieved maximum intake, and the bottom 50% achieved a lower rate of daily gain and mutton prices, gross margin is reduced to $7,800 with 3.5% shy feeding **(Table 12)**. This represented a cost of $5917 or $3.95 per head.

Table 10: Liveweight, SRW and age inputs, feed intake, ADG and average days on feed.

Induction weight kg lwt	37
Sale weight kg lwt	58.3
mean weight gain kg lwt	21.3
Standard reference weight (kg)	66.0
Age of lambs at feedlot entry (months)	6
Shy feeder drafting (days on feed)	35
Non shy feeders	
Days on feed	73
ADG kilo/day	0.294
Average daily intake (kg DM/day)	1.57
Shy feeder – weight loss period	
Shy feeder weight loss 0-35 days kg	6.00
Shy feeder daily intake 0-35 days kilo/d	0.123
Shy feeders top 50%	
Total days on feed	110
ADG kilo/day	0.193
Average daily intake day 36-110 (kg DM/day)	1.79
Shy feeders bottom 50%	
Total days on feed	197
ADG kilo/day	0.108
Average daily intake day 36-197 (kg DM/day)	1.115

Table 11: Gross margin sensitivity analysis 1500 head feedlot- all shy feeders 110 days on feed (heavy lamb pricing). Five-year average sheep meat prices

Shy feeder prevalence vs feed cost	0%	2%	3.5%	5%	8%	10%	15%	20%
$318.03/T - 20%	$27,139	$26,919	$26,754	$26,588	$26,313	$26,038	$25,487	$24,936
$397.54/T (April 2023)	$13,717	$13,442	$13,236	$13,029	$12,685	$12,341	$11,652	$10,964
$477.04/T +20%	$296	-$35	-$282	-$530	-$943	-$1,356	-$2,182	-$3,009

Table 12: Gross margin sensitivity analysis 1500 head feedlot - top 50% of shy feeders 110 days days on feed (heavy lamb pricing), bottom 50% 197 days on feed (mutton pricing). Five-year average sheep meat prices

Shy feeder prevalence vs feed cost	0%	2%	3.5%	5%	8%	10%	15%	20%
$318.03/T - 20%	$27,139	$23,872	$21,422	$18,972	$14,888	$10,805	$2,638	-$5,529
$397.54/T (April 2023)	$13,717	$10,336	$7,800	$5,263	$1,036	-$3,191	-$11,645	-$20,099
$477.04/T + 20%	$296	-$3,200	-$5,823	-$8,445	-$12,815	-$17,186	-$25,927	-$34,668

Depending on the proportion of shy feeders that achieve maximum intake during the growth period and depending the extent of shy feeder downgrading, shy feeding represents a cost of between $0.32 and $3.95 per head for a 1500 head feedlot with 3.5% shy feeders annually.

While some feedlots are operated on an annual basis, many feedlots are opportunistic. For many enterprises, feedlotting is only conducted where grain and lamb prices are conducive to profit. Therefore, the 5-year average lamb and sheep meat prices utlised for the model may not accurately reflect the more favourable market conditions though which opportunity feedlots operate. However, for the larger feedlots that operate on an annual basis, lamb feedlotting is a low margin, high turnover business. These producers may be invariably exposed to less favourable commodity prices and simple management changes that reduce the prevalence of shy feeding on farm may be of financial benefit.

It may be that the characteristics of individual enterprises dictate the performance of shy feeders post separation. 50% of producers (n=2) expressed that half of their shy feeders performed poorly despite segregation. Further research is required to better define the performance of shy feeders and to establish the proportion of animals that can be expected to receive a downgrade to mutton pricing.

7. Conclusion

7.1 Key findings

- The mean cumulative mortality within the current cohorts examines was 2.9% or 0.18% per day.
- Antibiotic resistance was identified in one lung sample. While this represents a single case, it underscores the need for further surveillance and preventive measures, as resistance in pathogens can have significant health and economic impacts. This detection, although not conclusive, highlights the importance of ongoing vigilance and highlights the need for further work on more:
    - effective prevention strategies such as vaccines
- improved treatment mechanisms that do not require blanket treatments of mobs which can lead to antibiotic resistance. Acidosis, water belly, salmonella, pulpy kidney and pneumonia had the highest incidences within this study.
- Most causes of death cannot be diagnosed without post mortem examination and further testing. This highlights the strong need for veterinary assistance during disease outbreaks. Producers involved found they were confident in diagnosing water belly and acidosis as a cause of death, however without post mortem examination and testing found conditions such as polioencephalomalacia (PEM), salmonella, plant toxicities and hypocalcaemia impossible to diagnose.
- Full vaccination status against clostridial disease was either unknown or incomplete for all cohorts examined and pulpy kidney had a high incidence within this study. This highlights the need for booster vaccination on entry onto the property and 4-6 weeks later when producers have bought in lambs with unknown vaccination statuses.
- Salmonella had a high incidence in specific cohorts. Further work on effective prevention options including vaccine development to reduce antibiotic use will be very important for both animal and human welfare concerns regarding resistant bacteria.
- Larger space allocation for lambs within feedlots (above 5m2/lamb) are beneficial for preventing death due to diseases such as acidosis, salmonella and pulpy kidney.
- Increasing the grain induction period beyond 7 days, utilising induction mob sizes of less than 350 head and purchasing lambs to achieve a minimum entry weight of 35 kgs, all represent low cost interventions to manage the risk of shy feeding in a feedlot.
- Depending on the proportion of shy feeders that achieve maximum intake during the growth period and depending the extent of shy feeder downgrading, shy feeding represents a cost of between $0.32 and $3.95 per head for a 1500 head feedlot with 3.5% shy feeders annually.

7.2 Benefits to industry

This project has provided:

- Industry data on lamb mortality within feedlots to inform industry benchmarks.
- Insights into the causes of feedlot related feedlot lamb mortality.
- Improved understanding of risk factors for disease related lamb mortality to inform industry best-practice management recommendations for lot fed lambs.
- Improved understanding of how veterinarians can aid livestock producers with their sheep management through their diagnostic expertise.
- Improved understanding of the risk factors associated with shy feeding and the economic costs associated with this condition
- The opportunity for a veterinary honours student to gain experience in the sheep industry and make valuable connections with sheep producers.

Findings from this study will inform guidelines for improved lamb survival within feedlots. This includes:

- The participatory research approach adopted during this study provided important insights into producer understanding of lamb health and management in feedlots.
- Producers gained valuable insight into diseases impacting lambs within their production systems.
- Participating producers indicated the need to be able to conduct a basic post mortem examination when veterinary assistance was unavailable to aid in understanding disease occurrence. Because of this, a basic post mortem guide and handbook of diseases has been created as an output of this project. It is important to note that this guide is not designed to replace veterinary assistance but rather as an ancillary aid when assistance is unavailable or to be used in conjunction with veterinary assistance via telephone consultation.

The veterinary post-mortem protocol developed during this project provides a consistent and defined methodology that can be used for research or in-farm investigations.

Information from the project will be disseminated to industry through:

- a project designed infographic
- a project designed producer post mortem guide
- presentations at industry events including: National conference for the Australian Sheep, Goat and Camelid Veterinarians, Wagga Wagga, June 2021; Adelaide June 2022; International sheep vets conference, Spain, March 2023; Local Land Services Conference May 2023, Wagga Wagga
- Results from this project will be published in at least one scientific journal article.

The project has supported development of skills, including:

- Veterinary students and graduate veterinarians gained practical skills in disease investigation and greater understanding of commercial sheep management practices and challenges particularly in lamb feedlots;
- Producer skills were increased through direct contact with project team on their property; and

- Collaborative relationships between government veterinarians and university research teams.

7.3 Future research and recommendations

Further key research areas in the realm of pneumonia and pleurisy include:

- Examination of data from pedigree-recorded flocks in Australia with a high incidence of severe pneumonia and pleurisy to enable more accurate estimates of genetic parameters, and subsequent correlations with production and disease traits;
- Investigating antibiotic use as a treatment for pneumonia in feedlots and the efficacy of these treatments with a strong focus on resistance issues with antibiotic use;
- Development of a multi-valent vaccine against organisms known to cause pneumonia in lambs.

Further research into effective salmonella prevention strategies is required given the high incidence of the disease determined within this study and the serious risk of antibiotic resistance development without judicial use.

With urolithiasis, understanding the role of dietary magnesium levels in feedlot rations as a cause of urolith formation and the role of ammonium chloride (used to prevent urolithiasis) in reduced growth rates is a current knowledge gap.

Further research is required to better define the performance of shy feeders and to establish the proportion of animals that can be expected to receive a downgrade to mutton pricing.

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