The effects of the pen feeding weaner lambs on their social interactions, wool production and weight performance.

Bridget Longley (11745051)

This dissertation is submitted to Charles Sturt University
for the Bachelor of Animal Science (Honours)

School of Agricultural, Environmental and Veterinary Sciences,
Faculty of Science,
Charles Sturt University

October 2024

Table of Contents

Abstract

The management of tail end weaner lambs is an extensive issue for the Australian sheep industry, with the lightest 25% of lambs being more than twice as likely to die than the rest (Hatcher et al., 2008). With up to 84% of producers stating that they offer supplementary feed to weaner lambs this paper aims to investigate different ways of supplementary pen feeding to get the best combination of social interactions, weight and wool performance. This was examined by having a treatment of only the lightest 25% of lambs and a treatment which had a mixture of light and heavy lambs. This was replicated to create 4 pens of 60 lambs in each, fed a grain and roughage diet daily. The key findings of this report were light lambs that are pen fed separately to mixed lambs were more likely to show increased weight gains of up to 0.8 kgs than those fed in a mixed pen. The difference in weight from the heaviest to lightest lamb increased at conclusion of grazing, showing that lighter lambs benefit more through the form of increased weight gains within a pen feeding system rather than grazing. This same result also displays those mixed lambs benefited more from grazing than lighter lambs did. As well as light lambs that were pen fed separately to heavier lambs showed no improvement in wool quality and quantity characteristics than those fed in a mixed pen. Light lambs that are fed in a separate pen were 44.8% less likely to experience bullying than all lambs fed in a mixed weight range. These findings are important because they can contribute to the practical implications of producers in field who are looking at the best way to pen feed weaner lambs. The key messages of this report regarding the Australian sheep industry are to examine each individual situation in conjunction with the key findings of this report to incorporate the aspects which are most related to your position to gain the best possible outcome.

Acknowledgments

I would like to firstly thank my supervisor Dr Susan Robertson, for all her knowledge, support and assistance during the entirety of my final year. Susan provided me with the feedback and motivation that I needed to complete this final dissertation to a level which I am proud of. My gratitude is also extended to the Australian Wool Education Trust for their generous scholarship which was used to fund the costs related to my trial, for this I am very grateful. I would also like to thank my family (Chris, Tracey, Edward and James) for their relentless assistance and support throughout the data collection period, weeks of feeding and overall encouragement throughout the final year of my study.

Ethics approval

This study was approved by the Charles Sturt Animal Care and Ethics Committee. The ethical project approval number A23921.

Chapter 1: Introduction

Minimising the mortality of weaner lambs is required to optimise production and avoid the perception of poor animal welfare. Previous studies have suggested that higher weaning weights in conjunction with positive post weaning growth rates can contribute to lower mortality rates in weaner lambs (Hatcher et al., 2010). The weaning weight of a lamb can have carry-over effects to the liveweight of lambs for up to 6 months post-weaning. There is evidence to show that the lightest 25% of weaner lambs are more than two times more likely to die than heavier lambs if compensatory nutrition is not provided (Hatcher et al., 2008). Under poor pasture conditions weaner lambs may need to be fed in confinement (pens), and pen-feeding introduces behavioural factors which may adversely impact on the feed intake and growth of light weaners. However, the key knowledge gap in the available literature is whether light weight lambs perform better if they are penned separately to heavy lambs when fed to a similar growth target. For Merino weaners, impacts on wool growth contributes to financial impact and is important as nutrition independently affects both liveweight gain and wool growth. The core focus of this research is to test whether separate pen feeding of light weight (tail end) weaners will improve their growth rates and wool production in comparison to feeding light weaners in the same pen as heavier weaners. This core scope will also include behavioural observations of these pen fed weaners to reveal if hierarchical behaviour is present which will assist in the explanation and incidences of shy feeders. The main objective of this report is to gain quantitive insights into the lamb's weight, wool and social interactions within each treatment. This will be used to determine what form of confinement feeding is associated with the best results of pen fed weaner lambs. It is hopeful that this report will assist in addressing the issues of weaner mortality by creating a practical solution with the findings. It is hypothesised that light lambs that are fed separately from heavier lambs will have increased weight gain and better wool production than those fed in a mixed pen. This will be examined further through an extensive literature review in chapter 2, materials and methods in chapter 3, with the results stated in chapter 4 and overall discussion of results in chapter 5 with key recommendations for practical implications from the findings included.

Chapter 2: Literature Review

2.1 Introduction

Tail end weaner management has been and continues to be an immense and extensive issue for the Australian sheep industry, with pen feeding being highlighted as an option to enhance lamb performance. Progressive growth rates post weaning are linked to improved weaner performance, which is only feasible if adequate nutrition and disease incidence is managed (Hatcher et al., 2010). Farmer intervention such as pen feeding can be reasoned when grazing lambs experience a decrease in pasture quality and quantity (Norris,1986). Campbell et al (2014) state that 84% of surveyed farmers frequently offer supplementary feed to weaner sheep when pasture supply is in deficit. Generating a question, what method of pen feeding weaner lambs will allow for better social interactions, increased wool production and enhanced weight performance.

Hatcher et al (2010) found that weaning weight can have lasting impressions on the liveweight of weaner lambs for up to 6 months and is a key factor in the determination of survival, post weaning growth rates, and liveweight. Consideration of management strategies involved with the lightest 25% cohort of the weaner lambs, which are more than twice as likely to die than that of the heavier weaners, has been a major focus in improving the growth rates of weaned lambs (Hatcher et al., 2008). Pen feeding has the ability to substantially escalate the feed efficiency of weaner lambs allowing for increased growth rates; however, lambs are known to be particularly variable in their adaption times to grain based diets leading to inconsistent growth rates and feed intakes (Keogh et al., 2021). The social interactions between lambs in pens are an essential element of the review as Rice et al (2016) discovered that up to 20% of lambs presented to a pen feeding situation are prone to displaying inappetence. In situations of compensatory feeding periods or drought, where weaners are placed into pen feeding situations, there are many factors including adaption times to diet, diet composition, diseases, environment, water quality, breed, feeding behaviour, and extreme temperatures which can influence their feed efficiency performance. Thus, the review is considering potential impacts that pen fed weaner lambs experience and discovering which of these influences has the greatest significance on post weaning growth rates, wool quality and quantity, survival and liveweight of weaners.

2.2 Pre weaning influences

Weaning weight is a critical factor in determining the profitability of an enterprise, through weaner survival rates. Studies suggest that the survival rate of a lamb post weaning, is significantly influenced by body weight at weaning (Mullaney, 1969). Creating an industry dispute of how-to best care for lambs in a way that encourages weight gains for improved survival rates. Weaning weight is a consequence of many pre weaning factors which play a contributing role towards the lamb. This analysis will further investigate these aspects and categorise their exact influence on lambs at weaning.

The industry recommendation for weaning age of merino lambs is 14 weeks of age; it is at this stage were only 10% of their diet is comprised of milk (Franklin et al, 1964). However, literature suggests that weaning should be more focused on a weight then age, a weaning weight of 40% of the mature ewe weight is the most ideal weight to wean lambs with the best odds of survival. When lambs present at less than 40% of the mature ewe weight at weaning time is when it is recommended to provide the tail end of the mob with compensatory nutrition (Hatcher et al., 2008). Franklin et al (1964) even suggested that in drought conditions were early weaning and pen feeding systems was necessary the minimum weaning weight can be around 7 kgs, with successful weaning in drought conditions of ages from 8-16 weeks old, as long as adequate nutrition post weaning is satisfied.

2.3 Incidence and causes of mortality post weaning

According to Campbell et al (2014), the average post weaning mortality rate across Australia is 4.6%, with 44% of producers indicating that they have above average weaner mortality. Incidences and causes of mortality post weaning can alter depending on the location and management of the enterprise, regardless the economic and welfare impact is significant. Fundamental emphasis on weight and age at weaning, nutrition, environmental factors, disease and parasites can all contribute to post weaning growth rates, liveweight and wool quality and quantity. Consideration of the management strategies involved with the lightest 25% cohort of the weaner lambs, which are more than twice as likely to die than that of the heavier weaners, has been a major focus in increasing the survival and production levels of weaned lambs (Hatcher et al., 2008). The scope of this segment will evaluate the influence that these factors have on the prevalence and origins of mortality in weaned merino lambs.

2.3.1 Nutrition

Campbell et al. (2014) emphasized that weaner flocks consistently separated by body weight or condition score experienced mortality rates up to 50% lower than those managed as a single unit. Supplementary feeding of high protein diets was correlated with a decreased mortality rate and increased weight gain. Common risk factors of weaned merinos are low body weight, growth rate, sex and time of shearing (Campbell et al, 2014). Weaners with a body weight lighter than 22 kgs had lower weight gains and higher mortality rates compared to weaners of 24 kgs. Clearly indicating lightweight weaners benefit from being managed separately from the heavier portion of lambs to better accomplish individual growth targets (Campbell et al., 2009).

Growth rates of weaners on high and low nutritional planes from weaning were found to be significantly different. Merino lambs fed on a high plane of nutrition gained 168 g/day compared to lambs on a low plane of nutrition which only gained 78 g/day, emphasising the significance that nutrition has on the growth potential of sheep (Asín et al., 2021). Nutritional management is used as a tool to safeguard productivity and to assist in preventing ill thrift. The nutritional requirements of a flock need to be met in both quality and quantity to evade animal health and welfare implications whilst maintaining a healthy body condition score. This is with inclusions of vitamins, minerals and micronutrients which all play an individual role in animal health (Asín et al., 2021).

2.3.2 Environmental factors

As the effects of climate change become ever more present in today's society, agricultural management practices are having to adapt to continue to maintain productivity. Lees et al (2017) examined the impact of thermal stress on small ruminants, which can result in reduced growth, lower production, weakened natural immunity, and potential death. Heat stress weakens immune function, raising the risk of illness and disease, which can adversely affect weight gain in pen feeding situations (Al-Dawood, 2017). Heat stress is proven to have negative influences on weaner weight gain through a reduced feed intake. This decrease in feed intake is associated with a 30% increase in maintenance requirements, resulting in reduced economic efficiency in pen-fed situations (Pluske et al., 2010; Lees et al., 2017).

2.3.3 Parasites

Gastrointestinal parasites are a common internal organism affecting the survival and welfare of weaners. Reducing voluntary feed intake and competence of feed utilisation through a reduction of utilisable protein in the gastrointestinal tract. Impacts from internal parasites can vary from low loss of liveweight to complete emaciation and death (Coop & Holmes, 1996). Abbott and Holmes (1990) examined the influence of dietary protein on the immune response to Barbers pole worm, showing dietary protein has no effect on the influence response of vaccinated lambs. Liver fluke is a major parasite affecting ruminant animals, leading to decreased productivity and welfare, particularly in weaner stock, which are at the highest risk of infestation. Research on the effects of liver fluke infestation on sheep production levels found that infected animals had an average daily weight gain that was 9% lower than that of uninfected animals. When not averaged, weaners experienced a 15% decline in daily weight gain, while mixed-age animals saw only a 4% reduction (Hayward et al., 2021). The most prominent impact that liver fluke has on stock is its effect on live weight gain and overall liveweight, creating constant struggles to keep weaners alive and healthy, increasing the managerial demands of younger stock (Hayward et al., 2021).

2.4 Influences on performance of weaners in pens

Pen feeding has the ability to substantially escalate the feed efficiency of weaner lambs allowing for increased growth rates however, lambs are known to be particularly variable in their adaption times to grain based diets leading to inconsistent growth rates and feed intake (Keogh et al., 2021). In situations of compensatory feeding periods or drought, where weaners are placed into pen feeding situations, there are many factors like adaption times to diet, diet composition, diseases, environment**,** water quality, breed, feeding behaviour, and extreme temperatures which can influence their performance. This evaluation will review these characteristics to better understand the precise influence that pen feeding has on the performance of weaned lambs.

2.4.1 Adaption times to diet

Temperament and dominant behaviour contribute to the variable adaption times to diets and pen feeding environments, giving a possible explanation on the inconsistent adaption times of individual lambs. Adaption time to diet is a determining factor in growth performances of lambs (Rice et al., 2016). Bowen et al (2022) suggested that exposure to concentrates pre weaning increases the frequency of acceptance to feed once in a pen fed situation and recommends it to be implemented as a routine management pre weaning. Exposure will allow lambs to gain an understanding of social arrays and have an increased feed intake in the first five days in the pen, reducing the number of lambs not approaching feed (Bowen et al, 2022).

2.4.2 Diseases

One of the most significant contributors to mortality within feedlots is acidosis, with Keogh et al (2021) reporting a mortality rate of 1%, the key contributor in restricting production efficiency. Preventative measures have been examined and concluded that acidosis can be managed through adaptation in the rumen, enzyme assembly in the small intestines and production of hind gut microbes. Bowen et al (2022) suggested, implement a carefully planned and scheduled introduction period of grain to assist in the advance of established bacterial populations, thus reducing the incidence of acidosis among the grain fed lambs.

2.4.3 Diet Composition

The composition of a young animal's diet can have varying effects on their production levels. Studies on lamb feedlot productivity found that a key limitation for pen-fed lambs was their consumption of lowly palatable feeds (Keogh et al., 2021). Different combinations of protein and energy diets need to be considered to get the best combination of performance and nutrient digestibility. Diets consisting of high energy and high protein will give the greatest average daily weight gain among other treatments, but if one had to be favoured over the other young stock would benefit more on a high protein diet over a high energy diet (Sultan et al., 2009).

2.4.4 Environment

Rice et al (2016) investigated the factors affecting lambs adapting to a feedlot environment and found that the environment significantly influences the prevalence of non-feeders, characterized by hollow flanks that indicate low gut fill. Factors which contributed to the increased incidence of shy feeders was the increased competition for environment resources like shade, trough space, access to water and lying areas. The environment of the feedlot pens can also have an impact on the welfare indicators of feedlot lambs. A study was conducted investigating the impacts of enriched vs barren pens, finding lambs within an enriched pen had greater average daily gains than those in the barren pens. Enforcing the idea that enrichment can improve the welfare of penned weaners through a decline in stereotypic behaviour and improving physical adjustment reaction to the new environment (Aguayo-Ulloa et al., 2014). The way feed is presented has a contributing factor in variable growth rates. An experiment examining three differing ways of presenting feed to merino wether lambs (42 kgs) concluded that the best carcase traits and average daily gains came from feeding a pelleted diet where selective feeding is eliminated. This was in comparison to feeding grain and hay separately in self-feeders and hay racks and a total mixed ration fed daily in a trough (Bowen et al, 2022)

2.4.5 Feeding behaviour

Keogh et al (2021) conducted a study which aimed to explore growth rates, feed conversion ratios, and identify possible significances which could increase feedlot production proficiency. The study reported significant results of rates of shy feeders being on average 3.5%. Feeding approaches that will lessen societal and nutritional disputes needs to be prioritised in feedlots to best encourage advanced nutritional consumption (Keogh et al., 2021). Additional literature suggest that other studies have had incidences of up to 5-20% classified as shy feeders. Key factors which contributed to the increased incidence of shy feeders was the increased competition for feed trough access, water trough space, shade and lying areas (Rice et al., 2016). Rice et al (2016) also discovered the hierarchy based on bullying characteristics was correlated with the size of the animal. Further exploring the issue of bullying amongst pen fed lambs, Rice et al (2016) concluded that a power hierarchy is expected to have implications on the welfare and growth performance of lamb's pen fed in a larger weight range.

According to Holst et al (1997) it can be determined that feeding intake isn't affected by sex of the lamb, rather directly linked to liveweight when the feeding commenced. However, regardless of sex there was a proportion of 11% of lambs that exhibited shy feeding behaviour which would benefit from separate feeding (Holst et al., 1997). With another significance drawn of male lambs consuming more lucerne pasture than the ewe portion of lambs (746 g vs 586 g) whilst at the exact same liveweight. Concluding the separate feeding of lambs should not be divided based on sex but rather on the proportion of light lambs, which are more inclined to be characterised as shy feeders.

2.4.6 Extreme temperatures

DiGiacomo et al (2021) examined the influences of heat stress in sheep and explored approaches to lessen the impacts. In his work he exposed the clinical signs of heat stress in sheep to involve increases in maintenance energy requirements due to the response of panting, sweating, respiration, and hormone control related to adjusting the internal body temperature. With impacts of heat stress also including distorted energy and nutrient metabolism and a decrease in feed intake, causing production losses and animal welfare issues within feedlot situations. Shade provided by mature trees was found to be the most efficient method of reducing the mortality related to excessive environmental temperatures.

Alternatively, exposure to cold temperatures, wind, and rain of sheep within feedlots can decrease the productivity of animals through the need for greater maintenance demands leading to smaller weight increases and decreased effectiveness of feed consumption. Longer wool length, the provision of added shelter and wind breaks can help relieve the impacts of thermal stress and consequently results in better growth rates and better feed conversion ratios which in feedlots is the key for increased profitability (Pluske et al., 2010).

2.4.7 Quality of water

Literature has suggested that water is the 'forgotten nutrient' as it has abilities for sustaining sufficient production levels. The water requirements of growing animals such as weaner lambs is increased compared to dry or mature animals, with a decrease in good quality clear water will come with a decrease in dry matter intake which is essential in feedlot conditions, leading to decreases in weight gains. Thus, ensuring animals have access to ad libitum good quality water is essential to ensure animals have maximum capability to continue to grow and thrive in their environment (DiGiacomo et al., 2021).

2.4.8 Crossbred lamb performance

Most literature concludes similar finding when reporting on the performance of merinos in feedlot situations compared to that of crossbreed species, which is merinos are a later maturing breed, more renowned for its wool growing abilities rather than growth characteristics of meat production (Brand et al., 2017). Crossbred lambs are capable of growing up to 57% faster and have better carcase fat than merino lambs (Yapi et al, 1990). This is a key reason why merinos and crossbreds should not be place into the same pen feeding situation, as there will become too much of a variance in liveweights. Dual purpose breeds have been selected based on their meat producing characteristics which make them perform better in feedlot situations, whereas merinos placed in pens because of restricted pasture availabilities or drought conditions are fed to maintain weight and wool growth and not so much focus on the meat production like alternative breeds (Brand et al., 2017). Reasoning why the separate pen feeding of these breeds would be necessary, as each breed needs to be managed differently to access their full potential.

2.5 Influences on wool quality and quantity

The price received for wool is dependent on the quality of the fibre thus ensuring that the product is being produced to the highest quality is essential for the profitability of merino wool producers. There are many characteristics of wool which have a direct impact on prices received, such as fibre diameter, length, and strength (Zenda et al., 2024). With many different factors like environmental**,** nutritional**,** mineral and trace elements, disease and parasites, management and genetics affecting these parameters, with both indirect and direct contributions to quality and quantity (Gelaye et al., 2021). This section will further explore these factors and classify their influence on the quality and quantity of wool.

2.5.1 Environmental Influence of weather conditions

The production of wool is significantly influenced by environmental variability. Seasonal changes in environmental conditions play a role in the nutritional needs of sheep, as well as affecting wool growth and the quality of the wool (Gonzalez et al., 2020). Dry weather can lead to seasonal weight loss which is a focal restriction of animal production. Drought prone areas where large scale wool producing farms are located are constantly fighting against the impacts that hot dry weather have on wool production. These areas are typically characterised by low rainfall and high temperatures, causing a high dust contamination within the fleeces of wool. Dust contaminated wool suffers a price reduction at market, particularly in the finer wool areas, this lower quality wool leads to reduced overall farm profitability (Huntley, 1970), (Almeida et al., 2014). André et al (2014) affirms what Almeida et al (2014) suggest, that with dry and drought conditions will also come a restricted diet primarily leading to a significant reduction in fibre diameter, which is one of the main determinants of price received. André et al (2014) also endorses that it is common for producers to supplementary feed to maintain wool production until time of shearing, to ensure the quality of wool doesn’t decline in the final months of growth (Almeida et al., 2014).

2.5.2 Nutrition

Gelaye et al (2021) articulates that it is the nutritional quality of feed that is a defining factor in the rate of wool growth, placing an emphasis on the nutritional needs of wool producing sheep in ensuring steady wool growth. Studies have shown that nutritional deficits of less than maintenance requirements in merino sheep can lead to a decrease of up to 29% less wool than that of merinos that have been met with adequate nutrition (Olivier & Olivier, 2006). A reduction of wool production of this magnitude can have negative effects to the profitability of an enterprise. Reis (1992) conveys a variety of physical and environmental influences that have impacts on the strength of wool fibres, with nutrient allocation having the largest influence on fibre diameter. Placing an emphasis on fibre strength during the season of pregnancy and lactation as foetus and ewe compete for essential nutritional needs. Fibre strength can be impacted by accumulative secretion of glucocorticoids, which is an endocrine response to stress caused by parasites and diseases, manipulating nutrient allocation through distribution of nutrients to stress related flight or fight responses rather than body reserves (Reis, 1992). Literature from Kellaway (2009) reported a nutritional effect on wool production amongst weaned merino lambs on a high vs low plane of nutrition. These differing nutritional planes did not have large effects on body weight, but lambs on a better-quality plane of nutrition had a 22% increase in wool production than lambs on a low plane of nutrition.

The genotype of a sheep is a pivotal point in shaping its capacity for fibre quality and production, however its ability to express this genetic potential is primarily based off nutritional intake. Through alterations to a flock's nutritional intake, the quality and performance of wool production can be controlled (Maley, 2021). Sahoo and Soren (2011) reiterates that production of wool is completely reliant on the supply of nutrients accessible to follicles during their growth phase and with adequate nutrition the characteristics of a fleece can be supported to grow. Olivier and Oliver (2006) investigated the impacts of short-term nutritional stress on wool production characteristics in merino sheep during a three-month period following weaning. They found that the body weight of the control group was up to 12 kg greater than that of weaners who did not experience nutritional stress. Wool production within the stressed group also decreased by a third than that of the group fed adequately. A noteworthy factor of this study revealed that if provided with ample nutrition the nutritionally deprived weaners were able to accomplish compensatory growth (Olivier & Olivier, 2006). Proving short-term nutritional stress does not have irreparably damaging outcomes on the wool producing abilities of sheep.

2.5.3 Mineral and trace element deficiencies

Wool production is reliant on the supply of nutrient to the follicle during growth. There are several minerals and macro minerals that have been shown to modify the construction of wool by upsetting feed intake, flow of nutrients to the rumen, altering rumen function and disruption on the metabolism of the sheep (Sahoo & Soren, 2011). Deficiencies in sheep can influence the quality of product, as Gelaye et al (2021) insinuates, a copper deficiency in sheep can result in the creation of steely wool, lessening the number of crimps and creating a reduced fibre strength. A secondary study displays the effects of zinc deficiencies on developing male merino lamb's wool follicles. The treatment group which had a clinical absence of zinc also had incorrectly keratinized wool fibres and follicles, compared to lambs that hadn't presented a zinc deficit. That study showed a zinc deficiency condenses the wool growth through the means of diminished protein amalgamation, caused by a zinc induced reduction in feed intake (White et al., 1994).

Maley (2021) has also identified selenium to play a central role in wool growth, by examining sheep with a known deficiency which exhibited a definitive reduction in wool growth. A correlating study reviewed the selenium intake in sheep and discovered that an average selenium supplementation increased wool growth by 5% and body weight by 3.9% (Sahoo & Soren, 2011), (Maley 2021). Maley (2021) also addresses the impacts of an iodine deficiencies in the diets of sheep and their contribution to the abnormal follicle development of the foetus, caused by the reduced production of the thyroid hormones. Creating a long-term impression into the next generation and collapse in wool growth and value in wool generating sheep (Hynd, 1994). Mineral and trace deficiencies in sheep vary between pasture type, soil type, seasons, and geographic location, making it vital for producers to understand the impact that mineral variations have on the health and production of their flock. By ensuring that their sheep obtain trace elements and minerals in moderation it will ensure the best possible wool quality and quantity (Maley, 2021).

2.5.4 Disease/parasites

The incidence of biological and non-biological agents within wool like the presence of microbes, urine, dags, colour of applied chemical solutions and sweat stains are a main cause for a lower quality or quantity wool clip from sheep. These characteristics can be caused by the presence or treatment of internal and external parasites and can diminished the quality of the final fibre product triggering a loss in profitability for the enterprise (Gelaye et al., 2021). Barger et al (1984) investigated the impact on liveweight and wool growth on chronically infected merino ewes with barber's pole worm (*Haemonchus contortus).* The study showed an increased seasonal decline in wool growth in the infected sheep opposed to the uninfected animals. Wool production could have a 10-30% reduction in young stock and a 5-20% reduction in mature sheep depending on the severity of the infection (Barger & Cox, 1984). Supporting evidence from additional literature confirms the Barger et al (1984) conclusion with the suggestion that the most significant symptoms of barber's pole worm are major reductions on clean wool production, processing losses and reduced mean fibre diameter (Angulo-Cubillán et al., 2007), (Albers et al., 1990). Not only will the chronic infection of worms have an effect on the physical production of wool, but there is evidence to suggest that Faecal egg count (FEC) and Dag score (DS) are interrelated. Suggesting that the greater the worm burden amongst a flock the higher the average DS. Increased DS will have negative impacts on the economic value of the fleece (Sajovitz et al., 2023).

Another key parasite which causes the sheep industry undesirable economic losses is sheep body lice (*Bovicola ovis).* With literature suggesting that a louse infestation can cause a loss of income to the farmer ranging from $0.72 to $1.92 for each infected sheep (Wilkinson et al., 1982). Although lice have no attributed affect to the liveweight of the animal the impacts that it has on the quality of the wool is much greater. Lice impact the worth of wool by irritating the sheep causing it to bite, scratch and rub producing damage to the fibres through breakages and cotting. Lice infected sheep will also often have a yellow-coloured wool due to the suint and skin secretions, further reducing quality and quantity of fibre (Niven & Pritchard, 1985). Australian sheep blowfly (*Lucilia Cuprina)* has similar affects to wool quality, as the irritation caused to a fly struck sheep will lead to rubbing, biting, and scratching of the infected area causing cotted and stained wool (Watts et al., 1981).

2.5.5 Management

Managerial elements such as weed management, shearing and crutching times, control of contamination material like paint brand applications can also influence wool quality and quantity. Gelaye et al (2021) insinuates that vegetable contamination and weathering of wool are some common faults attained from the environment, such as the contamination of wool via vegetable matter like thistles, grass seeds and animal matter. Vegetable matter contamination is an issue which can have inferior influences on processing effectiveness or overall garment worth (McGregor et al., 2016). Vegetable matter impurity can be controlled through altered management of weeds and selective grazing management techniques to help reduce and possibly eliminate the level of contamination within fleeces (Warr et al., 1979).

Shearing and crutching times and frequencies will have their own effect on wool quality. Time of shearing has been perceived to have effects on staple strength, site of weakness on the staple, fleece weight, yield, and fibre diameter (Gelaye et al., 2021) (Arnold et al., 1984). Gelaye et al (2021) suggests that the incidence of shearing will have a considerable influence on wool quality and quantity produced plus the general wellbeing of the sheep. Shearing frequency is determined by the availability of shearers, but as processors commonly favour a staple length between 60-90 millimetres, some producers are having to alter their shearing times to try and meet these firm market requirements (Nolan et al., 2013). Management has to consider the many different possibilities and consequences for shearing at a particular time to meet the capacity of both processor and consumer demands, with the primary foci point in the decision being related to the prospect of flystrike in unshorn sheep over the summer period (Arnold et al., 1984).

2.5.6 Genetics/breeding

The rate of wool growth and quality of the fleece is an attribute which is subjective from the genotype of the animal. With the objective features of wool, staple length, crimp, fibre type and fibre diameter being determined by genetic factors. Meaning the breeding program of an enterprises is a judicious factor in determining the best sire genetics and supplementary feeding levels used in conjunction to select and breed the most genetically capable sheep (Gelaye et al., 2021).

Literature examining the genetic parameters for wool production and quality traits of merino sheep examined the influence of sire choice on greasy and clean fleece weight, wool colour, yield, staple development, and other determining factors of fleece worth. The conclusions advocated that the selection of sires based on greasy wool colour should lead to the advances on scoured wool colour, along with the correlations of fleece weight and fibre diameter (James et al., 1990). Other literature assessed genetic parameters for wool production, wool quality, and bodyweight traits in merino sheep. Discovering that maternal genetic effects were substantial for fleece weight and bodyweight traits, with evidence from additional literature, showing that there are key economically antagonistic parallels between fleece weight and mean fibre diameter. With overall conclusions portraying that outcomes from selection programs will be similar across strains (Swan et al., 2008).

A number of factors can affect the capability to calculate the genetic value of merino sheep from its performance indicators. A paper investigates the proposal of weaning weight as a covariate modification to justify for early environmental outcomes. Results concluded that the cost to collect this data in relation to the improvements from the outcome are very marginal in reducing environmental variance and increasing heritability (Swan et al., 2008). Unlike another study which concluded the approximations of heritability for staple strength are considerable, provoking the formation of section curricula to support in the progressing of the merino breed via the genetic profiles of both sire and dam (Reis, 1992).

2.6 Conclusion/ gaps in literature

The ideal method for enhancing the performance of tail-end weaner lambs is still a topic of debate among Australian sheep producers. However, pen feeding has emerged as a promising option to improve performance indicators for these lambs. There is much literature exploring aspects of pen fed weaner lambs and what method will allow for better social interactions, increased wool production and enhanced weight performance. It is clear from the average post weaning mortality rate across Australia that producers are going to struggle to run their operations in the most economically and welfare considered way. A consistent indicator of lamb survival reviewed is weight at weaning, in conjunction with adequate nutrition and disease and parasite prevention and management. These factors are presented across many studies and all support each other in the fact that lamb liveweight has a significant influence on lamb survival, growth rates and wool quality and quantity. Considerable literature also places an emphasis on the importance of the separate management of the lightest 25% of lambs to access their potential through compensatory growth.

There is substantial literature emphasizing the importance of addressing shy feeders and the wide variation in weaners' adaptation times to new diets. Also exploring how to identify and manage these issues effectively to minimize production losses. However, there is limited literature on the effects of diet composition and feeding methods within pens, which makes it challenging to fully understand their impacts. Extensive literature on feeding behaviour highlights the importance of lamb liveweight and its direct link to bullying behaviour. This supports the hypothesis that segregating pen feeding based on liveweight can enhance growth rates, reduce bullying, and improve both the quality and quantity of wool in weaner lambs. Limited literature assisting the examination of behavioural issues specifically has limited the range available within the review.

The major limitation of wool-related literature is the high cost associated with collecting and processing genetic information related to the heritability of wool traits. There is literature to gain an understanding of some links between the heritability of specific wool characteristics, but not to the range in which this review needs. However, the wide availability of literature on nutritional, environmental and trace elements and minerals spotlights the importance of understanding weaner needs and the consequences that not meeting them may have on the quality and quantity of their fleece and bodyweight. There is also a significant amount of literature surrounding the importance of correct management of weaners specifically for disease and parasites. The reviewed literature all highlighted the need for a carefully designed disease and parasite management plan for young stock which are more susceptible, and the consequences more severe than mature animals. Thus, the review considered potential impacts and gaps within literature, that pen fed weaner lambs experience and discovered which of these influences had the greatest significance on post weaning growth rates, wool quality and quantity, survival and liveweight of weaners.

Chapter 3: Materials and methods

3.1 Experimental design

The study was conducted in 2024 on a commercial mixed sheep and cattle property located 35 km South of Yass, in the Southern Tablelands of NSW, Australia. With approval from the Charles Sturt University Animal Ethics Committee (Approval number A23921). 234 sixmonth-old merino wether lambs were pen fed a mixed ration then grazed pastures with results recorded. Two treatments were used, a control group of 25% light lambs with 75% heavy lambs formed the first treatment (mixed) and a second mob of 100% light lambs created a second treatment (light).

3.2 Sheep management

A mob of Merino wether lambs was used for the experiment, averaging six months of age at the start of the trail in January. Prior to being pen fed, the lambs were grazing on a combination of weeping grass (*Microlena* spp.), red grass (*Bothriochloa macra*), crown grass (*Paspalum scrobiculatum*) and subterranean clover (*Trifolium subterraneum*) as a mixed mob of ewes and wether weaners. Lambs were introduced to barley grain, via a trail fed system whilst still with the ewes.

Lambs were weaned at five months of age, at this time a Faecal Egg Count (FEC) was completed; the results of the FEC averaged 450 Eggs Per Gram (EPG). Lambs were shorn in December to remove lamb's wool, drenched with Sidewinder LA, (Four Seasons Agribusiness located and manufactured in Australia), which contains the active ingredient Moxidectin 20 g/L to treat and control roundworms, nasal bots, itch mites and protect against barber's pole worm (*Haemonchus contortus) for up to 4 months.* At this time, they also received a booster of Websters 6 in 1 (located and manufactured in Crookwell, Penrith and Macquarie Park, Australia) to prevent 5 clostridial diseases (pulpy kidney, tetanus, black disease, malignant oedema, and blackleg) and prevent cheesy gland. This was completed over the dates of the 12-14 of December.

Lambs were fed a ration to meet a desired 100g/head/d weight gain average over a 6-week period while in the pens, then grazed on pastures for another 6-week interval. Non-fasted weights were recorded fortnightly to assist in the possible removal of shy feeders, which can be characterised by hollow flanks indicating a low gut fill (Rice et al., 2016). Fasted weights were collected at the end of the 6-week pen feeding and 6-week pasture grazing.

Once removed from pens, lambs were placed into 8.35 ha then, two weeks later a paddock of 18.83 hectares consisting of weeping grass (Mi*crolena spp*), red grass (*Bothriochloa macra*), crown grass (*Paspalum* scrobiculatum) and subterranean clover (Tri*folium subterraneum*), in which they had access to mature trees for shade and a 3m water trough available from both sides. Pasture samples were taken whenever lambs changed paddocks, or every 4 weeks, as well as the end of the grazing period, using a 0.1 m^2 quadrat to cut five samples at random, diagonally across the paddock, at ground level using blade shears, to gain an estimate of the available biomass of the pasture. A feed test sample was taken by walking a transect across the paddock and plucking a sample of feed at a level which the sheep are eating at every 20 steps at 30 different sites. Pasture samples were oven-dried at 60°C and weighed to enable determination of dry matter (DM) biomass availability (kg DM/ha). The pasture feed tests were conducted by the Department of Primary Industries (DPI).

3.3 Feeding and pen design

Lambs were placed into pens of 45 m x 90 m, meeting the ethical requirements of greater than 1 m squared per animal mandated by ethics. A self-filling water trough measuring 2.8 m in length and available from both sides provided each lamb with 10 cm of water trough space. A 6 m feed trough was able to be accessed from both sides, allowing 40 cm of trough space per lamb. The total ration was fed out along the entire 6 m of feed trough, with the lucerne hay placed first, then the mixed barley and lupin grains on top. Allowing equal access of the total ration to all lambs. Each of the 4 pens provided the lambs with shade in the form of existing mature trees.

A ration was designed using feed tests in conjunction with GrazFeed software program (*GrazFeed,* 2023) to design a total ration of 70:30 grains to roughage, with results from feed tests as shown in Table 1. An introduction schedule lasting 8 days was employed, increasing the barley fed per lamb by 50g/head/day until the full ration was met. During this period ad-libitum lucerne hay and the full ration of lupins was provided.

Table 1.

Feed test results and total percentage of ration

	Lucerne Hay	Barley	Lupins
Dry Matter (DM) (%)	89.7	92.3	94.1
Crude Protein (CP) (%)	18.8	10.9	29.8
Metabolizable Energy (ME) (MJ/kg DM)	8.9	13.3	13.8

Total percentage of ration (%)	30	49	21

At the end of each week a new ration was designed using the GrazFeed software program (*GrazFeed,* 2023), and the quantity fed was based on the liveweight of the lambs and increased weekly (based on liveweight). Lambs were fed in the morning between the hours of 6:30- 9:30am.

During the entirety of the 6-week pen feeding period, lambs were provided with a ROD's livestock nutrition, green feed lick block (Rod's livestock nutrition, manufactured in South Australia) to provide them with salt and trace minerals. The lick block was placed beside the water trough in each pen.

3.4 Sheep measurements

3.4.1 Weights

Fasted weights were recorded at the start (12th January) and end (23rd February) of the 6-week pen feeding period and at the end of the 6-week grazing period (6th April). Non-fasted weight was recorded fortnightly (25th January and 9th February) for progress and welfare checks to assist in the possible removal of shy feeders. Condition scores were recorded at allocation only (12th January).

For the feeding trial, 234 fit and healthy 6-month-old Merino lambs were chosen and fasted overnight before a fasted weight is recorded on the day of allocation (12th January). Each lamb was individually identified with a hard numbered management ear tag, then weighed and their body condition score (CS) assessed on a scale of 1-5 (1=emaciated, 5= obese) (Kenyon et al., 2014).

After stratification on weight to identify light and heavy groups, each lamb was randomly allocated to treatment and replicate groups using Excel (Microsoft Excel 2014). Lambs were randomly allocated for dye-banding (15 light lambs per pen and 15 heavy lambs in mixed pens) and marked with coloured spray and brands correspondingly. The lambs were placed in their pre-determined pen, viz. either pen 1 (treatment = light, replicate = 2), pen 2 (treatment=

mixed, replicate= 1), pen 3 (treatment= mixed, replicate=2) or pen 4 (treatment= light, replicate =1) appropriately.

3.4.2 Wool

At allocation (12th January), conclusion of pen feeding and after 4 weeks on pasture a total of 90 lambs had a dye band applied at skin level on the left midside position (of the lamb) using permanent black hair dye (Schwarzkopf, 1.0 black, 2022). At each time, the dye bands were applied to the same 15 lambs in each of the light pens, and the same 15 heavy and 15 light lambs in both of the mixed pens. The purpose of the dye bands is to track total wool growth throughout the stages of pen feeding and grazing pasture.

The process of dye banding involved parting the wool on the lamb's left mid side and using a 10 mL syringe fitted with an 18-gauge needle (with the top blunted), a thin strip of dye was placed along the skin. The parted wool is then restored, and a blue spray mark placed on top of the area to ensure an easy find for further dye banding.

The wool containing dye band was removed using a shearing handpiece at the end of the 6-week grazing period and placed into a labelled bag correlating to the lamb's individual tag number. These samples were kept, to measure the length of wool (mm), including total wool growth, wool growth during pen feeding and wool growth during pasture grazing. At the same time, a second sample of wool was taken from the same left mid-side sample area, equating to a cupful of wool, and placed into a labelled bag with the individual lamb's tag number on it. These samples were sent away to Riverina Wool Testers to be tested for fibre diameter, yield, and possibly length and strength if the sample is long enough.

3.4.3 Monitoring

During daily feeding, monitoring was conducted within each pen to monitor the lamb's overall health through visual observations. A fresh faeces score was recorded daily to assess the presence of clinical ruminal acidosis. A visual estimation was made from a percentage of faeces within each pen and a score of 1 (hard pellets), 2 (thick faeces with pellet formation), 3 (soft, lacking pellets), 4 (runny faeces) or 5 (liquid faeces) was recorded (Dickson & Jolly, 2011) There were two instances of fly strike (head and shoulders) within the first two weeks of pen feeding which led to all lambs being treated with CLiK (manufactured by Elanco in Australia) on January 25th to prevent any further infestation.

3.4.4 Behavioural observations

Behavioural observations were recorded when lambs were fed their ration. Lambs were observed for 1 min while feeding at the trough. Incidences of bullying including butting, shoving, pushing, mounting, and jumping between each other was recorded. These observations were conducted on the same day for all four pens for consistency. The number of lambs feeding at the trough and those that were not coming to the feed trough was also recorded to determine the number and proportion of shy feeders. Any lambs that were consistently recorded as shy feeders (and not gaining an appropriate amount of weight) were removed.

3.5 GrazFeed

The rations, as seen in table 2 and 3 were designed using the GrazFeed software program using an estimated liveweight, which was updated weekly, from the lambs in light and mixed pens. From this liveweight, a ration was calculated of 70:30 grains to roughage, 21% lupins, 49% barley and 30% lucerne hay to give a total as-fed ration, as seen in Table 7 and 8.

Table 2.
GrazFeed rations on an as-fed basis for the light treatment lambs.

Date	Weight of lamb (kgs)	Total ration (g)
17/1/24	19.6	670
19/1/24	20.3	670
26/1/24	21.0	690
2/2/24	21.7	700
9/2/24	22.4	710
16/2/24	23.1	730

Table 3.
GrazFeed ration on an as-fed basis for the mixed treatment lambs.

Date	Weight of lamb (kgs)	Total ration (g)
17/1/24	23.1	730
19/1/24	23.8	750
26/1/24	24.5	770

2/2/24	25.2	770
9/2/24	25.9	800
16/2/24	26.6	820

3.6 Statistical analysis

Data was statistically analysed using Genstat® software 22nd edition (VSN International, Hemel Hempstead, UK). Data was assessed for assumptions of normal distribution and homogeneity. Linear mixed models were used to compare weight and wool variables. If results established similarity a Bonferroni test was completed to complete a comparison of means. No significant differences were detected within the Condition Score data. However, significant differences were detected among behaviour, weight and wool data. Three lambs that died (16, 196,170), during the experiment had all data excluded from the statistical analysis. Lamb 196 (light treatment) was found dead on the morning of the 28/02/24. Lamb 16 (light treatment) was found dead on the 07/03/24 with a suspected death from Barbers Pole worm (*Haemonchus contortus*) due to high FEC count found the day of death. Lamb 170 (mixed treatment) was found dead the morning of the 08/04/24. Two lambs (66 and 195) had flystrike in early data collection period were removed from data analysis. Leaving 229 lambs for analysis.

Chapter 4: Results

4.1 Weight

At the completion of pen feeding, the average lamb in the light treatment gained 0.8 kgs more (P = 0.007) than all lambs in the mixed treatment. The light lambs weighed 3.0 kg less (P±0.001) than the mixed lambs and 4.5 kg less than the heavy lambs in the mixed treatment. At the completion of grazing, mixed lambs were 0.5 kg heavier (P=0.002) than the light lambs. The same light lambs were 0.5 kgs heavier (P=0.016) than the light lambs in the mixed treatment. There was no further significance (P=0.555 and 0.726) detected across weight changes of light vs heavy (in mixed pens) while in pens or grazing, as seen in Table 4.

Table 4.
Mean (mean +/- standard error) weight change (kgs) of lambs in mixed and light treatments while in pens or grazing.

	Treatment				
Item	Light	Mixed	Light in mixed[1]	Heavy in mixed[2]	P-value
Pen feeding (all lambs)	4.5±0.20b	3.7±0.20a[3]	-	-	0.007
Pen feeding (light vs light in mixed treatment)	4.5±0.19	-	4.0±0.40	-	0.215
Pen feeding (light vs heavy in mixed treatment)	-	-	4.0±0.43	3.7±0.24	0.555
Grazing (all lambs)	2.8±0.11a	3.3±0.11b	-	-	0.002
Grazing (light vs light in mixed treatment)	2.8±0.18a	-	3.3±0.25b	-	0.016
Grazing (light vs heavy in mixed treatment)	-	-	3.3±0.24	3.2±0.14	0.726

[1] 25% light lambs allocated to mixed treatment
[2] 75% heavy lambs allocated to mixed treatment
[3] a, b: Different letter within rows indicate means differ at P<0.05.

In the weight change comparison of light vs heavy in the mixed treatment both date and treatment were significant (P±0.001). At the start of the trial, there was a mean difference of 3.4 kgs between the light and mixed treatments, with mixed presenting heavier. This difference decreased to 2.6 kg upon the end of pen feeding. Upon completion of the grazing period this mean difference increased to 3.1 kgs. During pen feeding, the light treatment gained 4.5 kgs compared to the mixed treatment which gained 3.7 kgs. During the grazing period, the light treatment gained 2.8 kgs compared to the mixed treatment which gained 3.3 kgs.

The date, when comparing light vs light in mixed treatment, was significant (P±0.001), with light lambs being consistently heavier. Across the three dates weighed (into pens, onto pasture and final), the light lambs in the light pens were on average 0.9, 0.7 and 0.5 kgs heavier, respectively, than the light lambs in the mixed pens, as seen in Table 5. The mean liveweight of lambs showed no interaction between date and treatment as shown in table 5, but the light treatment was lower (P±0.001) in weight (23.2±0.39) than the mixed treatment (27.7±0.22).

Table 5.

Mean (mean +/- standard error) liveweight (kgs) of lambs in mixed and light treatments while in pens or grazing.

		Treatment					
Item	Date	Light	Light in mixed	Heavy in mixed	P-value		
					Date	Treatment	Interaction
light vs heavy in mixed treatment	12/01/24 (into pens)	-	19.7±0.26	23.1±0.25	<0.001	<0.001	0.635
	23/02/24 (onto pasture)	-	24.2±0.26	26.8±0.25			
	08/04/24 (final)	-	26.9±0.26	30.1±0.25			
light vs light in mixed treatment	12/01/24 (into pens)	19.7±0.22	19.5±0.44	-	<0.001	0.431	0.235
	23/02/24 (onto pasture)	24.2±0.22	23.4±0.44	-			
	08/04/24 (final)	26.9±0.22	26.8±0.44	-			
Pen feeding (all lambs)	-	23.6±0.23a	26.6±0.23b	-	<0.001	<0.001	0.007
Pen feeding (Light vs heavy in mixed treatments)	-	-	23.2±0.39a	27.7±0.22b	<0.001	<0.001	0.635

4.2 Wool

There was no difference (P=0.922) in wool growth between the light and mixed treatments whilst being pen fed. However, the mixed treatment had 0.5 mm greater wool growth whilst grazing. No significant differences (P≥0.05) were found in the yield, growth (both grazing and in pens) and fibre diameter of light vs light lambs in mixed treatments. Of significance (P=0.025) was a 2.18% increase in yield of the heavy lambs in the mixed treatment compared to the light lambs in the mixed treatment. When comparing the light lambs to the heavy in mixed treatment, no significant differences (P≥0.05) were found between fibre diameter and wool growth in pens. However, the heavy lambs in the mixed treatment showed a 1.1 mm greater wool growth on pasture than the light treatment, as displayed in Table 6.

Table 6.
Mean (mean +/- standard error) of wool length growth (mm), yield (%) and fibre diameter (µm) of all lambs while in pens or grazing, in light and mixed treatments.

	Treatment				
Item	Light	Mixed	Light in mixed	Heavy in mixed	P-value
Wool growth in pens (all lambs)	11.4±0.38	11.3±0.27	-	-	0.922
Wool growth on while grazing (all lambs)	6.5±0.40	7.0±0.28	-	-	0.310
Yield (light vs light in mixed treatment)	67.7±0.74	-	67.1±0.75	-	0.560
Growth in pens (light vs light in mixed treatment)	11.4±0.42	-	11.4±0.42	-	0.970
Growth while grazing (light vs light in mixed treatment)	6.5±0.45	-	6.4±0.46	-	0.916
Fibre diameter (light vs light in mixed treatment)	14.5±0.17	-	14.5±0.18	-	0.820
Yield (light vs heavy in mixed treatment)	-	-	67.1±0.67a	69.3±0.66b	0.025
Fibre diameter (light vs heavy in mixed treatment)	-	-	14.5±0.16	14.8±0.16	0.178
Growth in pens (light vs heavy in mixed treatment)	-	-	11.4±0.40	11.3±0.40	0.934
Growth while grazing (light vs heavy in mixed treatment)	-	-	6.4±4.00	7.5±0.39	0.054

4.3 Behaviour

Eating and shy percentages were highly significant (P±0.001) over the weeks. However, the mixed treatment group had a 0.5% higher eating percentage than the light treatment group over the entire duration in the pens (P±0.001). The light treatment group has a 0.5% higher percentage of shy feeders compared to the mixed treatment group (P±0.001). Both treatment and week were significant for bullied percentages (P±0.001). The percentage of lambs bullied in the light pens was 44.5% less than the bullying in the mixed pens, as shown in Table 7.

Table 7.
Mean (mean +/- standard error) of eating, shy and bullied percentages (no. of lambs/1 min) of all lambs in light and mixed treatments while in pens.

	Treatment				
Item	Light	Mixed	P-values		
			Treatment	Week	Interaction
Eating	94.9±1.47	95.4±1.47	0.744	<0.001	0.840
Shy	5.1±1.47	4.6±1.47	0.744	<0.001	0.840
Bullied	3.0±0.59	7.0±0.59	<0.001	0.007	0.387

4.4 Condition score

The mean condition score of all lambs at the start of pen feeding was 2.8. Mean condition score did not vary between treatments (P≥0.05), as shown in Table 8.

Table 8.
Mean condition score (mean +/- standard error) of lambs at the start of pen feeding in light and mixed treatments.

	Treatment			
Item	Light	Light in mixed	Heavy in mixed	P value
Light vs light in mixed treatment	2.8±0.03	2.8±0.05	-	0.568
All lambs	2.8±0.02	2.8±0.02	2.8±0.02	0.330
Light vs heavy lambs in mixed treatment	2.8±0.04	-	2.8±0.02	0.288

4.5 Feed test results

The nutritive value of lucerne hay, barley and lupins that was fed to the weaners is shown in Table 9. The total ration was mostly consumed within 4 h of feeding, and there were no refusals across the pen feeding period.

Table 9.
Nutritive composition of the Lucerne Hay, Barley and Lupins.

Item	Lucerne hay	Barley	Lupins
Dry matter (DM) (%)	89.7	92.3	94.1
Moisture (%)	10.3	7.7	5.9
Crude protein (CP) (%)	18.8	10.9	29.8
Metabolizable energy (ME) (MJ/kg dm)	8.9	13.3	13.8
Acid detergent fibre (ADF) (%)	34.5	5.3	22.4
Inorganic ash (IA)	9.7	<3.0	4.3
Organic matter (OM) (%)	90.3	97.4	95.7
Dry matter digestibility (DMD) (%)	61.1	88.0	85.0
Neutral detergent fibre (NDF) (%)	48.6	19.6	38.3
Crude fat (EE) (%)	-	1.9	4.9
Total percentage of ration (%)	30	49	21

Chapter 5: Discussion

Light lambs that are pen fed separately to mixed lambs were more likely to show increased weight gains than those fed in a mixed pen. These results, support both the hypothesis and Campbell (2013) who states that lambs will have a reduced mortality and increased weight gains if consistently separated by body weight.

During pen feeding, the average lamb in the light treatment gained 0.8 kgs more than the average lamb in the mixed treatment. Olivier (2006) emphasised the importance of separate management of the lightest 25% of lambs to access their potential through compensatory growth. This has many applied benefits as it creates a more consistent mob for sale and management. The difference in weight between the light treatment and the light lambs in the mixed treatments determined that there were no practical benefits of weight gains from the separation of light and heavy lambs in pen feeding situations. Within the mixed pen it was found that the light and heavy lambs grew at the same rate. Compared to the light treatment which had greater weight gains, the implications from this suggest that the mixed treatment could have been underfed as a result of these weight differences.

The difference in weight from the heaviest to lightest lamb increased at conclusion of grazing, showed that lighter lambs benefit more through the form of increased weight gains within a pen feeding system rather than grazing. This same result also displays those mixed lambs benefited more from grazing than lighter lambs did. Short-term nutritional stress could have originated within the pen feeding period in which unequal consumption of daily rations lead to some lambs becoming nutritionally stressed. Pasture samples taken showed that all lambs had adequate nutrition while grazing to allow for fast growth, this was the time period where compensatory growth would occur (Thornton et al., 1979).

Light lambs that were pen fed separately to heavier lambs showed no improvement in wool quality and quantity characteristics than those fed in a mixed pen. Kellaway (2009) explained that the nutritional plane that weaners were placed on will have direct impacts on wool growth. Within each pen, there was a potential for uneven consumption of the daily rations allocated to each lamb. Individual intake measurements were not conducted to evaluate this, making it a key limitation. All lambs had access (ad-libitum) to a Rods lick block to give a supply of minerals and macro minerals. Literature from Sahoo & Soren (2011) discussed the influence that an expected deficiency in these minerals due to the pen feeding situation can have on a sheep and explained that they can cause modifications to the construction of wool by upsetting feed intake, flow of nutrients to the rumen, altering rumen function and disruption of the metabolism of the sheep. In feed lotted sheep a copper deficiency can create steely wool, reducing the fibre strength, a zinc deficiency can lead to keratinised wool fibres and follicles (White et al., 1994). Selenium deficiencies are also common in pen fed sheep with decreases in wool growth being the biggest implication which is relevant to this study (Maley 2021).

Within the grazing period, it was the heavier lambs which displayed increased wool quality and quantity characteristics. The mixed treatment had an increased mean wool length which presented greater than the light treatment. The heavy lambs in the mixed treatment compared to the light lambs in the mixed treatment displayed a 2.18% increase in yield and 1.1 mm greater wool growth. The enhanced wool characteristics observed in the heavier lambs on pasture may be explained by our results which indicated that even though all lambs experienced positive growth rates the lighter pen showed more positive growth rates which could lead to the possibility of the mixed treatments being slightly underfed over the pen feeding period. As length growth is highly correlated with nutrition, if the length grew at the same rate in mixed and light it indicated that both treatments were fed similar nutrition levels. Olivier (2006) suggested that nutritionally stressed sheep could benefit with ad-libitum nutrition. Thus, the separate feeding of light lambs from the heavier end of the mob purely to reflect improved wool length, yield and fibre diameter isn't an achievable decision.

The mean condition score of lambs was consistent across all pens with each pen having a recorded mean of 2.8. Displaying good practice as all lambs entered the trial at an equal condition, giving a good starting point across all treatments to maintain animal health and welfare implications (Asín et al., 2021). This equal condition score is not considered normal for a whole mob of lambs which have been consistently grazing as one mob on the same pasture types (Griffiths et al., 2016). As the producer excluded from the study all lambs under 17 kgs this was the new selection of lambs available, this could be considered as a limitation as we did not have the true tail end of lambs.

Light lambs that are fed in a separate pen were less likely to experience bullying than all lambs fed in a mixed weight range. The hierarchy based on negative social interactions is directly correlated to the size of the animal (Rice et al., 2016). The correlation of size of animal and bullying characteristics is reflected in these results with a 44.8% higher bullying percentage reflected in the mixed treatment. Rice et al (2016) confirmed this power hierarchy is expected to have implications on the welfare and growth performance on lambs fed in a larger weight range. Even though there was more bulling in the mixed pens the growth rates were still the same for both light and heavy lambs in the mixed treatment. Indicating that maybe bullying could have impacted their growth rates or weight gains.

Holst et al (1997) suggested that it was the light lambs which were considered being in the lightest 25% of the mob, were more inclined to be characterised as shy feeders. However, the shy feeding results of this study that compared the mixed and light treatments were not significant to report. Indicating that the behavioural results of this study did not have any implications on other factors of the study. Shy feeder percentages can vary from 5-20% (Keogh et al., 2021). Our results had a mean shy feeding percentage of 4.9% across all lambs, which was reduced to 0% after two weeks. This is on the lower side of shy feeding rates presented in Keogh et al (2021) literature. This low shy feeding frequency could be explained by the introduction to concentrates pre weaning which Bowen (2022) suggests increasing the lamb's acceptance to feed when in pen feeding situations. This low shy feeing frequency could also be explained by the overall equal access to shade, trough space, water and lying areas as Rice et al (2016) investigated these factors and concluded that the increased competition for these resources also came with an increased risk of presenting as a shy feeder.

The composition of a young animal's diet can have varying effects on their productivity in a feedlot (Keogh et al., 2021). As Sultan (2009) explains high energy and protein is favoured to get the best daily weight gains from weaners, however if one was to be favoured it would be a diet with higher protein levels. Karim and Santra (2003) completed a study indicating the difference in growth performance of lambs fed on high energy, high protein diets vs low energy, low protein diets with a total body weight gain difference of 7.2 kgs between the diets. This ration was designed based off 3.5% of the bodyweight throughout the study. This related to our study as the ration was also designed based on the bodyweight of lambs throughout the study. Each ration was presented in the same form fed out within a trough to reduce the lamb's ability to selectively eat, which Bowen (2022) highlights as a significant factor in ensuring uniform nutritional requirements of individual lambs are met.

The previous exposure that all lambs had to concentrates might have improved their acceptance of grains and thus feeding was enhanced. This could explain the absence of any acidosis cases across all lambs which Bowen et al (2022) states to have a 1% mortality rate within feedlots. Also supported by the carefully planned introduction schedule to grain concentrates which is encouraged by Bowen (2022) to reduce the incidence of acidosis among grain fed lambs.

All lambs had FEC done at the same time to calculate the worm burden within each treatment group, allowing for timely treatment to minimise any impacts on weight, wool and behaviour data related to high worm burdens. Coop & Holmes (1996) reviewed the impacts that high worm burdens could have on young stock, through reduced voluntary feed intake and competence of feed utilization in the gastrointestinal tract. The reasons behind completing FEC relate to the early treatment of high worm burdens that could be found during pen feeding and could be used to explain any minor decrease in weight for some individual lambs.

The main limitations within this study relate to the possible underfeeding of the mixed treatment lambs. As the GrazFeed ration was updated weekly the bodyweights of the lambs were either estimated based on the previous week or were real time weight based off an unfasted weight collected the previous day. The distinction between whether the heavy or light lambs were responsible for the bullying was not made; instead, only the total number of bullying incidents was recorded. This created a limitation in the behavioural observations, as it did not specify which lambs were engaging in the bullying. Individual consumption was also not measured which created a limitation of individual feed consumption vs growth rates of lambs within pens. With 60 lambs per pen, there were enough to observe changes in weights. However, having a greater number of lambs in the study might have led to more significant weight changes and potentially different results. Additionally, a treatment of just heavy lambs could have reflected a group growth rate to compare to the light treatment. Additional literature would also be beneficial to help justify and expand greater on the finding of this study.

5.1 Conclusion

Although weight gain and social behaviour findings supports the hypothesis, the result of wool data contradicts the hypothesis that light lambs that are fed separately from heavier lambs will have increased weight gains, better wool production and social interactions, than those fed in a mixed pen. If the main desire of producers was to reduce bulling and improve social interactions among pen fed lambs, then this study indicates the separation of lambs based on bodyweight may improve animal welfare through a 44.8% decrease in bulling. These results are expected as they align with current literature. This study reveals there are no differences in wool data between the mixed and light treatments during pen feeding, suggesting that the nutritional requirements was even for both treatments and no benefit towards wool would be achieved through the separation of lambs based on bodyweight. This is unexpected as most literature leads towards heavier lambs producing more wool. As the light and heavy lambs in the mixed treatment grew at the same rate during pen feeding it is not clear if there are any practical benefits from the separate feeding of light lambs to assist in their growth rates. This study and further studies could benefit from additional literature to validate findings and expand on the hypothesis.

Chapter 6: References

Abbott, E. M., & Holmes, P. H. (1990). Influence of dietary protein on the immune responsiveness of sheep to Haemonchus contortus. *Research in Veterinary Science, 48*(1), 103–107. https://doi.org/10.1016/s0034-5288(18)31518-2

Aguayo-Ulloa, L. A., Villarroel, M., M. Pascual-Alonso, Miranda-de, G. C., & María, G. A. (2014). Finishing feedlot lambs in enriched pens using feeder ramps and straw and its influence on behavior and physiological welfare indicators. *Journal of Veterinary Behavior, 9*(6), 347–356. https://doi.org/10.1016/j.jveb.2014.07.005

Albers, G. A., Gray, G. D., Jambre, L. F., Barger, I. A., & Barker, J. S. (1990). The effect of *haemonchus contortus*infection on haematological parameters in young merino sheep and its significance for productivity. *Animal Science*, *50*(1), 99–109. https://doi.org/10.1017/s0003356100004505

Al-Dawood, A. (2017). Towards Heat Stress Management in Small Ruminants – A Review. *Annals of Animal Science*, *17*(1), 59–88. https://doi.org/10.1515/aoas-2016-0068

Almeida, A. M., Plowman, J. E., Harland, D. P., Thomas, A., Kilminster, T., Scanlon, T., Milton, J., Greeff, J., Oldham, C., & Clerens, S. (2014). Influence of feed restriction on the wool proteome: A combined itraq and fiber structural study. *Journal of Proteomics*, *103*, 170–177. https://doi.org/10.1016/j.jprot.2014.03.036

Angulo-Cubillán, F. J., García-Coiradas, L., Alunda , J. M., de la Fuente, C., & Cuquerella, M. (2007). Haemonchus contortus-Sheep relationship: A review. *Haemonchus Contortus-Sheep Relationship*, *17*(6).

Arnold, G., Charlick, A., & Eley, J. (1984). Effects of shearing time and time of lambing on wool growth and processing characteristics. *Australian Journal of Experimental Agriculture*, *24*(126), 337. https://doi.org/10.1071/ea9840337

Asín, J., Ramírez, G. A., Navarro, M. A., Nyaoke, A. C., Henderson, E. E., Mendonça, F. S., Molín, J., & Uzal, F. A. (2021). Nutritional Wasting Disorders in Sheep. *Animals*, *11*(2), 501. https://doi.org/10.3390/ani11020501

Bowen, M. K., Ryan, M. P., Jordan, D. J., Beretta, V., Kirby, R. M., Stockman, C., McIntyre, B. L., & Rowe, J. B. (2022). Improving sheep feedlot management. *International Journal of Sheep and Wool Science*, *54*(2), 27–34.

Brand, T. S., Van Der Westhuizen, E. J., Van der Merwe , D. A., & Hoffman, L. C. (2017). Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. *South African Journal of Animal Science*, *47*(1).

Campbell, A. J., Broekhuizen, A., Curtis, K., Croker, K. P., Behrendt, R., & Thompson, A. N. (2014). A survey of post-weaning mortality of sheep in Australia and its association with Farm and Management Factors. *Animal Production Science*, *54*(6), 783. https://doi.org/10.1071/an13149

Campbell, A., Vizard, A., & Larsen, J. (2009). Risk factors for post-weaning mortality of Merino sheep in south-eastern Australia. *Australian Veterinary Journal*, *87*(8), 305–312. https://doi.org/10.1111/j.1751-0813.2009.00457.x

Coop, R. L., & Holmes, P. H. (1996). Nutrition and parasite interaction. *International Journal for Parasitology*, *26*(8-9), 951–962. https://doi.org/10.1016/s0020-7519(96)80070-1

Dickson, H., & Jolly, S. (2011). *Project B.CC.0118 National procedures and guidelines for intensive sheep and lamb feeding systems.*(Meat & Livestock Australia

DiGiacomo, K., Surinder Singh Chauhan, Dunshea, F. R., & Leury, B. J. (2021). Strategies to Ameliorate Heat Stress Impacts in Sheep. *Springer EBooks*, 161–174. https://doi.org/10.1007/978-981-16-9836-1_14

Franklin, M., Briggs, P., & McClymont, G. (1964). Early weaning of Merino lambs during drought. *Australian Journal of Experimental Agriculture*, *4*(13), 132. https://doi.org/10.1071/ea9640132

Gelaye, G., Sandip, B., & Mestawet, T. (2021). A review on some factors affecting wool quality parameters of sheep. *African Journal of Food, Agriculture, Nutrition and Development*, *21*(105), 18980–18999. https://doi.org/10.18697/ajfand.105.19330

Griffiths, K. J., Ridler, A. L., Heuer, C., Corner-Thomas, R. A., & Kenyon, P. R. (2016). The effect of liveweight and body condition score on the ability of ewe lambs to successfully rear their offspring. *Small Ruminant Research*, *145*, 130–135. https://doi.org/10.1016/j.smallrumres.2016.11.001

Gonzalez, E. B., Sacchero, D. M., & Easdale, M. H. (2020). Environmental influence on merino sheep wool quality through the lens of seasonal variations in fibre diameter. *Journal of Arid Environments*, *181*, 104248. https://doi.org/10.1016/j.jaridenv.2020.104248

Hatcher, S., Eppleston, J., Graham, R. P., McDonald, J., Schlunke, S., Watt, B., & Thornberry, K. J. (2008). Higher weaning weight improves postweaning growth and survival in young Merino sheep. *Australian Journal of Experimental Agriculture*, *48*(7), 966. https://doi.org/10.1071/ea07407

Hatcher, S., Eppleston, J., Thornberry, K. J., & Watt, B. (2010). High merino weaner survival rates are a function of weaning weight and positive post-weaning growth rates. *Animal Production Science*, *50*(6), 465. https://doi.org/10.1071/an09187

Hayward, A. D., Skuce, P. J., & McNeilly, T. N. (2021). The influence of liver fluke infection on production in sheep and cattle: a meta-analysis. *International Journal for Parasitology*, *51*(11). https://doi.org/10.1016/j.ijpara.2021.02.006

Holst, P. J., Hall, D. G., Stanley, D. F., & Nolan, J. V. (1997). Effects of sex and liveweight on feeding behaviour of crossbred weaner lambs receiving Oaten Grain supplement on Lucerne Pasture. *Australian Journal of Experimental Agriculture*, *37*(6), 611. https://doi.org/10.1071/ea96080

Huntley, C. D. (1970). A Study of dust contamination in merino wool in low rainfall areas. *Wool and Pastoral Sciences*. https://doi.org/https://doi.org/10.26190/unsworks/11942

Hynd, P. (1994). Follicular determinants of the length and diameter of wool fibres. 2. comparison of sheep differing in thyroid hormone status. *Australian Journal of Agricultural Research*, *45*(6), 1149. https://doi.org/10.1071/ar9941149

James, P., Ponzoni, R., Walkley, J., & Whiteley, K. (1990). Genetic parameters for wool production and quality traits in South Australian merinos of the Collinsville Family

Group. *Australian Journal of Agricultural Research*, *41*(3), 583. https://doi.org/10.1071/ar9900583

Karim, S. A., & A. Santra. (2003). Nutrient Requirements for Growth of Lambs under Hot Semiarid Environment. *Asian-Australasian Journal of Animal Sciences*, *16*(5), 665–671. https://doi.org/10.5713/ajas.2003.665

Kellaway, R. C. (2009). The effects of plane of nutrition, genotype and sex on growth, body composition and wool production in grazing sheep. *The Journal of Agricultural Science*, *80*(1), 17–27. https://doi.org/10.1017/s0021859600057014

Kenyon, P., Maloney, S., & Blache, D. (2014). Review of sheep body condition score in relation to production characteristics. *New Zealand Journal of Agricultural Research*, *57*(1), 38–64. https://doi.org/10.1080/00288233.2013.857698

Keogh, T. P., McGrath, S. R., Oddy, V. H., Hernandez-Jover, M., Dickson, H., & Allworth, M. B. (2021). Are there opportunities to improve Lamb Feedlot production efficiency? A cross-sectional survey. *Animal Production Science*, *62*(4), 381–391. https://doi.org/10.1071/an21309

Lees, A. M., Lees, J. C., Veerasamy Sejian, & Gaughan, J. (2017). Management Strategies to Reduce Heat Stress in Sheep. *Springer EBooks*, 349–370. https://doi.org/10.1007/978-981-10-4714-5_17

Maley, J. (2021). *Trace Minerals Importance to Wool Production and Grazing*.

Mullaney, P. (1969). Birth weight and survival of Merino, Corriedale, and Polwarth lambs. *Australian Journal of Experimental Agriculture*, *9*(37), 157. https://doi.org/10.1071/ea9690157

Niven, D., & Pritchard, D. (1985). Effects of control of the sheep body louse (Damalinia Ovis) on wool production and quality. *Australian Journal of Experimental Agriculture*, *25*(1), 27. https://doi.org/10.1071/ea9850027

Norris, R T. (1986), *Survey of post-weaning management, growth and mortality of Merino weaners*. Department of Primary Industries and Regional Development, Western Australia, Perth. Technical Bulletin 70.

Nolan, E., Farrell, T., Ryan, M., Gibbon, C., & Ahmadi-Esfahani, F. Z. (2013). Valuing quality attributes of australian merino wool. *Australian Journal of Agricultural and Resource Economics*, *58*(3), 314–335. https://doi.org/10.1111/1467-8489.12027

Olivier, W., & Olivier, J. (2006). The effect of nutritional stress on the wool production potential of strong and fine wool merino sheep. *South African Journal of Animal Science*, *35*(4). https://doi.org/10.4314/sajas.v35i4.3971

Pluske, J. M., Slade, A. M., & Vercoe, P. E. (2010). Weather and Wethers: effects of wind, temperature and rain on sheep feedlot production. *Australasian Agribusiness Review*, *18*, 193–214. https://doi.org/10.22004/ag.econ.114334

Reis, P. (1992). Variations in the strength of Wool Fibres - a review. *Australian Journal of Agricultural Research*, *43*(6), 1337. https://doi.org/10.1071/ar9921337

Rice, M., Jongman, E. C., Borg, S., Butler, K. L., & Hemsworth, P. H. (2016). Characterisation of shy-feeding and feeding lambs in the first week in a Feedlot. *Applied Animal Behaviour Science*, *179*, 39–45. https://doi.org/10.1016/j.applanim.2016.03.011

Sahoo, A., & Soren, N. M. (2011). Webmedcentral. *Nutrition for Wool Production* , *2*(10). https://doi.org/10.9754/journal.wmc.2011.002384

Sajovitz, F., Adduci, I., Yan, S., Wiedermann, S., Tichy, A., Joachim, A., Wittek, T., Hinney, B., & Lichtmannsperger, K. (2023). Correlation of faecal egg counts with clinical parameters and agreement between different raters assessing FAMACHA©, BCS and DAG score in Austrian Dairy Sheep. *Animals*, *13*(20), 3206. https://doi.org/10.3390/ani13203206

Sultan, J. I., Javaid, A., & Aslam, M. (2009). Nutrient digestibility and feedlot performance of lambs fed diets varying protein and energy contents. *Tropical Animal Health and Production*, *42*(5), 941–946. https://doi.org/10.1007/s11250-009-9511-8

Swan, A. A., Purvis, I. W., & Piper, L. R. (2008). Genetic parameters for yearling wool production, wool quality and bodyweight traits in fine wool merino sheep. *Australian Journal of Experimental Agriculture*, *48*(9), 1168. https://doi.org/10.1071/ea07425

Thornton, R., Hood, R., Jones, P., & Re, V. (1979). Compensatory growth in sheep. *Australian Journal of Agricultural Research*, *30*(1), 135. https://doi.org/10.1071/ar9790135

Warr, G., Gilmour, A., & Wilson, N. (1979). Effect of shearing time and location on vegetable matter components in the New South Wales woolclip. *Australian Journal of Experimental Agriculture*, *19*(101), 684. https://doi.org/10.1071/ea9790684.

Watts, J. E., Merritt, G. C., & Goodrich, B. S. (1981). The ovipositional response of the Australian Sheep Blowfly, *lucilia cuprina*, to fleece-rot odours. *Australian Veterinary Journal*, *57*(10), 450–454. https://doi.org/10.1111/j.1751-0813.1981.tb05762.x

White, C. L., Martin, G. B., Hynd, P. I., & Chapman, R. E. (1994). The effect of zinc deficiency on wool growth and skin and wool follicle histology of male Merino lambs. *British Journal of Nutrition*, *71*(3), 425–435. https://doi.org/10.1079/bjn19940149

Wilkinson, F. C., de Chanéet, G. C., & Beetson, B. R. (1982). Growth of populations of lice, damalinia ovis, on sheep and their effects on production and processing performance of Wool. *Veterinary Parasitology*, *9*(3–4), 171–177. https://doi.org/10.1016/0304-4017(82)90059-0

Yapi, C. V., Boylan, W. J., & Robinson, R. A. (1990). Factors associated with causes of preweaning lamb mortality. *Preventive Veterinary Medicine*, *10*(1–2), 145–152. https://doi.org/10.1016/0167-5877(90)90060-u

Zenda, M., Malan, P. J., & Geyer, A. C. (2024). An analysis of the wool characteristics that determine wool price for merino wool in South Africa. *Scientific African*, *23*. https://doi.org/10.1016/j.sciaf.2023.e02005