Impacts of Pregnancy Shearing Ewes on Lamb Performance:

A Systematic Review, Meta-Analysis and Narrative Synthesis of Birth-, Weaning- and Survival-Related Outcomes

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Abstract

The sale of lamb is now the largest income driver for New Zealand sheep farmers. Therefore, improving lamb pre-weaning survival and weaning weight are important for driving profitability. A management option that has been shown in many studies to result in increased lamb birth weights is shearing ewes during pregnancy. Many studies have also investigated the effects of mid-pregnancy shearing on lamb performance to weaning. This wealth of data can, therefore, provide data to conduct a meta-analysis to quantitatively summarize the effects of pregnancy shearing on both lamb birth and weaning weight. A meta-analysis is a systematic and quantitative literature review method that uses statistical methods to bring together data from existing research to provide a more objective overall conclusion than a purely narrative review.

The meta-analysis showed that overall, pregnancy shearing significantly ($p < 0.05$) increased lamb birth weight by an average of 0.50 standard deviations (Hedge's $d = 0.52$), with greater increases observed when shearing occurred between days 42 and 100 of gestation ($\beta = 0.63–0.70$). The positive effect of shearing was not present when shearing was conducted after 100 days of pregnancy. The single predictor of "timing of shearing" explained 65% of the variation across trials ($I^2_{total} = 77.5\%$). In contrast, the pregnancy shearing effect on weaning weight was non-significant ($d = 0.09$, $p > 0.05$). A qualitative review of the literature indicated that in addition to the timing of shearing, parameters potentially related to the lamb birthweight response included: the type of comb used increased gestation length, level of ewe nutrition offered in pregnancy, increased ewe intake, increased maternal glucose and elevated thyroid hormones (T3 and T4), enhanced placental development and whether the dam had the potential to deliver otherwise lightweight lambs (i.e. giving birth to multiples) and had the capacity and/or adequate body reserves at time of shearing.

Pregnancy shearing under either housed or pasture grazing conditions has on some occasions resulted in higher perinatal lamb survival rates. In addition, some reports on lamb behaviour have shown that pregnancy shearing can improve behaviours relating to survival and the establish lamb-ewe relationships. Pregnancy shearing, however, had little to no effect on

lamb wool characteristics. Pregnancy shearing has an effect on ewe behaviour, increasing their comfort behaviour and maternal behaviour, and resulted in increased ewe milk yield, higher milk protein and fat percentages, but had little or no effect on ewe wool traits.

In summary for farmers to get a consistent birth weight response to pregnancy shearing there are clear management plans they should follow. Ewes should be shorn between 42 and 100 days of gestation, have a minimum BCS of 2.5, be shorn with cover/winter comb, be offered pasture covers of a minimum of 1300 kg DM/ha and be provided with shelter post shearing.

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Chapter 1: Introduction

New Zealand's sheep industry operates under a low-cost extensive grazing system, where pasture accounts for more than 95% of the animal's annual intake (Morris, 2013). The drivers of income for sheep farmers include both on-farm and market factors.

Since 1999 the total number of sheep in New Zealand has decreased from 44 million to 23.54 million in 2024 (Stats NZ, 2025). Since 2018, lamb prices have generally increased (Figure 1), however, prices have fluctuated slightly between years (Figure NZ, 2025). The sources of farm income have also changed with the percentage of income from wool decreasing from 10.5% in 2014 to 5% in 2024 and that from sheep increasing from 42.8% to 47.9% (Figure 2). This shift in income has resulted in a focus on lamb production.

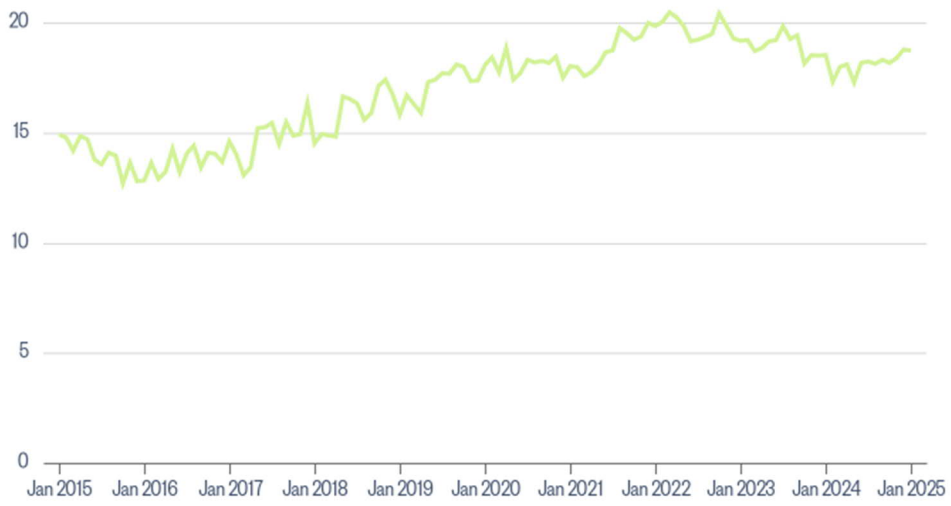

Figure 1. Monthly weighted-average retail price of lamb chops in New Zealand, January 2015 – January 2025 (NZD per kg, including GST). Source: Stats NZ, Food Price Index – Selected Monthly Weighted Average Prices (release: Jan 2025); visualised by Figure NZ (chart ID WNZOpEoBKRyz4hBh-3QsOhz7JNzUi7Bky).

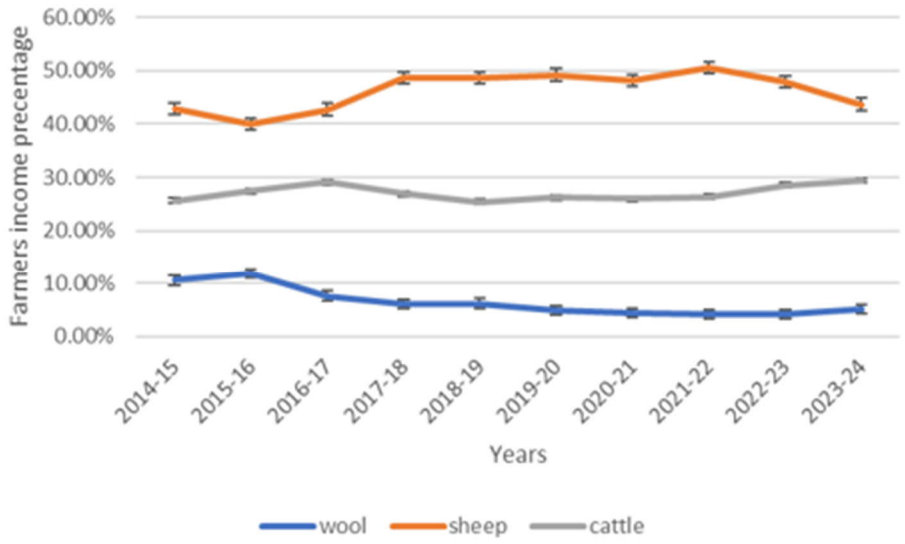

Figure 2. The average percentage of farm income for an average sheep and beef farm from wool (blue), sheep (orange) and cattle (grey) over time. Source: Beef + Lamb New Zealand. (2024). [*https://beeflambnz.com/industry-data/farm-data-and-industry-production/sheep-beef-farm-survey*](https://beeflambnz.com/industry-data/farm-data-and-industry-production/sheep-beef-farm-survey)

In New Zealand the average lambing percentage has increased from 107% in 1995 to 129.4% in 2023 (*Beef + Lamb New Zealand*, 2024a). This increase is due to greater reproductive rates resulting from improved management (Farrell et al., 2019). Average lamb carcass weights in New Zealand have also increased from approximately 13.9kg in 1990 to 19.4kg in 2023 (*Beef + Lamb New Zealand*, 2024b). Although the total number of ewes in the national sheep flock has decreased by approximately 53% over the last 30 years, lamb production has only decreased by 14% from 411,000 tons to 354,000 tons (Beef + Lamb New Zealand, 2022).

Recently, Moloney et al. (2023) using a bioeconomic modelling approach showed that producing a heavier lamb at weaning had a greater impact on farm profit than increasing ewe reproductive rate. Increasing pre-weaning lamb growth resulted in an increase in the proportion of lambs sold prime and at a younger age, thereby increasing the farm's cash operating surplus (COS). When lamb weaning weight was increased by 10%, 20% or 30% for lambs with an average weaning weight of 30kg for singles, and 25kg for twins, farm COS increased by 17.5%, 34.7% and 52.6% per hectare, respectively. While increasing lambing rate from 133.5% to 140%, 150% or 160%, increased farm COS by 7.6%, 18.5% and 26.4% respectively. They concluded that if a farm's lambing rate was 140% or higher, then increasing pre-weaning lamb growth rate should be prioritized over increasing lambing percentage (Moloney, 2022).

Farm income is determined by lamb weaning weight and the number of lambs that survive to weaning, therefore, management options to increase lamb survival rate and pre-weaning growth rates are critical. This review will focus on factors that influence the impact of pregnancy shearing on lamb birth and weaning weight and will also discuss lamb survival and growth rate.

Chapter 2: Literature review

In New Zealand if sheep production systems want to remain profitable, they must improve lamb survival and weaning weight. To do this, they first need to understand the causes of pre-weaning mortality and the key management factors that affect early lamb growth.

2.1 Brief review of factors that influence lamb survival, birthweight, postnatal growth and weaning weight

2.1.1 Causes of lamb death

In extensive pastoral sheep production systems such as in New Zealand, Australia, the United Kingdom, and South America, the main causes of lamb death are dystocia and starvation-exposure which account for between 19-67% and 30-48% of lamb deaths, respectively (Dennis, 1974; Bruce et al., 2021). Dystocia is death due to a difficult birthing process that may result in a ewe requiring human intervention (Jacobson et al., 2020). Starvation-exposure is the death of a lamb due to the lamb's inability to obtain adequate nutrition (starvation) or due to exposure to extreme climatic conditions (exposure) (Gudex et al., 2005). In New Zealand and Australia, postmortem examinations of lambs have shown that they can display signs of both starvation and exposure, so these are often combined into a single category (Refshauge et al., 2015). This combined classification includes lambs that have died due solely to starvation (exhausted body reserves, no hypothermia), simple exposure (fatal hypothermia, reduced body reserves), and the combined starvation-exposure syndrome (McCutcheon et al., 1981).

The optimum birth weight range for lamb survival for both singles and multiples has been reported to be between 4.2 and 7.4 kg (Dalton et al., 1980). The optimal birth weight of different breeds of sheep can differ slightly, although, in general as the birth weight increases above 5.5 kg, the mortality rate of triplet lambs begin to rise sharply (Smith, 1977).

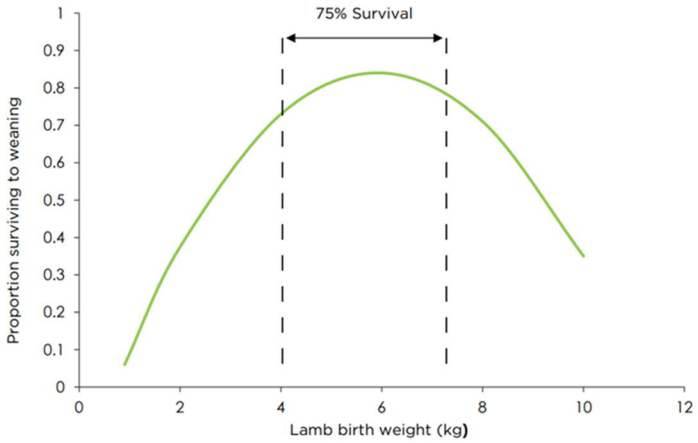

Figure 3. The relationship between lamb birth weight (kg) and the proportion of lambs that survive to weaning. Source: Geenty, 2013

Lambs with low birth weights are more prone to death due to starvation due to lack of sufficient body fat reserves to maintain heat production, while lambs with heavier birth weight are more likely to die of dystocia due to disproportional size compared with the birth canal of the ewe (Hight & Jury, 1970; Dalton et al., 1980). Appropriate birth weight is critical to high lamb survival rates (Schreurs et al., 2010a). It has been reported low mortality rates for lambs born within the range of 3.3-4.1 kg (McMillan & McDonald, 1983).

2.1.2 Dystocia

The rate of dystocia is greater among single- than multiple-born lambs as they are generally heavier and larger (Brown et al., 2014). The incidence of dystocia for different litter sizes changes with birth weight as shown in Figure 4. Dystocia, however, can be cause of death of lambs from any litter size (Holmøy et al., 2017; Kenyon et al., 2019). Dalton et al. (1980) suggested that it is not only heavy lambs that were susceptible to dystocia, but also smaller, weaker lambs and ewes where uterine contractions were poor. Among multiple-born lambs, especially at those with heavier birth weights, the mortality rate is increased compared to single-born lambs of the same birth weight (Purser & Young, 1964). This is due to complications in multiples due to limited space in the uterus resulting in foetal entanglement. Heavier, larger lambs that are also more likely to suffer from asphyxia or hypoxia, due to delays in the birth process (Brown et al., 2014).

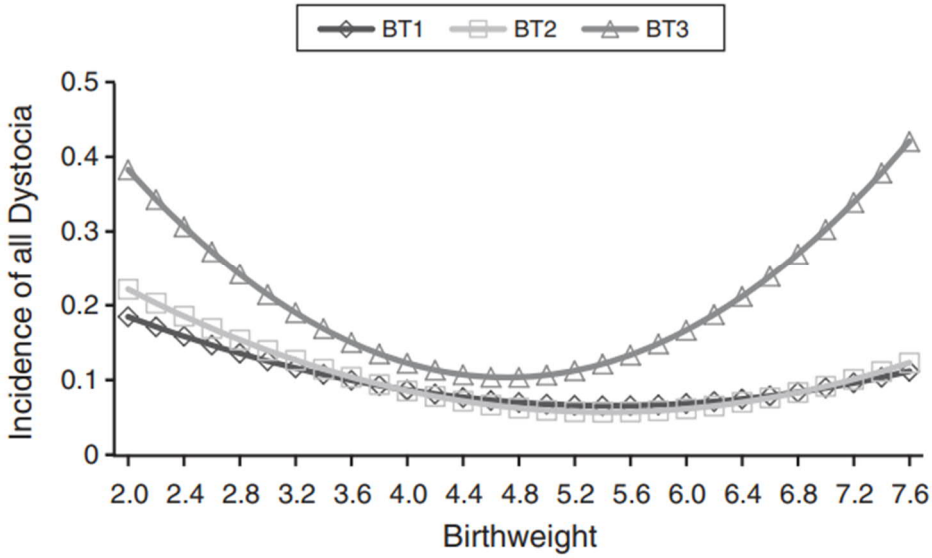

Figure 4. The relationship between lamb birth weight and the incidence of dystocia for different litter sizes: singles (BT1), twins (BT2) and triplets (BT3). Source: Brown et al. (2014)

2.1.3 Starvation-exposure

In studies in Australia and New Zealand, lamb mortality due to starvation-exposure was reported to be 30% and 68%, respectively (Refshauge et al. (2015) (Gudex et al., 2005). When the lamb transitions from the uterine environment to a cold external environment, heat production needs to increase 15 fold to maintain core body temperature (Dawes & Mott, 1959). Generally a lamb's body temperature will drop 2-3^{o}C soon after birth but for most lambs it will return to 39-40^{o}C within 3 hours (Alexander & McCance, 1958). If a lamb loses more heat than it can generate, it's body temperature will decrease and if the deep body temperature drops below 37^{o}C, sucking behaviour will weaken (Alexander & Williams, 1966). A slight drop in body temperature, therefore, does not directly lead to death but may indirectly lead to death due to starvation-exposure. When the rectal temperature of the lamb drops to 36^{o}C, the lamb's maximum metabolic rate or the maximum sustainable rate of heat production per unit of body weight will decrease (Alexander, 1962). If the body temperature continues to drop until the core body temperature is below 30^{o}C, fatal hypothermia will cause the death of the lamb (Alexander & McCance, 1958).

High heat loss requires the rapid utilization of lambs' energy reserves, therefore unless lambs are well fed their body heat production will decline rapidly (McCutcheon et al., 1981). In field conditions where temperatures were less than 10^{o}C, nearly 16% of lambs were observed to obtain less nutrition than the energy required for heat production (Parker & Nicol, 1990). In cold weather, not only are these lambs susceptible to starvation-exposure syndrome, they also show poor suckling ability and an inability to obtain colostrum from the mother (Alexander & Williams, 1966). Cold and windy weather conditions can also affect the behaviour of both ewes and lambs, with lambs taking longer to be fed than in milder weather (McBride et al., 1967). Small lambs are particularly susceptible to exposure, because of their lighter weight and large surface area to volume ratio resulting in more rapid dissipation of heat compared to heavier lambs. Heavier lambs generally have more fat reserves, which provide energy for heat production and reduce heat loss. Therefore, increasing lamb body weight into the optimal range is an important factor in improving lamb survival (Slee, 1978).

2.1.4 Options to increase lamb survival

To reduce the risk of dystocia and starvation-exposure, the choice of a suitable lambing paddock is important. Knight et al. (1989) reported that the survival rate of lambs born on slopes of <30° was ~30% higher than those on slopes of >30°. Steeper slopes increase the risk of newly born lambs slipping or rolling away from the lambing site, potentially causing injury and separation from their dam (Knight et al., 1989). Shelter such as grass wind-breaks, shelter-belts, straw-bale shelters and hedgerows can protect lambs from wind and rain, thus reducing heat loss and the risk of starvation-exposure by more than 30% (Upreti, 1989; Pollard, 2006).

When selecting dams, traits such as maternal behaviour have moderate heritability (0.13-0.2) (Everett-Hincks et al., 2005; Brown et al., 2016) and lamb tolerance for low-temperatures (0.146) (Sánchez-Molano et al., 2019) should be considered to increase lamb survival rates (Dwyer, 2014; Nel et al., 2021). Improvements in lamb survival rates, however, require long-term breeding efforts. The age of the ewe influences lamb survival (Aktaş et al., 2015), with lambs born to hogget and two-tooth ewes having lower survival rates than those born to mature ewes (Dalton et al., 1980; Geenty, 2013). It has been reported that parity has greater effect on

maternal behaviour than age of ewe, primiparous ewes show prolonged delivery time, high dystocia rate and high lamb abandonment rate, resulting in a significant increase in lamb mortality (Alexander et al., 1993).

Other factors that can affect lamb survival include seasonal factors. Lambs born in autumn and winter from ewes of a similar size tended to be smaller than lambs born in spring (Jenkinson et al., 1995). Morris et al. (1993) reported that even though the feed intake of ewes was similar in late pregnancy, the June-born lambs were lighter at birth than August-born lambs. There are also breed effects for example Matthews (1996) reported that Merino lambs had lower lamb survival rates than other commonly farmed breeds, with an average mortality rate of 35%, although the mortality rates of Romney-type lambs were similar (Geenty, 2013).

Heterosis or hybrid vigour was reported increase lamb birth weights by ~6% and the lambs were less likely to die from starvation-exposure in the same environment than purebred lambs Dalton (1980). Some hybrid breeds have also been reported to have higher weaning weights than their parents (Sidwell & Miller, 1971).

The sex of the lamb sex has been consistently reported to influence both lamb growth and survival with male lambs having a 6% higher survival rate than female lambs (Dalton et al., 1980; Knight et al., 1988). Male lambs also generally have heavier weaning weights than female or castrated male lambs (O'Riordan & Hanrahan, 1992)

2.1.5 Ewe factors that influence lamb birthweight

Maternal effects such as live weight, litter size, body condition, nutritional level during pregnancy are important factors affecting lamb birth weight (Gardner et al., 2007). In a flock of ewes monitored over their lifetime the birth weight of lambs was reported to increase from the first to fourth parity and then decreased in subsequent parities (Gardner et al., 2007). They also reported that the birth weight of a lamb born to a ewe with ≥ 2 barren seasons was reduced by about 0.77 kg.

A study conducted in the UK, suggested that there was a strong correlation between the birth weight of lambs and the live weight at mating of their dam. The reported regression

coefficient of ewe live and lamb birth weight was 0.721 for singles, 0.741 for twins, and 0.773 for triplets (Donald & Russell, 1970). Similarly, Schreurs et al. (2010b) reported a regression analysis showed that for lambs born to ewes hogget every 1kg increase in ewe weight during pregnancy resulted in a 15.5g increase in the birth weight of single lambs and 71.3g for each twin lambs. Ewe BCS can also affect lamb birth weight with lambs born to ewes with a BCS ≥ 3 showing ~58% higher birth weight than lambs from ewes with BCS ≤ 2 (Schreurs et al., 2010b). Corner-Thomas et al. (2014), however, reported that lambs born to ewes in excessive body condition (BCS ≥ 3.5) had birth weights ~11% lower than those born to ewes in moderate condition (BCS = 2.5).

To ensure that ewes have good body condition and nutritional level during pregnancy, farmers need to provide different feeding strategies throughout pregnancy. In early pregnancy (0-50 days of gestation) the foetus grows slowly, and the energy demand of the ewe is similar to non-pregnancy maintenance (Robinson, 1977). Therefore, for ewes weighing 50-60kg with body condition greater than 2.5, they should be offered 1.5-2.0kg of DM per ewe per day to meet the nutrient requirement of 8.0-10.0 MJ ME/day/ewe (Smeaton et al., 1999). In New Zealand, during early pregnancy farmers aim to maintain ewe live weight to conserve pasture for later in pregnancy (Rattray, 2017). Care should be taken as extreme under-feeding after mating can cause embryo implantation failure or embryo death (Rattray, 1977).

In New Zealand late-pregnancy coincides with winter when pasture growth is slow, therefore farmers hold pasture in reserve for periods of high ewe energy demand. Ewes with poor body condition (≤ 2.0), however, should be fed at slightly greater than maintenance level to allow them to gain condition (Rattray et al., 1983).

Mid-pregnancy (between 50 to 100 days of gestation) is an important period for the development of the placenta. Underfeeding during this period, can reduce lamb birth weight and impair ewe lactation (Mellor & Murray, 1982; Cannas, 2004). Lightweight ewes have less body reserves to buffer periods of underfeeding. Underfeeding ewes can result in impaired placenta and foetal development (Mellor, 1983). Supplementary feeding can increase ewe BCS to 3-3.5, which can significantly improve the birth weight of the foetus and the survival rate of the lamb (Mellor & Murray, 1982; Rattray, 2017). Ewe liveweight gain in mid-pregnancy

period should be between 50 and 100 g/day (Rattray et al., 1987). At this time, the ewe, foetus, and wool are all growing, so liveweight gain targets need to consider these factors (Rattray, 2017). During this period, the total metabolizable energy requirement of the ewe is approximately 10.1-18 MJME/d (Beef + Lamb New Zealand, 2019). In order to meet this requirement, ewes carrying multiple foetuses should be offered 2.0-3.0kg DM/d of forage per day (Rattray et al., 1987). If pasture masses are low (1000-1200kg DM/ha), the average daily DM intake of ewes needs to be supplemented to be at least 2.0kg DM/day (Jagusch, 1983). For ewes in good body condition carrying twin lambs or that are carrying single lambs ewes, providing pregnancy maintenance nutrition levels of approximately 20 MJ ME/day/ewe is sufficient (Beef + Lamb NZ, 2018). Studies have shown that providing twin-bearing ewes with nutrient levels that are greater than their maintenance requirements in mid-pregnancy has no benefit to lamb birth weight (Kenyon et al., 2011).

In the last eight weeks of pregnancy (late pregnancy), the foetus gains approximately 70% of its eventual birthweight (Rattray et al., 1974). To ensure the rapid development of the foetus, single bearing ewes need to consume 0.1-0.5kg more DM per day than their pregnancy maintenance level (11.5 MJ ME/day), and multiple bearing ewes need to consume 0.2-0.9kg more DM per day (13-13.5 MJ ME/day) (Geenty, 2013).

2.1.6 Methods to improve lamb growth rate to weaning

Poor lamb growth to weaning can have a significant impact on farm productivity and profitability, as fewer lambs are finished at weaning resulting in farmers missing the best market prices, increased days to slaughter and reduced flock uniformity (Moloney et al., 2023). Lamb prices fluctuate with season with prices usually reaching a peak in October then declining to their lowest level in March (*Beef + Lamb New Zealand*, 2024a). Increased lamb growth rates to weaning, therefore, should allow more lambs to be sold to slaughter during periods with relative high market prices. Further, it is generally accepted that lambs that grow faster have more intramuscular fat, greater fat depth and better-tasting meat when slaughtered a slower growing lighter lamb (Chestnutt, 1994; Oddy & Sainz, 2002).

Lamb birth weight has a significant impact on growth rate, Morel et al. (2008) reported that a 1kg increase in lamb birth weight resulted in a 15g/d increase in lamb daily growth rate. Ewe liveweight gain during pregnancy can also influence lamb pre-weaning growth. Schreurs et al. (2010b) reported that for every 1kg increase in ewe hogget liveweight at mating, the weaning weight of a single lamb can increase by 326.9g, and the weaning weight of each twin lamb can increase by 689.5g. Thompson et al. (2011) and Schreurs et al. (2012) also reported similar results among mature ewes. Paganoni et al. (2014) reported that for every 1kg increase in ewe live weight in early (D0-90) and late pregnancy (D90-140), the lamb weaning weight was increased by 0.26 and 0.09 kg respectively. Corner-Thomas et al. (2015) indicated that BCS of ewes in late pregnancy can affect lamb weaning weight with ewes in poorer body condition at late pregnancy (BCS 2.0) rearing approximately 1.3 kg lighter lambs than those from ewes in moderate (BCS 2.5) or good condition (BCS 3.0). Corner et al. (2008) suggested that the nutritional level of ewes in late pregnancy is particularly critical to the pre-weaning growth rate of lambs as ewes provided with high nutrition throughout mid- and late pregnancy (pasture height 4 cm, 1300 kg DM/ha) had lamb daily growth rates of 0.178–0.252 kg/day. When nutrition was restricted (2 cm, 700 kg DM/ha) in mid-pregnancy but improved (4 cm, 1300 kg DM/ha) in late pregnancy, growth rates were 0.184–0.228 kg/day. In contrast, continuously low nutrition (2 cm, 700 kg DM/ha) resulted in lower growth rates of 0.165–0.222 kg/day. Morris and Kenyon (2004), however, reported that among ewes offered different pasture heights (2, 4, 6, 8 cm) during late pregnancy (D70-lambing) there was no difference in lamb weaning weight. They suggested offering pasture heights above 4cm during pregnancy did not results in further increases in lamb weaning weights.

The main source of nutrition for lambs in the first six weeks after birth is from their dam's milk (Burris & Baugus, 1955). Thus after birth ewe milk production is essential for lamb survival and growth (Morgan et al., 2007). Maximum milk production of ewes occurs 2 to 4 weeks after lambing (Cardellino & Benson, 2002). Snowder and Glimp (1991) reported that the maximum daily milk production of single bearing ewes can reach about 2.7 to 2.9 L/day, and the maximum daily milk production of multiple bearing ewes is about 3.4 to 3.5 L/day. Peart (1968) reported that thin ewes (average weight of about 47.4kg) showed higher food

conversion efficiency under nutrient-restricted conditions, with the highest total milk yield (141.9kg), prioritizing energy for lactation. Ewes in better condition (average weight 57.1-58.9 kg) were able to maintain higher milk production (126.6 kg) when nutrition was adequate but performed worst with low milk production (108.3 kg) when nutrition level was restricted.

Lamb milk intake is influenced by factors including their birth weight, sex of the lamb and ewe milk production traits (Moore, 1966). Ewe milk production is determined by breed, number of sucking lambs, liveweight, BCS and nutrition (Abd Allah et al., 2011). Geenty (1979) observed that Dorset ewe milk production was higher than that of other breeds, including Romney, Corriedale, Romney x Dorset and Dorset x Romney. During a 9-week lactation period, the milk production of a single-rearing Dorset ewe ranged from 125-132 kg, and the milk production of a twin-rearing ewe was 133-220 kg. In comparison the milk production of a twins bearing Romney ewe was approximately 117 kg. They also showed a heterosis hybrid effect among crosses such as Romney and Dorset which showed 6% to 15% greater milk yield than purebred ewes (Geenty, 1979).

Bernard et al. (2024) suggested that at high nutritional levels (*ad libitum*), dairy sheep's milk production averaged 1.9 L/d, while, ewes on restricted feeding (65% of *ad libitum*) showed a 21% reduction in milk production of approximately 0.41L of milk per day (Bernard et al., 2024). To achieve optimal nutritional levels, the metabolic energy requirements of single bearing ewes during lactation should be 21.0-28.0 MJ ME/day, while the requirements of multiple bearing ewes are higher, ranging from 23.0-36.0 MJ ME/day (Beef + Lamb NZ, 2018). To meet these requirements they suggest lactating ewes should be kept on pasture with a mass of 1400-1800 kg DM/ha (4-6 cm sward height). Which will allow a daily dry matter intake of at least 1.8kg. Under New Zealand conditions the dry matter intake requirement of lactating ewes should be in the range of 1.4 to 2.7 kg DM/day, depending on the ewe's weight, parity and stage of lactation (Beef + Lamb NZ, 2018). Corner-Thomas et al. (2015) reported that the average weaning weights of lambs from ewes in low (800-1000 kg DM/ha), medium (1200-1400 kg DM/ha) and high (1500-1700 kg DM/ha) pasture allowances during lactation were 28.9, 29.8 and 31.7 kg respectively.

Milk production can be affected by the number of suckling lambs, with more lambs resulting in higher milk production (Alexander & Davies, 1959). Although multiple-bearing ewes tend to produce more milk than single-bearing ewes, the increase in milk production is not proportional to the number of additional lambs, for example, a twin-bearing ewe does not produce twice as much milk as a single-bearing ewe, multiple lambs often have lower milk intakes than singles (Gootwine & Pollott, 2000). As a result multiple lambs generally grow slower than singles and the lambs tend to show longer grazing time as they try to compensate nutritional deficiencies (Moffat et al., 2002). The size of the lamb's rumen, however, limits their ability to consume forage, thus the reduction in milk cannot be fully compensated (Moffat et al., 2002). This further emphasizes the importance of the nutritional level of multiple-bearing ewes to ensure maximum milk production.

Alternative forages such as a mixed pasture consisting of chicory, plantain, red clover and white clover has been reported to increase milk production in ewes by approximately 20-33% compared to a ryegrass-based pasture (Hutton et al., 2011). Similarly Corner-Thomas, Kemp, et al. (2014) reported that the average weaning weight of lambs born to ewes offered lucerne was 32.9 kg (423 g/day) compared with 28.4 kg (358 g/day) for those offered herb mix containing chicory, plantain, red clover and white clover and 26.0 kg for those offered ryegrass and white clover.

At four to six weeks of age, lambs begin eating forage and supplements, and after eight weeks of age, milk accounts for approximately 50% of energy intake (Gascoigne & Lovatt, 2015). The intake of solid feed requires the rumen to be functional developed if high lamb growth rate are to be achieved (Gascoigne & Lovatt, 2015).

The rumen of the lamb develops gradually between 3 and 8 weeks after birth, so it is important to optimize the age of weaning (Li et al., 2022). The optimal weaning age is determined by many factors, such as: ewe breed, lamb management, lambing date and season (Campbell et al., 2017). Geenty and Dyson (1986) reported that lambs weaned at 9, 12 and 15 weeks of age grew faster than those weaned at 4, 5 and 6 weeks. Gascoigne et al. (2015) suggested that the weight of the lamb at weaning should be no less than 16kg, preferably more than 25kg. Below this level some supplementary feed should be offered if lamb growth rate is

lower than 200g/day. DeNicolo et al. (2006) reported that the growth rate of lambs weaned at 91 days of age (0.260kg/d) was higher than that of lambs weaned at 69 days. Ekanayake et al. (2019) reported that lambs grazing on an herb-mix (chicory, plantain and red and white clover), the average growth rate of lambs weaned at 10-14 weeks of age was approximately 325g/day from birth to weaning, which was higher than the growth rate of lambs weaned at 8 weeks of age (approximately 251g/day). They also found that when the forage supply was good (>1200kgDM/ha) conventional weaning was sufficient. When the forage supply is insufficient (<1200kgDM/ha), weaned lambs can be weaned early onto a herb-mix and achieve higher lamb growth rates.

The timing of lambing to match the pasture growth curve and avoid bad weather also influences lamb weaning weight. Further ewe health status and management of her health in pregnancy and lactation and the health of the lamb in lactational also influence lamb growth and weaning weight (West, 2009). However, these topics are not covered in this brief review.

2.1.7 Genetic factors impact lambs pre-weaning performance

Heritability is the probability that a trait can be stably inherited, and also indicates the strength of the relationship between an individual's genetic potential for a trait and its actual performance (Berry et al., 2019). Haile et al. (2019) reported the heritability of birth weight, pre-weaning weight gain and weaning weight in Awassi sheep to be 0.03 (± 0.022), 0.09 ± 0.784 and 0.06 (± 0.042), respectively. The maternal effect heritabilities were 0.03 (± 0.050), 0.22 (± 0.835) and 0.02 (± 0.033), respectively. The range of heritability is 0-1. If heritability is closer to 0, it means that the heritability of this trait is lower, and the possibility of stable inheritance is smaller. Low heritability values indicate that the trait is influenced by other factors such as the environment or nutrition, and cannot be improved directly through genetic selection. Therefore, due to the low heritability of lamb weights, they also estimated the heritability of ewe milk production which was moderate at 0.29 (±0.10) indicating that improvements can be achieved through selective breeding. Therefore, more feasible to increase the milk production of ewes through selective breeding to indirectly increase weaning weight.

A study of Baluchi sheep showed that the individual and maternal heritability of lamb

birth and weaning weight across two flocks were as follows: individual heritability of birth weight was 0.14±0.02 in flock 1 and 0.20±0.02 in flock 2, whereas the maternal heritability was 0.12±0.02 in flock 1 and 0.07±0.01 in flock 2. For weaning weight the individual heritability was 0.19±0.02 in flock 1 and 0.13±0.02 in flock 2, whereas the maternal heritability was 0.03±0.01 in flock 1 and 0.03±0.01 in flock 2 (Yazdi et al., 1997). The maternal heritability of birth weight was higher than that of weaning weight, which showed that the mother has a greater influence on heredity during early gestation, and the influence of the mother on the weight becomes smaller as the lamb ages. The individual effect was moderately low for both birth and weaning weight, which indicates that genetics has a moderate effect on these two traits. Ozcan et al. (2005) reported that the heritability of birth weight, weaning weight and growth rate of Turkish Merino lambs were 0.08 ± 0.03, 0.12 ± 0.04 and 0.11 ± 0.04, respectively, which are all medium to low.

The heritability of lamb birth and weaning weight of different breeds of sheep varied slightly, therefore, to improve these traits of lambs through genetics, breeding plans need to be formulated accordingly. Breeding benefits will also vary for different breeds, however, in general, for traits with lower heritability, it is more reasonable to increase the milk production of ewes to increase the weight of lambs.

In addition to breeding selection, crossbred lambs can also improve birth weight and weaning weight (Sidwell & Miller, 1971). They reported that crossbred lambs of various breeds including Hampshire, Columbia-Southdale, Targhee, Suffolk and Dorset were 0.11-1.3kg heavier than purebred lambs. McGuirk et al. (1978) suggested that the birth weight, weaning weight and slaughter weight of crossbred lambs are 4%, 6% and 11% heavier than those of purebred lambs respectively. The phenomenon that the offspring bred through crossbreeding are superior to other purebreds in certain traits is called hybrid vigour. The crossbred offspring obtain genes from multiple genetic sources, thus improving their adaptability to the environment and certain traits (such as birth weight, weaning weight, and survival rate). Therefore, crossbreeding has a significant effect on increasing lamb body weight as heterosis can improve lamb performance.

The importance of birth weight to lamb survival rate has been mentioned above. There

are many ways to increase lamb birth weight, and shearing can also be an effective method. This thesis will focus on the impact of shearing of ewes during pregnancy on lamb birth weight, weaning weight and survival rate to weaning.

2.2 Can shearing in pregnancy influence lamb performance to weaning

The effect of mid-pregnancy shearing on both the ewe and lamb has received a great deal of attention with 127 studies reporting outcomes including birthweight, weaning weight, survival rate of lambs, pre-weaning growth rate, wool production of ewe and lamb, behaviour of ewe and lamb, lamb thermoregulatory capability, gestation length of ewe, milk production, feed intake of ewe, placental parameters and metabolic mechanisms of the ewe. In 2003, Kenyon et al. (2003) undertook a narrative review of studies including those undertaken in both pasture based and housed systems.

2.2.1 Summary of previous pregnancy shearing studies

In their review Kenyon and others (2003) reported that under housed conditions in the UK pregnancy shearing increased lamb birth weight and heat production, but under pasture conditions in New Zealand the effects were inconsistent. However, multiple studies have reported that pregnancy shearing increased lamb birth weight, although the size of the effect varied greatly between studies. The variability in results could not be explained by feed intake of the ewe (Parker et al., 1991; Husain et al., 1997; Revell et al., 2002), type of shearing comb (Husain et al., 1997; Morris & McCutcheon, 1997; Morris et al., 2000), or longer gestation length (Corner et al., 2006; Corner et al., 2007; Banchero et al., 2010). In order to attempt to isolate the reasons for the differences in results a meta-analysis can be used to provide more comprehensive and reliable results (Egger et al., 1997). To date no one has conducted a meta-analysis of the effect of pregnancy shearing on lamb birth and weaning weight.. Since then, there have been many new studies on pregnancy shearing, but no review has summarized these new findings and research data.

2.3 What is meta-analysis

Generally speaking, there are three common methods for conducting a comprehensive

literature review: 1. Narrative review 2. Qualitative systematic review 3. Quantitative systematic review and meta-analysis (Green et al., 2006).

Meta-analysis is widely used in biomedicine and social Sciences (Sutton & Higgins, 2008). The essence of meta-analysis is to provide a statistical basis and combine the independent research results in related fields, summarize the results of different studies and give a relatively objective overall result. It is a comprehensive study of research evidence (Egger et al., 1997). Compared with common narrative reviews, meta-analysis tends to quantitatively summarize experimental results by using data (Wachter & Straf, 1990).

The meta-analysis is divided into the following steps: 1. Formulating the research question, first need to formulate and understand the main content of the research. This is critical and determines the criteria for searching the literature, which helps to collect useful information and exclude non-informative data (Pigott, 2012). 2. Collecting the research evidence. The number of studies retrieved determines whether a meta-analysis can be performed (Cooper et al., 2019). 3. Specify criteria to determine whether the retrieved articles should be included in the meta-analysis (Pigott, 2012). 4. Analyse and integrate various research data. Meta-analysis must have a statistic that reflects the magnitude of the relationship between two variables. The most commonly used effect size statistics are calculated from two standardized means (such as Cohen's *d*) (Cohen, 2013). The overall effect across studies size should be estimated with fixed-effect model, random effect model or multilevel meta-analytic models (Borenstein et al., 2021). 5. Interpretation of the cumulative evidence. Heterogeneity assessment: use statistics such as Cochran's Q and the I^2 to measure the heterogeneity of study results (Cochran, 1954; Nakagawa & Poulin, 2012). Publication bias assessment: Detect and correct for possible publication bias using funnel plots or statistical methods (e.g., Egger regression) (Egger et al., 1997; Sterne & Egger, 2005). Sensitivity analysis: Test the robustness of the analysis results to different decisions, such as the impact of including/excluding specific studies (Higgins & Green, 2011). 6. Results presentation, use graphs (e.g., forest plots) and summary tables to visually present the results and clearly explain the analysis process and findings. Meta-analysis is a systematic, quantitative literature review method suitable for integrating and summarizing data across studies to provide a more comprehensive understanding.

Chapter 3: Meta-analytic and narrative review

A narrative review cannot provide intuitive quantitative results, while a meta-analysis can provide more objective results by systematically searching and combining multiple independent studies with statistical methods.

3.1 Pregnancy shearing effects on the lamb

For pregnancy shearing, meta-analysis can integrate the results of different trials, estimate the average effect on lamb birth weight, weaning weight, and test these moderators. Meta-analysis can provide more reliable conclusions and provide a basis for future management practices and research gaps.

3.1.1 Lamb birthweight & weaning weight

In their qualitative review, Kenyon et al. (2003) suggested that pregnancy shearing generally had a positive effect on lamb birthweight. Table 2, which includes studies from 1971 to 2024, indicates that 39 studies found a significant positive effect of pregnancy shearing on birth weight with increases of between 1.8% - 37.2%. Conversely, 17 studies reported no effect of pregnancy shearing on lamb birth weight. To date, the effects of pregnancy shearing on lamb weaning weight have not been summarized, however, examination of the literature indicates 7 studies reported a significant positive effect whereas 19 studies reported no effect.

It is unclear from the literature, what experimental factors determine the magnitude of the effect of pregnancy shearing, particularly on lamb birth weight. To date no meta-analysis has been performed to quantify effects or investigate these differences. Meta-analysis is a technique that can identify experimental factors that may drive these differences, along with estimating the overall effect of pregnancy shearing on lamb birth and weaning weight. The following section includes a systematic review and meta-analytic approach to investigate the experimental factors that may be responsible for the variation in the magnitude of the effect of pregnancy shearing on lamb birth and weaning weight. Other impacts of pregnancy shearing on the ewe and lamb traits will also be systematically reviewed and potential mechanisms discussed.

Literature Search for data on lamb birthweight and weaning weight

This systematic review and meta-analysis targeted experimental studies that investigated the effects of ewe pregnancy shearing on lamb birth and weaning weight. The literature search was conducted using three online scientific article databases (Google Scholar, Scopus and Discover) on 11/12/2024 without language restrictions. The search algorithm used:

Google Scholar: “shearing sheep pregnancy gestation” and select the item “anywhere in the article”

Scopus: pregnancy OR gestation OR prepartum AND stressor OR shearing AND sheep AND (LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "BIOC") OR LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "VETE") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "Undefined")).

Discover: pregnancy OR gestation, shearing, sheep OR ewe OR ovis aries.

All retrieved records were screened to find relevant studies and key reviews. These relevant studies were further checked for citations (backward and forward check). This literature search process obtained a total of 4231 records after removing duplicates (Fig. 5). These records were then screened based on information obtained from titles, abstracts, full texts, and supplementary materials.

Study selection criteria

To be included in the meta-analysis research papers needed to:

1. Have data from ewes shorn during pregnancy
2. Include the day of shearing
3. Have both a control (unshorn) and treatment (shorn) groups.
4. Clearly state the number of lambs born in the treatment group and the control group, with means and SE for each group.
5. Provided either the birth weight and/or weaning weight of naturally born lambs in both control and treatment groups.
6. Provided details on whether the study involved single lambs or twin lambs. This data

was coded as 1 (singles) and -1 (twins).

Note due to a low number of studies with experimental data on triplets were excluded

Studies that did not meet these requirements were excluded from the meta-analysis (Figure 5). A dataset was created for the meta-analysis by extracting data from tables and text from each study. To quantify the difference in lamb birth and weaning weight between the shearing and the control groups in the meta-analysis the effect size Hedge's g was used as the main effect size (Hedges, 1981). A conventional random-effects meta-analytic model, using experiment identity as a random effect, was used to estimate differences in the birth and weaning weight between lambs born to ewes in either the shorn or control groups across all studies. Meta-regression models were constructed by incorporating the following potential predictor variables: 1) Day of pregnancy when shearing was performed (3 levels: day 42 to 80, 81 to 100 and beyond 100 days of pregnancy), 2) litter size (coded as a binary variables where 1 was for singletons and -1 for twins) and 3) whether the study included additional treatments apart from pregnancy shearing (coded also as a binary variable with 1 for yes and -1 for no). Statistical analyses were performed using R v.4.5.1 (R Core Team, 2013). The two datasets were analysed independently using Bayesian multilevel mixed-effects meta-analysis as implemented in the MCM Cglmm package (Nakagawa & Santos, 2012).

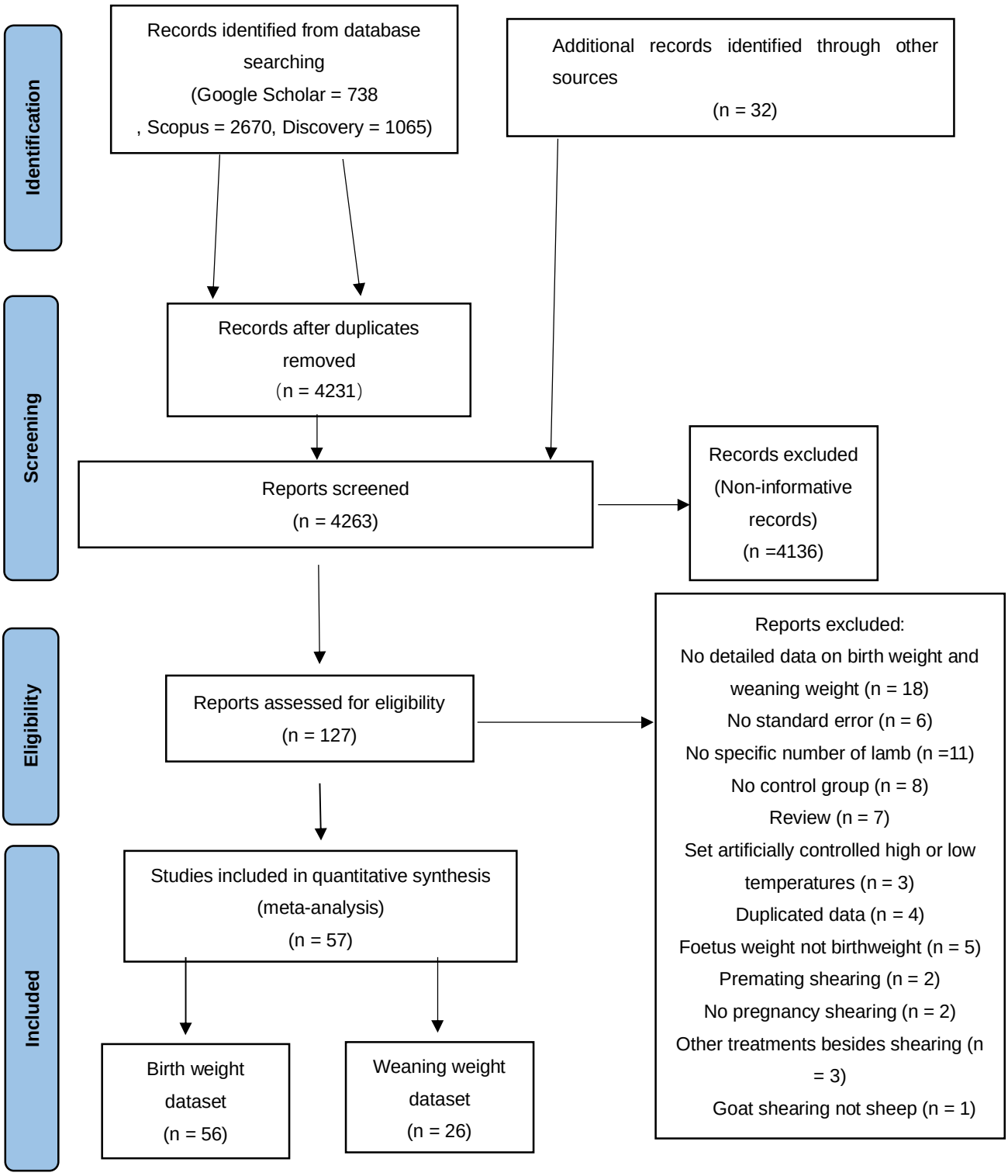

Figure 5 Flowchart for screening literature for meta-analysis

Results

After the initial scan, 127 experiments met the minimum criteria for inclusion in this study. Of these studies, however, 62 did not provide sufficient detail for data extraction and were subsequently removed from the meta-analysis (see Figure 5). A total of 57 studies were deemed adequate for meta-analysis with 56 studies having data available on birth weight (New Zealand 41.07%, England 14.29%, Uruguay 12.5%) and 26 for weaning weight (New Zealand 59.3%, Uruguay 22.2%, Turkey 3.7%).

Birthweight

The meta-analysis showed that across all the studies, the birth weight of lambs born to ewes shorn during pregnancy were 0.50 standard deviations significantly heavier ($d = 0.52$, $p<0.05$) than lambs born to unshorn ewes (Table 1, Meta-analytic model). However, there was large heterogeneity observed in the dataset ($I^2_{total} = 77.5\%$,) with ~24% associated with differences between experiments. This variability warranted further investigation. The overall meta-analytic model was extended sequentially with candidate predictor: shearing day category (Model 1), litter size (Model 2), and additional treatments (Model 3).

Model 1: the time of shearing during pregnancy was fitted in the model as a potential predictor of experimental outcome. Time of shearing was fitted as a categorical predictor (Table 1) and showed a non-significant ($p > 0.05$) difference between studies in which ewes were shorn between day 42 and day 100 of pregnancy. However, this resulted in the magnitude of the effect of shearing on lamb birth weight decreasing significantly ($p < 0.001$) (Table 1). This indicates that the best time for shearing is between 42 and 100 days of pregnancy and that shearing after 100 days of pregnancy was not effective. This single predictor model was able to: 1) explain 65% of the variation in outcomes across experiments, 2) increased the variance explained by experiment-level differences (proportion of change in variance (PCV) = ~84%) and 3) reduce the residual variance (PCV = ~34%). This suggested that an important structure in the model was captured by this predictor, which also increased the model fit (DIC = 40.14).

Model 2: litter size was fitted in the model. This model showed a non-statistically significant ($p > 0.05$) difference between studies conducted in singletons and twins. However,

the addition of litter size again captured an important structure within the data, thus increasing the variance explained by experimental differences, further reducing the residual variance (Model 2 residual PVC = 0.068) and increasing model fit (Table 1). No other significant predictor was able to further reduce the residual variance.

Model 3: studies that included other experimental treatments apart from pregnancy shearing had slightly lower differences in lamb birth weight than those studies that only dealt with pregnancy shearing, suggesting a confounding effect of experimental design. Model 3 did not effectively reduce residual variance and improve model DIC after adding other experimental treatments.

Table 1 Summary of the statistical results of meta-analytic and meta-regression models in the birthweight dataset. Posterior mean and 95% highest posterior density (HPD) intervals are shown for each model.

	Models of the birthweight			
		Meta-regression models		
Description	Meta-analytic Model	Model 1	Model 2	Model 3
Fixed effects	**β [95% HPD]**		**β [95% HPD]**	
Intercept	0.52 [0.38, 0.68]	-	-	-
Day 42 to 80	-	**0.63 [0.43, 0.82]**	**0.62 [0.42, 0.83]**	**0.52 [0.26, 0.78]**
Day 81 to 100	-	**0.70 [0.23, 1.18]**	**0.71 [0.43, 0.99]**	**0.58 [0.21, 0.91]**
After day 100	-	0.28 [-0.19, 0.73]	**0.28 [0.03, 0.51]**	0.14 [-0.18, 0.43]
Litter size	-	-	-0.05 [-0.15, 0.06]	-0.05 [-0.15, 0.06]
Additional treatments	-	-	-	-0.15 [-0.41, 0.10]
Random effect	**VC**	**VC**	**VC**	**VC**
Experiment	0.059	0.109	0.124	0.119
Residual	0.111	0.073	0.068	0.069
I^2 Experiment	24.3%	-	-	-
I^2 Residual	53.2%	-	-	-
I^2 Total	77.5%	-	-	-
R^2 LMM (M)	-	13%	14%	17%
R^2 LMM (C)	-	65%	69%	69%
DIC	68.56	40.14	34.73	34.15

95% Highest posterior density intervals (HPD) excluding zero can be considered statistically significant. DIC= deviance information criterion; VC = variance components; R^2LMM(M)= Marginal R-squared, to quantify the variance explained exclusively by the fixed-effect component; R^2LMM(C)= Conditional R-squared, to quantify the variance explained jointly by the fixed- and random-effect components; I^2 = It represents the proportion of total variation that is due to true heterogeneity among studies, rather than sampling error; Model 1= Bayesian linear mixed-effects meta-regression containing only shearing period as a categorical fixed effect. Model 2= Model 1 with litter size added as an additional fixed effect. Model 3= Model 2 with indicator(s) for additional experimental treatments (e.g., nutritional supplementation, environmental manipulation) included as further fixed effects.

Table 2 Supplementary material: Summary of lamb birth weight (BW;kg) mean ± SEM in the unshorn and shorn treatments reported in studies included in the meta-analysis including the day of pregnancy when ewes were shorn and the country. Multiple rows may be drawn from the same source and differ by factors such as year, breed, litter size and additional treatment

Author	Treatment day	Country	Unshorn BW (kg)	Shorn BW (kg)	Percentage difference (%)*
Cam & Kuran (2004)	D100	Turkey	3.2±0.08	3.8±0.12	18.7
Cam & Kuran (2004)	D100	Turkey	3.1±0.1	3.5±0.19	-
Cam & Kuran (2004)	D100	Turkey	3.2±0.07	3.7±0.11	12.9
Cloete et al (2000)	D120	South African	3.9±0.06	3.8±0.06	-3
Corner et al (2006)	D80	New Zealand	5.6±0.13	5.9±0.13	-
Corner et al (2006)	D80	New Zealand	4.3±0.1	4.8±0.09	11.6
Corner et al (2007)	D80	New Zealand	4.8±0.1	5.1±0.1	6.2
Corner et al (2010)	D76	New Zealand	4.8±0.1	5.9±0.1	22.9
Corner et al (2010)	D74	New Zealand	4.8±0.1	4.6±0.1	-
Barbieri et al (2012)	D85	Uruguay	3.7±0.13	4.2±0.18	13.5
Barbieri et al (2012)	D85	Uruguay	3.7±0.13	4.2±0.18	13.5
Barbieri et al (2012)	D85	Uruguay	4.6±0.1	5.1±0.15	10.9
Barbieri et al (2012)	D85	Uruguay	4.6±0.1	4.9±0.14	-
Barbieri et al (2012)	D85	Uruguay	3.3±0.09	3.3±0.15	-
Barbieri et al (2012)	D85	Uruguay	3.3±0.09	3.5±0.16	-
Barbieri et al (2012)	D94	Uruguay	4.5±0.06	4.9±0.11	8.9
Barbieri et al (2012)	D94	Uruguay	4.5±0.06	4.8±0.1	6.7
Barbieri et al (2012)	D94	Uruguay	3.5±0.11	4.1±0.17	17.1
Barbieri et al (2012)	D94	Uruguay	3.5±0.11	3.8±0.18	-
Barbieri et al (2012)	D90	Uruguay	4.05±0.036	4.45±0.04	9.9
Denicolo et al (2008)	D74	New Zealand	4.25±0.1	4.56±0.1	7.3
Gate et al (1999)	D120	England	4.72±0.17	5.08±0.36	-
Guyoti et al (2015)	D74	Brazil	4.53±0.68	5.46±1.05	20.5
Husain et al (1997)	D115	New Zealand	4.3±0.1	4.9±0.1	13.9
Husain et al (1997)	D115	New Zealand	4.3±0.1	4.5±0.1	-
Hyatt et al (2008)	D70	England	4.74±0.36	5.46±0.37	3.13
Hyatt et al (2008)	D70	England	4.27±0.29	4±0.21	
Jenkinson et al (2009)	D90	New Zealand	4.69±0.11	4.93±0.11	-
Jenkinson et al (2009)	D90	New Zealand	3.56±0.13	3.94±0.11	10.7
Jenkinson et al (2009)	D90	New Zealand	4.15±0.08	4.41±0.07	6.2
Kalhor et al (2023)	D80	Iran	4.2±0.1	4.3±0.1	-
Kalhor et al (2023)	D80	Iran	4.2±0.1	4.1±0.1	-
Kalhor et al (2023)	D80	Iran	4.2±0.1	4.5±0.1	7.1
Keady et al (2009)	D63	Ireland	3.79±0.145	4.46±0.15	17.7
Keady et al (2009)	D63	Ireland	4.08±0.145	4.54±0.15	11.2
Kenyon et al (2011)	D72	New Zealand	6.1±0.1	5.9±0.2	-3.2
Kenyon et al (2011)	D72	New Zealand	4.6±0.1	5.2±0.1	13
Kenyon et al (2002)	D70	New Zealand	4.9±0.2	5.6±0.2	14.3

Kenyon et al (2002)	D70	New Zealand	4.2±0.1	4.4±0.1	-
Kenyon et al (2002)	D70	New Zealand	5.1±0.1	5.4±0.1	5.9
Kenyon et al (2005)	D5	New Zealand	4.36±0.08	4.48±0.08	-
Kenyon et al (2005)	D30	New Zealand	4.36±0.08	4.64±0.09	6.4
Kenyon et al (2006)	D70	New Zealand	4.29±0.04	4.73±0.04	10.3
Kenyon et al (2006)	D70	New Zealand	4.28±0.04	4.41±0.04	3
Kenyon et al (2006)	D79	New Zealand	4.77±0.09	5.09±0.09	6.7
Kenyon et al (2006)	D119	New Zealand	4.77±0.09	4.72±0.09	-1
Kenyon et al (2006)	D79	New Zealand	3.51±0.16	3.88±0.13	-
Kenyon et al (2005)	D70	New Zealand	4.77±0.13	5.18±0.11	-
Lopez-Mazz et al (2018)	D50	Uruguay	5±0.1	5.5±0.1	10
Lopez-Mazz et al (2018)	D50	Uruguay	3.9±0.1	4.2±0.1	7.7
Morris et al (2000)	D50	New Zealand	5.1±0.2	5.8±0.2	13.7
Morris et al (2000)	D70	New Zealand	5.1±0.2	5.9±0.2	15.7
Morris et al (2000)	D100	New Zealand	5.1±0.2	5.9±0.2	15.7
Morris et al (2000)	D50	New Zealand	4.5±0.2	4.4±0.1	-2.2
Morris et al (2000)	D70	New Zealand	4.5±0.2	4.2±0.1	-6.7
Morris et al (2000)	D100	New Zealand	4.5±0.2	4.8±0.1	-
Parker et al (1991)	D91	New Zealand	4.98±0.97	4.86±0.97	-
Revell et al (2002)	D70	New Zealand	4.6±0.2	5.4±0.24	17.4
Revell et al (2002)	D70	New Zealand	4.2±0.12	4.4±0.1	-
Revell et al (2000)	D69	New Zealand	5.8±0.24	5.7±0.24	-1.7
Revell et al (2000)	D69	New Zealand	4.3±0.11	5.4±0.11	25.6
Russel et al (1985)	D114	Scotland	4.63±0.22	4.55±0.22	-1.7
Russel et al (1985)	D114	Scotland	3.67±0.14	3.88±0.14	-
Russel et al (1985)	D114	Scotland	4.62±0.14	4.81±0.14	-
Russel et al (1985)	D114	Scotland	3.69±0.01	3.79±0.01	-
Symonds et al (1986)	D91	England	3.74±0.22	4.35±0.15	16.3
Symonds et al (1988)	D51	England	3.86±0.19	4.19±0.19	-
Vipond et al (1987)	D112	Scotland	4.06±0.13	4.65±0.13	14.5
Vipond et al (1987)	D70	Scotland	3.62±0.14	4.55±0.14	25.7
Vipond et al (1987)	D70	Scotland	4.71±0.17	5.08±0.17	-
Banchero et al (2010)	D70	Uruguay	4.5±0.17	4.9±0.18	-
Banchero et al (2010)	D120	Uruguay	4.5±0.17	4.7±0.17	-
Banchero et al (2010)	D70	Uruguay	3.1±0.1	3.9±0.1	25.8
Banchero et al (2010)	D120	Uruguay	3.1±0.1	3.4±0.1	9.7
Cantou et al (2024)	D70	Uruguay	4.03±0.11	5.53±0.15	37.2
Cantou et al (2024)	D110	Uruguay	4.03±0.11	5.41±0.16	34.2
Dabiri et al (1995)	D114	New Zealand	4.29±0.07	4.41±0.07	-
Dabiri et al (1995)	D114	New Zealand	4.29±0.07	4.35±0.07	-
Dabiri et al (1996)	D118	New Zealand	4.5±0.1	4.4±0.1	-2.2
Denicolo et al (2008)	D74	New Zealand	4.24±0.1	4.56±0.1	-
Gonzalez-Luna et al (2023)	D100	Spain	4.62±0.21	4.23±0.21	-8.4
Gonzalez-Luna et al (2023)	D100	Spain	3.95±0.22	4.19±0.22	-

Kenyon et al (2004)	D70	New Zealand	4.65±0.05	5.12±0.05	10.8
Morris et al (1997)	D70	New Zealand	6.2±0.2	5.8±0.2	-6.5
Morris et al (1997)	D100	New Zealand	6.2±0.2	6±0.2	-3.2
Morris et al (1997)	D130	New Zealand	6.2±0.2	5.6±0.1	-9.7
Morris et al (1997)	D70	New Zealand	4.3±0.1	5±0.1	16.3
Morris et al (1997)	D100	New Zealand	4.3±0.1	4.7±0.1	9.3
Morris et al (1997)	D130	New Zealand	4.3±0.1	4.6±0.1	7
Nedkvitne (1972)	D120	Norway	4.4±0.13	4.6±0.12	-
Nedkvitne (1972)	D120	Norway	3.9±0.14	4.1±0.1	-
Nedkvitne. (1972)	D120	Norway	4.7±0.14	4.5±0.11	-4.3
Rosales Nieto et al (2020)	D107	USA	5±0.34	5.4±0.34	8
Rutter et al (1971)	D100	Scotland	8.4±0.55	9.5±0.55	-
Rutter et al (1971)	D100	Scotland	7.8±0.56	9.4±0.56	20.5
Rutter et al (1971)	D100	Scotland	8.1±0.11	9.4±0.11	16
Sphor et al (2011)	D53	Uruguay	4.4±0.3	5.8±0.29	31.8
Symonds et al (1989)	D88	England	4.11±0.15	4.55±0.34	-
Symonds et al (1992)	D119	England	4.32±0.19	4.96±0.18	14.8
Symonds et al (1990)	D85	England	3.94±0.17	4.19±0.26	-
Leibovich et al (2011)	D120	Israel	4.53±0.1	4.79±0.1	-
Vasquez et al (2018)	D105	USA	5.52±0.16	5.9±0.16	-
Clarke et al (1997)	D120	England	4.6±0.44	5.41±0.22	17.6
Rutter et al (1972)	D50	Scotland	4.3±0.48	5.5±0.48	27.9
Rutter et al (1972)	D50	Scotland	4.6±0.48	5.6±0.48	21.7
Rutter et al (1972)	D50	Scotland	4.5±0.48	5.5±0.48	22.2
Rutter et al (1972)	D50	Scotland	4.5±0.48	5.6±0.48	24.4
Adalsteinsson et al (1972)	-	Iceland	2.26±0.09	2.78±0.08	23
Kenyon et al (2002)	D70	New Zealand	6±0.07	6.2±0.06	-
Kenyon et al (2002)	D70	New Zealand	4.7±0.03	5.1±0.03	8.5
Kenyon et al (2002)	D70	New Zealand	3.9±0.09	4.2±0.1	-
Kenyon et al (2002)	D70	New Zealand	4.9±0.04	5.2±0.04	6.1
Salman et al (1986)	D84	Iraq	8.15±0.2	9±0.2	10.4
Salman et al (1986)	D42	Iraq	8.15±0.2	8.3±0.2	1.8
Ribeiro et al (2010)	D74	Brazil	4.76±1.17	5.47±0.94	14.9
Cal-Pereyra et al (2011)	D110	Uruguay	4.419±3.54	4.419±6.60	-
Kalhor et al (2021)	D76	Iran	4.8±0.1	5.9±0.1	22.9

* Only those with values are significantly ($P<0.05$) differ or if negative even if not significant; Dx = x days of pregnancy

Weaning weight:

The meta-analytic model of weaning weight showed a non-significant ($p>0.05$) effect of pregnancy shearing on lamb weaning weight (i.e. $d=0.09$). There was a large heterogeneity in the data ($I^2_{total} = 81.6\%$) with much of the difference (~58%) between experiments remaining unexplained.

Model 1: The time of shearing during pregnancy played a significant role in determining the size of the effect of pregnancy shearing on weaning weight. Results showed that lambs born to ewes shorn between day 50 and 100 days of pregnancy retained a small ($d = 0.21$) advantage in weaning weight compared to those born to unshorn ewes. In contrast, studies where shearing was performed after day 100 of pregnancy showed no significant effect on lamb weaning weight. This single predictor model (the time of shearing) was able to: 1) explain 63% of the variation in outcomes across experiments, 2) increased the variance explained by experiment-level differences (PCV = ~82%) and 3) reduce the residual variance (PCV = ~32%). This suggests that an important structure in the model was captured by the time of shearing, which also increased the model fit (DIC = 46.98).

Model 2: added the predictor "additional treatments", but it cannot explain more heterogeneity (66%), and the model fit is not as good as model 1 (DIC = 48.18). Given the small and heterogeneous dataset, model 1 (Table 3) was chosen as the best meta-regression model for weaning weight in the current study. Therefore, as pregnancy shearing had no significant effect on weaning weight it is not a tool that farmers could use to increase their lamb weaning weights.

Table 3 Summary of the statistical results of meta-analytic and meta-regression models in the weaning weight dataset. Posterior mean and 95% highest posterior density intervals are shown for each model.

Models of the weaning weight			
		Meta-regression models	
Description	Meta-analytic Model	Model 1	Model 2
Fixed effects	β [95% HPD]	β [95% HPD]	
Intercept	0.09 [-0.05, 0.25]	-	-
Day 50 to 100	-	**0.21 [0.05, 0.42]**	**0.23 [0.01, 0.48]**
After day 100	-	-0.19 [-0.48, 0.11]	-0.19 [-0.54, 0.09]
Additional treatments	-	-	-0.07 [-0.41, 0.30]
Random effect	**VC**	**VC**	**VC**
Experiment	0.056	0.102	0.124
Residual	0.114	0.078	0.068
I^2 Experiment	24.1	-	-
I^2 Residual	57.5	-	-
I^2 Total	81.6	-	-
R^2 LMM (M)	-	14%	14%
R^2 LMM (C)	-	63%	66%
DIC	65.43	46.98	48.18

95% Highest posterior density intervals (HPD) excluding zero can be considered statistically significant. DIC= deviance information criterion; VC = variance components; R2LMM(M)= Marginal R-squared, to quantify the variance explained exclusively by the fixed-effect component; R2LMM(C)= Conditional R-squared, to quantify the variance explained jointly by the fixed- and random-effect components; I^2 = It represents the proportion of total variation that is due to true heterogeneity among studies, rather than sampling error; Model 1= Bayesian linear mixed-effects meta-regression containing only shearing period as a categorical fixed effect. Model 2= Model 1 with indicator(s) for additional experimental treatments (e.g., nutritional supplementation, environmental manipulation) included as further fixed effects.

Table 4 Supplementary material: Summary of lamb weaning weight (WW;kg) mean ± SEM in the unshorn and shorn treatments reported in studies included in the meta-analysis including the day of pregnancy ewes were shorn and the country. Multiple rows may be drawn from the same source and differ by factors such as year, breed, litter size and additional treatment

Author	Treatment day	Country	Unshorn WW (kg)	Shorn WW (kg)	Percentage difference (%)
Cam & Kuran (2004)	D100	Turkey	20.2±1.02	24.6±1.27	21.7
Cam & Kuran (2004)	D100	Turkey	16.7±1.12	20.1±1.59	20.4
Cam & Kuran (2004)	D100	Turkey	19.5±0.91	23.6±1.1	17.9
Cloete et al (2000)	D120	South African	21.5±0.4	21.5±0.4	-
Corner et al (2006)	D80	New Zealand	23.7±0.4	25.4±0.4	-
Barbieri et al (2012)	D85	Uruguay	13±0.55	12.5±0.58	-3.8
Barbieri et al (2012)	D85	Uruguay	13±0.55	12.4±0.7	-4.6
Barbieri et al (2012)	D85	Uruguay	15.2±0.34	14.4±0.49	-5.3
Barbieri et al (2012)	D85	Uruguay	15.2±0.34	14.8±0.48	-2.6
Barbieri et al (2012)	D85	Uruguay	12.5±0.57	11.5±0.8	-8
Barbieri et al (2012)	D85	Uruguay	12.5±0.57	10.6±0.9	-15.2
Barbieri et al (2012)	D94	Uruguay	18.3±0.24	17.2±0.39	-6
Barbieri et al (2012)	D94	Uruguay	18.3±0.24	18.5±0.36	-
Barbieri et al (2012)	D94	Uruguay	18.1±0.76	18.9±1.1	-
Barbieri et al (2012)	D94	Uruguay	18.1±0.76	18.7±1	-
Barbieri et al (2018)	D90	Uruguay	13.4±0.14	13.9±0.15	3.8
Denicolo et al (2008)	D74	New Zealand	18.86±0.73	19.19±0.68	-
Husain et al (1997)	D115	New Zealand	20.4±1.1	21.3±0.9	-
Husain et al (1997)	D115	New Zealand	20.4±1.1	21.7±0.9	-
Keady et al (2009)	D63	Ireland	31.8±0.85	33.6±0.85	5.7
Keady et al (2009)	D63	Ireland	31.6±0.85	33.8±0.85	7
Kenyon et al (2002)	D70	New Zealand	25.5±0.7	25.6±0.8	-
Kenyon et al (2002)	D70	New Zealand	21.6±0.4	21.8±0.4	-
Kenyon et al (2002)	D70	New Zealand	21.9±0.4	21.8±0.3	-0.4
Kenyon et al (2005)	D5	New Zealand	18.93±1.47	17.6±1.44	-
Kenyon et al (2005)	D30	New Zealand	18.93±0.28	18.01±1.47	-4.9
Kenyon et al (2006)	D70	New Zealand	25.64±0.25	26.71±0.28	4.2
Kenyon et al (2006)	D70	New Zealand	22.49±0.46	22.58±0.24	-
Kenyon et al (2006)	D79	New Zealand	25.93±0.46	26.35±0.46	-
Kenyon et al (2006)	D119	New Zealand	25.93±0.46	20.3±0.33	-21.7
Kenyon et al (2006)	D79	New Zealand	20.05±0.77	21.54±0.66	-
Kenyon et al (2005)	D70	New Zealand	25.48±0.83	24.8±0.71	-2.7
Lopez-Mazz et al (2018)	D50	Uruguay	20.9±0.5	23.2±0.6	11
Lopez-Mazz et al (2018)	D50	Uruguay	17.3±0.5	17.9±0.1	3.5
Morris et al (2000)	D50	New Zealand	26.1±1	26.2±0.7	-

Morris et al (2000)	D70	New Zealand	26.1±1	27.4±0.7	-
Morris et al (2000)	D100	New Zealand	26.1±1	26.3±0.8	-
Morris et al (2000)	D50	New Zealand	20.8±0.9	19.9±0.6	-
Morris et al (2000)	D70	New Zealand	20.8±0.9	18.7±0.7	-
Morris et al (2000)	D100	New Zealand	20.8±0.9	20.9±0.6	-0.5
Parker et al (1991)	D91	New Zealand	22.93±3.32	23.39±3.32	-
Revell et al (2002)	D70	New Zealand	34.2±6.79	31.3±7.92	-8.5
Revell et al (2002)	D70	New Zealand	27.3±3.80	27.2±3.28	-0.4
Russel et al (1985)	D114	Scotland	33.6±1.06	34.2±1.06	-
Russel et al (1985)	D114	Scotland	28.9±0.66	27.9±0.66	-3.5
Russel et al (1985)	D114	Scotland	31.0±0.73	30.8±0.73	-0.6
Russel et al (1985)	D114	Scotland	29.6±0.57	29.4±0.57	-0.7
Cantou et al (2024)	D70	Uruguay	27.24±0.69	34.7±0.39	-
Cantou et al (2024)	D110	Uruguay	27.24±0.69	37.05±1.78	36
Dabiri et al (1995)	D114	New Zealand	17.44±0.45	18.06±0.46	-
Dabiri et al (1995)	D114	New Zealand	17.44±0.45	17.9±0.46	-
Dabiri et al (1996)	D118	New Zealand	18.4±0.4	17.6±0.5	-4.3
Denicolo et al (2008)	D74	New Zealand	18.86±0.73	19.19±0.68	-
Gonzalez-Luna et al (2023)	D100	Spain	12.72±0.57	11.6±0.57	-8.8
Gonzalez-Luna et al (2023)	D100	Spain	12.32±0.6	12.92±0.6	-
Lopez-Mazz et al (2020)	D50	Uruguay	21.3±0.7	22.7±0.9	-
Lopez-Mazz et al (2020)	D50	Uruguay	16.8±0.7	16.8±0.7	-
Morris et al (1997)	D70	New Zealand	25.6±0.9	24.3±1.9	-5.1
Morris et al (1997)	D100	New Zealand	25.6±0.9	23.9±0.8	-6.6
Morris et al (1997)	D130	New Zealand	25.6±0.9	23.8±0.8	-6.5
Morris et al (1997)	D70	New Zealand	18.3±0.8	19.2±0.5	-
Morris et al (1997)	D100	New Zealand	18.3±0.8	19.7±0.6	-
Morris et al (1997)	D130	New Zealand	18.3±0.8	18.7±0.6	-
Sphor et al (2011)	D53	Uruguay	23.6±1.4	28.1±1.4	19

* Only those with values are significantly ($P<0.05$) differ or if negative even if not significant; Dx = x days of pregnancy;

3.1.2 Effect on pre-weaning growth rate of lambs

Due to differences in the duration of the period between birth and weaning between studies, and the low number of studies examining growth as an indicator of productivity, a meta-analysis could not be undertaken for these parameters, however, it is appropriate to report findings in the literature. Therefore, the following sections are a qualitative review of the literature.

Several experiments conducted under housed conditions have shown that pregnancy shearing can improve the growth rate of in lambs between 3 weeks and 3 months of age (Kneale & Bastiman, 1977b) (~D70-100), (Morgan & Broadbent, 1980) (~D70-100), (Kirk et al., 1984) (~D90), (Glanville & Phillips, 1986) (~D105), (Austin & Young, 1977) (D58). Four experiments, however, reported that pregnancy shearing had no effect on lamb growth rate (Russel et al., 1985) (~D77), (Murray & Crosby, 1986) (D77), (Black & Chestnut, 1990), (D85-120), (Symonds et al., 1992) (~D120).

Under pasture grazing conditions similar results have been reported, with some studies showing a positive effect of pregnancy shearing on pre-weaning lamb growth rates. Van der Merwe et al. (1993) (~D120-130) and López-Mazz et al. (2017) (D50) reported that late pregnancy shearing increased lamb pre-weaning growth rate to 8 weeks of age. Most experiments, however, reported no effect of pregnancy shearing on the lamb growth rate of lambs to weaning (Dabiri et al., 1994) (~D130), (Dabiri, Morris, et al., 1995) (D114), (Dabiri et al., 1996) (D118), Husain et al. (1997) (D115), (Morris & McCutcheon, 1997) (D70-130), (Morris et al., 2000) (D70-100), (Kenyon et al., 2002b) (D70), (Kenyon et al., 2002c) (D70) (Revell et al., 2002) (D70). Two studies reported that although pregnancy shearing increased lamb weaning weight, it was not due to the increased lamb growth rate, but rather that lambs born to shorn ewes had higher birth weights than their counterparts born to unshorn ewes (Kenyon et al., 2004) (D70) (Smeaton et al., 2000) (D70). Furthermore, in a mixed house and pasture study conducted in Spain mid-pregnancy shearing (D100) had no effect on the growth rate of lambs prior to weaning (González-Luna et al., 2023).

Regardless of whether ewes were housed, at pasture or a mix of the two, the effect

of pregnancy shearing on the pre-weaning growth rate of lambs was not consistent. Kenyon and Morris Kenyon and Morris (2002) suggested that to achieve higher pre-weaning growth rates, pregnancy shearing alone was not enough and the ewes needed to maintain good body condition throughout lactation.

3.1.3 Survival rate of lambs

Pregnancy shearing under housed conditions has been reported to improve lamb survival (Rutter et al., 1971) (~D100), (Nedkvitne, 1972) (~D120), (Austin & Young, 1977) (~D58), (Maund, 1980b) (~D88) (Salman & Owen, 1986) (~D64-106) (Vipond et al., 1987) (~D80-110) (see Table 5). While Rutter et al. (1972) reported that pregnancy shearing at ~D100 slightly reduced mortality in lambs, but this was not statistically significant. Cam and Kuran (2004) reported that lambs born from pregnant shorn ewes (D100) raised in a mixed system of grazing during the day and being housed at night also had a higher survival rate. Kenyon, Revell and Morris (2006) (D70), López-Mazz et al. (2017) (D50) and De Barbieri et al. (2018) (D108) reported that pregnancy shearing improved lamb survival rate under New Zealand's and South American pastoral conditions. Two studies, however, reported no effect of pregnancy shearing on lamb survival. Under New Zealand's pasture based grazing system (Kenyon, Sherlock, et al. (2006)) (D79-119) and in a study with mixed housing (Kalhor et al. (2023)) (D80) reported no effect of pregnancy shearing on lamb survival rate.

It has been suggested that ewes shorn during pregnancy may be more aware of the lambs near their bodies, thus promoting lactation behaviours. Further, studies of housed ewes has suggested that shearing reduces the difficulty for the lambs to locate the teat thus increasing lamb survival (Rutter et al., 1971; Black & Chestnut, 1990). Therefore, the improved survival of lambs born to housed shorn ewes may be due to improved maternal performance.

Under the pasture-based management conditions in New Zealand, pregnancy shearing is thought to encourage ewes to seek shelter during pregnancy (Frengley, 1964; Lynch & Alexander, 1976). Shearing can also reduce the difficulty of the ewe to transition from sitting to standing due to a heavy fleece, which can lead to the death of

lambs, and lambs can find teats more easily and suckle milk faster thus increasing survival rates (Wodzicka-Tomaszewska, 1963).

Nowak and Poindron (2006) reported that the birth weight of lambs has a curved relationship (U-shaped) with lamb mortality, that means both very light and very heavy lambs have higher mortality than lambs in the optimal birth weight range. In addition, the body condition and nutritional reserves of the ewe at the time of shearing may also impact on the survival rate of lambs to weaning. Ewes with greater body condition may be more able to respond to the metabolic stimulation caused by shearing thus resulting in an increase in lamb birth weight and therefore survival rate (Kenyon, Revell, & Morris, 2006). Kenyon, Sherlock, et al. (2006) (D108) reported that if pregnancy shearing increased birth weight of lambs to above the optimal survival range when they were already within or close to that range, survival will not be increased by pregnancy shearing. Kenyon, Revell and Morris (2006) (D79-119) suggested that if increases in lamb birth weight from pregnancy shearing resulted in lambs with very high birth weights they may result in reduced lamb survival. In addition, they suggested that the warm environment for lambing in spring makes the increase in birth weight have no additional benefit to survival. Kalhor et al. (2023) (D80) suggested that only an increase in proportion of lambs with birth weights below the optimal range would result in changes in survival. In general, lamb pre-weaning survival was influenced by many factors, including environmental conditions, management systems, and the effect of shearing on the balance between lamb birth weight gain and the optimal birth weight range.

Table 5. Reported pre-weaning survival (%) of singleton and multiple lambs born to pregnancy-shorn vs unshorn ewes

Reference	Breeds	Age of ewe	Shearing time	Single unshorn ewe	Single shorn ewe	Multiple unshorn ewe	Multiple shorn ewe
López-Mazz et al. (2017)	Polwarth	Mature	D50	85.3%	82%	70.6%[b]	78.9%[a]
Kenyon, Revell and Morris (2006)	Romney	Mature	D70	-	-	75.2%[a] 76.5%	80.7%[b] 77.2%
Kenyon, Sherlock, et al. (2006)	Romney	Hogget	D79 D119	71.1%	72.9% 80.0%	79.2%	72.2%
De Barbieri et al. (2018)	Corriedale	Hogget	D108	71%[a]	80%[b]	-	-
Cam and Kuran (2004)	Karayaka	-	D100	84%[a]	100%[b]	-	-
Kalhor et al. (2023)	Zandi	Mature	D80	-	-	74%	79%
Rutter et al. (1972)	Cheviot	Mature	D120	94.1% 84.6%	87.5% 92.3%	-	-
	Greyface	Mature		46.7% 86.4%	100% 92.3%		
Rutter et al. (1971)	Cheviot Greyface	Mature	~D100	72.2%[a] 54.8%[a]	80.9%[b] 82.1%[b]	-	-
Adalsteinsson (1972)	-	Mature		83.3%	91.7%	-	-
Grosser et al. (1991)	Merino	Mature	-	80.3% 89.3% 90.7%	82.2% 95.4% 91.1%	65.2% 47.4%	60.6% 68.8%
Austin and Young (1977)	Masham	Mature	~D58	93%[a]	98%[b]	-	-

Salman and Owen (1986)	ISB	Mature	D64 D106	80%[a]	90%[b]	-	-
Vipond et al. (1987)	Crossed	Mature	D80-100	88%[a]	94%[b]	-	-
Smeaton et al. (2000)	Finn	Mature	D70	90% 95%	92% 97%	-	-

ISB = Improver x Scottish Blackface; Dx = x days of pregnancy; Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$).

3.1.4 Effect on wool production of lambs

The effects of ewe pregnancy shearing on the wool traits of lambs have been inconsistent. Van Reenen et al. (2010) reported that shearing Merino ewes in late pregnancy (D141), but not in mid-pregnancy (D106), increased the total and secondary follicle density and number of lambs at approximately 7 months of age. Similarly, Revell et al. (2002) reported that among Romney-type ewes, skin samples from single- and twin- bearing foetuses at day 140-141 of gestation whose dams were shorn at mid-pregnancy (D70) showed a higher density of secondary wool follicles, and an increased secondary-to-primary follicle ratio than foetuses of unshorn ewes. In contrast, Kenyon et al. (2005) reported that in Romney-type ewes, mid-pregnancy shearing (D70) had no effect on the number of secondary follicles nor the ratio of the secondary to primary follicles in lambs at approximately 5 months of age. In a subsequent study of ewe hogget Kenyon and others also reported no effect on the number or ratio of follicles (Kenyon, Revell, & Morris, 2006) (D70). Sherlock et al. (2002) reported that mid-pregnancy shearing (D70) resulted in a decrease in the number of secondary follicles in offspring at 6 months of age but there was no effect on the ratio of secondary to primary follicles. It should be noted that the density and/or number of primary follicles in lambs was unaffected by pregnancy shearing in all studies in which it was measured (Revell et al., 2002; Sherlock et al., 2002; Kenyon et al., 2005; Kenyon, Sherlock, et al., 2006; Van Reenen et al., 2010).

Pregnancy shearing of the ewe has been reported to affect fleece characteristics of lambs such as fleece weight or on fibre and staple characteristics (Tables 6, 7 and 8). Revell et al. (2002) reported that mid-pregnancy shearing (D70) of Romney-type ewe increased the greasy fleece weight of single-born, but not twin-born lambs at ~3-months of age. Kenyon et al., (2005) and Van Reenen et al., (2010), however, reported that pregnancy shearing (D70-141) had no effect on lamb greasy fleece weight. Mean fibre diameter (MFD) of ~6-month-old lambs was reported to be increased by mid-pregnancy shearing (D70) (Sherlock et al. (2002)), but other studies reported no effect (Kenyon et al., 2005) (D70), (Kenyon, Sherlock, et al., 2006) (D70), (Van Reenen et al., 2010)

(D141). Pregnancy shearing has also been reported to have no effect on other lamb fleece characteristics including curvature (Sherlock et al., 2002; Kenyon, Sherlock, et al., 2006), medullation (Kenyon et al., 2005; Kenyon, Sherlock, et al., 2006), yield (Revell et al., 2002; Kenyon et al., 2005; Kenyon, Sherlock, et al., 2006; Van Reenen et al., 2010), staple length (Sherlock et al., 2002; Kenyon et al., 2005; Kenyon, Sherlock, et al., 2006; Van Reenen et al., 2010), staple strength (Van Reenen et al., 2010), and bulk (Sherlock et al., 2002; Kenyon et al., 2005). Kenyon, Sherlock, et al. (2006) reported that single-born lambs at ~3-months of age born to late pregnancy (D119) shorn ewes had whiter wool, but there was no difference among single-born lambs born to ewes shorn at D79. Overall, these studies indicate that pregnancy shearing has little effect on lamb wool characteristics.

Table 6. Effects of pregnancy shearing (shorn vs unshorn) on lamb wool and follicle traits including follicle density (follicles/mm^2; mean ± SEM), primary follicle density (follicles/mm^2; mean ± SEM), secondary follicle density (follicles/mm^2; mean ± SEM), secondary to primary ratio, total follicle number index, primary follicle number index and secondary follicle number index

Reference	Breed	Treatment	Follicle density (follicles/mm^2)	Primary follicle density (follicles/mm^2)	Secondary follicle density (follicles/mm^2)	Secondary: primary ratio	Total follicle number index	Primary follicle number index	Secondary follicle number index
Kenyon, Sherlock, et al. (2006)	Romney	Unshorn	-	4.43±0.28	16.72±0.89	4.25±0.07	-	-	-
		D79		4.27±0.28	18.17±0.89	4.74±0.07			
		D199		4.76±0.28	18.87±0.89	4.08±0.07			
Kenyon et al. (2005)	Coopworth	Unshorn	-	16.80±1.08	65.31±2.79	4.08±0.28	-	-	-
		D70		17.48±1.03	65.65±2.66	3.95±0.27			
Revell et al. (2002)	Romney	Single unshorn	-	53.0^a±1.73	114.2^a±4.58	2.17^a±0.07	-	-	-
		Single D70		52.0^a±1.73	126.5^b±4.58	2.45^b±0.07			
		Twin unshorn		63.0^b±1.73	134.7^c±4.58	2.19^a±0.07			
		Twin D70		59.7^b±1.73	114.1^d±4.58	2.43^b±0.07			
Sherlock et al. (2002)	Romney	Unshorn	-	6.5±0.3	52.4^b±1.9	9.8±0.6	-	-	-
		D70		5.8±0.3	46.5^a±1.9	9.7±0.6			
Van Reenen et al. (2010)	Merino	Unshorn	81.1^a±3.4	5.0±0.2	76.2^a±3.3	16±0.7	69.3^a±3.0	4.2±0.2	65.2^a±2.9
		D106	86.3^a±3.5	5.2±0.2	81.4^a±3.4	16.3±0.6	72.7^a±3.1	4.3±0.2	68.5^a±3.0
		D141	94.6^b±3.5	5.5±0.2	89.3^b±3.4	17.2±0.7	79.5^b±3.1	4.5±0.2	75.0^b±3.0

Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

Table 7. Effects of pregnancy shearing (shorn vs unshorn) on lamb wool traits including greasy fleece weight (kg; mean ± SEM), MFD (μm; mean ± SEM) , cvMFD (%; mean ± SEM), curvature (°/mm; mean ± SEM), medullation (%; mean ± SEM) and yield (%; mean ± SEM)

Reference	Treatment	Breed	Greasy fleece weight (kg)	MFD (μm)	cvMFD (%)	Curvature (°/mm)	Medullation (%)	Yield (%)
Kenyon, Sherlock, et al. (2006)	Unshorn	Romney	-	30.59±0.29	26.32±0.35	53.57±0.93	5.38±1.67	82.91±0.50
	D79			30.34±0.29	26.54±0.35	53.50±0.93	4.35±1.67	82.32±0.50
	D119			29.98±0.29	26.04±0.35	53.19±0.93	7.61±1.67	81.77±0.50
Kenyon et al. (2005)	Unshorn	Coopworth	2.3±0.2	33.6±0.4	26.7±0.4	-	112.5±0.4	81.5±0.9
	D70		2.1±0.2	32.8±0.4	26.7±0.4		109.5±0.4	81.8±0.8
Revell et al. (2002)	Single unshorn	Romney	1.49^{c}±0.07	32.5^{c}±0.60	-	-	-	79.6±1.04
	Single D70		1.24^{b}±0.07	31.5^{bc}±0.60				78.7±1.04
	Twin unshorn		1.05^{a}±0.07	31.2^{ab}±0.60				78.7±1.04
	Twin D70		1.19^{ab}±0.07	30.3^{a}±0.60				79.4±1.04
Sherlock et al. (2002)	Unshorn	Romney		31.3^{a}±0.5	26.7±0.3	50.7±1.1		
	D70			32.9^{b}±0.5	25.8±0.3	49.5±1.1		
Van Reenen et al. (2010)	Unshorn	Merino	2.4±0.1	17.1±0.1				72.5±0.8
	D106		2.5±0.1	17.1±0.1				70.9±0.8
	D141		2.4±0.1	16.9±0.1				70.6±0.9

Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

Table 8. Effects of pregnancy shearing (shorn vs unshorn) on wool characteristics of lamb including staple length (mm; mean ± SEM), staple strength (N/ktex; mean ± SEM), colour (Y-Z; mean ± SEM), bulk (cm^3; mean ± SEM) and Yellowness (Y; mean ± SEM)

Reference	Treatment	Breed	Staple length (mm)	Staple strength （N/ktex）	Colour (Y-Z)	Bulk (cm^3/g)	Y
Kenyon, Sherlock, et al. (2006)	Unshorn	Romney	55.27±1.45	-	0.63^{b}±0.12	-	70.19±0.35
	D79		52.97±1.45		0.41^{ab}±0.12		70.20±0.35
	D119		52.93±1.45		0.17^{a}±0.12		70.32±0.35
Kenyon et al. (2005)	Unshorn	Coopworth	112.5±3.1	-	2.0±0.3	20.6±0.5	-
	D70		109.5±2.7		1.2±0.2	20.9±0.4	
Sherlock et al. (2002)	Unshorn	Romney	73.0±2.0	-	0.3±0.1	20.8±0.3	-
	D70		74.0±2.0		0.3±0.1	21.1±0.3	
Van Reenen et al. (2010)	Unshorn	Merino	69.6±1.5	37.3±2.1	-0.02±0.2	-	-
	D106		69.8±1.4	40.8±2.0	0.20±0.2		
	D141		67.5±1.5	39.3±2.1	-0.10±0.2		

Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

3.1.5 Effect on lamb behaviour

Neonatal lamb behaviours such as standing, finding the udder, suck and bleating are important to ewe-lamb bonding and directly influences milk intake and survival (Owens et al., 1985; Nowak, 1990; Cloete, 1993; Brien et al., 2010). There is some evidence that pregnancy shearing may result in behavioural changes in new-born lambs. Labeur et al. (2020) reported that during a behavioural test lambs born to ewes shorn in mid-pregnancy (D90) took twice as long to bleat as those born to unshorn ewes which appeared to be driven by differences among single-born lambs. This relationship was also observed 90 minutes later after the lambs had been exposed to 4°C for one hour. No differences were observed among lambs born to ewes shorn at D130. This result suggests that early vocal response was suppressed. It appears there are no other studies that have examined the impact of pregnancy shearing on lamb vocalisation.

Pregnancy shearing at D70 or D120 has been reported to have a positive influence on newborn lamb latency to stand (lambs born to shorn ewes stood up more frequently and faster within the first hour after birth) which was more pronounced among twin- than single-born lambs (Banchero et al., 2010). Other studies reported no difference in latency to stand among lambs born to shorn and unshorn ewes at normal shed temperatures (López-Mazz et al., 2017; Labeur et al., 2020). The time it takes for a newborn lamb to actively walk back to the ewe when isolated for a short period assesses the lambs' sensory responsiveness, motor coordination, willingness to bond with their mothers (Labeur et al., 2020). Labeur et al. (2020) reported that at normal shed temperatures, shearing had no effect on how quickly lambs returned to ewe, however, after an hour at 4°C, lambs born to shorn ewes returned to their dams sooner than those born to unshorn ewes. This effect was greater among lambs born to ewe shorn in mid- rather than late pregnancy.

López-Mazz et al. (2017) (D50) and Corner et al. (2006) (D79) reported that lambs born to pregnancy shorn ewes attempted to suck earlier and were quicker to successfully suck than those born to unshorn ewes. Similarly, Banchero et al. (2010) reported that within one hour of birth a greater percentage of lambs born to ewes shorn on D70 (78%) or D120 (61%), successfully sucked than those born to unshorn ewes (21%). These reported changes in lamb behaviour associated with pregnancy shearing appear to have a positive effect on lamb survival. These effects, however, do not fully explain the increase in lamb survival seen as a result of pregnancy shearing.

3.1.6 Lamb thermoregulatory capability

Under outdoor spring lambing grazing conditions, lambs are often exposed to cold environments and a lambs thermoregulatory capability directly impacts on their survival (Plush et al., 2016). Lambs utilize brown adipose tissue (BAT) located around the heart and kidneys rapidly generate heat (Plush et al., 2016). Among animals with relatively long gestation lengths, such as sheep, the presence of BAT at birth helps newborns maintain their body temperature (Alexander & Williams, 1968). Labeur et al. (2017) hypothesized that shearing ewes during pregnancy would increase the deposition of BAT in newborn lambs, thereby improving their non-shivering thermogenesis. In their study, infrared thermal imaging showed that lambs born to shorn ewes (D125) maintained their body surface temperature better than those born to unshorn ewes in a cold challenge (a cold room at 4 °C for 1 h), but their rectal temperature was lower. They suggested that pregnancy shearing resulted in lambs relying on enhanced BAT thermogenesis to respond to cold and maintain thermal balance whereas, lambs born to unshorn ewes constricted blood vessels in the skin to reduce heat loss (Labeur et al., 2017).

Pregnancy shearing has been reported to increase the heat production of newborn lambs maintained in housed conditions (Stott & Slee, 1985; Symonds, 1995; Egan et al., 1997). Stott and Slee (1985) and Symonds et al. (1992) reported that late pregnancy shearing (~D130 and exposed to 6°C) enhanced foetal BAT deposition. Symonds et al. (1992) reported that late pregnancy shearing (D120) increased BAT mitochondrial protein level and thermogenin synthesis in lambs, thereby increasing their heat production efficiency and BAT activity. Under housed conditions, however, the effects of shearing are inconsistent, with studies reporting that shearing (D120-140) had a positive effect on BAT only when the nutrient level of ewes was below maintenance (Clarke et al., 1997; Gate et al., 1999).

The effects of shearing on thermoregulation of newborn lambs have not been demonstrated under pasture conditions in New Zealand. Revell et al. (2002) reported that twin lambs born to shorn ewes (D70) had a higher maximum heat production rate or summit metabolic rate (SMR) than lambs born to unshorn ewes. The SMR of single-born lambs, however, was not affected by pregnancy shearing presumably because the single-born lambs born to unshorn sheep had a lower birthweight than those born to shorn ewes. Additionally, studies reported no effect pregnancy shearing on lamb SMR,

rectal temperature or rate of change of heat production stimulated by cold conditions in the first 48 hours after birth (Kenyon & Morris, 2002; Kenyon et al., 2002b, 2002a). Overall, it remains unclear whether shearing during pregnancy can consistently improve lamb thermal regulation.

3.1.7 Effect on lambs' parasite

Shearing ewes during pregnancy may have a positive impact on lamb resistance to parasite challenge. López-Mazz et al. (2020) reported that at 62 days of age lambs born to ewes shorn at D50 showed greater parasite resistance than control group. Lambs born to ewes shorn in pregnancy had a 13.7% lower faecal egg count (FEC) than ewes shorn postpartum. Lambs born to pregnancy shorn ewes also showed lower Famacha index scores which provide an indication of the severity of anaemia and parasite infection. While these results are promising further experiments are needed to confirm this finding.

3.2 Pregnancy shearing effects on ewes

3.2.1 Effect on gestation length

Approximately 70% of foetal growth occurs during the last trimester of pregnancy (Joubert, 1956), therefore a possible mechanisms for the increase in lamb birth weight is an increase in gestation length. Several studies have reported that pregnancy shearing can extend the length of pregnancy by between 0.5 to 2 days (Table 9 and 10). In some studies, this longer gestation period appears to be more pronounced in ewes carrying single than twin lambs (Revell et al., 2002; Cam & Kuran, 2004). López-Mazz et al. (2017), however, reported an increase in gestation length for both single and twin ewes.

The meta-analysis conducted in the current study showed that in general there was a positive linear relationship between the difference in gestation length between shorn and unshorn ewes and Hedge's d (Figure 6). A higher Hedges' d means the pregnancy shearing had a stronger effect, and this was associated with a greater increase in gestation length in ewes.

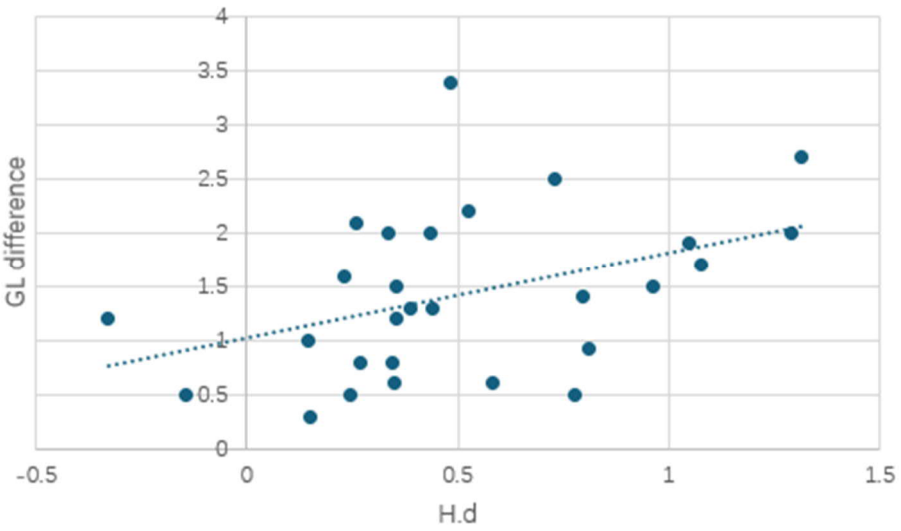

Figure 6. Relationship between Hedges' d and gestation Length (day) difference in sheep

An increase in both gestation length and lamb birth weight in response to pregnancy shearing was reported by Revell et al. (2002), Kenyon et al. (2002c), Cam and Kuran (2004), Corner et al. (2007), López-Mazz et al. (2017) and Vipond et al. (1987). Other studies, however, have reported an increase in birth weight without a change in gestation length (Corner et al., 2006) or an increase in gestation length without an increase in birth weight (Banchero et al., 2010 and Nedkvitne, 1972).

The effect of pregnancy shearing on gestation length appears to be affected by the timing of shearing. Banchero et al. (2010) reported that shearing ewes at d70, but not d120, increased gestation length. A summary of the relationship between the timing of shearing, litter size and the occurrence of an increase in gestation length is shown in Table 10. In general, shearing in mid- or late pregnancy was more effective than in early pregnancy and the increase in gestation length was greater among ewes bearing singles than twins lambs. The variability in the results suggest that changes in gestation length cannot fully explain the effect of pregnancy shearing on lamb birth weight, and is unlikely to be the primary mechanism.

Table 9. Gestation length (days; mean ± SEM) of single and twin bearing ewes that were unshorn or shorn during pregnancy showing day of pregnancy at which they were shorn.

Study	Breed	Treatment day	Single		Twin	
			Unshorn	Shorn	Unshorn	Shorn
Revell et al (2002)	Romney	D70	146.9±0.58	148.4±0.58	146.3±0.58	146.7±0.58
Cam et al (2004)	Krayaka	D30	145.8±0.46[a]	147.8±0.50[b]	146.3±1.33	148.0±0.87
López-Mazz et al (2017)	Polwarth	D50	149.3±0.3[b]	150.7±0.4[a]	149.3±0.3[d]	150.6±0.3[c]
Scaglione-Sanson et al. (2025) *	Corriedale	D70	147.9 (144.2 – 151.6)[*]	148.6 (145.4–151.7)*		
		D100		148.7 (145.4–151.9)*		

* data are presented as the median and 95% confidence interval; Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

Table 10. Gestation length of ewes (days; mean ± SEM) of ewes with mixed pregnancy rank (single and twin) that were unshorn or shorn during pregnancy showing and day of pregnancy at which they were shorn.

Study	Breed	Treatment day	Mixed pregnancy rank	
			Unshorn	Shorn
Cam & Kuran (2004)	Karayaka	D100	147.8±0.5^{b}	145.9±0.4^{a}
Kenyon et al (2002)	Romney	D70	148.7±0.2	149.2±0.2
Kenyon et al (2005)	Romney	D5	147.3±0.2^{ab}	147.6±0.2^{bc}
		D30	147.3±0.2^{ab}	148.1±0.2^{c}
Corner et al. (2006)	Romney	D79	146.6±0.2	147.2±0.2
Corner et al (2007)	Romney	D79	147.5±0.3^{a}	148.7±0.3^{b}
Vipond et al (1987)	Suffolk and Greyface	Exp 1: D84	144.2±0.3^{a}	145.5±0.3^{b}
		Exp 2: D84	146.3±0.6^{c}	148.8±0.6^{d}
Banchero et al (2010)	Corriedale	D70	146.8±0.6^{b}	149.0±0.6^{a}
		D120		147.6±0.5^{ab}
Nedkvitne et al (1972)	Ryjga	1967: D110	147.3±0.6	149.4±0.7
		1968: D110	146.0±0.5	148.0±0.4
		1969: D110	147.6±0.4	148.8±0.4

Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

3.2.2 Wool production of ewes

Wool growth of temperate sheep breeds is slowest in winter and early spring (Sumner et al., 1994; Champion & Robards, 1995; Dick & Sumner, 1997). In extensive pasture-based spring-lambing systems most pregnancy shearing studies were undertaken in this period. Pregnancy shearing studies, therefore, may be limited in detecting any effects on ewe wool characteristics. Hawker and Littlejohn (1989) suggested that an advantage of winter pregnancy shearing was that the finest part of the wool fibre would be at the base of the staple, which can reduce the risk of fibre breakage, optimize the consistency and length of wool fibres, and improve the processing quality of wool. Elvira et al. (2006) reported that pregnancy shorn (~D100) Merino ewes had greater staple strength than unshorn ewes but did not affect mean fibre diameter. Similar results were observed in studies with pregnancy shorn (D84-108) Corriedale (De Barbieri et al., 2018) and (D118) Romney-type ewes (Table 11; (Dabiri et al., 1996; Husain et al., 1997). De Barbieri et al. (2018) also reported that shearing ewes in pregnancy did not alter the coefficient of variation in mean fibre diameter. In Romney-type ewes, however, Morris et al. (2000) reported that pregnancy shearing (D50-100) had no effect on staple strength. In contrast, De Barbieri et al. (2018) reported that pregnancy shearing (~D84-100) of Corriedale ewes increased staple strength, but decreased staple length and yield. It appears only one study has examined brightness and yellowness of ewe fleece (De Barbieri et al., 2018) and found no effect of pregnancy shearing.

Pregnancy shearing has been reported to have no effect on greasy wool production in Romney-type ewes (see Table 11) (Morris & McCutcheon, 1997) (D70-130), (Morris et al., 2000) (D50-100), (Kenyon et al., 2002b) (D70), (Revell et al., 2002) (D70), Dabiri et al. (1996) and Husain et al. (1997) reported that pregnancy shearing (~D110) of Romney-type ewes had no effect on wool growth rate, supporting general lack of an effect on greasy fleece weight. but in Corriedale ewes there was an increase in greasy wool production (De Barbieri et al., 2018). Smeaton et al. (2000), however, reported that pregnancy shearing (D70) increased annual wool production of Finnish Landrace × Romney ewes.

Optimizing wool traits, therefore, requires a shearing strategy tailored to the breed's fleece characteristic, although, the primary aim of pregnancy shearing is to improve lamb survival. In New Zealand if pregnancy shearing is used ewes need to be

shorn twice a year to prevent the wool from turning yellow and to reduce the risk of heat stress and fly strike, which results in increased costs (Kenyon et al., 2003).

Table 11. Effects of pregnancy shearing (shorn vs unshorn) on wool and follicle characteristics of ewes including greasy wool production (GWP;kg; mean ± SEM), staple strength (SS; N/ktex; mean ± SEM), fibre diameter (μm; mean ± SEM) and wool growth rate (mg/cm^2 per day; mean ± SEM).

Reference	Breeds	Treatment	GWP (kg)	SS (N/ktex)	Day trait measured	Fibre diameter (μm)	Interval measured	Wool growth rate (mg/cm^2 per day)
Dabiri et al. (1996)	BLR	Unshorn	-	-	D118	37.9 ± 0.30	D73- D118	0.7 ± 0.03 *
					L13	38.4 ± 0.5	D118 - L13	0.7 ± 0.03 #
					L84	37.9 ± 0.4	L13 - L84	0.8 ± 0.03
		D110			D118	38.1 ± 0.3	D73 - D118	0.7 ± 0.03
			-	-	L13	38.6 ± 0.4	D118 - L13	0.7 ± 0.03
					L84	38.6 ± 0.4	L13 - L84	0.9 ± 0.02
Husain et al. (1997)	Romney	Unshorn	-	-	-	37.6 ± 0.5	-	0.8 ± 0.05
		D110 - SC				37.9 ± 0.4		0.9 ± 0.04
		D110 - CC				38.5 ± 0.4		0.9 ± 0.04
Morris and McCutcheon (1997)	BLR	Unshorn	3.8 ± 0.1	-	-	-	-	-
		D70	3.9 ± 0.1					
		D100	3.9 ± 0.1					
		D130	3.9 ± 0.1					
Morris et al. (2000)	BLR	Unshorn	4.2 ± 0.2	11.1 ± 2.0	-	-	-	-
		D50	3.9 ± 0.1	14.5 ± 1.5				
		D70	3.8 ± 0.1	-				
		D100	4.1 ± 0.1	-				
Kenyon et al. (2002b)	BLR	Unshorn	4.2 ± 0.9	-	-	-	-	-
		D70	4.2 ± 0.9					
Revell et al. (2002)	BLR	Single unshorn	5.5 ± 1.0	-	-	-	-	-
		Single shorn D70	5.5 ± 1.0					
		Twin unshorn	4.6 ± 1.0					
		Twin shorn D70	5.1 ± 1.0					
Smeaton et al. (2000)	FLR	Unshorn-year 1	3.5^b ± 0.1	-	-	-	-	-
		D70 shorn-year 1	3.7^c ± 0.1					
		Unshorn-year 2	3.3^a ± 0.1					
		D70 shorn-year 2	3.9^d ± 0.1					
De Barbieri et al. (2018)	Corriedale	Unshorn	3.5^b ± 0.04	31.9^a ± 1.16	-	28.9 ± 0.26	-	-
		D84-108	3.3^a ± 0.04	35.9^b ± 1.62		29.3 ± 0.25		

*= Growth between D73-118; #= Growth between D118-L13 (L = lactation); BLR = Border Leicester X Romney; FLR = Finnish Landrace × Romney; SC = Standard comb; CC = Cover Comb; GWP = Greasy wool production; SS = Staple strength; Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

3.2.4 Milk production

To date the small number of studies that have examined the impact of mid-pregnancy shearing on ewe milk and colostrum production have reported inconsistent results. Two studies have reported an increase in total milk production after shearing on D53 by 22.2% (Sphor et al. (2011) and D74 by 26% (Guyoti et al., 2015), respectively. Banchero et al. (2010), González-Luna et al. (2023) and Leibovich et al. (2011), however, reported no difference in milk production of ewes unshorn ewes and those shorn at D70 or D120, D100 or D120, respectively. Similarly, Banchero et al. (2010) also reported no effect of shearing at D70 and D120 on colostrum yield, composition or immune components.

The impact of pregnancy shearing on milk composition also differs across studies. Knight et al. (1993) (D110) and González-Luna et al. (2023) (D100) reported that shearing on D110 or D100 increased milk protein percentage by 7.4%. In contrast, although Sphor et al. (2011) reported a significant increase in milk protein (P=0.02) among ewes shorn at D53 and those left unshorn however the difference was small (4.3±0.02 vs.4.4±0.02, respectively). Banchero et al. (2010) reported no difference in milk protein content. Only one study has reported an effect of pregnancy shearing on milk fat and lactose content between ewes shorn at D110 and unshorn ewes. Knight et al. (1993), reported that shearing at D110 slightly increased the milk fat percentage by 0.79%. Conversely they also reported that, pregnancy shearing reduced the lactose content of milk by 0.1-0.2%. All other studies reported no effect of pregnancy shearing on the lactose content of milk (Banchero et al., 2010; Leibovich et al., 2011; Sphor et al., 2011; González-Luna et al., 2023). Milk total solid content has been reported in two studies which both reported no effect of pregnancy shearing at D100 (González-Luna et al. (2023) (Sphor et al., (2011). Overall, the available evidence suggests that pregnancy shearing may increase milk production or alter specific components such as milk protein and fat content, but these effects are generally small and inconsistent across studies.

3.2.5 Feed intake of pregnant ewes

Pregnancy shearing results in an increase in ewe feed requirements to varying degrees based on ambient temperature, wind velocity, and other environmental factors (Frengley, 1964; Elvidge & Coop, 1974). The effect of pregnancy shearing housed ewes is inconsistent with some studies reporting greater feed intakes (Nedkvitne, 1972)

(D92-120), (Maund, 1980a) (~D88), (Morgan & Broadbent, 1980) (~D70-100), (Glanville & Phillips, 1986) (D106), (Salman & Owen, 1986) (D64-106), (Vipond et al., 1987) (D84-112), (Phillips et al., 1988) (~D110). (Keady & Hanrahan, 2009) (D63) whereas other studies report no effect of shearing (Rutter et al., 1972) (D100), (Black & Chestnut, 1990) (D85-120). Vipond et al. (1987) (D84-112) suggested that for housed ewes an increased proportion of barley in their forage would increase palatability and result in greater intake of smaller ewes which may improve the effect of pregnancy shearing on lamb birthweight.

Under New Zealand's pastoral conditions, results of the effect of pregnancy shearing on ewe voluntary food intake are again mixed. The majority of studies have reported no effect of pregnancy shearing on intake (Parker et al., 1991) (D90), (Dabiri, Morris, et al., 1995) (D114), (Husain et al., 1997) (D115), (Kenyon et al., 2002a) (D70), (Revell et al., 2002) (D70). Some studies, however, have reported the feed intake of some pregnant ewes increased, but the results were inconsistent (Parker et al., 1991) (D90), (Dabiri et al., 1996) (D118), (Kenyon et al., 2002b) (D68). Kenyon et al. (2002b) reported that after pregnancy shearing, there was an intermittent increase in the feed intake of shorn ewes. Dabiri et al. (1996) (D118) reported that the increase in feed intake for pregnancy shorn ewes occurred approximately 20 days after shearing. The relationship of ewe intake with lamb birth weight is unclear as some studies have reported an increase in lamb birth weight without an increase in ewe feed intake (Husain et al., 1997; Kenyon et al., 2002a; Revell et al., 2002). Therefore, this suggests that the increase in lamb birth weight due to pregnancy shearing is not driven by an increase in ewe intake. Parker et al. (1991) (D90) reported that the feed intake of pregnancy shorn ewes was not higher than unshorn ewes during pregnancy, but was higher than unshorn ewes during lactation. While an increase in intake may occur, it does not appear to be driving mechanism. Farmers should consider that pregnancy shearing may results in extra feed demand which needs to be planned for.

3.2.6 Shearing affects ewe possible metabolic mechanisms

Shearing often causes physiological changes in ewe metabolism. Symonds et al. (1988) reported that, within the final 7 weeks before lambing, mid-pregnancy shorn ewes (D50) had higher plasma glucose levels than unshorn ewes. Similarly, Nieto et al. (2020) (~D107), Clarke et al. (1997) (~D120), Morris et al. (2000) (D50-100) and Symonds et al. (1986) (~D92) all reported that shearing ewes in either mid or late

pregnancy resulted in increased plasma glucose concentrations within 24 h of shearing which remained elevated for up to 28 days. Revell et al. (2000) suggested that mid-pregnancy shearing (D69) increased the glucose transport capacity of the placenta to improve foetal nutrient supply, and hypothesized that as foetal uptake of glucose across the placenta depends on the maternal-foetal glucose concentration gradient greater transport capacity would likely increase uptake. Increased maternal glucose levels also results in increased foetal glucose levels (Hay Jr et al., 1984).

In late gestation, even when well fed, ewes are usually in a lipolytic state as maternal tissues become more dependent on non-fat fatty acids (NEFA) as the primary source of energy for metabolic processes, thereby sparing glucose for the growing foetus (Petterson et al., 1994). Pregnancy shearing causes only a short-term increase in NEFA (a few hours after shearing), which return to levels seen in unshorn ewes (Symonds et al., 1986) (~D92), Symonds et al. (1988) (~D91). Nieto et al. (2020) (~D107), Murphy et al. (2019) (~D100) and (Symonds et al., 1989) (~D102), however, reported that NEFA concentrations of pregnancy shorn ewes did not differ from unshorn ewes which is in agree with Symonds et al. (1986) (~D92) and (Clarke et al., 1997). Elvidge and Coop (1974) (D106-120) reported that pregnancy shearing increased maternal NEFA within 6 to 8 weeks after shearing. The type of shearing comb used can influence NEFA concentrations with Dabiri, Holmes, et al. (1995) reporting that a standard comb resulted in higher NEFA levels on the day of shearing than a cover comb. They suggested that ewes shorn with the standard comb would need to mobilize more body fat to maintain body temperature, resulting in higher circulating NEFA levels.

β-hydroxybutyrate (BHB) is a ketone body that is formed by the liver during fat mobilization (Bergman, 1971). Plasma concentrations of BHB can be used as an indicator of the ability of the ewe to utilise fat and their energy status (Heitmann et al., 1987). BHB, therefore, is an ideal indicator of whether pregnancy shearing can enhance body fat metabolism. Murphy et al. (2019) (~D100), Symonds et al. (1988) (~D91) and Vipond et al. (1987) (~D120) reported that pregnancy shorn ewes exhibited persistently lower BHB concentrations than unshorn ewes from the time of shearing through to ~1 to 5 weeks prior to lambing. In contrast, González-Luna et al. (2023) (D100), Sherlock et al. (2003) (~D70), Black and Chestnut (1990) (~D106), Symonds et al. (1986) (~D92), Symonds et al. (1992) (~D120) reported no effect of shearing on BHB concentrations. Clarke et al. (1997) reported that although both shorn and unshorn ewes

showed an increase in plasma BHB concentrations around day 140 of gestation, the rise was greater in shorn ewes even though there was no difference in BHB levels of the two groups over the course of the entire pregnancy.

Symonds et al. (1986) reported mid-pregnancy shorn (~D92) ewes had lower insulin concentrations after approximately 40 days after pregnancy shearing than unshorn ewes which they suggested may have been due to shearing triggering a metabolic mechanism to reduce maternal glucose utilization and increase supply to the foetus. Revell et al. (2000) (D69), however, found that shorn ewes, especially those bearing twins, had lower basal insulin levels and a weaker insulin secretion response in late pregnancy compared to unshorn ewes which may have been due to the foetus increasing its glucose uptake capacity through the placenta rather than relying on insulin. In contrast, González-Luna et al. (2023) (D100), Revell et al. (2000) (D69) and Morris et al. (2000) (D50-100) reported no differences in mean plasma insulin concentrations between shorn and unshorn ewes with measurements taken from roughly 40 days after shearing up to the day of lambing.

Thyroid hormones play an important role in the energy metabolism of sheep, particularly in the foetal stage (Fowden & Silver, 1995). These hormones not only directly promote the oxidation of oxygen and glucose, but also improve the overall metabolic efficiency by regulating multiple metabolic links and enzyme activities (Symonds, 1995; McAninch & Bianco, 2014). Deficiencies in these hormones can retard foetal growth, affect lipid metabolism and cause metabolic disorders (Danforth Jr & Burger, 1984; Fowden & Silver, 1995). In both new born lamb and foetal stage, thyroid hormones promote the maturation tissues and organs, including the liver, lungs and brown adipose tissue (BAT) (Symonds & Clarke, 1996). If ewe thyroid hormone secretion is changed by pregnancy shearing, the growth and development of the foetus will be affected. Symonds et al. (1988) (D91), Symonds et al. (1989) (~D90), Revell et al. (2002) (D50 and D70) and Sherlock et al. (2003) (~D70) reported that ewes shorn in pregnancy had increased plasma concentrations of tri-iodothyronine (T3) and thyroxine (T4). Morris et al. (2000) also reported that pregnancy shearing (D50-100) increased ewe T3 levels from the naturally decline during pregnancy back to a persistently higher level with later shearing showing a more pronounced increase. This suggests that sustained up-regulation of T3 may be one of the signals by which shearing promotes foetal growth.

3.2.7 Placental parameters of ewes

The foetus obtains nutrition from its dam via the placenta (Mellor, 1983), which therefore plays a key role in the foetal growth and development. Placental weight and size are important parameters that influence foetal growth and weight gain in late pregnancy (Clarke et al., 1997; Greenwood et al., 2000). Cantou et al. (2024) showed that both mid- (D70) and late-pregnancy shearing (D110) increased placental weight by 20-30%. Similarly, Banchero et al. (2010) reported that the weight of the ewe placenta was increased by 18% at 130 days of pregnancy after mid-pregnancy shearing at D70. In contrast, both Banchero et al. (2010) and Revell et al. (2002) reported no effect on placental weight after shearing at D110 and D70, respectively.

While lamb birth weight is related to placental cotyledon number, it is more closely related to cotyledon weight (Alexander, 1964). Cantou et al. (2024) suggested that mid- (D70) and late-pregnancy shearing (D110) could increase the weight of 2-3cm cotyledon by more than 70%. They reported that mid-pregnancy shearing (D70) increased the number of cotyledons by 55%, while late pregnancy shearing (D110) had no effect. In contrast, De Barbieri et al. (2018) reported that mid pregnancy shearing (D80-108) had no influence on cotyledon weight or size, but reported a 7.5% increase in cotyledon number. Revell et al. (2002) reported that while mid-pregnancy shearing (D70) did not alter the cotyledon weight, the proportion of occupied caruncles was increased in single-bearing ewes by 15%.

Placental efficiency is indicated by the ratio of lamb weight at birth to placental weight and can be used to assess the ability of the placenta to transfer nutrients (Coan et al., 2008; Fowden et al., 2009). Cantou et al. (2024) reported that late pregnancy shearing (D110) improved placental efficiency by 9%. Nieto et al. (2020) reported that late pregnancy shearing (~D110) did not cause changes in placental pregnancy-associated glycoprotein (PAG1) which is associated with birthweight. Across the various placental parameters few studies have been undertaken to allow for firm conclusions to be drawn, however, some studies have shown changes that are associated with increased birth weight. There is potential that changes in placental size and function are involved in increased birthweight from pregnancy shearing.

3.2.8 Ewe behaviour after shearing

Among farmed sheep shearing is a common stressor (Fulkerson & Jamieson, 1982). Shearing stress can induce immediate changes in ewe behaviour, particularly comfort behaviour (e.g. self-oral grooming, head shaking, complete body shaking and standing idle) (Hart & Pryor, 2004; Mousa-Balabel & Salama, 2010). Mousa-Balabel and Salama (2010) reported that mid- (D70-100) to late (D130) pregnancy shearing of ewes increased the frequency of self-oral grooming and complete body shaking but decreased head shaking and standing idle compared to unshorn ewes. Pregnancy shearing has also been reported to change ewe feeding behaviour. Mousa-Balabel and Salama (2010) reported that mid- (D70-100) to late (D130) pregnancy shearing increased the frequency of eating and decreased the frequency of drinking water in housed ewes. There are a few studies to date examining the impacts on shearing on ewe behaviour in the period post shearing, although, published data suggest an increase in comfort and feeding behaviour indicating an adaptation to their new environmental conditions (Hart & Pryor, 2004). Increased feeding can promote foetal development by increasing nutrient intake and thus increase lamb birth weight and survival (Mousa-Balabel & Salama, 2010).

3.3 Factors that affect the effectiveness of pregnancy shearing

3.3.1 Type of comb

Winter shearing is a common practice in New Zealand pasture grazing systems, but can impair the ability of the sheep to maintain body temperature, leading hypothermia and even death (Gregory, 1995). To reduce the risk of winter shearing farmers can use a cover comb which leaves a stubble length of 9mm compared to the traditional standard comb which leaves a stubble length of 4mm (Dabiri, Holmes, et al., 1995). Husain et al. (1997) (D115) reported that lambs born to ewes shorn with a standard comb gave birth to heavier lambs than unshorn ewes, but those shorn with a cover did not differ from those born to unshorn ewes. Morris et al. (2000) (D50-100), however, reported that neither the cover comb nor standard comb increased lamb birth weight. De Barbieri et al. (2012) reported that mid-pregnancy shearing (D85-94) with both R13 comb (10mm stubble) and cover comb increased single lamb birth weight. The type of comb used, however, shows no clear pattern with lamb birth weight. It appears that there is no effect of stubble length on the birthweight response, therefore

farmers should prioritise ewe thermoregulation and use a cover comb to improve the survival rate of pregnant ewes.

Table 12 Effects of different types of shearing combs on lamb birthweight (kg; mean ± SEM).

Reference	Breed	Treatment	Birth weight (kg)	
			Unshorn	Shorn
Corner et al (2006)	Romney	D80 CC single	5.6 ± 0.1	5.9 ± 0.1
		D80 CC twin	4.3 ± 0.1[a]	4.8 ± 0.1[b]
Corner et al (2007)	Romney	D80 CC	4.8 ± 0.1[a]	5.1 ± 0.1[b]
Corner et al (2010)	Romney	D80 CC	4.80 ± 0.10[a]	5.90 ± 0.10[b]
Barbieri et al (2012)	Corriedale	D85 CC hogget	3.70 ± 0.10[a]	4.20 ± 0.20[b]
		D85 CC single	4.60 ± 0.10[a]	5.10 ± 0.20[b]
		D85 CC twin	3.30 ± 0.10	3.30 ± 0.20
		D94 CC single	4.50 ± 0.10[a]	4.90 ± 0.20[b]
		D94 CC twin	3.50 ± 0.10[a]	4.10 ± 0.20[b]
		D85 R13 hogget	3.70 ± 0.10[a]	4.20 ± 0.20[b]
		D85 R13 single	4.60 ± 0.10[a]	4.90 ± 0.20[b]
		D85 R13 twin	3.30 ± 0.10	3.50 ± 0.20
		D94 R13 single	4.50 ± 0.10[a]	4.80 ± 0.20[b]
		D94 R13 twin	3.50 ± 0.10	3.80 ± 0.20
Barbieri et al (2018)	Corriedale	D90 Winter comb	4.05 ± 0.04[a]	4.45 0.04[b]
De Nicolo et al (2008)	Romney	D74 SC	4.25 ± 0.10[a]	4.56 ± 0.10[b]
Husain et al (1997)	-	D115 SC	4.30 ± 0.10[a]	4.9 ± 0.10[b]
		D115 CC	4.30 ± 0.10	4.5 ± 0.10
Jenkinson et al (2009)	-	D90 CC single	4.69 ± 0.11	4.93 ± 0.11
		D90 CC twin	3.56[a] ± 0.13	3.94 ± 0.11[b]
		D90 CC	4.15 ± 0.08[a]	4.41 ± 0.07[b]
Kalhor et al (2023)	Zandi	D80 CC twin	4.20 ± 0.10[a]	4.50 ± 0.10[b]
Kenyon et al (2011)	Suffolk	D72 CC	6.10 ± 0.10	5.90 ± 0.20
	Cheviot	D72 CC	4.60 ± 0.10[a]	5.20 ± 0.10[b]
Morris et al (2000)	Romney-based	D50-100 CC	5.20 ± 0.10	5.20 ± 0.10
		D50-100 SC	5.10 ± 0.10	5.10 ± 0.10
Morris and McCutcheon (1997)	Romney-based	D70-130 SC	5.30 ± 0.10	5.30 ± 0.10
		D70-130 CC	5.30 ± 0.10	5.30 ± 0.10
Kenyon et al (2002)	Romney-based	D70 SC	5.10 ± 0.1[a]	5.40 ± 0.10[b]
Kenyon et al (2006)	Romney	D70 CC	4.29 ± 0.04[a]	4.73 ± 0.04[b]
		D70 CC	4.28 ± 0.04[a]	4.41 ± 0.04[b]
Kenyon et al (2006)	Romney	D79 CC single	4.77 ± 0.09[a]	5.09 ± 0.09[b]
		D119 CC single	4.77 ± 0.09	4.72 ± 0.09
		D79 CC twin	3.51 ± 0.16	3.88 ± 0.13
Lopez-Mazz et al (2018)	Polwarth	D50 CC single	5.00 ± 0.10[a]	5.50 ± 0.10[b]
		D50 CC twin	3.90 ± 0.10[a]	4.20 ± 0.10[b]
Vipond et al (1987)	SBLC	D112 SC	4.06 ± 0.13[a]	4.65 ± 0.13[b]
	CS	D70 SC	3.62 ± 0.14[a]	4.55 ± 0.14[b]

	Greyface	D70 SC	4.71 ± 0.17	5.08 ± 0.17
Banchero et al (2010)	Corriedale	D70 CC single	4.50 ± 0.17	4.90 ± 0.18
		D120 CC single	4.50 ± 0.17	4.70 ± 0.17
		D70 CC twin	3.10[a] ± 0.10	3.90[b] ± 0.10
		D120 CC twin	3.10[a] ± 0.10	3.40[b] ± 0.10
Cantou et al (2024)	Corriedale	D70 R13	4.03 ± 0.11[a]	5.53 ± 0.15[b]
		D110 R13	4.03 ± 0.11[a]	5.41 ± 0.16[b]
Dabiri et al (1995)	Romney-based	D96 SC	4.29 ± 0.07	4.41 ± 0.07
		D96 CC	4.29 ± 0.07	4.35 ± 0.07
De Nicolo et al (2008)	Romney	D74 CC	4.24 ± 0.10	4.56 ± 0.10
Gonzalez-Luna et al (2023)	Manchega	D100 SC	4.62 ± 0.21	4.23 ± 0.21
	Lacaune	D100 SC	3.95 ± 0.22	4.19 ± 0.22
Kenyon et al (2004)	Romney	D70 CC	4.65 ± 0.05[a]	5.12 ± 0.05[b]
Rosales Nieto et al (2020)	Dorset	D107 SC	5.00 ± 0.34[a]	5.40 ± 0.34[b]
Sphor et al (2011)	Polwarth	D53 CC	4.4 ± 0.30[a]	5.8 ± 0.29[b]
Kenyon et al (2002)	Romney	D70 CC- farm 1	4.70 ± 0.03[a]	5.10 ± 0.03[b]
		D70 CC- farm 2	4.9 ± 0.04[a]	5.2 ± 0.04[b]

CC = Cover comb; SC = Standard comb; SBLC = Suffolk x (Border Leicester x Cheviot); CS = Cheviot x Shetland; Different superscript letters (e.g., a, b) within the same row indicate significant differences ($P < 0.05$); Dx= x days of pregnancy

3.3.2 Feeding level of pregnant ewes

The effect of ewe feeding level on the birth weight response to pregnancy shearing is inconsistent both under housed and pasture-based management systems. Under housed conditions pregnancy shearing can increase lamb birth weights compared to those born to unshorn ewes when ewes are provided either a low (Hyatt et al., 2008) (~D70), (Symonds et al., 1992) (~D120), (Clarke et al., 1997) (D120), maintenance (Rutter et al., 1971) (~D100), (Kirk et al., 1984), (Symonds et al., 1986) (~D90), (Keady & Hanrahan, 2009) (D63), (Kalhor et al., 2023) (D80), high (Rutter et al., 1972) (~D50) or even *ad libitum* feeding level (Rutter et al., 1972) (~D50), (Austin & Young, 1977) (Dx), (Maund, 1980a) (~D88), (Glanville & Phillips, 1986) (D42), (Salman & Owen, 1986) (~D42-84), (Vipond et al., 1987) (~D70-112), (Black & Chestnut, 1990) (~D100-120), (Hyatt et al., 2008) (D70). Pregnancy shearing, however, has also been reported to have no effect on lamb birth weight when ewes offered low (Lodge & Heaney, 1975), maintenance (Nedkvitne, 1972) (~D66-90) (Russel et al., 1985) (~D114) or *ad libitum* feeding levels (Kneale & Bastiman, 1977a) (~D70-100) (Leibovich et al., 2011) (D120).

In some mixed housing and pasture studies, the effect of pregnancy shearing on lamb birth weight has generally not been related to either maintenance or *ad libitum* feeding level of ewes. Cam and Kuran (2004) reported that under maintenance feeding levels, pregnancy shearing (D100) only increased the birth weight of single lambs but not twins. Revell et al. (2000) and Banchero et al. (2010) reported that pregnancy shorn twins-bearing ewes (~D70-120) fed *ad libitum* under mixed conditions gave birth to heavier lambs, whereas singles-bearing ewes did not. González-Luna et al. (2023) reported that ewes fed *ad libitum* levels showed no birth weight differences as a result of shearing.

Under traditional New Zealand pasture conditions, some the lamb birth weight response to pregnancy shearing was inconsistent across feeding levels (Morris & McCutcheon, 1997) (D70), (Kenyon et al., 2002b) (D70) (Kenyon et al., 2011) (D72). Kenyon et al. (2011) (D72) reported that when the nutritional level of ewes in the mid- to late pregnancy reached at least the maintenance level, pregnancy shearing increased the birth weight of lambs. If the nutritional level was lower than the maintenance level, it would limit the effect of pregnancy shearing. However, if the nutritional level was increased to more than the maintenance level, it would not bring more benefits to the effect of pregnancy shearing. Morris and McCutcheon (1997) reported that pregnancy

shearing only improved twin lamb birth weight when their dams were in maintenance levels during pregnancy.

These results indicate no clear relationship between the birth weight response to pregnancy shearing and the amount of feed a ewe is offered. Kenyon et al. (2002a) suggested that the effect of pregnancy shearing on lamb birth weight depends on two factors: 1) whether the lamb has the "potential" to respond to pregnancy shearing (i.e. it would have otherwise had a low birth weight) and 2) whether it has the "ability" to respond to pregnancy shearing (i.e. the ewe has adequate feeding levels). Only when both conditions are met can the birth weight response to pregnancy shearing be seen.

3.3.3 Shearing stress as a driver of lamb birth weight

Shearing is known to be one the largest stresses a sheep experiences (Fulkerson & Jamieson, 1982) and is associated with a rise in cortisol (Kilgour & De Langen, 1970; Corner et al., 2006). Cortisol is an indicator of stress and rapidly increases when sheep are exposed to stressors (Arfuso et al., 2022). Increased maternal cortisol may increase the metabolism of the ewe by stimulating gluconeogenesis and increasing glycogen in the liver, which in turn increases circulating glucose concentrations (Antolic et al., 2015). It has been hypothesized therefore, that the physiological response to chronic stress may be the mechanism for the increased lamb birth weight response from pregnancy shearing (Cunningham JG, 2002).

Sham shearing whereby shearing is simulated without the removal of has been used to determine if the stress associated with shearing drives the lamb birth weight response by eliminating the effect of cold stress. Sham-shearing involves the movement of ewes from the paddock to the shearing site and the use of shearing equipment (the shearing machine is turned on, making noise) and movement of the handpiece over the fleece for a similar duration to normal shearing (Corner et al., 2010; Kalhor et al., 2023) which can induce some of the psychological and physiological responses to stress in ewes (Dýrmundsson, 1991; Sanger et al., 2011; Yardimci et al., 2013). It has been hypothesized that sham shearing would influence foetal growth (Corner et al., 2010). Pregnancy sham-shorn ewes gave birth to lighter lambs than pregnancy shorn ewes, but did not differ from those born to unshorn ewes (Corner et al., 2007). Pregnancy crutched ewes have not given birth to heavier lambs than unshorn ewes (Kalhor et al., 2023). Further, Corner et al. (2007) (D80) reported that sham-shearing had no effect on lamb dimensions or gestation length compared to both unshorn and crutched ewes treatments

but, that both components were less than that observed in shorn ewes. While, Corner et al. (2010) reported that the birth weight of lambs born to sham-shorn ewes did not differ to those born to unshorn ewes, but interestingly lamb body dimensions were smaller.

Crutching is another potential stressor which involves the removal wool form around the britch and the udder without removing the entire fleece (McGarry & Butler, 1952). Therefore, the effect of crutching likely lies somewhere between sham-shearing and shearing (McGarry & Butler, 1952; Kalhor et al., 2023) . Kalhor et al. (D80) reported that pregnancy sham-shorn ewes had higher plasma cortisol levels than unshorn ewes, but overall, they were lower than those displayed by crutched and/or shorn ewes. Corner et al. (2007) (D80) and Kalhor et al. (2023) (D80) reported that the peak cortisol concentration of crutched ewes did not differ from shorn sheep, and the change curve over time was similar (Kalhor et al., 2023). Kalhor et al. (2023) (D80) reported that peak cortisol concentrations in crutched ewes were higher than those in unshorn ewes after shearing, which contrasts with the findings of (Corner et al., 2007) (D80).

Combined these studies indicate both sham-shearing or crutching does not induce a birth weight response in lambs born to pregnancy shorn ewes. Therefore, the effect of pregnancy shearing is not driven by the shearing event itself (Corner et al., 2010).

3.4 A suggested management plan to ensure the birthweight response to pregnancy shearing

To ensure that pregnancy shearing will increase lamb birth weight farmers should aim to shear their ewes between days 42 and 100 of gestation and ewes should have a BCS >2.5 otherwise the birth weight response will not occur. In practice, pregnancy dates should be recorded and shearing timed to ensure all ewes, whether bred over 34 or 51 days (2 or 3 breeding cycles), will fall within the optimal shearing window. Pregnancy shearing has a greater effect on increasing the birth weight of lambs that otherwise would be born with low birth weights for example those in multiple litters. Therefore, farmers should identify ewes with multiple foetuses by pregnancy scanning as single bearing-ewes are likely to give birth to heavier lambs.

To protect ewes from cold, wet, and or windy pastoral conditions post shearing a cover or winter comb (~9mm stubble) should be used. The greater fleece stubble length

provides greater insulation without sacrificing the increase in lamb birthweight. Post-shearing shelter should also be provided in a paddock with pasture covers not falling 1300 kg/DM/ha, to ensure their pasture intake is not limited.

Conclusion

The results of the meta-analysis conducted in this thesis showed that pregnancy shearing promotes birth but not weaning weight. Across the studies included in the analysis, pregnancy shearing increased lamb birth weight by 0.5 standard deviations, but had high heterogeneity ($I^2 = 77.5\%$). The timing of shearing was an important factor in the analysis with shearing being most effective when conducted between 42 and 100 days of pregnancy, whereas shearing after day 100 of pregnancy was ineffective. The factor of "timing of shearing" alone explained 65% of the variance within studies and significantly improved the model fit. In contrast, the overall effect on weaning weight was non-significant. Therefore, pregnancy shearing cannot be used as an effective tool to increase lamb weaning weight.

Overall, the qualitative review indicated that pregnancy shearing has a number of other potential advantages including; faster lamb-ewe bonding and suckling, and lambs returning to their dam more quickly in cold conditions. Some studies reported that pregnancy shearing under either housed or pasture conditions resulted in higher perinatal lamb survival rates. Pregnancy shearing has little effect on wool traits of either lambs or ewes. Housed studies also reported increased lamb heat production, enhanced foetal or/and newborn BAT deposition, and increased mitochondrial protein after pregnancy shearing. However, under New Zealand grazing conditions, pregnancy shearing had no effect on rectal temperature and SMR of lambs. Pregnancy shearing has the potential to result in increases in ewe milk yield, higher milk protein and fat percentages. In addition, shearing during pregnancy may improve parasite resistance in lambs, but this finding still needs more research to be verified.

Shearing during pregnancy is often accompanied by an lengthening of gestation length of about 0.5 to 2 days, which is generally positively correlated with the effect size of pregnancy shearing. Some studies, however, have reported lamb birth weight gains without an increase in gestation length and others an extension in gestation

length without an increase in birth weight. This suggests gestation length is not main mechanism driving the birth weight response to pregnancy shearing, but in some studies at least may have contributed to the response.

Pregnancy shearing, in some studies, increased T3 and T4 levels and maternal plasma glucose. This may an enhanced placental glucose transport capacity, however, there are inconsistent results on the effects on maternal insulin and BHB. There are also inconsistent reports on the effect of pregnancy shearing on the placenta development and size. It can be speculated that changes in placental size and function are one of the potential factors involved in the lamb birth weight effect, although the mechanism has not been identified.

To optimise the effects of pregnancy shearing on lamb birth weight it is recommended to shear ewes between days 42 and 100 of gestation and avoid shearing in bad weather. Cover/winter combs should be used to reduce the negative effects of cold weather. Only ewes in good body condition (BCS > 2.5) should be shorn. Dams that are expected to deliver lamb with birth weights in the optimal range of 4 to 6.5kg should remain unshorn, saving labour and resources. After lambing, the focus should be on ewe and lamb nutrition and reducing lamb stress. Weaning weight relies much more on nutrition and management than on pregnancy shearing.

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