Investigation of lameness and claw disorders in New Zealand dairy goats: a multidisciplinary approach

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Abstract

New Zealand dairy goat farmers have problems preventing and treating lameness caused by claw disorders within their herds. There is scarce information about lameness and claw disorders in commercial dairy goat herds nationally and internationally. The two aims of this thesis were: to acquire information on the level of clinical lameness and the types and level of claw disorders present on three dairy goat farms in New Zealand and to explore the epidemiological, productivity, and genetic aspects of lameness and claw disorders. Information on lameness and claw disorders was collected on herds 4 or 5 times between July 2019 and June 2020. Additional information collected were age, stage of lactation, milk production, pedigree, kidding date, and lactation type. The prevalence of clinical lameness and claw disorders fluctuated across the production year at levels that differed on each farm. Farm A had the highest average of clinical lameness (23%), followed by farms B and C (12 and 10%, respectively). For the investigation of claw disorders, the main claw disorders studied were horn separation, granulomas, and rot. Farm C had the highest prevalence of horn separation (83%), while farm A had the highest prevalence of rot and granulomas (19 and 14%). Rot and granulomas increased the odds of clinical lameness (OR= 2.10-7.02). Compared to goats walking normally, severe lameness had the highest milk production losses of 7.10% and 8.56% in extended and seasonal lactation goats, respectively. The average income losses ranged from NZD 26 to 104 per goat. The heritability (h^2) estimates for lameness occurrence and susceptibility were 0.07 and 0.13, respectively, and the h^2 estimates of claw disorder susceptibilities ranged from 0.02 to 0.23.

This thesis identified that clinical lameness caused by claw disorders is a problem on dairy goat farms in New Zealand and reported the negative impact of severe lameness on milk production. Additionally, breeding for resistance or tolerance of clinical lameness and claw disorder may be possible. Further large-scale studies are needed to understand the risk factors of clinical lameness and claw disorders. Small-scale studies are required to investigate effective treatments to manage claw disorders in dairy goats.

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Chapter 1

General introduction

New Zealand dairy goats produced 2% of the total milk produced in New Zealand in 2017 (Prosser and Stafford, 2017). Most New Zealand dairy goat farms are situated in the Waikato region and are shareholders in the Dairy Goat Co-operative (DGC) (Scholtens et al. 2017). Under the DGC management, the New Zealand dairy goat industry became the first commercial producer of dairy goat infant formula and has continued to dominate this niche market internationally (Prosser and Stafford, 2017).

The only study in New Zealand investigated lameness in a small cohort of goats in their first two years of life (Deeming et al. 2021). Only two measurements were taken after parturition and reported a small percentage of lame goats within the group. It is unknown what causes lameness in dairy goat herds and whether claw disorders are the predominant reason for causing lameness. The factors increasing the risk of lameness in dairy goat herds and how this may affect the goat's production are also undetermined. Lameness should be targeted to make the industry more efficient, sustainable, and productive by improving goat welfare.

Lameness in dairy cattle and sheep has been extensively researched compared to dairy goats, with its economic importance being quantified. In dairy cows, lameness is one of the costliest issues farmers face today (Dolecheck and Bewley, 2018). Over thirty years ago, lameness was estimated to cost New Zealand farmers, on average, NZD 94 per cow (Tranter and Morris, 1991). More recently, a USA study estimated that digital dermatitis and white line disease (claw disorders associated with lameness) cost farmers USD 64 (NZD 94.00) and USD 152 (NZD 234.89), respectively (Dolecheck et al. 2019). In sheep, footrot is the second most costly health problem after gastrointestinal parasites. In New Zealand, footrot costs the sheep industry an estimated NZD 9 million annually (Nieuwhof and Bishop, 2005). Despite economic losses not being quantified yet in dairy goats, lameness is a welfare issue associated with reduced fertility, production, and longevity (Eze, 2002; Christodoulopoulos, 2009). A dairy goat that is lame would have low milk production, reduced fertility and a higher risk of being culled early (Solis-Ramirez et al. 2011). More research is needed in the dairy goat industry to determine the extent of the lameness in herds, its subsequent effects, and solutions to reduce lameness in this industry.

Causal factors of lameness and claw disorders need to be identified to implement evidence-based prevention and control measures on the farm. Lameness has a complex, multifactorial aetiology. Literature across dairy cows and sheep research studies has identified causal variables that can be split into three categories: management, environment, and genetics (Solano, 2015; Heringstad et al. 2018). To further complicate identifying factors of lameness, factors within each category can interact, predisposing one factor to another. Management factors include nutrition and flooring. Environmental factors include the presence of bacteria and climate. Changes in both variables to reduce lameness in a herd could be short-term solutions. Management and environmental causal variables reported in dairy cows and sheep studies may be significantly different to variables involved in dairy goat lameness because they are managed differently (Groenevelt, 2017), goats are farmed indoors and use a cut-and-carry method (Brakenrig, 2017; Scholtens et al. 2017). Lameness in New Zealand has not been extensively researched. The Dairy Goat Co-operative (NZ) Ltd have identified lameness as the primary welfare problem and potentially the highest production impairment in their industry (McLean, personal communication). Research in New Zealand needs to focus initially on the extent of lameness farms and identify strategies for dairy goat farmers to implement to reduce the burden of lameness.

The overall objective of this thesis was to investigate the lameness status of dairy goat farms in New Zealand. The research describes the prevalence and incidence rate of lameness and claw disorders, evaluates the association of lameness and claw disorders with dairy goat production, and estimates the milk income losses attributed to lameness in dairy goat farms in New Zealand. This thesis provides a better understanding of the extent of the lameness problem in dairy goat herds. Following this, the genetic parameters were investigated to determine if breeding can be a tool to reduce lameness in herds. The specific objectives were the following:

1. Summarise the scientific literature on lameness and claw disorders in dairy goats.
2. Identify the types of claw disorders and identify their strength of association with lameness.

3. Estimate the prevalence, incidence rate and duration of lameness and claw disorders in dairy goats on selected New Zealand commercial farms.
4. Identify potential risk factors associated with lameness and claw disorders.
5. Estimate the association between lameness and claw disorders.
6. Estimate production and income losses associated with lameness.
7. Determine the heritability of lameness and claw disorders.

Chapter 2

Literature review

2.2 Introduction

This chapter will review lameness on commercial, intensively managed dairy goat farms, specifically adult dairy goats. The narrative literature review investigates the causes of lameness and the risk factors associated with lameness, emphasising lameness caused by claw disorders. The reviewed literature was limited to infectious and non-infectious factors that may be relevant to New Zealand dairy goats. This review will also include a brief outline of the current research on how lameness can be measured and managed in dairy goats. Lastly, breeding is reviewed to determine if it can be used to reduce lameness and claw disorders in dairy goats.

There is limited research on lameness and claw disorders in dairy goats. Information from other meat or dual-purpose goats, sheep and dairy cattle will be drawn upon when little or no information is available on dairy goats. Extrapolation of this information to commercial dairy goats has to be taken with caution as dairy goats differ from dairy cows and sheep by a) being of another species and b) being managed differently.

2.3 Factors that cause lameness in dairy goats

Lameness can be defined as the impairment of normal locomotion due to pain caused by an injury, disease, or claw disorder (Vieira et al. 2015). It is caused by infectious diseases and non-infectious factors (Figure 2.1; Mathews, 2016). Infectious claw diseases are due to pathogenic bacteria or viruses that colonise on or within their host animal and cause injury to that animal when the conditions are favourable. Non-infectious factors like farm management, environment, or genetics may predispose the goat to lameness. Figures 2.1 and 2.2 indicate the interactions between infectious and non-infectious risk factors to demonstrate how lameness can be a multi-factorial disease.

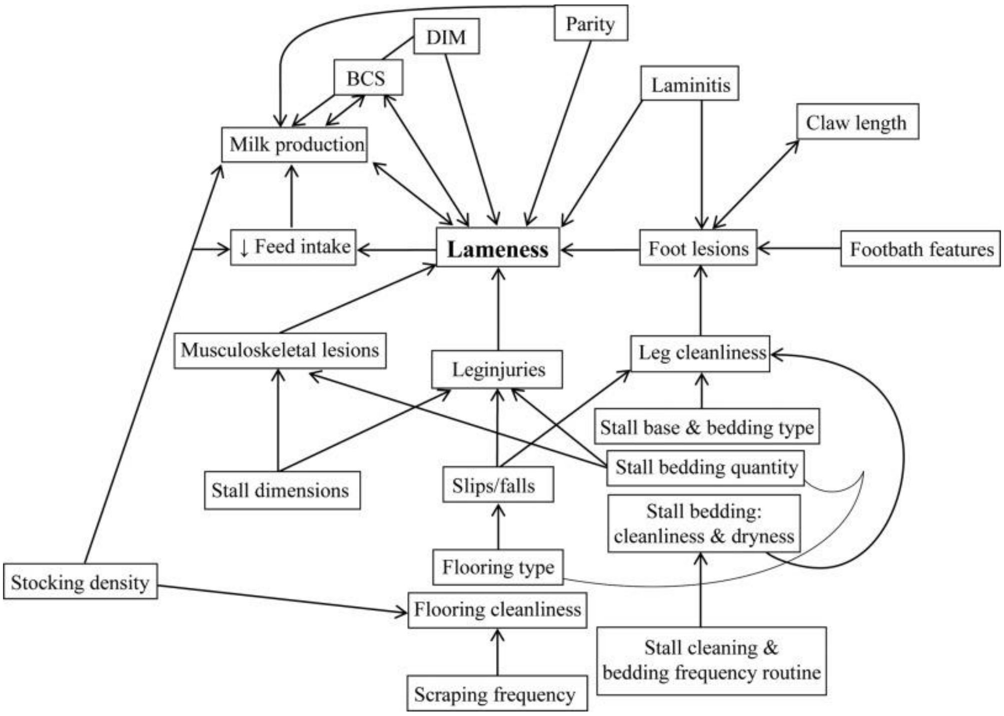

Figure 2.1. Causal diagram of lameness in dairy cattle. Source: Solano et al. (2015). BCS: body condition score and DIM: days in milk.

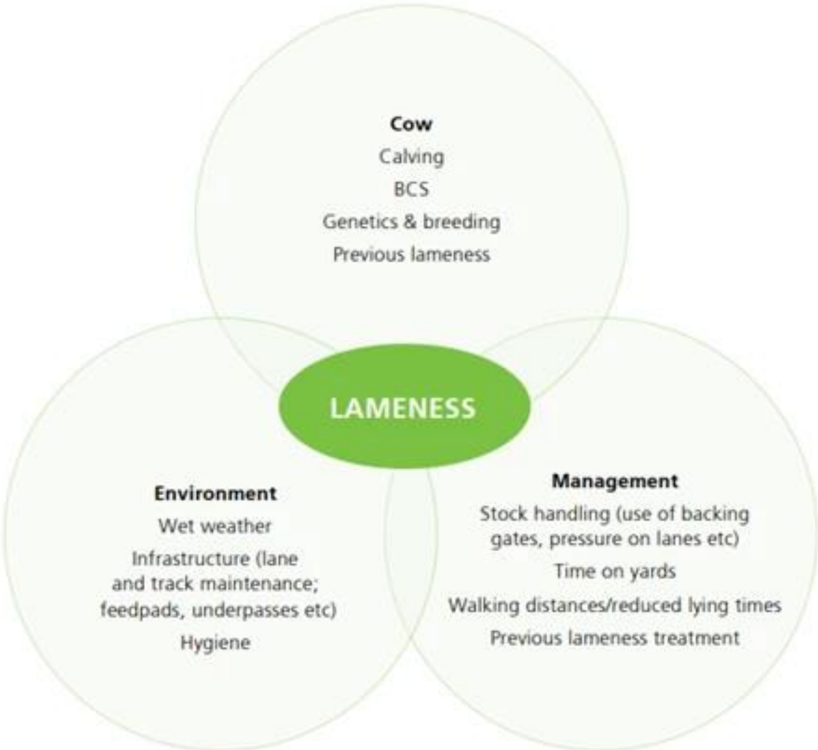

Figure 2.2. Lameness risk factors in dairy cattle. Source: DairyNZ (2022). BCS: body condition score.

2.3.1 *Infectious diseases of the claw*

Worldwide the common bacterial infectious diseases of dairy goats are foot scald (interdigital dermatitis), footrot, and contagious caprine digital dermatitis (Hill et al. 1997; Groenevelt et al. 2015a; Sullivan et al. 2015). The bacteria that cause these diseases favour warm, moist areas that lack oxygen. Viral infectious diseases are bluetongue and foot-and-mouth disease. As these viral infections are not present in New Zealand, they will not be further discussed.

2.3.1.1 *Interdigital dermatitis (foot scald)*

Interdigital dermatitis is an inflammation and redness of the skin between the claws. It is caused by the bacteria *Fusobacterium necrophorum*. It is a gram-negative anaerobic bacteria in the animal's digestive tract and is excreted in their faeces (Nagaraja et al. 2005; Witcomb et al. 2014). Despite this bacterium not being known to be contagious, it has been known to interact with other bacteria. Synergic interaction between the bacterium *Dichelobacter nodosus* and *F.necrophorum,* which increases the severity of the footrot, has been hypothesised (Witcomb et al. 2014). Another bacteria that *F.necrophorum* has been known to interact with is the bacteria from the *Actinomyces* genus, resulting in foot abscesses (Mathew, 2016).

2.3.1.2 *Footrot*

Footrot develops due to the bacteria, *Dichelobacter nodosus*, infecting and multiplying within the claw horn. It is a gram-negative, anaerobic bacteria that is contagious. It has been reported to survive up to 3 years on the claw, 14 days on soil, faeces and pasture, and 6 weeks on hoof clippings (Mulvaney, 2013). It is usually a secondary infection, where the bacteria enters the claw via damage to the skin or horn. Damage to the skin could be from an injury or interdigital dermatitis (Mathews, 2016). Upon entry into the claw, *D.nodosus* degrades the connective tissue (collagen) between the horn and hoof flesh. Subclinical infection can occur within the skin for months, while the clinical symptoms are underrunning of the horn, lesions in the claw and sole, inflammation of the interdigital skin area, pus and a foul odour (Stewart, 1989; Mulvaney, 2013). It usually affects both claws of one foot and sometimes the other claws of the goat.

Many studies have been conducted on sheep, however, studies on goats suggest that footrot is different in goats and that their reaction is different (Bennet et al. 2009; Ghimire et al. 2002; Hill et al. 1997). Ghimire et al. (2002) suggested footrot was less invasive in goats than sheep despite also causing under-running lesions. The theory of footrot being a different disease in goats was also suggested by Christodoulopoulos (2009), who described that goat footrot was more similar to pig footrot than sheep. Additionally, it has been reported that infection by the footrot bacteria does not mean that lameness is a consequence (Knappe-Poindecker et al. 2015). In these cases, it could have been that footrot was within its subclinical phase or that goats could have developed a tolerance or resistance to the infection, which suggests a genetic component involved.

2.3.1.3 Contagious caprine digital dermatitis

Digital dermatitis is the initial development of a lesion at the coronary band-hoof wall junction of the claw. The bacterium from the *Treponema* genus causes it (Groenevelt et al. 2015a). These are gram-negative bacteria that are present in the surrounding environment. A hypothesis is that digital dermatitis evolves from a primary lesion into a secondary infection. This infection has been discovered to infect dairy goats and is referred to as contagious caprine digital dermatitis (Groenevelt et al. 2015a, 2015b; Sullivan et al. 2015). This disease resembles bovine digital dermatitis in cattle and contagious ovine digital dermatitis in sheep.

Contagious caprine digital dermatitis shares similarities with footrot and contagious ovine digital dermatitis, however, there are differences. The symptoms of infection by *Treponema spp* are similar to footrot, except there is no underrunning of the claw horn or infection of the interdigital space. Farmers are likely overdiagnosing footrot cases as digital dermatitis is unknown to most goat farmers (Groenevelt et al. 2013). Groenevelt et al. (2015b) published the results of *Treponema ssp* being present in five herds tested in the UK. Two of the five herds had lame goats that were a part of the previous study and had previously tested negative for *Dichelobacter spp*, but were now positive (94.7%) for *Treponema ssp*. On these farms, the lame goats had lesions similar to footrot however also had lesions where the clinical diagnostics were unclear.

Groenevelt et al. (2017) confirmed that this digital dermatitis in goats was clinically different from previous reports in cows or sheep. In goats, the lesions started on the sole of the claw rather than the coronary band, which has been demonstrated in sheep and cattle studies (Wassink et al. 2003b; Moore, 2005; Solano et al. 2017). The strains of *Treponema ssp*, isolated from lesions on goats, has also been different from that reported on sheep and cattle. It has also been hypothesised that there could be some interaction between *Dichelobacter spp* and *Treponema ssp* through the presence of both species of bacteria being found in the same locations on the hoof (Groenevelt et al. 2015a, 2015b).

2.3.2 Non-infectious claw disorders

Non-infectious claw disorders can develop because of the climate, the animal's genetics, nutrition, environment, management, or a combination of the factors. In some cases, non-infectious diseases can predispose the claw to infectious diseases (secondary infection). A few studies indicated the most common non-infectious claw disorders that cause lameness in dairy goats were overgrown hoof, white line disease, granulomas, laminitis, claw deformation, and foreign body penetration of the sole (Hill et al. 1997; Christodoulopoulos, 2009; Groenevelt et al. 2017). Additionally, not all non-infectious claw disorders cause lameness.

2.3.2.1 Overgrown hoof

Overgrown claws cause unequal weight distribution across the foot, with the joints, the ligaments and the tendons in the area experiencing unusual forces and stresses (Mathews, 2016). An abnormal gait develops in response to the goat's pain as it walks. Overgrown claws result from the hoof horn not being naturally worn by the animal walking on rough surfaces. Dairy goats on commercial farms are usually managed indoors with soft bedding in the barns, such as straw or sawdust (Zobel et al. 2018). In contrast to sheep and dairy cows out in the pasture and walking on harder and rougher surfaces, dairy goats' claws would be worn down to a lesser extent.

2.3.2.2 White line disease

White line disease is the disruption or damage to the normal formation of the white line area (separation and abscesses). Many factors, including laminitis and mechanical stresses, can disrupt the white line area. Foreign objects that penetrate the white line also damage it. Anything that contributes to the increased corium inflammation or disrupts blood flow to the claw can reduce the claw horn quality, which results in a weakened, widened or haemorrhaged white line area. A weakened or widened white line increases the risk of white line separation and the infiltration of pathogens into the claw's exposed underlying tissue area, causing infections (Shearer et al. 2015).

2.3.2.3 Laminitis (coriosis)

Coriosis (also referred to as laminitis) is the term for inflammation of all the corium (Blowey and Weaver, 2011). Laminitis develops from reducing or losing blood supply to the laminae corium due to its inflammation. The aetiology of coriosis and laminitis is still unclear. They have been associated with hoof trauma, nutrition, physiological changes, genetic predisposition or a combination of these factors (Blowey and Weaver, 2011).

Laminitis can be acute or subacute. Goats affected by acute laminitis have tender feet and are reluctant to walk. Therefore, they will spend most of their time on their knees. The coronary band is cold, while the rest of the foot is warm. Sub-acute laminitis animals reportedly have minor gait abnormalities (Mathews, 2016). Currently, there is limited research on dairy goats regarding the association between laminitis and nutrition, physiological factors, or genetics.

In dairy cattle, nutrition and physiological changes play a role in developing laminitis. Rumen acidosis, subacute rumen acidosis, and hindgut acidosis have been hypothesised to induce laminitis, though the mechanisms surrounding this have not yet been elucidated. It is thought that endotoxins released from the gastrointestinal tract into the bloodstream cause inflammation of the corium. Physiological changes cause the release of hormones, such as histamine, associated with causing corium inflammation. Metritis (uterus infection) is associated with laminitis due to the release of endotoxins from the uterus and into the bloodstream, causing corona inflammation. For a more in-depth review of laminitis causes and symptoms in dairy cows, Blowey and Weaver, (2011) and Lean et al. (2013) are recommended.

2.3.2.4 *Other non-infectious disorders causing lameness*

Other non-infectious disorders of the hoof include granulomas (also known colloquially in New Zealand as "cherries"), heel horn erosions, sole haemorrhaging, foreign penetration of the sole, abscesses, and ulcers. Granulomas are a collection of immune cells in areas of tissue inflammation. These are sole lesions caused by trauma such as severe hoof trimming, previous footrot, or footbathing (Reeves et al. 2019).

Foot abscesses are caused by foreign objects damaging the hoof wall or horn. Access to underlying hoof tissue allows common bacteria from the environment, such as *Actinomyces* species, to infect and colonise the area. Abscesses are painful, causing inflammation in the affected area with the development and build-up of pus. The development of infection will continue until it is uncovered from hoof trimming or pus bursting out of the coronary band. Alternatively, the infection can develop into granulomas or sole ulcers (Winter, 2011; Mathew, 2016).

2.3.2.5 *Claw conformation*

Claw conformation is dependent on the environment, genetics and nutrition. The hoof horn is the first line of defence from foreign objects or pathogens (Stokka et al. 1996). Claw deformation is discomforting to animals because it causes irregular weight distribution across the hooves and, consequently, an irregular gait (Ajuda et al. 2019; Deeming et al. 2019). An irregular gait increases stress on unfamiliar musculoskeletal areas causing inflammation and impaired function and, in some cases, irreversible damage (i.e. shortening of ligaments) (Mathews, 2016). Poor claw conformation could predispose the animal to other non-infectious and infectious diseases of the claw, increasing the risk of lameness (Kaler et al. 2010a).

2.4 Factors associated with lameness and claw disorders

There is a lack of information on risk factors associated with claw disorders and subsequent lameness in dairy goats. In dairy goats, animal, management, and environment have been reported to be associated with claw disorders, with claw disorders also predisposing one disorder to another (Table 2.1). Literature from dairy cows and sheep was referenced in cases where there was no information for goats.

At the animal level in meat goats, age and breed were significantly associated with lameness (Browning Jr. et al. 2011). Where 2-year-olds had significantly lower levels of lameness than goats older than 3-years-old, and Boer had significantly higher rates of lameness than Kiko and Spanish goats (Browning Jr. et al. 2011). Due to the study being conducted on meat goats housed outside, it is hard to determine if these trends are also apparent in dairy goats predominately housed indoors in New Zealand. Quintanilla et al. (2006) suggested genetic factors involved with claw horn growth rate, while genetics was hypothesised not to be associated with horn separation (Hill et al. 1997). In meat goats, it has been reported that lameness occurrence was significantly different between breeds (Browning Jr. 2011). Breed could be considered a risk factor for lameness in dairy goats and should be investigated further.

At the animal level in dairy cows, hormonal changes, milk production, and body condition score have been associated with lameness (Tarlton et al. 2002; Randall et al. 2015; Barkema et al. 1994). They do appear to be related to each other and centred around calving. Calving is related to physiological and physical changes in the body. Tarlton et al. (2002) indicated that elevated levels of oestrogen and relaxin could be related to claw disorders through changes in the strength and integrity of the hoof's connective tissues. This disruption to the structure and integrity would alter the load distribution within the claw, which could lead to claw disorders (Tarlton et al. 2002). Calving is also related to the drastic reduction in body condition and the high demands of milk production through the negative energy balance at the beginning of calving (Collard et al. 2000; Huxley et al. 2013). Literature on the body condition and milk production will be discussed further in section 2.5.

Management factors such as hoof trimming, nutrition, flooring type and milking parlour terrain could be indicative of a goat's risk to claw disorders and lameness. Hill et al. (1997) reported that hoof trimming reduced the risk of lameness events within herds. However, incorrect trimming could result in claw trauma followed by the development of granulomas or abscesses. Groenevelt et al. (2015b) studied lameness and claw disorders within two herds and also took rumen samples from two groups of goats. The rumen samples indicated that 40 % of goats sampled from two herds within their study had *ad libitum* concentrate, and had rumen acidosis, which has been linked with poor horn quality. This study indicated that nutrition could be a factor, however, a more controlled study is needed to elucidate further the relationship between acidosis and claw disorders in dairy goats. Groenevelt et al. (2015b) indicated that the two participating farms in their study had two different types of entry and exits to the milking parlour and with different terrain. One farm, with the lower prevalence of lameness (37.1%), had flat surfaces around the farm with little time standing on concrete. The other farm with the higher prevalence of lameness (69.6%) had steep ramps entering and exiting the milking parlour. A large study involving many farms needs to be conducted to determine whether these management types are risk factors for claw disorders and clinical lameness developing in dairy goats.

Environmental factors such as temperature and rainfall have been reported to affect hoof growth, which could affect the prevalence of claw disorders such as overgrown horn separation in goats. Increasing rainfall has been associated with longer claw horns (Smith et al. 2014) and increased claw disorders (Hill et al. 1997). In New Zealand, the temperature and rainfall vary depending on the time of year and the location, therefore, it would be interesting to understand how New Zealand's climate may be associated with claw disorders in goats within commercial goat herds.

Table 2.1. The different factors associated with increased (+) or decreased (-) probabilities of claw disorders and lameness events in goats and, in some cases, other livestock.

Factors	Claw disorders	Lameness	Reference
Hoof trimming	-/+	-/+	Hill et al. (1997) Groenevelt et al. (2015b)
Season	+	+	Christodoulopoulos (2009); Eve (2002)
Hind feet	+		Christodoulopoulos (2009)
Bacterial[1]	+	+	Hill et al. (1997); Groenevelt et al. (2015a, 2015b); Christodoulopoulos (2009); Sullivan et al. (2015)
Poor hygiene	+		Groenevelt et al. (2015a)
Nutrition	+	+	Groenevelt et al. (2018)
Flooring type and terrain	+	+	Groenevelt et al. (2015b)
Age		+	Browning Jr. et al. (2011)
Breed		+	Browning Jr. et al. (2011)
Hormonal changes[2]	+		Tarlton et al. (2002)
Body condition score[2]	+		Randall et al. (2015)
High production level[3]	+		Barkema et al. (1994); Green et al. 2014; Gelasakis et al. (2016)

[1]Bacteria include *Treponema spp*, *D.nodosus*, and *F.necrophorum,* which cause contagious caprine digital dermatitis, footrot, and interdigital dermatitis, respectively.

[2]These factors were associated with claw disorders and lameness in dairy cow studies, which could be the same for dairy goats.

[3]This risk factor has been associated with claw disorders or lameness in dairy sheep and cows.

2.5 Prevalence of lameness and claw disorders in dairy goat herds

Several European studies have quantified the prevalence of lameness in dairy goats (Table 2.2). Twenty-five years ago, they reported that the prevalence of lameness was estimated to be between 2.7 and 23.4%, depending on the farm (Hill et al. 1997). More recent prevalence studies have seen an increase in lameness on UK dairy goat farms, with some farms having 67% of their herd being lame (Anzunio et al. 2010; Groenevelt et al. 2015b). In France, within one herd of 108 dairy goats, 12.5% were reported to be lame (Mazurek et al. 2007). A Greek study reported that 39% of one herd containing 170 dairy goats were lame. Of the herd, 39% were recorded as lame, where 15% of the lame goats had a foot lesion, while 24% were lame without a lesion (Christodoulopoulos, 2009). The fluctuation of lameness prevalence over the year was reported in meat goats and dairy cow studies. Fluctuation could be due to changes in seasonality and lactation stage (Eze, 2002; Solano et al. 2015). Body condition score also fluctuates over the milking season, which has been associated with lameness in dairy cows (Randell et al. 2015). Prevalence of lameness fluctuating over the year could correspond to seasonality, stage of lactation or parity being risk factors of lameness.

Claw disorders reported in dairy goats have been similar to those reported in dairy cow studies (Table 2.3). Claw disorders reported consisted of claw overgrowth, footrot, foot scald, digital dermatitis, heel erosion, white line disease, laminitis, granulomatous lesions, slippering, foreign bodies, sole abscesses, and horn separation (Hill et al. 1997; Christodoulopoulos, 2009; Anzuino et al. 2010; Groenevelt et al. 2017; Groenevelt et al. 2015a). Hill et al. (1997) saw that horn separation, sole abscess, and footrot were significantly associated with the incidence of lameness. Therefore, it is suggested that the focus be shifted to these disorders as they are more likely to be causing animal discomfort and reduced production performance. It could be hypothesised that these disorders would result in more significant economic losses incurred by farmers (Amory et al. 2008).

In New Zealand, the prevalence of lameness in dairy goat herds has not been established. The most recent research in New Zealand studied a small sub-group of dairy goats (61-78) from one commercial dairy goat farm for the first two years of their life (Deeming et al. 2021). During this period, the tri-annual prevalence of lameness fluctuated between 0 and 8.9% across six scoring events. A couple of limitations within this study are that it follows one age group of goats on the farm, and it is a small group that may not represent the entire group of one-year-olds as it was unclear what the herd size was on the farm.

There is little information on claw disorders in New Zealand dairy goat herds. Two papers have reported footrot in New Zealand goats (Bennet et al. 2009; Laven, 2012). Bennet et al. (2009) established that from 24 goats with clinical signs of footrot (underrunning rot), *F.necrophorum* and *Dichelobacter spp* could be detected within the same location. *Dichelobacter spp* was more likely to be found by itself rather than *F.necrophorum*. A limitation of this study was that it was unclear whether the samples taken from the goats were from the same herd and whether the goats that had footrot were lame (Bennet et al. 2009). Another limitation acknowledged by the author was that the bacteria found depended on the sampling procedure used. Laven (2012) successfully treated dairy goats diagnosed with footrot using parenteral and topical spray oxytetracycline. Digital dermatitis has not been studied in New Zealand dairy goats, though it has been reported in New Zealand dairy cattle (Yang et al. 2016). Due to the lack of biosecurity practices within New Zealand (in general, due to the low prevalence or absence of some diseases in the country), it would not be surprising if digital dermatitis was present within dairy goat farms. Swabs taken from dairy goat claw lesions could confirm this. Both New Zealand studies did not indicate the prevalence and incidence level of footrot or other types of claw disorders, which could be present in New Zealand goat farms.

Table 2.2. Lameness prevalence studies have been conducted worldwide on commercial dairy goat farms.

Country	Locomotion scoring system	Locomotion scoring system developer	Prevalence (%)[1]	No. of herds	Herd or animal level[2]	Reference
UK	4	Hill et al. (1997)	2.7-23.4	4	Herd	Hill et al. (1997)
UK	4	Anzunio et al. 2010	19.2[3]	24	Herd	Anzunio et al. (2010)
UK	4	Anzunio et al. 2010	31-67	3	Animal	Groenevelt et al. (2015a)
UK	4	Anzunio et al. 2010	12-45	2	Estimated animal	Groenevelt et al. (2015a)
UK	4	Anzunio et al. 2010	37	1	Animal	Groenevelt et al. (2015b)
UK	4	Anzunio et al. 2010	67	1	Animal	Groenevelt et al. (2015b)
UK	2	Phythian et al. 2013	24.4	1	Animal	Crosby-Durrani et al. (2016)[4]
UK	2	Phythian et al. 2013	65	1	Animal	Sullivan et al. (2015)[4]
Greece	Unknown	Unknown	39	1	Animal	Christodoulopoulos, (2009)
France	4	Mazurek et al. 2007	12.5	1	Animal	Mazurek et al. (2007)
Norway	4	Flower & Weary, 2006	1.7[3]	30	Herd	Muri et al. (2013)
USA	2	Hempstead et al. 2021	1.2[3]	30	Herd	Hempstead et al. (2021)
NZ	5	Deeming et al. 2018	0-8.9[5]	1	Animal	Deeming et al. (2021)

[1]Prevalence of lameness is defined as the number of lame goats out of the total goats assessed.

[2]Herd, a random sample that was taken to estimate the herd; Animal, each animal was scored individually; Estimated animal, each animal was observed in a group and then scored.

[3]This value is the average prevalence of lameness across the visited farms.

[4]These two studies used the same herd, except the data collection was 12 months apart.

[5]A group of 61-78 goats followed for their first two years of life.

Table 2.3. Claw disorder prevalence studies conducted worldwide in dairy goat farms.

Claw disorder	Prevalence (%)	No. of goats observed	Herd size	No. of farms	No. of events per farm[4]	Reference
Overgrown claws	91.2	307	350-450	4	1	Hill et al. (1997)
Horn separation	29.6					
Slippering	10.1					
Footrot	3.60					
Foreign body	1.60					
White line	13.0					
Sole abscess	4.20					
Granuloma	1.00					
Claw disorders	15.0	170	170	1	52[5]	Christodoulopoulos (2009)
Begien footrot	10.0	10[a]				
CCDD[1]- treponema	70.0	10[a]				
CCDD- treponema	100	10[a]	1,000	1	1	Sullivan et al. (2015)
CCDD- treponema	83.1	59	80-1,200	5	1	Groenevelt et al. (2015a)
Footrot	33.9					
CCDD- treponema	100	21[2]	856	1	2[6]	Crosby-Durrani et al. (2016)

Table 2.3 continued

Claw disorder	Prevalence (%)	No. of goats observed	Herd size	No. of farms	No. of events per farm[4]	Reference
Overgrown claws	79.8	1520		24	1	Anzuino et al. (2010)
Overgrown claws (mild to extreme)	58.0	120	100-1,155	10	1	Kooring (2016)
Overgrown claws (mild to extreme)	66.4	597	50-236	30	1	Muri et al. (2013)
Overgrown claws	55.5	894	18-912	30	1	Battini et al. (2016)
Claw deformation	58.0	38	1400	1	1	Ajuda et al. (2019)
Overgrown claws	5.10	484	Unknown	71	1	Eze (2002)
Foreign bodies	1.20					
Sole wear	1.20					
Overgrown claws	51.4	4520	36-6,500	30	1	Hempstead et al. (2021)
Slippering	2.20	569[3]	20-260	28	2[7]	Sailer et al. (2021)
Horn separation	85.8, 87.3	260, 309				
Sole haemorrhage	49.8, 53.5	260, 309				

[1]CCDD = Contagious caprine digital dermatitis

[2]Biopsy was taken from foot claw disorders and was positive for *Treponema spp.*

[3]The combined number of goats in Autumn and Spring.

[4] The number of data collection events the farms had across an experimental period.

[5] Roughly 52 weeks, the information provided stated weekly visits from December 2006 until November 2007.

[6] Six months between visits.

[7] Visited twice between September 2018 and July 2019, once in Spring and once in Autumn.

2.6 Impact of lameness and claw disorders on dairy goat performance

Lameness and claw disorders are associated with decreased performance in dairy goats. Lower milk production, reduced fertility, and reduced longevity have been associated with lame goats (Eze, 2002; Christodoulopoulos, 2009; Solis-Ramirez et al. 2011). Christodoulopoulos (2009) reported a significant difference between the milk production of lame and non-lame goats. It was estimated that lame goats had, on average, a 16 kg decrease in their milk yield in contrast to non-lame goats when they were compared at 220 days in milk. Lame goats with foot lesions had significantly lower annual milk production than lame goats with no foot lesions and non-lame goats. There was no significant difference in annual milk yield between lame goats with no foot lesions and non-lame goats. A hypothesis could be dairy goats with a high milk yield are associated with an increased risk of lameness and claw disorders, as this phenomenon has been seen in dairy cows and dairy sheep (Barkema et al. 1994; Gelasakis et al. 2010). In dairy sheep, it was reported that there was a significant reduction in milk yield when lameness was present, with an association between high-yielding sheep and the increased risk of lameness also being reported in the same study (Gelasakis et al. 2010). High-yielding sheep had a reportedly greater milk loss than the control group of sheep. This association has yet to be studied in dairy goats.

Reduced fertility was associated with lameness. The kidding interval was longer, and the number of kids per goat declined due to lameness (Eze, 2002). It is hypothesised that body condition was the cause because lame animals had a lower body weight due to a possibly lower DMI. Additionally, as natural mating was the usual method to conceive, the lame goat may not have been able to tolerate the buck's weight during mating (Eze, 2002). In sheep, other lameness-associated factors were pregnancy toxaemia and neonatal diseases (Clarkson and Winter, 2012). In dairy cows, longer calving intervals, increased return rate after the first insemination and increased days to the first service were signs of infertility and were associated with lame cows (Barkema et al. 1994; Pryce et al. 1998). The association between fertility and lameness has not been studied in dairy goats.

One study that looked at an overview of the dairy goat industry in New Zealand reported that 6% of culling is attributed to lameness (Solis-Ramirez et al. 2011) though this percentage is likely to be underestimated. Solis-Ramirez et al. (2011) reported that the principal reason for culling is low production and fertility problems, however, some of these goats could also have been lame. For example, for some goats with low milk production and lameness, the farmer may have recorded the goat as being culled for low production rather than lameness because lame and high-producing goats are more likely to remain in the herd. This scenario has been reported in dairy cattle (Barkema et al. 1994).

In dairy cows, lame cows have also been associated with a lower body condition score and other health problems (Green et al. 2014). The relationship between body condition score and lameness works in two ways. The first case is when the animal becomes lame, and over some time, the cow will lose its body condition as its DMI decreases. The second case is the animal becomes lame because it has a lower body condition score (Green et al. 2014; Randall et al. 2016). Therefore, diagnosing the cause of lameness in these cases becomes more difficult. As there has not been a large-scale study on lameness in dairy goats, there may be other unknown consequences of claw disorders and lameness.

2.7 How is lameness measured

Lameness is an animal behaviour used in reaction to pain located in one or more hooves or limbs. The severity of lameness can be measured to indicate the location and the intensity of pain the animal may be experiencing. Signs that indicate that a goat is lame include: a stiff gait, non-weight bearing on the affected hoof or limb, the reluctance to move, and walking on their knees. If a goat walks on its knees for an extended period, the tendons and joint capsule will contracture (permanent shorten; Mathews, 2016). A consequence of lameness is a decrease in the animal's activity, which will continue to decrease as the severity of the lameness increases (O'Callagan et al. 2003).

Lameness can be measured using subjective and objective methods. Locomotion scoring using scorers is the most common method of scoring lame and non-lame goats. Other more technological and objective methods of studying lameness include utilising equipment such as accelerometer sensors and pressure sensing mats (Barwick et al. 2018; Rifken et al. 2019). These technologies measure activity or downward pressure on the hoof when they walk. Each method has its advantages and disadvantages. This section will briefly discuss farmers' and researchers' options to measure dairy goat lameness.

2.7.1 Subjective measurements

Locomotion scoring is a scoring system that categorises the severity of the lameness based on the severity of the animal's abnormal gait and stance when standing still. It uses different behavioural characteristics corresponding to a certain point on a scoring scale.

Locomotion scoring is an affordable way to measure an animal's gait. Anyone can be trained to use a locomotion scoring system. Several scoring systems have been developed to record lameness. They range from the 2- to the 9- point locomotion scale (Fabian et al. 2014). The only point systems developed in goats are the 2-, 3-, 4- and 5-point systems (Table 2.4). However, a disadvantage to locomotion scoring is that it is a subjective technique, and as the scoring system increases in complexity, it reduces the reliability and repeatability between scores (Laven, personal communication).

Another disadvantage to locomotion scoring of lameness is the difficulty of observing the goats while they are walking in a familiar environment in standardised conditions. The observation needs to be done in a natural environment on a hard surface, which can be difficult if many goats need to be measured. Firstly, goats usually are kept on soft bedding such as straw or saw shavings. Soft bedding can distort the reviewer's score and underestimate the number of lame goats and, if lame, its severity (Hill et al. 1997; Deeming et al. 2018). Secondly, the goats need to walk freely without disruptions for other goats or people. The ideal place for locomotion scoring on NZ commercial farms would be after milking when the animals return from the milking parlour and walk on a hard surface such as concrete. Scoring would need to be after milking because udder size would be less likely to alter the gait (Deeming et al. 2018).

Table 2.4 Various locomotion point scoring strategies that have been used to measure lameness in dairy goats (adapted from Deeming et al. 2018).

2 pt score [1]	3 pt score [2]	4 pt score [3]	5 pt score [4]	Locomotion definition	Gait description [4]
0	1	0	1	Normal/not lame	Moving forward with even strides where hooves track up. Weight-bearing, and having an absent head nodding.
			2	Uneven gait	Moving forward with shorter strides where hooves do not track up. Weight-bearing, and having an absent head nodding, however, have joints that may show stiffness
1	2	1	3	Mildly lame	Moving forward with shorter strides where hooves do not track up. One or more legs/feet may be affected. Weight-bearing, and having an absent head-nodding, however, may show a mild limp
		2	4	Moderately lame	Reluctant to move forward and may display a moderate limp. One or more legs could be affected and may display some goose-stepping.
	3	3	5	Severely lame	Walking on the knees. Refusal to bear any weight on one foot. Severe limping or extreme goose-stepping.

[1]Phythian et al. (2013).

[2]Hill et al. (1997).

[3]Anzunio et al. (2010); Muri et al. (2013); Groenevelt et al. (2015a).

[4]Deeming et al. (2018).

2.7.2 Objective measurements

Precision farming technology will be increasingly critical for the future evaluation of efficient livestock farming (Brochers, 2015). This type of technology provides real-time feedback on the behaviour of animals that are under observation. The increasing advancement of technology allows measuring once subjective observations objectively. Regarding measuring lameness objectively, accelerometers have been used to measure the activity of animals such as sheep and goats (Zobel et al. 2015; Moreau et al. 2009; Barwick et al. 2018). A disadvantage to this technology is that the information received from the device varies when positioned differently on the animal, i.e. the neck *vs.* the ear. Another type of technology that has been researched is pressure-sensing mats (Rifkin et al. 2019; Reppert et al. 2020). This technology has been used to measure the stride length, gait, and downward force of goats walking normally. It used the information generated from the mat to determine no significant differences between the paired limbs of goats walking normally. With more validation, this technology has the potential to be used to assess the gait characteristics of lame goats.

A lot of time and animals are needed to develop algorithms that can accurately measure animal activity that can be applied to a general population (Moreau et al. 2009). Many animals would be needed to calibrate this, along with the device being in different positions (top/bottom/side of the neck, ear or leg) to make robust algorithms that can be used in a commercial setting. Other disadvantages are the difficulty of obtaining a device with a long battery life and large memory space while remaining physically small enough to be unintrusive to the animal's movement. Battery life and storage space vary depending on how the device is used, with device expense also another factor that needs to be considered when measuring activity on many animals, especially in a commercial setting. On commercial dairy goat farms, with many goats present, lameness monitoring needs to be affordable and easy to implement by the farmer for its regular use within the herd.

2.7.3 Objective versus subjective measurements

To date, no one has evaluated objective versus subjective measures in dairy goats under commercial environments, one study has investigated the visual scoring of lameness and pressure mats under controlled conditions (Reppert et al. 2020). Lameness was induced in nine goats and their locomotion was evaluated by a trained veterinarian using a visual scoring system developed by Deeming et al. (2018) and by a pressure mat. Lameness could be detected by observation and the pressure mat analysis though the two methods were unable to be compared due to the small sample size of goats used in the analysis. Due to the lack of validation of objective measures of goat's locomotion on commercial farms, the subjective measure of scoring locomotion was used in our study.

2.8 Economic losses cause by lameness

Farmers incur economic losses from animals that have lameness. The cost of lameness consists of direct and indirect expenditures. The cost of lameness and claw disorders have not been quantified in dairy goats, however, estimates have been established in dairy cattle and sheep.

In dairy cattle, the annual cost of lameness per year that the industry incurs varies from country to country and depends on the cause of lameness. Ózsvári (2017) reported that the annual cost for the United Kingdom (UK) increased from £15.5 million in 1978 to £90 million in 1999. As this cost was nearly 20 years ago, this figure has most likely increased as the prevalence of lameness in dairy cow herds has also increased. For example, the average prevalence of lameness in dairy cow herds in the UK, across multiple studies before the year 2000, was 20%. After 2000, the average lameness prevalence across studies had increased to 35% (Afonso et al. 2020). Meanwhile, within the EU-15, the annual cost of lameness was € >1 billion in 2002. While on a per-cow basis, it has been estimated lameness costs farmers between $US 1.70 to $US 415, depending on the case and the country (Chawala, 2011; Huxley, 2013).

The most expensive claw disorders in dairy cows have been estimated to be sole ulcers and footrot. Sole ulcers cost farmers $US 216 per cow, while footrot costs $US 120 per cow (Cha et al. 2010). Division of the costs indicated that milk production losses were the main proportion of costs (40%). Treatment and fertility reductions had the second and third highest (34 and 26%, respectively) expenditures due to claw disorders. The result differed depending on the claw disorder (Cha et al. 2010). Cows with sole ulcers or white line disease had significantly lower milk yields than non-lame dairy cows, however, dairy cows diagnosed with digital dermatitis indicated no significant difference in their milk yield before and after treatment compared with non-lame dairy cows (Amory et al. 2008). Therefore, treatment and prevention would make up most of the cost associated with digital dermatitis.

In the sheep industry, total losses that have been incurred from lameness due to footrot have been estimated to be £25 million per year in the UK and NZD 9 million per year in New Zealand, with about NZD 18-19 million per year spent on footrot preventative measures (Nieuwhof and Bishop, 2005; Zhou, 2001). The cost of footrot has been further broken down to a 10% prevalence level with no control or treatment, which can result in £14.16 loss per ewe. Treating the flock with footbaths only increases the losses to £14.46 per ewe, while treating ewes with antibiotics and vaccinations resulted in losses of £5.74 per ewe when footrot prevalence is at 10%. If the prevalence of footrot is at 3%, the costs are even less, with it only costing the farmer £3.98 per ewe (Lovatt, 2015). These costs accounted for extra labour, culled costs, selling prices, and vaccination and medicine costs. As footrot attributes to 90% of lameness cases in sheep (O'Kane et al. 2017), it is assumed that the cost of other lameness cases is not as high and, therefore, has not been estimated.

The economic losses for dairy cow farms have been divided into direct or indirect costs associated with the animal (Figure 2.3). Direct costs are prevention costs, such as footbath installation, hoof trimming and treatment costs (veterinary or medicine supplied), labour to treat the animal, and impact of early culling. Indirect costs have been decreased fertility, loss of milk production, extra labour associated with increased milking periods, increased amount of milk disposed, feed waste, decreased herd longevity, reoccurrence of future lameness depending on time and severity of the first lesion, increased probability of obtaining other health problems, such as mastitis, and increased replacement herd costs (Huxley, 2013; Randall et al. 2016; Ózsvári, 2017). All these losses mean that farmers are economically worse off when there is a high prevalence of lameness in the herd. In addition, market prices would also affect the impact of the cost of lameness within the herd to the farmer (Cha et al. 2010).

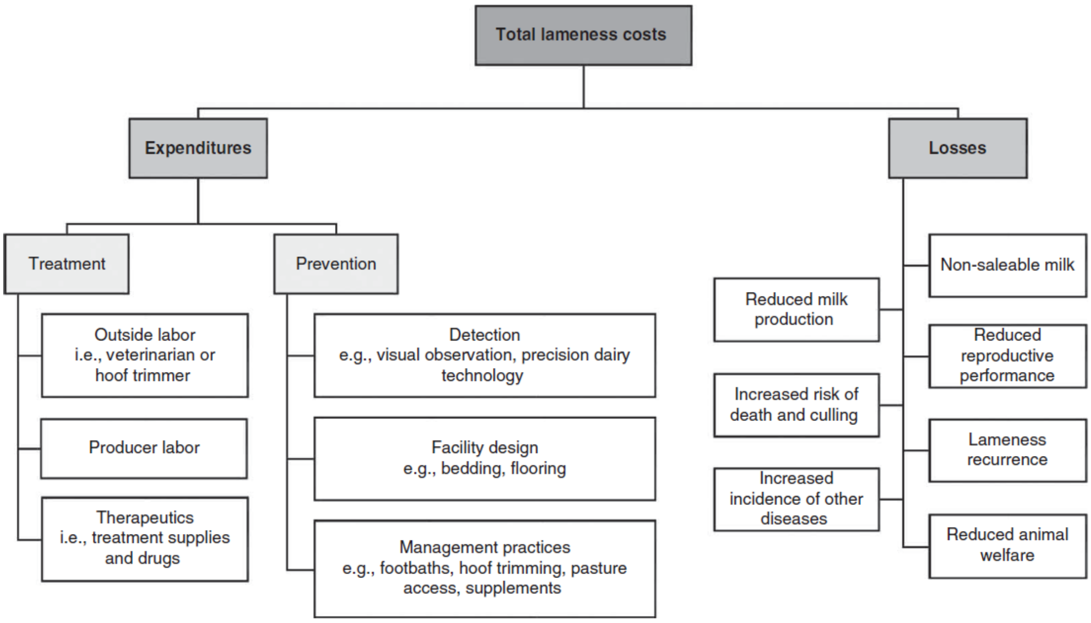

Figure 2.3. The division of expenditures and losses in dairy cows caused by lameness. Source: Dolecheck and Bewley (2018).

In dairy goats, it is expected that the division of costs towards lameness may be a combination of those factors seen in sheep and dairy cows (housed indoors). Therefore, the cost of lameness at the farm level will depend on the type of claw disorder, lameness prevalence, control, treatment and prevention strategy in the herd.

2.9 Dairy goat milk production

The milk characteristics of dairy goats have been researched in New Zealand. A recent study reported average daily milk characteristics of 3.40 kg milk, 114.4 g fat, and 106.5 g protein yield, with an average somatic cell score of 9.1 (Scholtens et al. 2019). Lactose yield has not been researched extensively in dairy goats. Only two international studies have reported results on lactose yield in goats where the average production over 270 days was 17.7 kg or 66.6 g per day, and another reported 122 g lactose/day (Brito et al. 2011; Morris et al. 2011). Differences within the yields could be due to the lactose percentage where the lactose percentage in Morris et al. (2011) was 4.82%, while Brito et al. (2011) reported 4.23%. This could be due to the herd in New Zealand (Morris et al. 2011) being of a higher genetic merit than the herd from Brazil (Brito et al. 2011), as it appeared that the environment and nutrition were similar. Despite the difference in the average daily yields and percentages, Morris et al. (2011) figures fit within the lactose yield and percentage range reported by Brito et al. (2011), which was between 3.37 and 184.7 g per day, and 0.67 and 5.02%, respectively.

2.10 Milk production losses and lameness

The effect of lameness on milk production has not been investigated in dairy goats. Research has been focusing on dairy cows and sheep. In dairy cows, many studies have investigated milk production and lameness, however, it is hard to compare studies because of the different methodologies that each study uses. For example, there are different definitions of lameness, number of lameness cases and milk yield observations taken, and statistical analyses performed within each study. Also, the different causes of lameness included, and therefore, the duration of lameness would have a different effect on milk production. For example, the causes of lameness would differ between farming systems (indoor and outdoor). These considerations should be taken into account when comparing studies.

In dairy cattle, the cows' daily milk yield loss was between 0.82 – 11.1% (Enting et al. 1997; Kocak and Ekiz, 2006; Bicalho et al. 2008). Depending on the cause of lameness, the milk yield reduction was between 2.38-9.92% over a lactation (305 days; Hernandez et al. 2002). In dairy cows, reduced milk yields were apparent for up to four months before and five months after diagnosis (Warnick et al. 2001; Green et al. 2002). Another study on dairy cows reported that lame cows had a reduced test-day milk yield until up to eight months after diagnosis (Archer et al. 2010). In contrast, there are reports that lame cows had higher production than healthy cows before the onset of lameness (Green et al. 2002; Hernandez et al. 2002). This would imply that high production predisposed cows to lameness.

Only one study has investigated the impact of lameness on milk production in dairy sheep (Gelasakis et al. 2015). Lameness affected milk production, depending on the time of diagnosis during a lameness episode. Milk production was recorded two weeks before, during the week, and one week after diagnosis resulted in a 10.8, 32.5 and 35.8% reduction in milk for lame sheep. This study also suggested that high-producing sheep were more likely to become lame than average or low-producing sheep.

Due to dairy goats being managed differently from dairy sheep and cows, it is unclear what impact lameness will have on milk production or whether high-producing dairy goats have a higher risk of developing lameness.

2.11 Claw disorders treatment and prevention

Hoof trimming and foot baths are used in cattle and sheep farming to prevent claw disorders and, subsequently, lameness. Routine hoof trimming was thought to be necessary for mitigating claw disorders and lameness events within a herd (Winter, 2004; Mathews, 2016). In the UK, sheep farmers used routine hoof trimming to reduce overgrown claws in their herds. The theory of this routine claw trimming in sheep and dairy cows has now been discouraged.

Routine claw trimming of sheep in the UK is targeted as a factor that could be counter-active in reducing lameness. It was initially thought that overgrown claws would result in the collection of debris under the overgrown horn (encouraging footrot growth) and impede the sheep's locomotion or increase the chances of hoof horn tearing, exposing the underlying sensitive laminae (King, 2013). Hoof trimming was associated with high incidences of lameness in sheep (Wassink et al. 2003a). The reasoning is that hoof trimming could spread diseases, for example, footrot, or it could delay healing due to physical damage to the horn (Kaler et al. 2010b; Smith et al. 2014; Sullivan et al. 2014). In sheep, it is now recommended that routine hoof trimming is stopped and only used when it is needed (Kaler et al. 2010b). This philosophy is also being encouraged on sheep farms in New Zealand (Kaler et al. 2010b; Mulvaney, 2013).

For the treatment of footrot, healing was faster when hoof trimming was not used on sheep (Kaler et al. 2010b; Lovatt, 2015). Kaler et al. (2010b) reported that after 10 days, 91% of the lame animals recovered after being treated with parenteral and topical antibiotics, in contrast to 60% of the recovered lame animals treated with corrective hoof trimming and topical antibiotic spray. To date, a couple of studies have successfully treated goats using this method (Laven, 2012; Bitrus et al. 2017). Therefore, refraining from routine hoof trimming in treating footrot may be beneficial. However, both of these studies were completed under non-experimental conditions. The results could not conclude that treatment with hoof trimming was a worse treatment than not trimming.

Additionally, it was unknown whether these goats were managed indoors (no natural wear of the hoof horn) or outdoors (natural wear of the hoof horn).

The decision not to hoof trim may not be applicable in the commercial dairy goat industry. Hill et al. (1997) reported a significant inverse relationship between the frequency of trimming and lameness. There could be a couple of reasons for this difference in results compared with Kaler et al. (2010b). Firstly, Hill et al. 1997 reported that footrot only made up 3.6% of lame goats, which is different in sheep, where footrot makes up 90% of lameness cases (O'Kane, 2017). Therefore, no trimming may only apply to treat footrot cases in goats. Alternatively, commercial dairy goats are usually kept indoors on soft bedding all year round and only tend to walk on dirt tracks and stand on concrete flooring of the milking waiting area a parlour two-three times a day. The amount of time the goats spend standing on concrete would vary depending on the farmer's milking system. This means that wear on the hoof horn would be less than livestock kept outdoors all year round. In previous sheep studies, which indicated the negative impact of hoof trimming, the flocks were kept mostly outside in paddocks. This management system allows the sheep's hooves to wear down naturally. Therefore, hoof trimming may not be necessary for most sheep kept outdoors though it is for dairy goats kept on soft bedding where their hooves cannot be worn down naturally.

Footbaths or mats have been suggested to be implemented on farms. Footbath containing zinc or copper sulphate has been used to treat claw diseases such as footrot, foot scald, digital dermatitis and heel erosion (Winter, 2009; Chesterton et al. 1989). Depending on what the farmer wants to treat, sometimes the footbaths are useless and have adverse effects. Footbaths need to be regularly cleaned to maintain efficiency and are prone to contamination by urine and faeces and, in some cases, diluted by rainfall. Therefore, instead of being useful, it becomes a breeding ground for bacteria (Winter, 2011). Then the constantly wet hooves may encourage infections such as foot scald and footrot (Smith et al. 2014).

As Bishop and Stear (2003) explained, the prevention of pathogenic infectious diseases using a combination of control strategies will decrease the infection's incidence rate and reduce the risk of rapid pathogen evolution. Providing many different barriers to the disease would be significant in controlling it (Bishop and Morris, 2007). When it is cost-effective, the combination of management and perhaps breeding would be ideal to be implemented at a herd level.

In New Zealand, there are no protocols or training that hoof trimmers and farmers can attend. Everything that is learnt is from veterinaries or through word of mouth. Anecdotally, one goat hoof trimmer in New Zealand reported that they treated claw disorders, such as overgrown claws, white line disease, granulomas and footrot with corrective trimming, topical oxytetracycline spray (Aerotet Forte, Virbac New Zealand), copper sulphate or cauterisation when necessary. Corrective trimming consists of cutting away overgrown hooves and dead tissue and exposing infected and footrot-infected areas to air to kill off any anaerobic bacteria (Hunt, personal communication).

2.12 Prevention of lameness and claw disorders incidence using breeding

Breeding has become another alternative to increasing livestock resistance to health problems, including foot diseases. No heritability (h^2) estimates for claw disorders or lameness have been established for goats though they have been estimated for sheep and cattle, which will be discussed in further detail. Claw disorders and lameness in both species had low to medium heritability (Raadsma et al. 1994; Nieuwhof et al. 2008; Heringstad et al. 2018). Therefore, any genetic improvement of claw health within a herd needs to be undertaken with the goal of long-term improvement. Genomic selection would be beneficial in these situations because it has higher accuracy in predicting breeding values than the traditional progeny testing method when a trait has a low heritability and polygenic background (Mucha et al. 2015).

Using genomic selection to estimate breeding values of animals can be established when the animals are young. This method will shorten the generation interval in response to selection. There are concerns that breeding for disease resistance selection may reduce the production performance of the animal, for example, selecting for less lameness may reduce milk production performance (i.e. health has a negative genotypic correlation with milk production traits in dairy cows (Pritchard et al. 2013). The statement could be true, however, the overall goal would be to increase the animal's longevity. The aim would be to at least maintain or increase the lifetime milk production of the disease-resistant or disease-tolerant animal and to increase the animal's welfare in the process.

2.12.1 Estimation of heritabilities of lameness and claw disorders incidences

Determining the heritability of claw disorders and lameness in dairy goats will indicate whether selective breeding can be used as a long-term strategy within herds. Heritability follows this equation:

$$h^2 = \frac{\sigma_G^2}{\sigma_P^2}$$

Where heritability is the proportion of phenotypic (σ_P^2) variance explained by genetic (σ_G^2) variance within a given population (Lush, 1943; Dempster and Lerner, 1950). The higher the heritability, the higher the accuracy of the estimated breeding values, as phenotypes are better indicators for estimating the true breeding values. The more genetic variation within the population, the higher the chances of a trait being manipulated at the population level. Phenotypic variance is the sum of the genetic and environmental variances within the population. Genetic variance can be divided into genetic variance obtained from the sire and dam and into additive, dominant, and epistatic genetic variance. Dominance and epistatic genetic variance are difficult to measure and will not be further discussed in this review (Dempster and Lerner, 1949). Environmental variance can be divided into temporary and permanent environment variance (when repeated measurements are taken) and common environment variance (when animals are within similar environmental interactions).

Genetic and environmental variances can be obtained using linear models and liability-threshold models. Threshold models are better to use in instances where the trait of interest has a low heritability and is either of binary or categorical nature, though with a potentially underlying continuous phenotype (Dempster and Lerner, 1949). It is the probability of a phenotype expressed depending on one or more environmental or genetic conditions. However, depending on the information available and the trait used, there may not be much difference between the results of the two models (Varona et al. 1999). As linear models are simple and more widely used to estimate genetic parameters, this model may be a better alternative to use in an analysis (Varona et al. 1999; Raadsma et al. 1994).

2.12.2 Genetic studies in dairy cattle

Heringstad et al. (2018) extensively reviewed the genetics of claw health in dairy cattle. It was reported that claw disorders (singular or grouped) have low to moderate (0.01-0.39) heritability depending on whether a threshold or linear model is used. Interdigital hyperplasia had the highest heritability, while wall ulcers and double soles had the lowest heritabilities. Grouping the claw disorders as one claw health trait or grouping the claw disorders based on aetiology resulted in higher estimates for heritabilities. Grouping phenotypes increased the number of observations per group resulting in better reliability. Infectious claw disorders or having any claw disorder appeared to have the highest heritabilities (0.11-0.13). Claw disorders grouped by location (front or rear leg) had the lowest heritability (0.015-0.079). Heritabilities for lameness and locomotion scoring, indicator traits of claw health, were also low (0.02-0.15). Lameness, treated as a categorical trait (1-5 score), had higher h^2 estimates compared with lameness used as a binary (presence/absence) trait (0.08-015 *vs.* 0.02-0.04, respectively). When comparing different models used to estimate heritability, threshold models tended to estimate higher heritabilities than linear models.

2.12.3 Genetic studies in sheep

A few studies have investigated the heritability of claw disorders and lameness in sheep. Depending on the model used (linear or threshold, sire or animal) and the trait definition (binary or count), claw disorders and lameness were reported to be heritable in sheep (Table 2.5). Studies investigating footrot in lambs (8-9 months old) reported heritabilities between 0.03-0.41 when a presence/absence recording system was used (Nieuwhof et al. 2008; Skerman et al. 1988; Raadsma et al. 1994). Again, threshold models tended to have higher h^2 estimates than linear models.

The other two genetic studies looked at white line degradation and lameness. Conington et al. (2010) studied white line degradation or "shelly hoof" and reported heritabilities between 0.09-0.33. The presence/absence of shelly hoof had higher h^2 estimates than the number of feet affected (0.15-0.33 *vs.* 0.09-0.29, respectively).

Table 2.5. Heritbility estimates (and standard errors) from sheep studies on lameness and claw disorders were classified as various traits using either linear (LM) or threshold (TM) models.

Trait	Breed	Age	Heritability (SE)	Model	Reference
Footrot (binary)	Blackface	Ewes	0.04-0.08 (0.01-0.02)	LM	Nieuwhof et al. (2008)
	Blackface	Ewes	0.09-0.26 (0.04-0.14)	TM	
	Mules	Ewes	0.11 (0.06)	LM	
	Mules	Ewes	0.12-0.26 (0.06-0.15)	TM	
	Merino	Lambs	0.07-0.31 (0.02-0.08)	LM	Raadsma et al. (1994)
			0.10-0.41 (0.02-0.07)	TM	
	Romney	Lambs	0.14-0.17 (0.03)	TM and LM	Skerman et al. (1988)
Foot Infection			0.28 (unknown)	TM	Skerman et al. (1988)
Shelly hoof	Texel	Lambs	0.09-0.33 (0.08-0.07)	TM	Connington et al. (2010)
	Texel	Ewes	0.10-0.29 (0.04-0.08)	TM	
	Blackface	Lambs	0.11-0.15 (0.04-0.07)	TM	
	Blackface	Ewes	0.29-0.32 (0.05-0.06)	TM	
Lameness[1]	Various [2]	Lambs	0.06 (0.02)	LM	O'Brien et al. (2017)
	Various	Ewes	0.12 (0.02)	LM	

[1] Three-point scale (0 = not lame, 1 = Slightly lame, 2 = Moderate to severely lame)

[2] Various breeds = Belclare, Charollais, Suffolk, Texel, Vendeen or other

The heritability also appeared independent of prevalence levels. O'Brien et al. (2017) analysed lameness in various breeds of ewes and lambs and reported overall h^2 estimates between 0.06 and 0.12.

2.12.1 Factors to be considered in dairy goat genetic models

Several factors were accounted for in the models across the various dairy cow and sheep studies depending on the claw disorder. In dairy cows, Heringstad et al. (2018) reported that age, contemporary group, parity, stage of lactation and scorer were effects to be considered in models looking at claw health. Breed and heterosis are two other effects that should be considered in the model (Chawala et al. 2011; Browning Jr et al. 2011). In sheep, the breed, the sex, the age and the prevalence of footrot have been reported to affect the heritability of footrot. Nieuwhof et al. (2008) reported that herds with a higher footrot prevalence were associated with a higher footrot heritability. Skerman et al. (1988) and Raadsma et al. (1994) did not find this relationship, however, Nieuwhof et al. (2008) calculated that these latter studies also had a high prevalence of footrot, supporting their theory. The heritability of white line disease and lameness in sheep was affected by similar factors that affect footrot, excluding the prevalence of footrot. Additional environmental variables to consider are study time of year, scorer, and dam type for white line disease in sheep (Connington et al. 2010). Other factors to consider accounting for within the heritability models for lameness are parity, contemporary group, and heterosis (O'Brien et al. 2017).

While there are no genetic studies on lameness and claw disorders in goats, one study did speculate that some claw disorders may not be genetic. Hill et al. (1997) suggested that horn separation was not genetic. If horn separation had some genetic element, then the probability of it establishing in another hoof (of the same animal) increases, which was not reported in this study (Hill et al. 1997). In this study, horn separation was random, therefore, most likely caused by external factors.

2.12.2 *Genotypic and phenotypic correlations of claw disorders and lameness*

Genetic and phenotypic correlations identify relationships between different attributes of the animal. High genetic correlations can establish whether a trait can be predicted from another measured trait. Predictor or indicator traits are helpful if the desired trait is hard to measure, therefore, measuring an indirect trait would increase selection efficiency (Isik, 2009). This is possible because the two traits may be genetically correlated as they may share some genetic background. The accuracy of the breeding value of the desired trait obtained depends on the genetic correlation and heritability of the recorded indicator trait (Morde, 2013). For example, lameness or locomotion scores can be used as an indicator trait for claw health.

Phenotypic and genetic correlations can be used to predict the correlated response of one trait when selection is practised on another different trait. For example, in cows, lameness has been correlated with mastitis (Koeck et al. 2012); if lameness improves, then mastitis will also be positively affected. This is useful when establishing a breeding goal as it indicates the potential response of traits to selection.

In dairy cows, Heringstad et al. (2018) identified some genetic and phenotypic correlations between lameness and claw disorder traits. There has been a moderate genetic correlation (0.55) between claw lesions in the front and hind legs. The moderate genetic correlation indicates that claw lesions in the front and hind legs could be considered different traits. Parity number has been reported to have a high genetic correlation with claw disorders. The high genetic correlation indicates that observations across parties could be treated as repeated events rather than as different traits for some claw disorders such as dermatitis. A few studies have reported that both infectious and non-infectious claw disorders have moderate to high genetic correlation across the stage of lactation ranging from 0.53-1.00. This suggests that the claw disorder could be treated as one trait within one lactation. A positive correlation between lameness and health traits has been reported, where lame cows were more likely to have mastitis (Pritchard et al. 2013). However, this indicates that improved claw health would also subsequently increase mastitis health.

In sheep, genetic correlations have been limited to studies examining claw lesions, footrot, and lameness (Table 2.6). O'Brien et al. (2017) calculated low genetic correlations between lameness and mastitis (0.34), and lameness and body condition score (-0.39), with high standard errors for each. Despite this, the direction of both correlations is favourable. For example, if the selection were made for lower lameness, the selection for mastitis would also decrease, similar to what has been reported in dairy cattle (Heringstad et al. 2018). Also, if there was a genetic predisposition, if a sheep had a high body condition score, it may reduce the probability of the animal becoming lame. A very low genetic correlation (0.05) for lameness between lambs and ewes indicates that this is a different trait and that lameness could be different across ages.

Estimates of genetic correlations between five footrot traits in Merino sheep were reported by Raadsma et al. (1994). The five traits were the sheep’s ability to contract footrot following an infectious challenge, ability to contain infections to lesions of low severity, ability to show signs of spontaneous healing, accelerated healing after therapeutic vaccination, and absence of clinical footrot following preventive vaccination. The genetic correlation between induced and natural footrot ranged from 0.14 to 0.95, with an average of 0.67. The authors reported significant within-flock genetic variation in resistance to footrot, however, these estimates of genetic correlations have limited application in developing a selection index. This is because these traits describe footrot traits related to an experimental infectious challenge in a small number of goats. Genetic correlations between footrot and production traits would be more informative when developing a selection index for breeding.

Table 2.6. Genetic correlations between lameness with other physical sheep characteristics. Standard errors are indicated in parenthesis.

Trait	Mastitis	BCS	LW	Reference
Lameness (lambs)		-0.89 (0.16)	-0.13 (0.09)	O'Brien et al. (2017)
Lameness (lambs)		0.07 (0.21)	0.03 (0.14)	
Lameness (ewes)	0.25 (0.20)	-0.34 (0.20)	-0.15 (0.16)	
Lameness (ewes and lambs)	0.34 (0.28)	0.39 (0.11)	-0.03 (0.07)	

Abbreviations: BCS, body condition score; LW, liveweight.

2.12.3 Models to estimate genetic parameters

In many studies, claw disorders and lameness have been treated as either binary or continuous traits using mixed linear models. In these models, the phenotype is modelled as having a combination of fixed (e.g., herd, parity number, kidding date and breed) and random (additive genetic animal and residual) effects. In matrix algebra, this model is represented as follow:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{Wp} + \mathbf{e}$$

where:

y = vector of phenotypic observations, lameness or claw disorder.

b = vector of fixed effects, for example, contemporary group (herd-year-season).

a = vector of random additive genetic animal effects using pedigree information or genomic information.

p = vector of random permanent effects for lameness or claw disorders (includes non-additive genetic effects) with a mean = 0 and variance = σ^2_{pe}.

e = vector of random residual effects with a mean = 0 and variance = σ^2_e.

X = matrix that relates the observations in **y** to the fixed effects parameters in vector **b**.

Z = matrix relates the observations in **y** to the vector **a** of the animal with records.

W = identity matrix that relates the observations in **y** to random permanent environmental effects, vector **p**, of the animals with records.

The univariate model has a few assumptions regarding its expectations and variances.

Expectations:

$E(\mathbf{y}) = \mathbf{Xb}$

$E(\mathbf{a}) = 0$

$E(\mathbf{e}) = 0$

Variances:

$\mathrm{var}(\mathbf{a}) = \mathbf{A}\sigma^2_a = \mathbf{G}$

$\mathrm{var}(\mathbf{p}) = \mathbf{I}\sigma^2_{pe}$

$\mathrm{var}(\mathbf{e}) = \mathbf{I}\sigma^2_e = \mathbf{R}$

$\mathrm{var}(\mathbf{y}) = \mathbf{ZAZ}'\sigma^2_a + \mathbf{WI}\sigma^2_{pe}\mathbf{W}' + \mathbf{R}$

$\mathrm{cov}(\mathbf{a}, \mathbf{e}) = 0$ where it is assumed that the random additive genetic and random residual effects are independent of each other.

Where:

A= numerator relationship matrix containing pedigree information on the animal's sire and dam

I = identity matrix

σ^2_a = random additive genetic effect variance

σ^2_{pe} = random permanent environmental effect variance

σ^2_e = random residual effect variance

The mixed model equations that estimate the parameters for the fixed, the genetic and the permanent environment effects is presented below:

$$\begin{bmatrix} \mathbf{X'X} & \mathbf{X'Z} & \mathbf{X'W} \\ \mathbf{Z'X} & \mathbf{Z'Z} + \mathbf{A}^{-1}\alpha_1 & \mathbf{Z'W} \\ \mathbf{W'X} & \mathbf{W'Z} & \mathbf{W'W} + \mathbf{I}\alpha_2 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{a}} \\ \hat{\mathbf{p}} \end{bmatrix} = \begin{bmatrix} \mathbf{X'y} \\ \mathbf{Z'y} \\ \mathbf{W'y} \end{bmatrix}$$

Where:

$\mathbf{A}^{-1}$ is the inverse of the relationship matrix and $\alpha_1 = \frac{\sigma^2_e}{\sigma^2_a}$ and $\alpha_2 = \frac{\sigma^2_e}{\sigma^2_p}$

The landmark paper of Henderson (1963) demonstrated that the solution of these mixed model equations produces best linear unbiased predictors (BLUP) of animal effects, which can be considered as estimated breeding values. The resulting solutions to the estimates are as follows:

$$\begin{bmatrix} \hat{b} \\ \hat{a} \\ \hat{p} \end{bmatrix} = \begin{bmatrix} \mathbf{X'X} & \mathbf{X'Z} & \mathbf{X'W} \\ \mathbf{Z'X} & \mathbf{Z'Z} + \mathbf{A}^{-1}\alpha_1 & \mathbf{Z'W} \\ \mathbf{W'X} & \mathbf{W'Z} & \mathbf{W'W} + \mathbf{I}\alpha_2 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{X'y} \\ \mathbf{Z'y} \\ \mathbf{W'y} \end{bmatrix}$$

These equations require knowledge of σ^2_a, σ^2_{pe} and σ^2_e. When these variances are unknown, then these mixed model equations are solved to find the solution for fixed and random effects and the variance components simultaneously by maximizing the likelihood of **y** with respect to each element of **b** and with respect to each of the variance components over a restricted parameter set (REML; Patterson and Thompson, 1971).

In dairy goats, using a common environmental effect may be appropriate in the model as goats can produce 1.9 kids per lactation on average (Turner, Personal communication). Therefore, these siblings would have shared the same maternal environment, which could explain some similarities between the offspring. It is unknown if this effect would be significant as the shared environment would be the uterus only as the kids are taken from the mother immediately after birth, ideally before feeding off the doe.

The mixed model equations were developed under the assumption that the phenotypic records are continuous variables. In the case of lameness or claw disorders, these traits can be considered as binomial (yes or no) and the distributional properties of the mixed model equations were modified considering an underlying liability model (Gilmour, 1983).

Threshold models use an underlying liability model that is continuous and normally distributed. The liability would depend on genetic and environmental conditions to indicate whether a phenotype is expressed and the probability of response being observed within a category, k, (P (k)). The function, Φ (k), gives the area under the curve up until and including the threshold point, k.

The advantage of this model is that it can be used with binary and categorical data. The disadvantage is that this model does not account for the independence of environment variance from the genotypic variance. Additionally, this model is not as robust as linear models, as it tends to have biased variances if data is not complete (Moreno et al. 1997; Pryce et al. 1998).

While studies have calculated both linear and threshold model heritabilities, only a few studies have compared the results between the threshold and linear models. Threshold models calculate heritabilities that are generally higher than linear models, however, the linear models had better predictive ability than threshold models. Additionally, it has been reported that estimating the breeding values obtained from a threshold and linear model have a high correlation indicating no significant differences between the two models (Imbayarwo-Chikosi et al. 2015).

2.12.4 Heritability, genetic and phenotypic correlations of milk characteristics in dairy goats

There has been a lot of research into the genetic parameters of milk characteristics in dairy goats, nationally and internationally. However, there is limited literature on milk component ratios. The results of the studies are shown in Tables 2.7 and 2.8. Estimates varied depending on the model used (test day or across the lactation) or goat breed within the study. Only two studies published protein to fat ratio h^2 estimates, and no previous reports on the lactose to fat and protein ratio (Torres-Vazquez, 2008; Garcia-Peniche et al. 2012). Due to the limited studies on milk component ratios in dairy goats, dairy cattle were referenced where necessary.

Table 2.7. Estimates of heritability for milk characteristics for dairy goats.

Trait	Heritability	Average heritability	Reference
Milk yield (kg)	0.10		Mucha et al. (2014)
	0.17		Torres-Vazquez et al. (2009)
	0.19		Brito et al. (2011)
	0.20		Breznick et al. (2000)
	0.21		Pesce Delfino et al. (2001); Muller (2005)
	0.22		Valencia et al. (2007); Maroteau et al. (2014); Selvaggi and Dario (2015)
	0.23		Morris et al. (1997)
	0.24		Maroteau et al. (2014); Rabasco et al. (1993)
	0.25		Scholten et al. (2018)
	0.26		Teissier et al. (2019); Biffani et al. (2020)
	0.27		Arnal et al. (2019); Biffani et al. (2020)
	0.28		Arnal et al. (2019)
	0.29		Boichard et al. (1989)
	0.30		Rupp et al. (2011)
	0.31		Boichard et al. (1989); Teissier et al. (2019)
	0.32		Belichon et al. (1998)
	0.34		Rupp et al. (2011)

Table 2.7 continued

Trait	Heritability	Average heritability	Reference
	0.35		Morris et al. (2006); Garcia-Peniche et al. (2012); Valencia-Posadas et al. (2017)
	0.37		Castaneda-Bustos et al. (2014)
	0.39		Morris et al. (2011)
	0.45	0.27	Mucha et al. (2014)
Fat yield (kg)	0.10		Brito et al. (2011)
	0.19		Torres-Vazquez et al. (2009); Muller (2005)
	0.20		Rabasco et al. (1993)
	0.24		Scholten et al. (2018); Arnal et al. (2019)
	0.25		Selvaggi and Dario (2015); Teissier et al. (2019)
	0.28		Teissier et al. (2019)
	0.31		Arnal et al. (2019)
	0.32		Boichard et al. (1989); Rupp et al. (2011)
	0.35		Rupp et al. 2011); Garcia-Peniche et al. (2012)
	0.36		Morris et al. (2011)
	0.37		Belichon et al. (1998); Castaneda-Bustos et al. (2014)
	0.39		Boichard et al. (1989)
	0.40	0.28	Belichon et al. (1998)
Protein yield (kg)	0.04		Rabasco et al. (1993)
	0.12		Brito et al. (2011)

Table 2.7 continued

Trait	Heritability	Average heritability	Reference
	0.17		Torres-Vazquez et al. (2009)
	0.20		Muller (2005)
	0.23		Selvaggi and Dario (2015)
	0.24		Scholten et al. (2018)
	0.25		Teissier et al. (2019); Arnal et al. (2019)
	0.29		Arnal et al. (2019)
	0.31		Boichard et al. (1989); Rupp et al. (2011); Teissier et al. (2019)
	0.34		Belichon et al. (1998); Rupp et al. (2011)
	0.36		Boichard et al. (1989); Belichon et al. (1998)
	0.37		Garcia-Peniche et al. (2012)
	0.38		Castaneda-Bustos et al. (2014)
	0.41	0.27	Morris et al. (2011)
Somatic cell score[1]	0.09		Maroteau et al. (2014)
	0.12		Apodaca-Sarabia et al. (2009)
	0.15		Maroteau et al. (2014)
	0.20		Rupp et al. (2011)
	0.21		Bagnicka et al. (2016); Scholten et al. (2018)
	0.25	0.18	Rupp et al. (2011)
Lactose yield (kg)	0.15		Brito et al. (2011)

Table 2.7 continued

Trait	Heritability	Average heritability	Reference
	0.35	0.25	Morris et al. (2011)
Fat content (%)	0.14		Rabasco et al. (1993)
	0.16		Analla et al. (1996)
	0.17		Muller (2005)
	0.18		Breznick et al. (2000)
	0.20		Maroteau et al. (2015)
	0.21		Brito et al. (2011)
	0.23		Maroteau et al. (2014)
	0.32		Torres-Vazquez et al. (2009)
	0.41		Prajapati et al. (2017)
	0.46		Garcia-Peniche et al. (2014)
	0.47		Boichard et al. (1999)
	0.48		Teissier et al. (2019)
	0.50		Boichard et al. (1998); Arnal et al. (2019)
	0.51		Garcia-Peniche et al. (2012); Teissier et al. (2020)
	0.54		Castaneda-Bustos et al. (2014); Arnal et al. (2020)
	0.56		Garcia-Peniche et al. (2013)
	0.58		Belichon et al. (1998)
	0.59		Garcia-Peniche et al. (2015)

Table 2.7 continued

Trait	Heritability	Average heritability	Reference
	0.61		Rupp et al. (2011)
	0.62	0.42	Rupp et al. (2012); Bagnicka et al. (2016)
Protein content (%)	0.21		Prajapati et al. (2017)
	0.24		Breznick et al. (2000)
	0.25		Analla et al. (1996)
	0.28		Muller (2005)
	0.30		Rabasco et al. (1993)
	0.38		Torres-Vazquez et al. (2009)
	0.39		Brito et al. (2011); Maroteau et al. (2014)
	0.40		Maroteau et al. (2014)
	0.41		Boichard et al. (1998)
	0.43-0.57		Garcia-Peniche et al. (2012)[2]
	0.50		Belichon et al. (1998)
	0.52		Boichard et al. (1998)
	0.56		Arnal et al. (2019)
	0.58		Belichon et al. (1998)
	0.60		Rupp et al. (2011)
	0.62		Arnal et al. (2019)

Table 2.7 continued

Trait	Heritability	Average heritability	Reference
	0.64		Castaneda-Bustos et al. (2014)
	0.67	0.45	Rupp et al. 2011; Bagnicka et al. (2016)
Lactose content (%)	0.17		Brito et al. (2011)
	0.23		Breznick et al. (2000)
	0.27		Andonov et al. (2007); Bagnicka et al. (2016)
	0.36	0.26	Prajapati et al. (2017)
	0.27		Sneddon et al. (2015)[3]
Protein: fat ratio	0.33		Torres-Vazquez (2008)
	0.29-0.51		Garcia-Peniche et al. (2012)[2]
	0.58		de Jager and Kennedy (1987)[3]
	0.69	0.44	Meinert et al. (1989)[3]
Fat: protein ratio	0.19-0.27	0.24	Puangdee et al. (2016)[3]
Lactose: protein ratio	0.47		Costa et al. (2019)[3]

[1] Somatic cell score = average $\log_2$ (somatic cell count).

[2]Study includes goats of various breeds.

[3]Due to limited or absent studies on milk characteristics, these values were from dairy cow studies.

Table 2.8. Phenotypic and genotypic correlations of milk characteristics in dairy goats of various breeds.

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation	Reference
Milk yield	Fat yield	0.72	0.85	Torres-Vazquez et al. (2009)
		0.77	0.85 to 0.86	Belichon et al. (1998)
		0.80 to 0.84	0.87 to 0.89	Bolichard et al (1989)
		0.86		Brito et al. (2011)
		0.75	0.80	Muller (2005)
	Protein yield	0.87	0.95	Torres-Vazquez et al. (2009)
		0.89 to 0.92	0.93 to 0.95	Belichon et al. (1998)
		0.90 to 0.93	0.94 to 0.95	Bolichard et al (1989)
		0.96		Brito et al. (2011)
		0.92	0.95	Muller (2005)
	Lactose yield	0.98		Brito et al. (2011)
	Somatic cell score[1]	0.59		Bagnicka et al. (2016)
	Fat content	-0.24	-0.23	Torres-Vazquez et al. (2009)
		-0.18 to -0.10	-0.16 to -0.12	Belichon et al. (1998)
		-0.16 to 0.07	-0.17 to -0.13	Bolichard et al (1989)
		-0.47		Brito et al. (2011)
		-0.48	-0.89	Analla et al. (1996)
		-0.32	-0.25	Brenick et al. (2000)
		-0.34	-0.09	Muller (2005)

Table 2.8 continued

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation	Reference
Milk yield	Protein content	-0.3	-0.29,	Torres-Vazquez et al. (2009)
		-0.28 to -0.29	-0.40 to -0.38	Belichon et al. (1998)
		-0.30 to -0.08	-0.36 to -0.35	Bolichard et al (1989)
		-0.47		Brito et al. (2011)
		-0.47	-0.65	Analla et al. (1996)
		-0.41	-0.19	Brenick et al. (2000)
		-0.25	-0.08	Muller (2005)
	Lactose content	-0.46		Bagnicka et al. (2016)
		0.15		Brito et al. (2011)
		-0.14	0.09	Brenick et al. (2000)
	Protein:fat ratio	0.06	0.09	de Jager and Kennedy (1987)[2]
		0.19	0.14	Mainert et al. (1989)[2]
		0.42	0.15	Sneddon et al. (2015)[2]
Fat yield	Protein yield	0.80	0.88	Torres-Vazquez et al. (2009)
		0.83 to 0.86	0.88 to 0.91	Belichon et al. (1998)
		0.82 to 0.91	0.80	Bolichard et al (1989)
		0.93		Brito et al. (2011)
		0.86		Muller (2005)
	Lactose yield	0.88		Brito et al. (2011)

Table 2.8 continued

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation	Reference
Fat yield	Lactose yield	0.88		Brito et al. (2011)
	Fat content	0.49	0.30	Torres-Vazquez et al. (2009)
		0.49 to 0.56	0.38 to 0.39	Belichon et al. (1998)
		0.45 to 0.59	0.31	Bolichard et al (1989)
		0.35	0.43	Muller (2005)
	Protein content	0.1	-0.04	Torres-Vazquez et al. (2009)
		0.08 to 0.14	-0.16 to -0.11	Belichon et al. (1998)
		0.06 to 0.19	-0.14	Bolichard et al (1989)
		0.26	0.01	Muller (2005)
	Protein:fat ratio	-0.68	-0.48	de Jager and Kennedy (1987)[2]
		-0.54	-0.34	Mainert et al. (1989)[2]
		-0.53	-0.40	Sneddon et al. (2015)[2]
Protein yield	Lactose yield	0.94		Brito et al. (2011)
	Fat content	0.03	-0.09	Torres-Vazquez et al. (2009)
		0.10 to 0.11	-0.02 to 0.01	Belichon et al. (1998)
		-0.02 to 0.34	-0.05 to 0.01	Bolichard et al (1989)
		-0.07	-0.04	Muller (2005)

Table 2.8 continued

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation	Reference
Protein yield	Protein content	0.21	0.02	Torres-Vazquez et al. (2009)
		0.10 to 0.19	-0.11 to -0.04	Belichon et al. (1998)
		0.14 to 0.29	-0.06 to -0.05	Bolichard et al (1989)
		0.14	0.18	Muller (2005)
	Lactose content	0.05		Brito et al. (2011)
	Protein:fat ratio	0.11	0.13	de Jager and Kennedy (1987)[2]
		0.18	0.19	Mainert et al. (1989)[2]
		0.41	0.17	Sneddon et al. (2015)[2]
Lactose yield	Protein:fat ratio	0.41	0.15	Sneddon et al. (2015)[2]
Somatic cell score[1]	Fat content	-0.19		Bagnicka et al. (2016)
	Protein content	0.00		Bagnicka et al. (2016)
	Lactose content	-0.14		Bagnicka et al. (2016)
Fat content	Protein content	0.50	0.46	Torres-Vazquez et al. (2009)
		0.51 to 0.61	0.41 to 0.49	Belichon et al. (1998)
		0.44 to 0.56	0.43 to 0.45	Bolichard et al (1989)
		0.61		Brito et al. (2011)
		0.93	0.54	Analla et al. (1996)
		0.39	0.10	Prajapati et al. (2017)
		0.57	0.40	Brenick et al. (2000)
		0.72	0.11	Muller (2005)

able 2.8 continued

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation	Reference
Fat content	Lactose content	0.62		Bagnicka et al. (2016)
		0.20		Brito et al. (2011)
		0.20	-0.04	Prajapati et al. (2017)
		0.27	0.12	Brenick et al. (2000)
	Protein:fat ratio	-0.80	-0.79	de Jager and Kennedy (1987)[2]
		-0.79	-0.75	Mainert et al. (1989)[2]
		-0.85	-0.79	Sneddon et al. (2015)[2]
2Protein content	Lactose content	0.54		Bagnicka et al. (2016)
		0.05		Brito et al. (2011)
		0.78	0.48	Prajapati et al. (2017)
		0.01	0.09	Brenick et al. (2000)
Protein content	Protein:fat ratio	0.04	0.06	de Jager and Kennedy (1987)[2]
		-0.20	0.01	
Lactose content	Protein:fat ratio	-0.06	0.02	Sneddon et al. (2015)[2]

[1] Somatic cell score = average $\log_2$ (somatic cell count).

[2]These values have been taken from dairy cow studies has they have not been calculated in dairy goats.

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2.13 The inapplicability of sheep and dairy cow studies to dairy goats

For a few reasons, claw disorders and lameness results from the sheep and dairy cow research cannot be applied to the dairy goat industry. Firstly, dairy goats are a different species. Secondly, they are managed differently from sheep and dairy cows, and thirdly limitations seen in sheep and dairy cow genetic studies would not be the same in dairy goats. Combining these reasons means the results from past literature should be applied to the dairy goat industry with caution.

Firstly, dairy goats share similar characteristics with sheep and dairy cows though they are physically and physiologically different. Goats farmed for meat are managed differently than dairy goats, which are often extensively farmed. Therefore, meat goat studies are more likely to be more similar to sheep farmed for meat than dairy goats. The closest species to dairy goats would be sheep, however, these studies are focused on sheep for meat production, which are also usually extensively managed. Dairy cows are physically more different from sheep to dairy goats, however, they are managed under similar circumstances to dairy if they are farmed intensively.

In dairy cows, not all the cows are trimmed regularly. Heringstad et al. (2018) stated in their review that, ideally, all cows should be recorded at hoof trimming events. In reality, this does not happen, and usually, only cows that are moderately to severely lame are selected for hoof trimming. A couple of studies noted that because of this selection, there is a bias in the statistical analysis where, even though the heritability is not significantly different, the genetic correlation between claw disorders is significantly different. In commercial dairy goat farms, all goats are routinely trimmed, therefore, information would be obtained on all goats to avoid this selection bias.

2.14 Knowledge gaps in the New Zealand dairy goat industry

In New Zealand, there has been little research into the lameness of dairy goats. A recent study completed by Deeming et al. (2018) was a gait analysis that established a 5-point locomotion scoring schedule in dairy goats. Deeming et al. (2021) also studied lameness in a small cohort of goats in their first two years of life. Only two measurements were taken after parturition and reported a small percentage of lame goats within the group. It is unknown what is causing lameness in dairy goat herds and whether claw disorders are the predominant reason for causing lameness. It is also unknown what factors increase the risk of lameness in herds and how this may affect the goat's production. Research needs to be completed in this area to determine the extent of the lameness problem, and the prevalence of lameness in New Zealand herds needs to be estimated. For dairy goat farmers, estimating possible causes, risk factors associated with lameness and the income losses associated with lameness would be helpful to know to work out a solution.

As seen with sheep studies and, now more recently, cows, breeding could be used as an additional tool to reduce lameness in herds. As the breeding goal of the New Zealand dairy goat industry is gradually becoming important, incorporating lameness into the breeding goal would allow long-term resistance or tolerance to diseases to be established.

Chapter 3

Prevalence, incidence and duration of clinical lameness on three New Zealand dairy goat farms

3.1 Abstract

Clinical lameness negatively impacts an animal's welfare and is an economic problem within the livestock industry. This study aimed to estimate the prevalence, incidence and duration of clinical lameness within commercial dairy goat farms in New Zealand. Three dairy goat farms participated in the study, with up to 3246 goats observed multiple times over one year. Data on locomotion score, age, parity, and herd-level information, such as management practices, were collected. A 5-point locomotion scoring scale was used. The prevalence of clinical lameness fluctuated over the production year for all farms. The average prevalence of clinical lameness for farms A, B and C was 23, 12, and 10%, respectively. The annual incidence rate of clinical lameness for farms A, B and C were 104, 56, and 55 cases per 100 goat-years. The duration of clinical lameness cases depended on the farm events and ranged from 34 to 321 days. The variation in prevalence and incidence rates of clinical lameness between farms suggests underlying farm factors that may increase the risk of clinical lameness within the herd. A risk analysis should be undertaken to identify variables affecting the goat's odds of becoming clinically lame. This study sets the foundation for future study of lameness on commercial dairy goat farms nationally and internationally.

3.2 Introduction

Lameness is a manifestation of pain, making it an animal welfare concern. It is becoming more evident that consumers are concerned about animal welfare through changes in their buying behaviour (Alonso et al. 2020). Animal welfare is an essential aspect of farming and has recently been the subject of multiple studies on dairy goats (Anzunio et al. 2010; Muri et al. 2013; Hempstead et al. 2021). Lameness can be defined as the impairment of normal locomotion of an animal due to pain caused by an injury, disease, or claw disorder and is an indication of claw health (Vieira et al. 2015). The aetiology of lameness can be infectious and non-infectious. Infectious diseases of the claw are due to pathogenic bacteria or viruses that colonise on or within their host animal, causing injury when the conditions are favourable. Non-infectious factors are events that may predispose the animal to lameness, such as nutrition, management, environment, and genetics (Mathews, 2016).

Regardless of what causes lameness, the impact on the animal's productivity and longevity is reported to be negative. In dairy cattle and sheep, lameness was associated with a low body condition score, reduced milk production and reproductive performance, and an increased risk of culling or death within the herd (Booth et al. 2004; Clarkson et al. 1996; Green et al. 2014). A body condition score ≤2.5 was associated with lameness, and milk production was lower in lame cows than in non-lame cows (Randall et al. 2015). Depending on the stage of lactation, it was also estimated that lame cows were 1.1 to 2 times more likely to be culled than non-lame cows (Booth et al. 2004). In dairy goats, reduced milk production, fertility, and longevity have been associated with lameness (Eze, 2002; Christodoulopoulos, 2009; Solis-Ramirez et al. 2011). Annual milk production (220-day) decreased by 16.4 kg in lame goats, while it decreased by 25.7 kg in lame goats with a foot lesion (Christodoulopoulos, 2009). Kidding intervals for lame goats were 4.3 months longer than for non-lame goats, which Eze (2002) hypothesised was due to the lower body condition of the lame goats. One study surveyed the dairy goat industry in New Zealand and reported that lameness represented 6% of the culled goats (Solis-Ramirez et al. 2011). The authors reported that the principal reason for culling was low production and fertility problems, however, some of these goats could have been lame as a secondary reason.

There have been no large-scale studies on lameness or clinical lameness in dairy goats on commercial farms. The extent of lameness has not been fully realised from the industry's welfare, production and economic aspect. Many international studies conducted so far on dairy goat farms are welfare studies. These studies only provided the prevalence of lameness, the percentage of lame goats on a farm at a given time. These studies' limitation was that the lameness prevalence may have been under- or overestimated because the results were based upon a subset group within the herds. Another limitation was that there were no follow-up observations of the herds. In dairy cows, lameness prevalence changes throughout the year (Clarkson et al. 1996). One study has only reported the duration of lameness events, with one event lasting 3 to 6 days (Christodoulopoulos, 2009). It was unclear how severe the cases of lameness were in that study. The duration of lameness events is important to estimate as it indicates how lameness affects goat's welfare and farm costs. The incidence rate, defined as the number of new lameness cases between two time points (Dohoo et al. 2003), and duration, is defined as the inverse of the cure rate (Tumwiine et al. 2005), of lameness have also been overlooked in the past studies.

There are currently no studies on lameness, specifically clinical lameness, of dairy goats on commercial farms in New Zealand. The incidence rate and duration of lameness are novel aspects of this study because it is yet to be studied in dairy goat herds. This study aimed to determine the prevalence of clinical lameness, estimate its annual incidence rate, and the duration in three dairy goat herds.

3.3 Material and methods

3.3.1 Study population

Data were collected from three commercial dairy goat farms in the Waikato region of New Zealand between July 2019 and June 2020 (Table 3.1). All farms volunteered to participate in this study and were a part of the Dairy Goat Co-operative (NZ) Ltd. These farmers had witnessed lameness within their herds and were interested in reducing its prevalence on the farm. All farms kept goats of various breeds, including Saanen, Toggenburg, Alpine and their crosses. Like most New Zealand farms, most goats were Saanen (Scholtens et al. 2017). Two of the selected farms had herd sizes around the national average of 750 milking does (Scholtens et al. 2017), while one farm was significantly larger, containing over 1600 milking does. The participating farms were required to have at least four herd tests throughout the year. Goats were classified as seasonal or extended lactation goats.

The seasonal goats were defined as having given birth between August and December 2019, while the extended lactation goats had kidded before June 2019 and were over 305 days in milk at the beginning of the study. Overall, the extended lactation goats had been lactating continuously for, on average, 2.97 years, with a median of 2 years. All goats were milked twice a day.

The diet consisted of a total mixed ration with freshly cut grass-fed *ad libitum*. The total mixed ration varied from farm to farm. It generally consisted of forage, such as grass and/or maize silage, a protein meal, such as dried distillers grain, and additional supplements. All farms fed corn kernel or goat meal as part of their total mixed ration or in the milking parlour.

3.3.1 Locomotion scoring

Depending on the farm, locomotion scoring events were carried out 4 – 5 times a year during milking, either in the morning or the afternoon (Figure 3.1). The goats were video-recorded walking as they exited the milking parlour, thereby reducing the impact of the udder on the goat's gait. Two cameras were used to record their movement to ensure that the goats were observed moving without being disturbed. The cameras were positioned to capture at least four strides of walk (Deeming et al. 2018) from both the back and side of the goats. Farms A and C had a rotary milking parlour system that meant goats could exit the milking parlour 2-3 at a time. Farm B had a herringbone milking parlour, which released 40 goats at once. For farm B, to see the goats one at a time, a race was created to ensure goats made their way back to the barn in single file. All goats were filmed walking across a flat, concrete surface. The goats were identified on the video footage using a unique number sprayed onto their rump that corresponded to their electronic identification. Two video-recording sessions were conducted at each locomotion scoring event. Where it was possible, goats were scored at both video sessions.

Table 3.1. Descriptive statistics for three dairy goat farms, located in Waikato, New Zealand, within the July 2019 – June 2020 production year.

Farm characteristic	Farm A	Farm B	Farm C
Number of locomotion scoring events/year	5	4	4
Herd size (lactating goats, May 2020)	1497	623	763
Milking parlour setup	Rotary (100 bales)	Herringbone (40 aside)	Rotary (80 bales)
Kidding season	July 2019-October 2019	July 2019-August 2019	July 2019-August 2019
Bedding type	Wood shavings	Wood shavings and elephant grass	Wood shavings
Percentage of goats with extended lactation (>305 DIM)	55.6	23.9	38.6
Median age of the extended lactation group (years)	3.19	2.00	2.93
The number of herd groups [1]	2	1	4
Stocking density (m^2 per goat)	2.19-2.68	2.94-3.61	2.63-2.70 [2]
Treatment between hoof trimming events [3]	Sometimes [4]	Weekly	Sometimes
Footbath or mat protocols (using $CuSO_4$)	Sometimes [5]	Sometimes	Daily [6]

[1] This excludes farms' hospital pen, if present, throughout the season.
[2] The area inside the barn. These goats have access to an outside area that decreases the stocking density to 3.59-3.77 m^2 per goat.
[3] Comprised of drafting out a lame goat, inspecting the affected foot and treating it.
[4] When the workers had time to treat the goats.
[5] After hoof trimming or a couple of times a week after milking.
[6] Only daily from February 2020 onwards and was not present before this time.
[7] $CuSO_4$ = Copper Sulphate.

3.3.2 Subjective locomotion assessment

Using the videos, the first author conducted the locomotion analysis. They were familiar with goats' lameness and was trained to use the 5-point scoring system developed by Deeming et al. (2018) (Table 3.2). Two segments of video footage were used to train the observer, and a third video segment was used to cross-check the scores with the developer of the scoring system (inter-reliability) and cross-check the scores over time (intra-reliability). For more information on the validation of the locomotion scoring system refer to Appendix VI.

The first video segment was obtained from Deeming et al. (2018) and showed one goat at each locomotion score. The second video segment was collected during a pilot study at farm A. This pilot study was also used to review the procedure's logistics. The third video segment contained approximately 60 goats at each locomotion score. The third video segment is the farm reference footage used for the validation analysis. Each farm needed a reference video as the camera positions differed slightly because of the different milking parlour designs between farms. The reference videos were obtained when a trial run of the locomotion scoring event was conducted at each farm.

Two considerations were needed when scoring a goat. Firstly, for a goat to be scored, it needed at least two consecutive strides at one gait (walk) (Flower and Weary, 2006). This excluded goats who displayed irregular transitioning from one gait to another, jogging, rushing from the parlour (fast trotting or cantering), head shaking, coughing and obstruction from anything within the goat's environment. Secondly, it was determined that the locomotion scoring system did not quite capture the goats with multiple leg/feet issues, as often these goats were not limping. Therefore, if the goat was not limping but was reluctant to move forward and bear weight, then the score of this goat was considered ‘severe’ and was given a four.

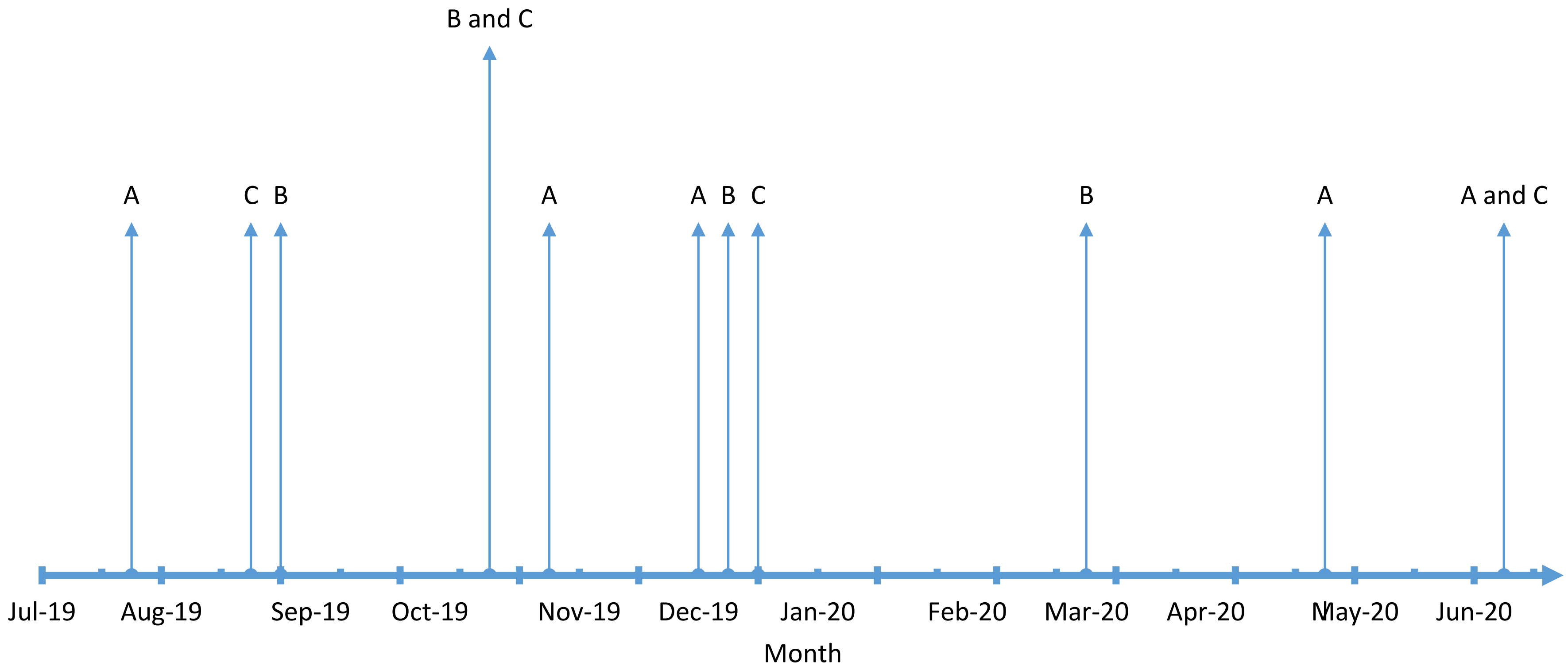


Figure 3.1. The timeline of locomotion scoring events for each dairy goat farm A, B and C- located in Waikato, New Zealand. The x-axis is the month starting with the first week of July 2019 and ending in the third week of June 2020.

Table 3.2. Locomotion scoring strategy used to measure lameness in dairy goats (adapted from Deeming et al. 2018).

Severity score	Label	Clinically lame	Limping	Gait description	Modifications
0	Normal/not lame	No	No	Moving forward with even strides where hooves track up. Weight-bearing and no apparent head nodding.	
1	Uneven gait	No	Uneven	Moving forward with shorter strides where hooves do not track up. Weight-bearing, and having an absent head nodding, however, have joints that may show stiffness.	
2	Mildly lame	No	Yes	Moving forward with shorter strides where hooves do not track up. One or more legs/feet may be affected. Weight-bearing, and having an absent head nodding however may show a mild limp.	
3	Moderately lame	Yes	Yes	Reluctant to move forward and may display a moderate limp. One or more legs could be affected and may display some goose-stepping.	
4	Severely lame	Yes	Yes	Refusal to bear any weight on one foot. Severe limping or extreme goose-stepping or walking on the knees.	If there is no limp, but are very reluctant to move forward and weight-bear due to multiple feet involved.

3.3.3 Prevalence, incidence rate, and duration of lameness

Clinical lameness was defined as a goat having a locomotion score of 3 or 4. The prevalence of clinical lameness was defined as the proportion of cases within a herd at a given locomotion scoring event. The incidence rate was the number of new clinical lameness cases between two time points (Dohoo et al. 2003) over the total animal-time at risk for the considered period. The prevalence (P) and incidence rate (I) of clinical lameness were calculated using the following equations (Dohoo et al. 2003),

$$P = \frac{a}{b} \times 100$$

where

a = the number of cases of clinical lameness (locomotion severity scores 3-4) in a population at a point in time.

b = the number of goats in the population at risk at that point in time.

$$I = \frac{\text{Number of new cases}}{\text{Goat-days at risk}} \times 365 \times 100$$

$$\text{Goat-days at risk} = c - 28\text{ days}(d) - 14\text{ days}(e)$$

where

I = annual incidence rate per 100 goat-years.

c = the number of days between the first and last locomotion scoring event.

d = the number of clinical lameness cases present between the first and last locomotion scoring event multiplied by the assumed lameness duration of 28 days (Clarkson et al. 1996).

e = the clinical lameness status, absence or presence (0/1), at the last locomotion scoring event multiplied by half the assumed duration (14 days).

The duration, D, was calculated using the inverse of the cure rate equation below (Tumwiine et al. 2005). The days at risk to be cured are the number of days between the date when clinical lameness was first recorded (f) minus the date when clinical lameness was not present (g).

$$D = \frac{1}{\text{cure rate}}$$

$$\text{Cure rate} = \frac{\text{Number of new cases}}{\text{Days at risk to be cured}}$$

$$\text{Days at risk to be cured} = \text{f-g}$$

The prevalence and incidence rate calculation was carried out with R (R Core Team, 2021) data.table package (Dowle and Srinivasan, 2021). The 95% confidence intervals (CI) for incidence and cure rate (h) were calculated using the following equation (Dohoo et al. 2003):

$$95\%\ \text{CI} = \text{h} \pm 1.96 \times \sqrt{\frac{\text{annual rate per 100 goats}}{\text{sum of goat days at risk}}}$$

The data analysis was carried out with SAS (version 9.4, SAS Institute Inc., Cary, NC) using the PROC GENMOD function. A logistic regression model tested the difference in prevalence, incidence rate, and duration of clinical lameness between farms. The dependent variables used for the prevalence, incidence rate and duration analysis were the number of clinical lameness cases, number of new cases, and duration, respectively. The number of new cases was adjusted for over-dispersion (determined by the Lagrange Multiplier test) using a negative binomial distribution instead of a Poisson distribution. Farm was the only independent variable used in the model.

3.4 Results

3.4.1 Prevalence and incidence rate of clinical lameness

At each locomotion scoring event, 77-91% of the herd was scored at least once (Table 3.3). The average prevalence and incidence rate of clinical lameness are presented in Table 3.4. The prevalence of clinical lameness fluctuated across the season that differed between farms across the 2019-2020 production year (Figure 3.2). Farm A had the highest prevalence of clinical lameness (estimate difference = -0.106 to -0.096, P-values <0.0001) across all the farms. It fluctuated between 18-29% across the year, with clinical lameness peaking in December 2019 at 29%. Farms B and C had similar levels of clinical lameness. They fluctuated between 9 and 14% across the year and peaked in October 2019 with 12 and 14% clinically lame goats, respectively.

Farm A had the highest incidence rate of clinical lameness (difference between estimates = -0.61 and -0.68, P-value <0.001). For every 100 goats within a year, 104 cases had a locomotion score of 3 or 4. Farms B and C had 57 and 55 cases of clinical lameness over one year in every 100 goats scored.

Table 3.3. The total number of dairy goats present within the herd at each locomotion scoring event during the 2019-2020 production year across the three commercial farms in New Zealand. The percentage of the herd scored at least once at each scoring event are displayed in parathesis.

Locomotion scoring event	Farm A	Farm B	Farm C
July 2019	1,229 (80)		
August 2019		758 (77)	840 (80)
October 2019	1,626 (89)	767 (84)	825 (91)
December 2019	1,639 (90)	749 (90)	798 (88)
March 2020		744 (90)	
April 2020	1,542 (87)		
June 2020	1,366 (80)		401 (87)

Table 3.4. Average prevalence and annual incidence rates (with 95% confidence intervals in parenthesis) of lameness and clinical lameness in dairy goats within three New Zealand commercial farms across the 2019-2020 production year.

	Lameness[1]		Clinical lameness[1]	
Farm	Prevalence[2] (%)	Incidence rate[3]	Prevalence (%)	Incidence rate
A	38 [a] (28-48)	172 [a] (163-181)	23 [a] (18-28)	104 [a] (97-111)
B	31 [b] (20-42)	191 [b] (174-208)	10 [b] (8-12)	57 [b] (48-66)
C	34 [b] (29-39)	161 [a] (147-175)	12 [b] (9-15)	55 [b] (47-63)
P-value	<0.001	0.0252	<0.001	<0.001

[1]Lameness and clinical lameness are defined as having a locomotion score of 2 to 4 and 3 to 4, respectively, using a 5-point scoring system (0 to 4).

[2]The average prevalence across the 2019-2020 production year.

[3]The annual incidence rate was defined as the number of new cases per 100 goat-years.

[a,b] Means with different superscripts within the same column are significantly different ($P < 0.05$)

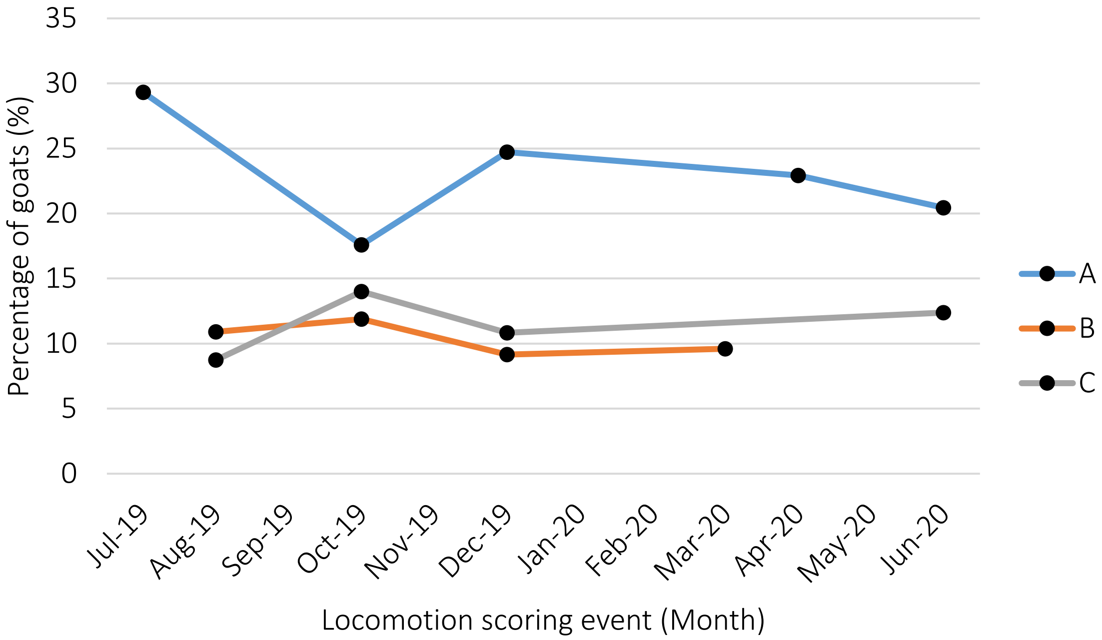


Figure 3.2. The prevalence of clinical lameness (locomotion severity scores 3 or 4) in dairy goats across three New Zealand farms (A, B, and C) during the 2019-2020 production year.

3.4.2 Duration of clinical lameness

Variation in the duration of clinical lameness is presented in Figure 3.3. There was a significant difference in the duration between all the farms (P-value <0.001). Clinical lameness lasted significantly longer on farm A than on farm B (-60 days, P-value <0.0001) and C (-25 days, P-value <0.001), while farm B was a significantly shortest duration. Farm A also had the largest variation in the length of lameness events, ranging from 34 to 321 days. The median duration of clinical lameness events was estimated to be 131 days. The duration of clinical lameness on farm B ranged from 48 to 139 days, with a median length of 55 days. It was estimated that the duration of clinical lameness events for Farm C varied from 59 to 235 days, with a median of 63 days.

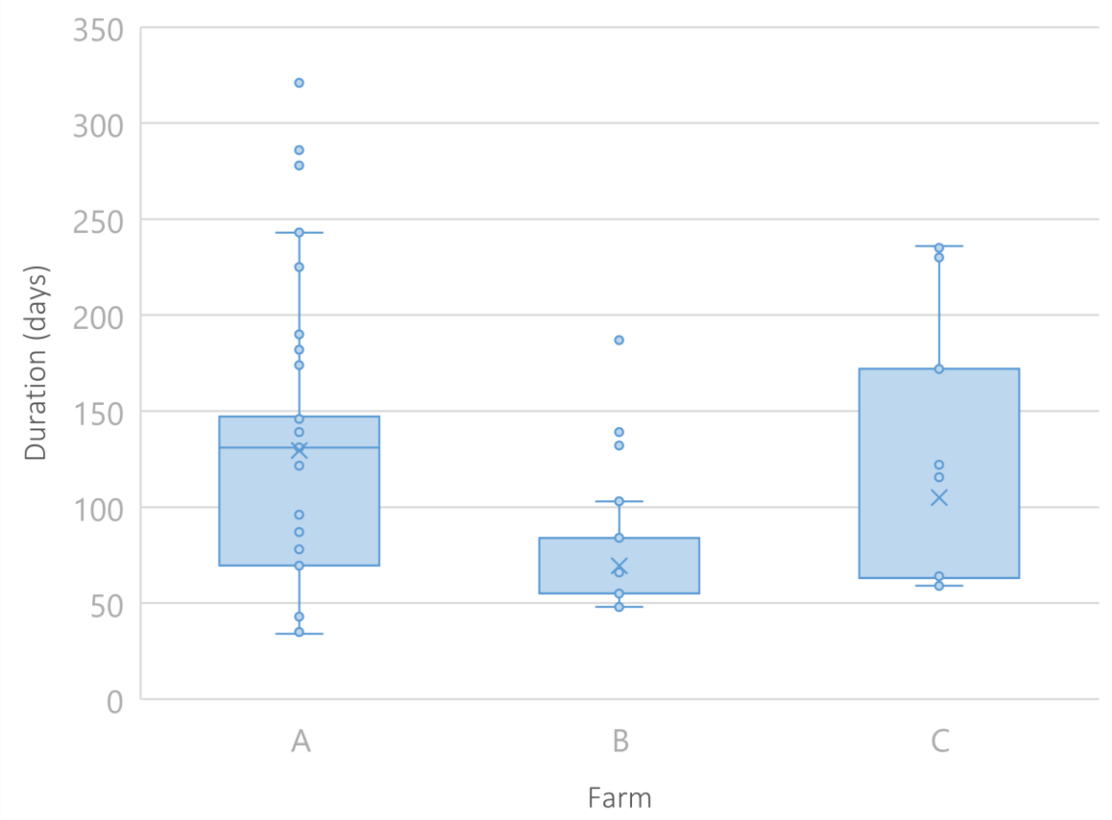


Figure 3.3. Duration of clinical lameness events in dairy goats from three commercial farms across the 2019-2020 production year. 'x' marks the mean duration. Farms were located in Waikato, New Zealand.

3.5 Discussion

Lameness is one part of animal welfare that needs to be investigated. Until now, no studies have carried out a lameness study on commercial dairy goat farms with a strategy that can measure many goats over a series of events. The objective of this study was to provide insight into the lameness situation on three commercial dairy goat farms in New Zealand. A verified locomotion 5-point scoring system analysed the goat's gaits. Once the scores were collated, the prevalence, incidence rate and duration of the lameness and clinical lameness were calculated.

3.5.1 Prevalence of clinical lameness

The prevalence estimated from the three farms within this study (lameness, 34-38% and clinical lameness, 12-23%) was similar to the prevalence reported in international lameness studies (Chapter 2, Table 2.2). In Europe, over the last ten years, the prevalence of lame goats within a herd has ranged from 1.7 to 67%. In the UK, twenty-two years ago, lameness prevalence in dairy goat herds was estimated to be between 2.7 and 23.4%, with an average of 9.1%. Since then, lameness has increased in dairy goat farms, with some reporting that 67% of the goats were lame (Hill et al. 1997; Anzunio et al. 2010; Groenevelt et al. 2015a, 2015b). A Norwegian and an American study had the lowest prevalence of lameness in their herds (1.7 and 1.2%, respectively), however, these figures are suggested to be underestimated (Muri et al. 2013; Hempstead et al. 2021) due to possible differences in the methodology used to score locomotion. All the past studies have reported that lameness is present within dairy goat farms, with the current study also reporting that lameness is a problem that New Zealand farmers could frequently face.

Many past studies have observed sub-groups of goats, and only a few observed entire herds. All past studies observed the herds at only one point in time. A potential issue with observing sub-groups of a herd is that this could calculate a lameness prevalence that under or over-estimates the true prevalence within the herd, depending on how the goats were selected. In these studies, lameness prevalence is often scored while goats are within a pen with other goats present, which limits the interpretation of results. These limitations include- missing goats, goat or environmental obstruction, and soft bedding. Firstly, looking at goats within the pen increases the risk of missing or double-counting goats. Secondly, having goats in one pen leads to goats or environmental obstruction, which obscures how the goats walk. Lastly, scoring the goats while walking on a soft surface often masks the more subtle cases of lameness. Potential risk factors such as age, breed, parity, stage of lactation or time of year have not been analysed statistically. As a result, applying these results to a region's whole herd or potential goat population should be used with caution due to differences between farms, for example, age and breed structures.

This study's prevalence of clinical lameness fluctuated over the farms' 2019-2020 production year. Farm A appeared to fluctuate more than farms B or C (Figure 3.2). Clinical lameness appeared to peak between October and December 2019 on all farms. On farm A, clinical lameness elevated in July 2019, which was not recorded on other farms. In other goat, dairy cows and sheep studies, fluctuation in lameness prevalence could also be due to the season's climate and lactation stage (Eze, 2002; Christodoulopoulos, 2009; Smith et al. 2014, Solano et al. 2015). Christodoulopoulos (2009) reported in dairy goats that the prevalence of lameness fluctuated over the year, which could have corresponded to changes in the climate between seasons. In dairy cows, studies reported the prevalence of lameness changing over time, where more lameness was observed in Winter and Spring than in Summer (Rowlands et al. 1985; Clarkson et al. 1996; Haskell et al. 2006). Body condition score, which can also fluctuate over the milking season due to changes in the stage of lactation, has been associated with lameness in dairy cows (Randall et al. 2015). The current study indicates that the time of year could affect the prevalence of lameness and clinical lameness, and it should be considered a possible risk factor in future analyses.

The number of goats scored per locomotion scoring event varied between events for each farm (Appendix I, Figures 1 to 3). This may have influenced the prevalence, incidence rate, and duration of clinical lameness. Firstly, there were some logistical issues with the first locomotion scoring event. These issues were corrected at subsequent locomotion scoring events. Secondly, the first locomotion scoring event occurred at the beginning of the kidding season, corresponding to the introduction of goatlings (one-year-olds) into the main herd. The younger goats were less likely to walk back to the barns from the milking parlour in an orderly behaviour. The goatlings either trotted or stayed in the race around the milking parlour and obstructed other goats as they walked back to the barn. The obstruction from the goatlings reduced the number of young goats being scored during this time. Thirdly, fewer goats were recorded for farm A or had only one score in June 2020 because of technical issues with the cameras, so not all goats were recorded twice. Lastly, some goats were not scored due to environmental obstructions, including obstruction by surrounding goats or their behaviour, such as trotting or cantering instead of walking, as they exited the milking parlour. These three reasons could have influenced the results, resulting in an over-or underestimated lameness prevalence within the herd.

There were two visits on separate farms where there could be potential bias within the prevalence results. These visits occurred in farm A in July 2019 and Farm C in June 2020. For farm A, the locomotion scoring event occurred halfway through the farm's kidding season. Many goatlings were not scored for lameness at this event because they had yet to kid and enter the main herd. Due to the prevalence of clinical lameness in the younger age groups being lower than in older goats, the herd lameness prevalence could have been overestimated at this time point compared with the other two farms. Due to the covid outbreak, farm C postponed its last herd test from March 2020 until June 2020. By this time, half of their herd had already been dried off in preparation for the next kidding season. The change in the herd's age structure created a bias within the data at this time point because most of the younger goats (aged less than three years old) had been dried off. Due to lameness being more prevalent in the older goats and the possible selection against lame goats for breeding, lameness on this farm would have been overestimated in June 2020.

Since the logistics of lameness scoring have been developed within this study, the next phase of this research would be to conduct lameness scoring on multiple farms to identify risk factors associated with clinical lameness. Currently, the number of farms included in this sample is too small to look at the herd-level factors such as bedding type, herd size, bedding dryness, footbath or mat use, and other management issues associated with clinical lameness (Solano et al. 2015). Other variables that were not measured at the goat-level should be considered for future studies: presence of claw disorders or leg injuries, body condition score, and milk production. Investigating the diagnosis of clinical lameness was small part of this study (and will be discussed further in Chapter 7), where other clinical signs of leg or foot problems, such as inflammation, were not investigated as it was out of the scope of this study. Other clinical signs should be investigated further and would be interesting to study in goats that are clinically lame but without claw disorders. Body condition score and milk production are considered to be associated with lameness in dairy cows (Green et al. 2014, Solano et al. 2015). Milk production and its association with lameness in dairy goats will be discussed further in Chapter 8, while body condition score was not investigated in this study but should be considered for future research.

3.5.2 The incidence rate of clinical lameness

The clinical lameness incidence rate was higher in farm A than in farms B and C. To date, no studies have reported lameness incident rates on dairy goat or sheep farms. Only one meat goat study has reported annual incidence rates of lameness between 66 to 113 cases per 100 goats, which appears to be similar to the results estimated in my thesis (Browning Jr et al. 2011). Though it is unclear how Browning Jr et al. (2011) defined a lameness case as no locomotion scale was given. For dairy cows, the reported incidence rates are between 1.5-111.5 cases per 100 cows per year (Barkema et al. 1994; Clarkson et al. 1996; Hedges et al. 2001). The results from this study are similar to the results by Hedges et al. (2001), which reported an average lameness incidence rate of 70 cases per 100 cows across the year across 5 farms, with a range of 31.6 to 111.6 cases per 100 cows per year. In that study, the definition of clinical lameness used by the farmers and veterinarians identifying only lame cows was unclear, with authors mentioning that cases of mild lameness may have also been included. Clarkson et al. (1996) calculated the clinical lameness (scores >3 on a scale of 1-5) incidence rate, which was, on average, 18.3 cases per 100 cows across a year. This incidence rate was lower than the current study's incidence rate of clinical lameness. The current study's incidence rates are perhaps under-estimated: there were fewer visits per farm within a season than Clarkson et al. (1996) or Hedges et al. (2001), with 4 or 5 visits versus at least 3-11 visits per farm per year. In the study reported by Hedges et al. (2001), veterinarians were called out to treat cows when farmers found them lame, in addition to veterinarians visiting the farms every two months. Conversely, the assumption by Clarkson et al. (1996) that lameness events lasted 28 days, which was used to estimate the lameness duration, may not be valid for dairy goats. For example, in Appendix I, Figure 4, there were a number of goats that had been identified as having clinical lameness over a number of consecutive events indicating either multiple new cases of lameness or one lameness which endured for months.

A limitation to the interpretation of the results of this study is that the number of locomotion scoring events for each farm was different, and farmers did not record lameness events between locomotion scoring events. Farm A had five locomotion scoring events, while farms B and C only had four. Also, the time interval between locomotion scoring events was different. Incidence rate can be used to monitor lameness within a farm and is independent of the herd’s changing population (due to the entry and exit of goats). Including reliable information on lameness diagnosis and treatments between locomotion scoring events would improve the accuracy of the incidence rate and duration of lameness events at each farm.

3.5.3 Duration of clinical lameness

The duration of clinical lameness was significantly longer on farm A than on farm B or C. A difference in clinical lameness duration could be due to the inconsistencies in the treatment of lameness cases on each farm. Farm A did not have a treatment protocol, while farms B and C did have one. In dairy cows, it has been reported that the shorter the amount of time between diagnosis and treatment of lameness, the shorter the duration that the cow was lame (Barker et al. 2010). In dairy goats, the treatment reduced the lameness severity within one day of treatment (Christodoulopoulos, 2009). In the current study, it is unclear how the treatment affected the severity of lameness, as individual treatment of lameness cases was not followed. This is one aspect that should be investigated further.

The duration of lameness may be shorter or longer depending on the farmer's lameness management on the farm. For farm A the treatment of clinically lame goats was irregular and did not necessarily occur weekly. For farm B, the treatment of clinically lame goats was weekly, or sometimes a goat was drafted out the same day it was seen to be lame. Farm C was also irregularly treating clinically lame goats but changed its management to weekly treatment of the clinically lame goats over the year. The time between identification of clinical lameness and treatment would affect the goat's duration of being lame. This would either under-or over-estimate the incidence rate. Clarkson et al. (1996) reported this and suggested that a farm could have a high incidence rate but a short lameness duration. Therefore, duration is also an important factor in helping understand the effect of lameness on a farm.

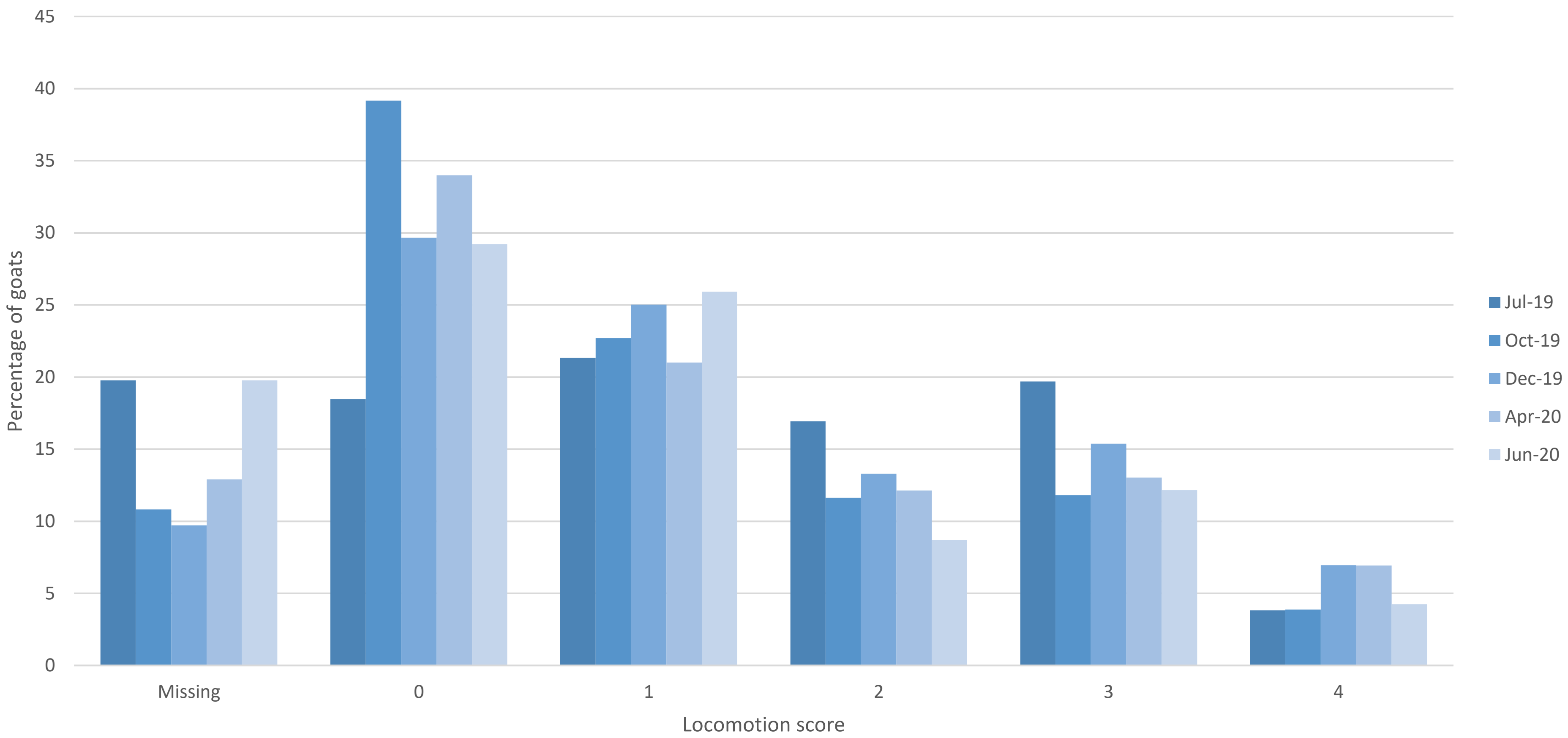
In this study, the duration of clinical lameness was calculated using the inverse of the cure rate. The duration of lameness would also be related to the number of consecutive times the goat was clinically lame (scored 3 or 4). The more times consecutively scored the goat was, the longer the duration of lameness. The percentage of times a goat was consecutively lame differed between the farms. There was a higher percentage of goats on farm A with consecutive events than on farms B and C. The higher number of goats with consecutive lameness could be why the duration of lameness appeared higher on this farm, despite having more farm visits (Appendix I, Figure 4). The cure rate assumed a limb could not be cured between lameness events and a new incidence of lameness on the same limb. In reality, this may not be the case because the problem may not be isolated to one claw from one foot. Alternatively, the cause of lameness could be higher up and be unrelated to the foot. Due to logistical reasons, information on the potential foot and leg problems was unavailable at the time of locomotion scoring.

3.6 Conclusion

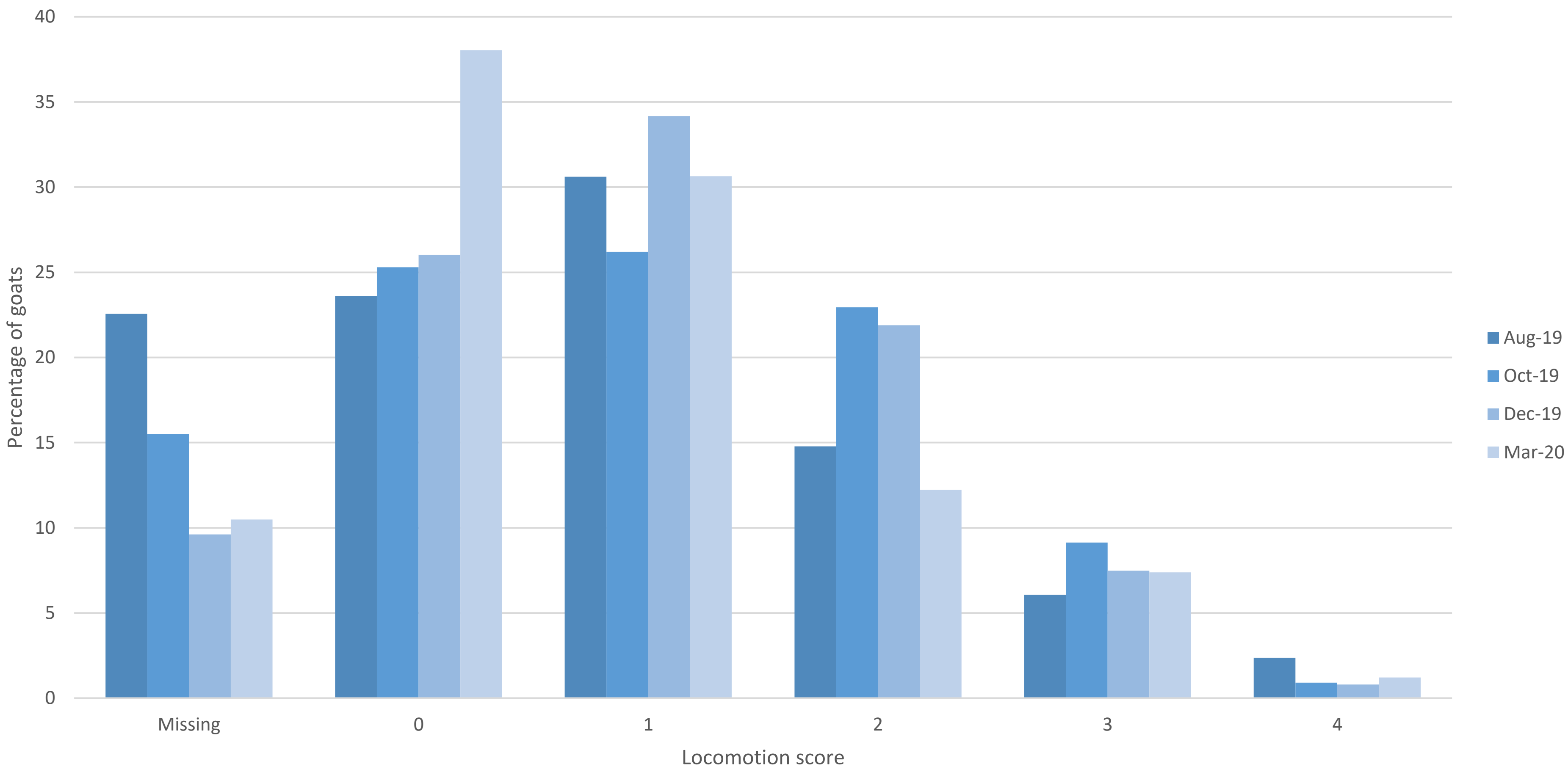
Clinical lameness is a problem within dairy goat farms in New Zealand. The average herd prevalence of clinical lameness across three farms was between 10 and 23%. The prevalence differed between farms and fluctuated over time. Therefore, the timing of locomotion scoring events should be considered when comparing farms within the same study and within the farm to accurately quantify the problem. This study creates a foundation for future epidemiological research to identify more risk factors associated with lameness and increase the understanding of lameness within dairy goat farms at a commercial level.

Appendix I

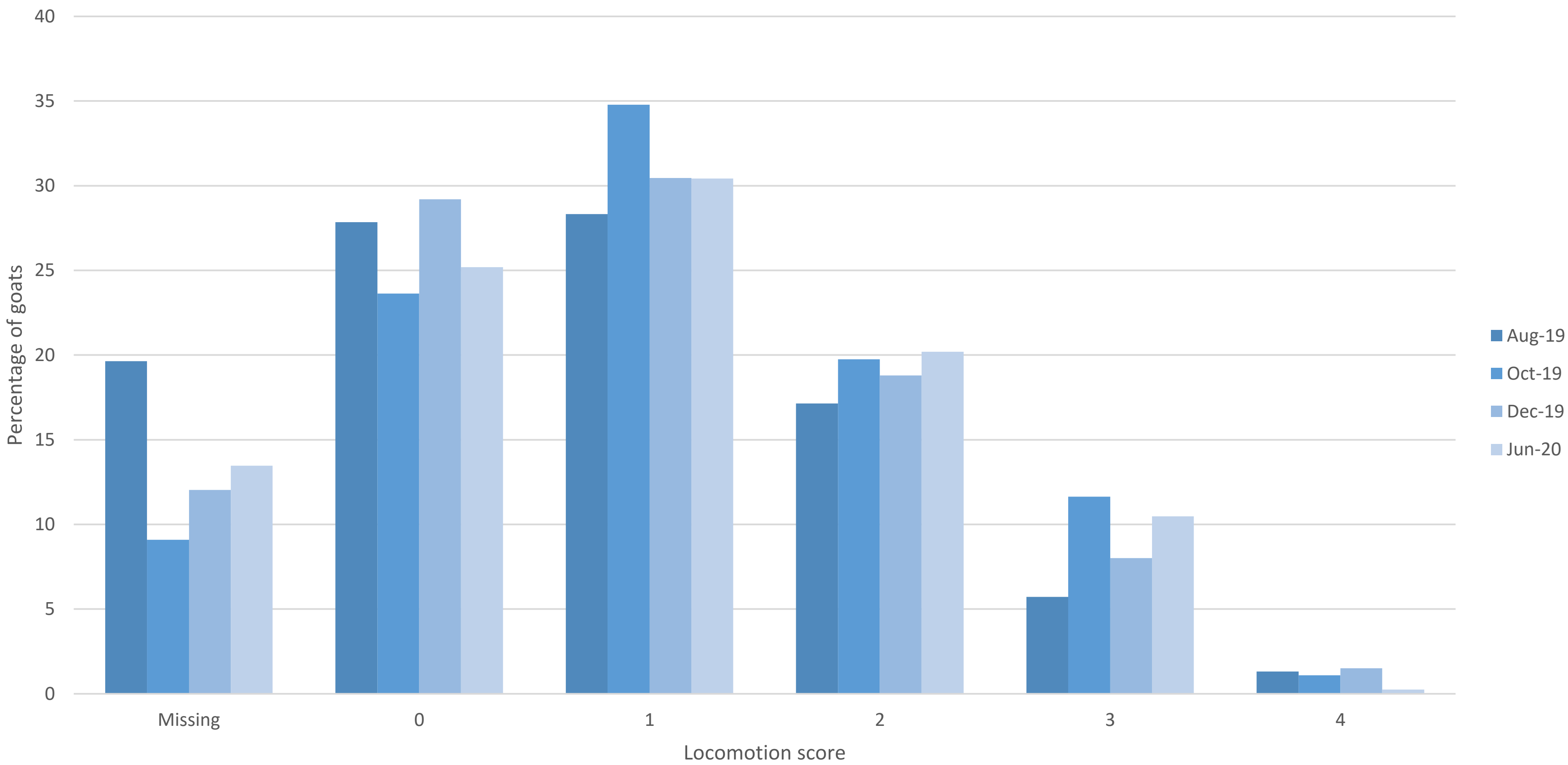
Supplementary information for Chapter 3



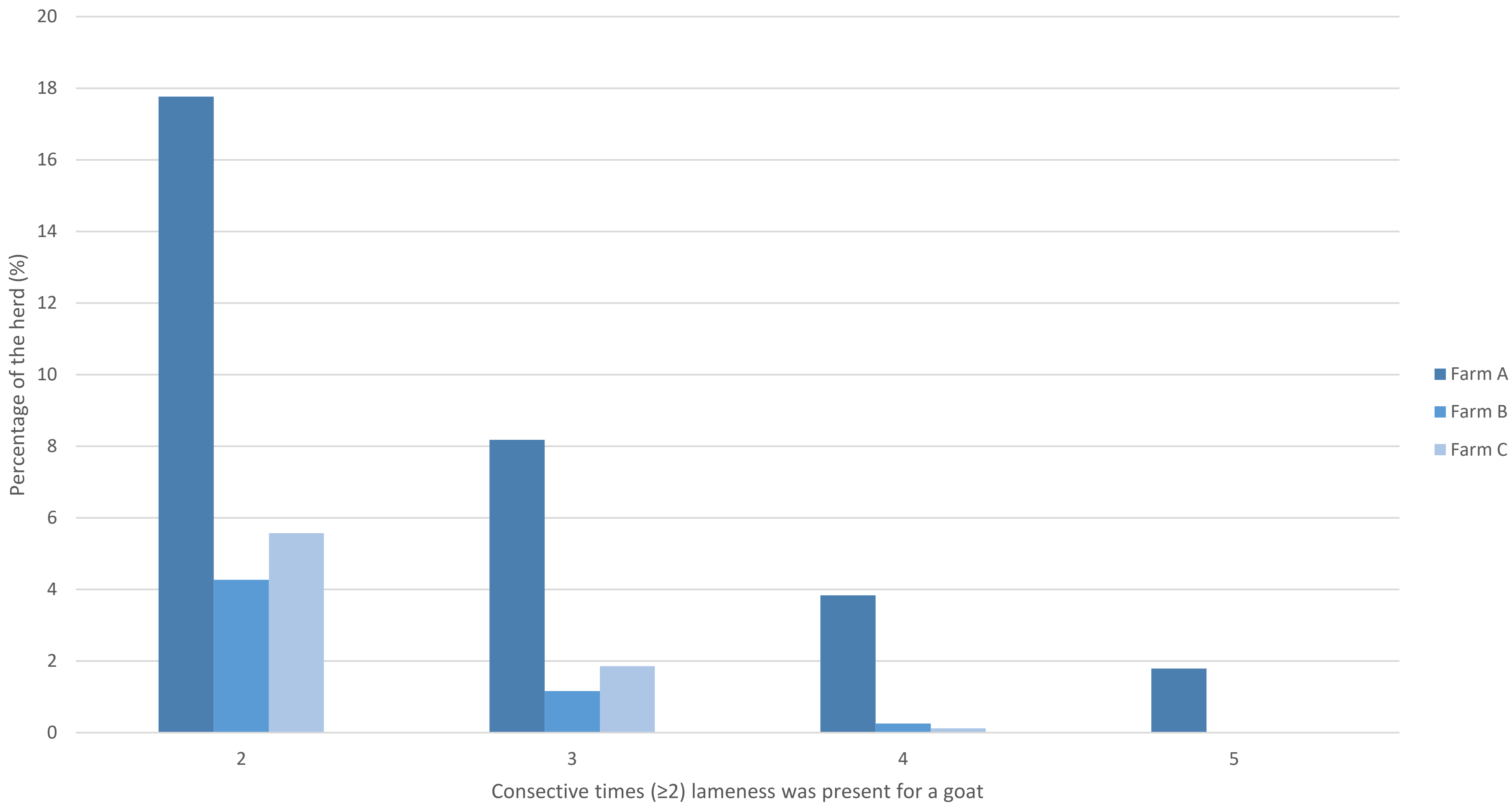
Appendix I Figure 1. The percentage of goats, across locomotion recording events within farm A that were classified within each locomotion score (including goats that did not have a score). The farm was located in Waikato, New Zealand.



Appendix I Figure 2. The percentage of goats, across locomotion recording events within farm B that were classified within each locomotion score (including goats that did not have a score). The farm was located in Waikato, New Zealand.



Appendix I Figure 3. The percentage of goats, across locomotion recording events within farm C that were classified within each locomotion score (including goats that did not have a score). The farm was located in Waikato, New Zealand.



Appendix I Figure 4. Percentage of dairy goats within the herd with consecutive clinical lameness events (locomotion score 3 or 4) across recording events within the 2019-2020 production year in three commercial farms (A, B and C). Farms were in Waikato, New Zealand.

Chapter 4

Risk factors of prevalence and incidence of clinical lameness on three New Zealand goat farms

4.1 Abstract

Clinical lameness has been identified as a problem within the dairy goat industry. This study aimed to evaluate risk factors associated with the prevalence and incidence of clinical lameness in dairy goats. Three dairy goat farms located in New Zealand participated in this study. The locomotion of goats was scored across 4 or 5 events within one year. Information on farm management, weather, animal age and parity was recorded. Goats within the dataset were split into 1,805 seasonal lactation goats with 6,422 observations and 1,385 extended lactation goats with 5,552 observations. A logistic regression model analysed risk factors associated with the prevalence of clinical lameness. Risk factors investigated were farm, age, season, stage of lactation, and deviation from the median kidding date. A Poisson regression model analysed risk factors associated with the incidence rate. Risk factors investigated were farm, age, and deviation from the median kidding date. The average prevalence of clinical lameness was between 13 to 22% depending on the farm. The average annual incidence rate of clinical lameness was between 27.5 to 127 cases per 100 goat-years depending on the farm. The odds of clinical lameness in goats on farms B and C were lower (between 0.42-0.59) than in farm A. The odds of clinical lameness prevalence in goats aged older than one was 1.18-2.39 times higher than in one-year-old goats. The odds of a goat, which had previously been clinically lame, having clinical lameness was 3.04-10.9 times higher than if the goat had not had a previous case of clinical lameness. This study identified the farm, the goat's age, and the previous clinical lameness status were factors significantly associated with the prevalence of clinical lameness in dairy goats. Farm and age effects were significantly associated with the incidence rate of clinical lameness.

4.2 Introduction

Lameness is a manifestation of pain, making it an animal welfare concern. It is becoming more evident that consumers are concerned about animal welfare through changes in their buying behaviour (Alonso et al. 2020). Animal welfare is an important aspect of farming and has recently been the subject of multiple studies on dairy goats (Anzunio et al. 2010; Muri et al. 2013; Hempstead et al. 2021). Lameness can be defined as the impairment of normal locomotion of an animal due to pain caused by an injury, disease, or claw disorder and is an indication of claw health (Vieira et al. 2015). The aetiology of lameness can be infectious and non-infectious. Infectious diseases of the claw are due to pathogenic bacteria or viruses that colonise on or within their host animal and cause injury when the conditions are favourable. Non-infectious factors are events that may predispose the animal to lameness, such as management, environment, and genetics (Mathews, 2016).

No risk analysis has been conducted on non-infectious factors associated with increased lameness prevalence and incidence rate in dairy goats. In meat and dairy goats, dairy cow and sheep studies, breed, age, the season's weather, and lactation stage were hypothesised to influence lameness prevalence within a herd (Eze, 2002; Christodoulopoulos, 2009; Browning Jr et al. 2011; Smith et al. 2014, Solano et al. 2015). Browning Jr et al. (2011) reported differences in the number of lameness cases per year between meat goat breeds and age groups. Christodoulopoulos (2009) reported that in dairy goats, the prevalence of lameness fluctuated over the year, which could have corresponded to seasonal change in climate (lameness prevalence highest in Spring) or stage of lactation or both. In dairy cows, other studies have also reported that the prevalence of lameness changed over time, where there was more lameness in winter and spring than in the summer associated with increased rainfall in the Spring and Winter compared with Summer (Rowlands et al. 1985; Hirst et al. 2002; Haskell et al. 2006). Body condition score also fluctuates over the milking season, and it is associated with lameness in dairy cows (Green et al. 2014; Randall et al. 2015). These are just some of the risk factors affecting the prevalence of lameness in past studies.

This study aims to identify some risk factors associated with lameness, specifically clinical lameness, prevalence and incidence rate in dairy goats. Risk factors associated with the prevalence refer to the odds of clinical lameness being present within a particular group. In contrast, risk factors associated with the incidence rate refer to the odds of clinical lameness developing within a particular group.

4.3 Materials and methods

4.3.1 Study background

Data were collected from three commercial dairy goat farms in the Waikato region of New Zealand from July 2019 to June 2020 (Chapter 3.3.3). All farms volunteered to participate in this study. The farms kept goats of various breeds, including Saanen, Toggenburg, Alpine and their crosses. The breed was not included as a risk factor as the accurate recording of the breed was inconsistent across farms. There were two classifications of goats- seasonal or extended lactation goats. Seasonal lactation goats had given birth between August and December 2019 and were ≤305 days in milk. Extended lactation goats had been milking for at least one year (>305 days in milk). The goats were milked twice a day. The bedding commonly used was wood shavings. There was a shortage of wood shavings from August 2019 to December 2019, meaning that the bedding was wetter for longer periods than usual. Information regarding rainfall during the 2019-2020 production year was collected from the National Institute of Water and Atmospheric Research Limited (Appendix II, Figure 1). Depending on the farm, locomotion scoring events were carried out 4-5 times a year. The 5-point locomotion analysis system analysed the goat's locomotion (Chapter 3, Table 3.2). More detailed information on the study design, farms involved, and the locomotion scoring procedure is given in Chapter 3.3.

4.3.2 Prevalence and incidence rate of clinical lameness

The prevalence of clinical lameness is the proportion of goats with clinical lameness present at one locomotion scoring event compared with the total number of goats scored at that event. The denominator is different across locomotion scoring events as not all goats in a herd were able to be scored at each event. The incidence rate of clinical lameness is the number of new cases of clinical lameness between July 2019 and June 2020. A new case was defined as a clinical lameness case more than 28 days from the last reported case. For an in-depth explanation of these calculations and the results, refer to Chapter 3.

4.3.3 Risk factors associated with clinical lameness

Several factors were considered risk factors for the prevalence (Table 4.1) and incidence rate (Table 4.2) of clinical lameness. For the analysis of risk factors, the dataset was split by their type of lactation. Goats were classified as being either seasonal or extended lactation goats.

Table 4.1. Independent variables that were considered as risk factors for the prevalence of clinical lameness in seasonal (≤305 days in milk) and extended (>305 days in milk) lactation goats from farms located in Waikato, New Zealand.

Factor	Seasonal lactation goats	Extended lactation goats
Farm	A, B, and C	A, B, and C
Age	1, 2, 3, and 4+	2 and 3+
Season	Not applied	Winter-Spring (June to November) Summer-Autumn (December to May)
Stage of lactation	Early (≤120 days) Late (>120 days)	Not applied
A previous case of clinical lameness	Yes or No	Yes or No
Deviation from the median kidding date	Covariate	Not applied

Table 4.2. Independent variables that were considered as risk factors for the incidence rate of clinical lameness in seasonal (≤305 days in milk) and extended (>305 days in milk) lactation goats from farms located in Waikato, New Zealand.

Factor	Seasonal lactation goats	Extended lactation goats
Farm	A, B, and C	A, B, and C
Age	1, 2, 3, and 4+	2 and 3+
Deviation from the median kidding date	Covariate	Not applied

The respective datasets contained 1,805 seasonal lactation goats with 6,422 observations and 1,385 extended lactation goats with 5,552 observations. The risk factors tested in each model depended on the lactation type (seasonal *vs.* extended lactation).

There were differences in the tested variables for the seasonal and extended lactation groups of goats. For the extended lactation goats, the season instead of the stage of lactation was used to determine if clinical lameness changed over time. Another difference was the omission of deviation from the median kidding date as a potential risk factor for extended lactation goats. These two differences are because there was a large variation in their last kidding date in the extended lactation group of goats. In this dataset, the stage of lactation and kidding date varied by years rather than days (over 1,000 days difference between goats). This large variation made it difficult to stratify the dataset by stage of lactation and by deviation from the median kidding date. Instead, the season was used, and the deviation of the median kidding date was omitted from this dataset.

Regarding both types of datasets, a previous case of clinical lameness refers to whether the goat was diagnosed as clinically lame at the previous locomotion scoring event or not. There were a couple of assumptions. Firstly, it was assumed that each goat had not been clinically lame before the first locomotion scoring event. Secondly, if the goat was not scored at an event, it was assumed that this goat was not clinically lame at this event.

The association of potential risk factors with the prevalence of clinical lameness was evaluated at the animal level and performed with a logistic regression model using the GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). The dependent variable was the clinical lameness status of the goat at each locomotion scoring event. The model included the fixed effects described in Table 4.1 and the random intercept of animal to account for repeated measures on the same goat. The GLIMMIX procedure with a logit link function and the residual marginal pseudo-likelihood (RMPL) method were used to analyse and fit the model. While fitting the model, the residual dispersion was monitored, where a generalised chi-square statistic and the degrees of freedom close to one indicated that over-dispersion was not present (Schabenberger, 2005). The log estimate, standard errors, odds ratio, and 95% confidence intervals are presented. The differences between the means were adjusted with the Tukey correction.

The incidence rate of clinical lameness was the number of new clinical lameness cases between the first and last scoring event (between July 2019 and July 2020). The association of potential risk factors on the incidence rate of clinical lameness was analysed at the animal level and performed with a Poisson regression model, using the GENMOD procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). The model included the fixed effects described in Table 4.2. The Akaike Information Criterion (AIC) was used to measure the model's goodness of fit, where the lower the AIC, the better-quality model. The model included an offset, the log-transformed sum of days at risk, to account for the effect of time. A Poisson distribution was used to transform the data. A Lagrange Multiplier test was used to determine if there was overdispersion within the models. If there was overdispersion, the negative binomial distribution was used as the alternative binomial distribution (Yang and Berdine, 2015). The differences between marginal means were adjusted with the Tukey correction.

4.4 Results

4.4.1 Risk factors associated with the prevalence of clinical lameness

For seasonal goats, the predictors retained in the model were farm, age, stage of lactation, and the presence of a prior case of clinical lameness (Table 4.3). The average prevalence of clinical lameness varied from 0.13 (farm C) to 0.22 (farm A). The odds of clinical lameness on Farms B and C were 0.61 and 0.51 times less than farm A. There was a significant interaction between age and stage of lactation and between age and the presence of a prior case of clinical lameness. Age interacted with two predictors, stage of lactation and previous cases of lameness. The odds of clinical lameness being present in one-year-olds in early lactation were significantly higher than in late lactation (OR = 0.47, 95% CI [0.27-0.82]). This trend was also significant in goats four years and older. Overall, the odds of clinical lameness increased as the goats became older. Goats diagnosed as clinically lame at the previous locomotion scoring event had significantly increased odds of presenting with clinical lameness at the next locomotion scoring event (OR range 2.24 to 10.9, P-value = 0.01 to <0.001).

For goats undergoing extended lactations, farm, age, and the interaction between farms and a previous case of lameness were significant factors associated with the prevalence of clinical lameness being present (Table 4.4). Similar to the seasonal lactation goats, the odds of clinical lameness being present on farms B and C were significantly lower (OR= 0.45-0.48, P-value <0.001) than farm A, although they were not significantly different from each other. The odds of clinical lameness being present in goats aged three or over were significantly higher than for two-year-old goats in Winter-Spring and Summer-Autumn (OR = 2.11-2.23, P-value <0.001). The odds of clinical lameness being present in the Summer-Autumn period were higher than in the Winter-Spring period, however, it was not significant across ages (P-value >0.05). The odds of clinical lameness being present in goats previously diagnosed at the previous locomotion scoring as clinically lame were higher than if there had been no previous clinical lameness (OR = 3.02, 95% CI [2.53-3.60]).

Table 4.3. Risk factors associated with the prevalence of clinical lameness and odd ratios in <u>seasonal lactation</u> goats (≤305 days in milk) located on three commercial dairy goat farms in Waikato, New Zealand, during the production season 2019-2020.

Predictors		Estimate (SE)	Mean (SE)	Odds Ratio	95% CI	P-value
Farm	A	-1.24 (0.08)	0.22 (0.01)	Reference		
	B	-1.73 (0.09)	0.15 (0.01)	0.61	0.47 -0.80	<0.001
	C	-1.91 (0.12)	0.13 (0.01)	0.51	0.38 -0.70	<0.001
Age	1	-1.94 (0.11)	0.13 (0.01)	Reference		
	2	-2.07 (0.14)	0.11 (0.01)	0.88	0.56 -1.36	0.868
	3	-1.29 (0.11)	0.22 (0.02)	1.92	1.29 -2.85	<0.001
	4+	-1.21 (0.09)	0.23 (0.02)	2.09	1.47 -2.95	<0.001
Stage of lactation	Early	-1.51 (0.09)	0.18 (0.01)	Reference		
	Late	-1.74 (0.08)	0.15 (0.01)	0.79	0.65 -0.97	0.023
Previously lame	No	-2.51 (0.06)	0.07 (0.00)	Reference		
	Yes	-0.74 (0.11)	0.32 (0.02)	5.89	4.70 -7.39	<0.001

Table 4.3 continued

Predictors			Estimate (SE)	Mean (SE)	Odds Ratio	95% CI	P-value
Age x Stage of lactation	1	Early	-1.57 (0.14)	0.17 (0.02)	Reference		
		Late	-2.32 (0.15)	0.09 (0.01)	0.47	0.27 -0.82	0.001
	2	Early	-2.24 (0.21)	0.10 (0.02)	0.72	0.38 -1.36	0.761
		Late	-1.90 (0.17)	0.13 (0.02)	0.51	0.24 -1.06	0.097
	3	Early	-1.23 (0.16)	0.23 (0.03)	1.25	0.69 -2.26	0.953
		Late	-1.35 (0.14)	0.21 (0.02)	1.40	0.75 -2.60	0.724
	4+	Early	-1.00 (0.12)	0.27 (0.02)	1.17	0.69 -1.98	0.987
		Late	-1.41 (0.11)	0.20 (0.02)	1.76	1.05 -2.96	0.022

Table 4.4. Risk factors associated with the prevalence of clinical lameness and odd ratios in extended lactation goats (>305 days in milk) located on three commercial dairy goat farms in Waikato, New Zealand, during the production season 2019-2020.

Predictors			Estimate (SE)	Mean (SE)	Odds Ratio	95% CI	P-value
Farm	A		-0.85 (0.07)	0.30 (0.01)	Reference		
	B		-1.65 (0.15)	0.16 (0.02)	0.45	0.32 -0.64	<0.001
	C		-1.58 (0.12)	0.17 (0.02)	0.48	0.37 -0.63	<0.001
Age	2		-1.63 (0.13)	0.16 (0.02)	Reference		
	3+		-1.09 (0.07)	0.25 (0.01)	1.72	1.36 -2.19	<0.001
Season	Winter-Spring		-1.46 (0.10)	0.19 (0.02)	Reference		
	Summer-Autumn		-1.26 (0.10)	0.22 (0.02)	1.22	0.99 -1.50	0.0567
Previously lame	No		-1.91 (0.08)	0.13 (0.01)	Reference		
	Yes		-0.81 (0.11)	0.31 (0.02)	3.02	2.53 -3.60	<0.001
Age x Season	2	Winter-Spring	-1.86 (0.16)	0.13 (0.02)	Reference		
		Summer-Autumn	-1.41 (0.16)	0.20 (0.02)	1.58	0.97 -2.59	0.0807
	3+	Winter-Spring	-1.06 (0.08)	0.26 (0.01)	2.23	1.48 -3.38	<0.001
		Summer-Autumn	-1.12 (0.08)	0.25 (0.01)	2.11	1.38 -3.21	<0.001

4.4.2 Risk factors associated with the incidence rate of clinical lameness

Farm and age effects were significantly associated with the incidence rate of clinical lameness for seasonal and extended lactation goats (Tables 4.5 and 4.6). The annual mean incidence rate varied from 28.5 and 65 (farm C) to 67.7 and 127 (farm A) cases per 100 goat-years at risk for seasonal and extended lactation goats. The incidence rate of clinical lameness in goats on farms B and C was significantly lower than on farm A (P-value <0.05). The risk of clinical lameness developing increased as the goat age increased. In seasonal lactation goats, the odds of clinical lameness developing for a goat four years of age or older were 2.85 times greater than a one-year-old goat (P-value <0.001). For extended lactation goats, the risk of a goat three years of age or older developing clinical lameness was 1.52 times greater than a two-year-old goat.

Table 4.5. Risk factors associated with the incidence rate of clinical lameness in seasonal lactation goats (≤305 days in milk) located on three commercial dairy goat farms in Waikato, New Zealand, during the production season 2019-2020.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR[2]	95% CI	P-value
Farm	A	-6.29 (0.09)	67.7 (5.84)	Reference		
	B	-6.63 (0.11)	48.1 (5.37)	0.71	0.51 -0.98	0.037
	C	-7.16 (0.16)	28.5 (4.45)	0.42	0.28 -0.64	<0.001
Age	1	-7.23 (0.15)	26.5 (3.87)	Reference		
	2	-7.05 (0.16)	31.6 (5.00)	1.20	0.69 -2.08	0.842
	3	-6.31 (0.13)	66.4 (8.72)	2.50	1.48 -4.25	<0.001
	4+	-6.18 (0.10)	75.5 (7.92)	2.85	1.79 -4.53	<0.001
Deviation from the median kidding date		0.001 (0.004)	-	-	-	0.767

[1]Annual cases per 100 goat-years at risk.

[2]Incidence rate ratio.

Table 4.6. Risk factors associated with the incidence rate of clinical lameness in <u>extended lactation</u> goats (>305 days in milk) located on three commercial dairy goat farms in Waikato, New Zealand, during the production season 2019-2020.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR[2]	95% CI	P-value
Farm	A	-5.66 (0.07)	127 (8.40)	Reference		
	B	-6.14 (0.17)	78.5 (13.0)	0.62	0.42 -0.92	0.012
	C	-6.33 (0.13)	65.0 (8.14)	0.51	0.38 -0.68	<0.001
Age	2	-6.26 (0.13)	70.1 (9.20)	Reference		
	3+	-5.84 (0.07)	107 (7.30)	1.52	1.18 -1.96	0.001

[1]Annual cases per 100 goat-years at risk.

[2]Incidence rate ratio.

4.5 Discussion

The prevalence and incidence rate of clinical lameness was significantly different across farms suggesting that farm management influenced the occurrence or development of clinical lameness regardless of lactation type. The average prevalence of clinical lameness for the farms ranged from 13 to 22%. The average annual incidence rate for clinical lameness varied from 27.5 to 127 cases per 100 goat-years. For seasonal and extended lactation goats, the prevalence of clinical lameness was associated with effects of farm, goat age, and whether goats have had a previous case of lameness.

Management factors that have been reported to affect the prevalence of clinical lameness in dairy cows, which may be relevant to dairy goats, are herd size, time spent away from the barn, condition of the bedding, conditions within the milking parlour, and treatment time (Barker et al. 2010; Jewell et al. 2019). Studies reporting herd size's effects on lameness prevalence have reported that a larger herd size increases the cows' odds of lameness (Barker et al. 2010; Oehm et al. 2019). Despite the current study not including herd size as a factor due to the small sample size, Farm A, the largest herd, did have the highest prevalence and incidence rate of clinical lameness, supporting this hypothesis. With the stocking rate being similar across all farms, the relationship between herd size and lameness prevalence could be due to farm management and the lack of time staff may have to treat lame goats within a day.

Like dairy cows, dairy goats are away from their barns for a certain about of time each day. In this study, depending on the order the goat was milked in, some goats could spend up to 4 hours a day standing on a wet concrete surface away from their barn. In dairy cows, cows that spend ≥3 hours from the barn are reported to be two times more likely to be clinically lame (Jewell et al. 2019). One reason for this could be that most lame cows are found in the last group coming through the milking parlour (Beggs et al. 2019). Standing and walking on concrete for long prolonged periods has been associated with an increased risk of claw or leg disorders developing and leading to lameness in dairy cows (Cook and Nordlund, 2009; Bell et al. 2009; Griffiths et al. 2018). This is one aspect that could be investigated further in dairy goats.

Wet bedding was also reported to increase the odds of a dairy cow being lame by 2.5 times (Jewell et al. 2019). For cows, the prolonged period of being in a damp environment causes the hoof to absorb the water and become soft. This softness has been linked to the increasing severity of hoof lesions (Borderas et al. 2004; Flower and Weary, 2006). For goats, their feet were exposed to a lot of moisture or slurry on the three farms. A slurry was created when urine or water was combined with their faeces, similar to dairy cow slurry. This happened mainly in the milking parlour but could happen in the barns close to the feeding passage. The area in front of the feeding passage was relatively wet due to farmers feeding fresh-cut grass (which has a higher water content than grass silage; DairyNZ, 2021). Anecdotally within the current study, the barn conditions may have been worse within the winter-spring period, which is most likely due to increased levels of rain in the region (Appendix II, Figure 1). According to interview records, the farmers may not have topped up or replaced the bedding daily due to logistics and only replaced it when necessary, which is potentially too late in its effects on the goat's feet. In dairy cows, increased wetness of the bedding and the milking parlour waiting area would also contribute to poor leg hygiene; poor leg hygiene has been associated with lameness (Sadiq et al. 2017). Finding alternative approaches to keeping bedding dry, such as feeding out differently or increasing the number of times the bedding is replenished, keeping in mind the logistics of practices, would be important to improving dairy goat foot health.

The conditions of the milking parlour, such as surface type, could also affect lameness in dairy goats. Another aspect of milking that increased lameness in dairy cows was cows pushing each other and turning sharply into the milking parlour entrance. Barker et al. (2010) reported that this phenomenon increased lameness within the herd. This scenario occurs in the dairy goat farms within the current study and usually arises at the beginning of each group entering the milking parlour. This could be an aspect to explore in the future.

A few studies have reported that the time of treatment after lameness identification is significant with lameness prevalence within the herd (Dembele et al. 2006; Bell et al. 2009; Barker et al. 2010). Barker et al. (2010) reported that treating a lame cow after 48 hours decreased the prevalence of lameness within a herd. The other studies reported associations between lameness frequency and workers not being proactive in detecting and treating lame cows (Dembele et al. 2006; Bell et al. 2009). Anecdotally within this study, farm A had limited resources to treat and effectively monitor lame goats over time due to the large numbers of lame goats present. In contrast, farm B was more proactive in identifying lame goats and routinely treated lame goats at least once a week. While farm C did not have protocols, they were proactive in treating lame goats with antibiotics as they were detected within the herd. This lameness management may have impacted the results of this study, where farm A had significantly higher prevalence and incidence rate levels of clinical lameness than farms B and C. Time of lameness treatment in dairy goats could be an important factor in maintaining low levels of lameness within the herd.

Prevalence and incidence rates of clinical lameness were significantly higher in older goats (four-year-olds or older) than in younger goats. This has been reported in meat goats within the US, where 2-year-old does had a significantly lower number of cases per year than goats 4-year-old and older (0.66 verses 0.98-1.13 cases/doe/year; Browning et al. 2011). In dairy cows, older cows had a higher probability of being lame within a herd (Onyiro et al. 2008; Solano et al. 2015; Jewell et al. 2019). Cows in their fourth or higher lactation (roughly five years of age or more) were 7.58 times more likely to be lame than cows in their first lactation (roughly two years of age; Jewell et al. 2019). In dairy cows, age was linked with body condition scores. Older cows with a body condition score ≤2.5 (on a scale from 1 to 5; Vasseur et al. 2013) had a higher probability of becoming lame than the other cows. This relationship was also reported by Solano et al. (2015). However, it is currently debated whether lameness causes a lower body condition score or if lameness results from a lower body condition (Solano et al. 2015). Extended lactation goats may still be within a positive energy balance at the start of a 'new season' compared with seasonal lactation goats, which start with a negative energy balance (Douhard et al. 2013). Therefore, the association between lameness and body condition could differ between the two lactation types as they progress across the year or season. This debate around body condition score and lameness could be elucidated further in dairy goats by comparing seasonal and extended lactation goats, including measures of body condition score and energy balance.

Another aspect of being an older goat is the length of time the animal has been in its environment. This includes continual exposure to direct environmental pressures such as wet bedding, and continual stresses such as metabolic changes, kidding stresses, and perhaps deficiencies in their housing or nutrition, which may increase their susceptibility to lameness (Solano et al. 2015; Oehm et al. 2019). These conditions could contribute to the reoccurrence of lameness in milking animals.

In this study, seasonal lactation goats with a previous case of clinical lameness increased the odds of the clinical lameness occurring again. For extended lactation goats, the odds of clinical lameness being present also increased if the goats had had a previous case of clinical lameness, however, this relationship was different between farms. There was no interaction between farm type and previous clinical lameness cases in seasonal lactation goats. In extended lactation goats, there was a significant interaction between age and previous clinical lameness case, however, this interaction was insignificant when the interaction between farm and previous clinical lameness was added to the model. The model was better (lower AIC) when the interaction between farm and previous clinical lameness was used rather than having no interaction present. The association of previous lameness cases with increased odds of a goat experiencing another case of clinical lameness has also been reported in dairy cows (Green et al. 2014; Randall et al. 2018). There were no interactions between farm or age in these studies. Clinical lameness susceptibility could have a genetic or environmental aspect or both and could contribute to the animal's lameness reoccurring more often.

In general, the prevalence of clinical lameness was higher in early lactation than in late lactation and increased with age. If there is an interaction between the stage of lactation and age, the prevalence of clinical lameness was not the same between stages of lactation across goat ages. For example, in one-year-olds goats, the prevalence of clinical lameness was significantly higher in early lactation than in late lactation. This was not seen in two-year-old goats. One explanation would be that two-year-old goats would have been physically more mature than one-year-old goats and perhaps have a higher body condition score than one-year-old goats, which would still be growing in their first year of lactation.

This contradicts the results reported from dairy cow studies (Solano et al. 2015; Jewell et al. 2019), where the risk of lameness increased with the increasing stage of production. Jewell et al. (2019) postulated the occurrence was linked to changes in body condition score and milk production. It is hypothesised that an increased risk of lameness is related to a lower body condition score (Green et al. 2014; Solano et al. 2015) and a thin digital cushion (Jewell et al. 2019; Bichalho et al. 2009). Bichalho et al. (2009) reported a significant positive association between body condition score and digital cushion thickness. Solano et al. (2015) reported that a body score condition score ≤ 2.5 increased the odds of lameness by 1.6 times. These previous studies, supported by Stambuk et al. (2018), reported the relationship between digital cushion thickness and body condition score that both change over time, and was an important predictor of lameness and non-infectious claw disorders, such as white line disease and sole ulcers, in dairy cattle. It is unclear why the stage of lactation was only significant for one-year-old dairy goats. Perhaps by including more goats from more than three farms, this relationship between the stage of lactation and lameness will be clarified. Including body condition score measurements would also help clarify the relationship between the stage of lactation and the risk of lameness.

In dairy goats, the season was hypothesised to be a risk factor for lameness. Christodoulopoulos (2009) reported a significant association between season and lameness. Most lameness' occurred between December and June, peaking in April. This occurred during or just after the wet period in Greece. Despite not being significant, Eze (2002) reported more lameness in Nigeria's wet season than in the dry season. The current study reported no significant difference in clinical lameness prevalence between seasons. A reason that there was no influence of time on the occurrence or development of clinical lameness in this study could be the goats were indoors and less exposed to changes in weather conditions. However, the p-value for the effect of the season (0.0567) suggests further investigation to validate this risk factor, including measures of temperature and relative humidity inside the shed.

Other factors associated with lameness in meat goats and dairy cows are breed, milk production and the amount of concentrate in the diet. In meat goats, the occurrence of lameness between breeds was significantly different (Browning Jr et al. 2011). Boer goats had a significantly higher number of cases than Kiko and Spanish goats. As the breed records of goats were not precisely recorded, the association between breed and lameness could not be estimated. Dairy cows that produce more milk on average are at an increased risk of developing lameness (Onyiro et al. 2008; Green et al. 2014). Feeding large amounts of concentrates have also been associated with an increased risk of lameness (Griffiths et al. 2018). Information on the classification of high or low producing dairy goats was obtained and will be further investigated in Chapter 8. The amount of concentrates fed to goats was not recorded, and the nutrition and its relationship with lameness need further investigation in dairy goats.

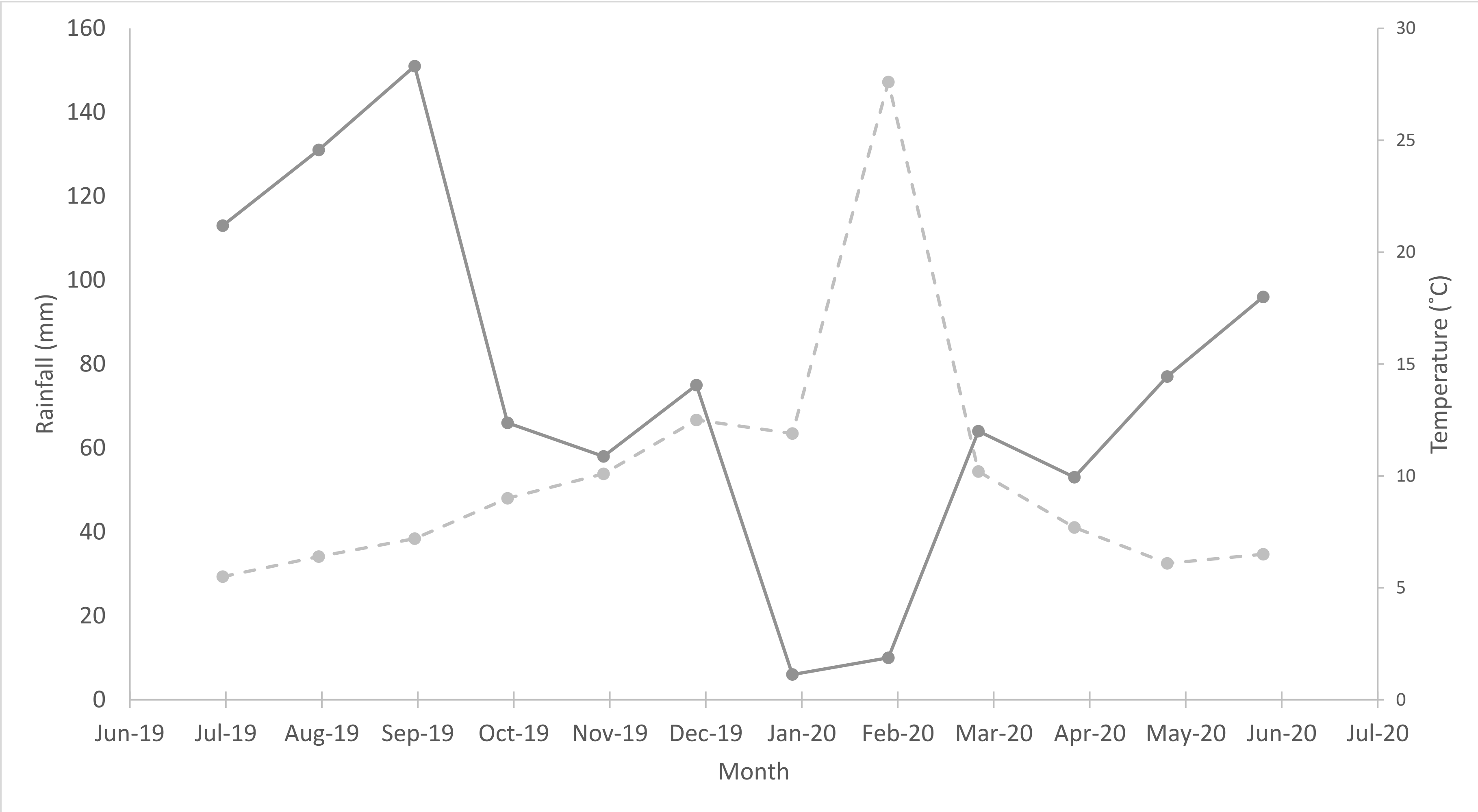
There are a few limitations of this study to acknowledge. Firstly, the farms were only visited four or five times a year. As a result, goats that had become lame but recovered between the recording events would not have been included in the analysis. Secondly, the assumption that one lameness event lasts 28 days may also not be true. These two factors would have affected the incidence rate of the study and subsequent risk factors. Thirdly, this study has a small sample size, so we could not evaluate herd-level factors that may increase the risk of clinical lameness, such as the effect of foot bathing on lameness. Lastly, seasonal and extended lactation goats had a mixture of goats in different age and parity combinations. For example, dairy goats can have a mismatch between their age and their parity, whereas a three-year-old can be a parity 1, 2 or 3. In this study, 51.7% of the goats had a mismatch between their age and parity. For this reason, age instead of parity was used in the model. If there was a larger sample size, the age-parity interaction should be investigated to dissociate the effects of age from parity on clinical lameness' prevalence and incidence rate.

4.6 Conclusion

This study identified that farm, age, stage of lactation and history of clinical lameness are risk factors associated with the prevalence of clinical lameness. Farm and age effects were significantly associated with the incidence rate of clinical lameness. The prevalence of clinical lameness was estimated between 13 to 22%, which indicates that lameness is an issue for the New Zealand goat industry. Training farmers to detect early lameness and implementing proactive treatment protocols may decrease the prevalence of lameness and potential reoccurring cases of clinical lameness.

Appendix II

Supplementary information for Chapter 4



Appendix II Figure 1. Average rainfall (solid circle, solid line) and average temperature (solid circle, dashed line) in the Hamilton area (Station: Hamilton, Ruakura), within the Waikato region of New Zealand, over the 2019-2020 production year. Source: NIWA; https://niwa.co.nz/climate/monthly

Chapter 5

Prevalence, incidence rate and duration of three claw disorders in three dairy goat herds

5.1 Abstract

Claw disorders are one of the causes of lameness, which is a well-known welfare indicator on farms. The claw disorders present on commercial dairy goat farms in dairy goats are poorly understood. The study aimed to determine the prevalence and incidence rate of common claw disorders on New Zealand dairy goat farms. Three dairy goat farms participated in this research study and were visited 4 or 5 times during routine hoof trimming events between July 2019 and June 2020 production year. A total of 3,200 goats were observed. The presence and severity of claw disorders were recorded at the time of hoof trimming. Prevalence was calculated at the animal level, while the incidence rate was calculated at the foot level. Prevalence was defined as the number of animals with at least one claw disorder by the number of animals trimmed. The incidence rate was determined by the number of new cases by the total number of animals trimmed between June 2019 and June 2020. The duration of claw disorders was calculated as the reciprocal of the cure rate.

Horn separation, rot and granulomas were identified as the main claw disorders. Horn separation, diagnosed as moderate to severe white line disease, was the most common claw disorder on all three farms. All three claw disorders fluctuated during the production year, though they all tended to peak around November - December 2019. On the farm with the highest prevalence of claw disorders (83%), the majority of cases were horn separation. On the second farm, the highest prevalence of rot (19%) and granuloma (14%) were concurrently recorded. The incidence rate for the claw disorders paralleled the prevalence results, where horn separation had the highest incidence rates (57-118 cases per 100 foot-years) across all farms compared with rot and granulomas. Recovery from granulomas was estimated to take the longest, with the median time ranging from 86-125 days, depending on the farm.

This study suggests that claw disorders are present on at least three New Zealand goat farms and at high levels. Due to the differences between farms, it is important to conduct a larger study to identify potential management risk factors for these claw disorders. This study also reports the importance of quantifying the types of claw disorders present within commercial dairy goat farms to obtain a baseline of results to work from and to provide farmers with additional health information on their herds.

5.2 Introduction

Lameness is a broad topic; this study targets claw disorders causing lameness. Lameness is an impairment of normal locomotion due to pain caused by an injury, disease, or claw disorder (Hill et al. 1997; Vieira et al. 2015). Claw disorders are caused by infectious diseases and non-infectious factors (Mathews, 2016).

Pathogenic bacteria cause infectious claw diseases that colonise within the foot tissue when conditions are favourable and can potentially lead to lameness. Infectious claw disorders identified as problematic in dairy goats are footrot and contagious caprine digital dermatitis (Mathews, 2016). Footrot develops because the bacteria, *Dichelobacter nodosus* has infected and cultivated on the claw of the foot. It is thought that a synergic interaction between the bacterium *D.nodosus* and *F.necrophorum* exists, increasing the footrot's severity. Upon entry into the claw, *D.nodosus* begins degradation of the connective tissue (collagen) between the horn and hoof flesh. Subclinical infection can occur within the skin for months while the clinical symptoms are underrunning the horn, lesions in the claw and sole, inflammation of the interdigital skin area, pus and a foul odour (Stewart, 1989; Mulvaney, 2013). It usually affects both claws of the goat and develops within 10-20 days of exposure (Maulin and Peters-Kennedy, 2016).

Contagious caprine digital dermatitis, caused by *Treponema spp.*, shares similarities with the footrot, bovine digital dermatitis, and contagious ovine digital dermatitis, however, significant differences have been reported. Groenevelt et al. (2015a) confirmed that this disease in goats was clinically different to previous reports in cows or sheep. Firstly, the *Treponema* species identified in goat lesions have also been different from sheep and cattle *Treponema* species. Secondly, in goats, the lesions could also start on the claw sole, in contrast to the coronary band previously reported on sheep and cattle. It is hypothesised that contagious caprine digital dermatitis develops as a second infection from a primary lesion. Lastly, the symptoms of infection from *Treponema spp* are similar to footrot except that there is no underrunning of the claw horn or infection of the interdigital space. It has also been hypothesised that there could be some interaction between *Dichelobacter spp* and *Treponema ssp* through the presence of both species of bacteria in the same areas on the claw (Groenevelt et al. 2015a, 2015b; Sullivan et al. 2015).

Non-infectious diseases of the claw can develop for a variety of reasons. These variables include the climate, the animal's genetics, nutrition, environment, management, or a combination of the previously mentioned factors (Mathews, 2016). In some cases, non-infectious diseases can predispose the claw to infectious diseases (secondary infection). Additionally, not all non-infectious claw disorders can cause lameness.

Some studies have indicated non-infectious claw disorders such as white line disease and granulomas to be causes of lameness in dairy goats (Hill et al. 1997; Christodoulopoulos, 2009; Groenevelt et al. 2013). White line disease is the disruption or damage to the normal formation of the white line area. Many factors can disrupt the white line area, including laminitis, foreign object penetration, and mechanical stresses. Anything that contributes to increased corium inflammation, or the disruption in blood flow in that area, reduces the horn quality and can weaken and widen or haemorrhage the white line area. A weakened and widened white line increases the risk of white line separation and the infiltration of pathogens into the claw's exposed area, as this is the weakest part of the claw, causing secondary infections (Shearer et al. 2015). Granulomas are a collection of immune cells found in addition to inflammation of the surrounding area. Granulomas are hypothesised to be caused by primarily traumatic events such as severe hoof trimming or the development of abscesses followed by ulceration (Winter, 2011).

While there has been some published information on claw disorders in dairy goats (Hill et al. 1997; Sailer et al. 2021), there has been no information on the incidence rate and duration of claw disorders. The prevalence of claw disorders can be defined as the proportion of cases within a herd at a given hoof trimming event (Dohoo et al. 2003). To understand claw disorders' dynamic nature, we need to understand how the prevalence of claw disorders may change over time. The incidence rate was defined as the number of new lameness cases between two time points (Dohoo et al. 2003). The duration was defined as the inverse of the cure rate (Tumwine et al. 2005).

In dairy goats, claw disorders associated with lameness have been linked with impaired welfare, reduced fertility, production and longevity (Eze, 2002; Christodoulopoulos, 2009). A lame dairy goat with low milk production and reduced fertility would increase its chances of being culled prematurely and thus reduce the expected income from dairy goat farming (Solis-Ramirez et al. 2011). There has been no large-scale monitoring of claw disorders of entire dairy goat herds farmed commercially to date. This study aimed to describe, classify, and quantify claw disorders in three commercial dairy goat herds in New Zealand.

5.3 Materials and methods

5.3.1 Study population

A full description of the study population is provided in Chapter 3.3. Briefly, three dairy goat farms were enrolled in the study on a volunteer basis. There was a mixture of extended lactation and seasonal goats on the three farms. The goats were made up of pure- and cross-bred goats.

5.3.2 Development of claw disorder scoring system

Appendix III, Table 1 describes the claw disorder severity categories created based on the results of a pilot study conducted on farm A (results not shown) and on the findings of Foddai et al. (2012). During a pilot study conducted in April 2019 on farm A, the most frequently observed claw disorders were granulomas, rot, and severe white line claw disorders. White line claw disorders will be referred to as horn separation. Rot encompassed all infectious diseases bacteria may cause because the rot was not limited to the soft tissues of the interdigital space commonly associated with footrot. A four-point foot integrity scale was used to classify rot (Foddei et al. 2012), encompassing footrot and digital dermatitis. White line claw disorder included horn separation between the white line and the sole. Less severe white line claw disorders, such as widening of the white line, were also considered. However, due to the time it took, the hoof trimmers' inconsistency in identifying it and severe white line claw disorders being relatively common in dairy goats, we limited our recording to minor to extensive horn separation (Winter and Arsenos, 2009). A three-point severity score was developed for granulomas and horn separation due to the absence of available measurement scales. In cases where the goats had more than one separation case on one foot, the most severe separation case was recorded. Other recorded claw abnormalities were abscesses, hard claws, platforms, healing rot and separation/scar tissue, interdigital hyperplasia, irregular foot conformation, haemorrhaging, foot scald and blood blisters.

The claw disorder scores were developed during the pilot study: the hoof trimmers, the PhD candidate, and veterinarians created a definitive, appropriate severity score for each claw disorder of interest. External veterinarians not involved in the study were invited to comment on the scoring system that was developed. Information on the validation of the claw disorder scoring system is further discussed in Appendix VI.

5.3.3 Claw disorder data collection

Data collection occurred during routine hoof trimming events between July 2019 and June 2020 (Figure 5.1). Depending on the farm, hoof trimming events took place 4-5 times a year. Despite each claw being analysed, only foot-level information was recorded. For example, if two horn separation events were on both claws, the most severe score was taken. The information was recorded on a scoring sheet and entered into a Qualtrics database (Qualtrics. 20, Provo, UT). The time required for each data collection event varied between farms and depended upon the number of hoof trimmers present. Farm A took five days to collect information on all the goats, while farms B and C took two or three days.

5.3.4 Data analysis

All claw disorders were recorded during the hoof trimming events, though only rot, granulomas, and horn separation will be presented. The prevalence of claw disorders (presence or absence; 1/0 of any claw disorder) was analysed at the animal level across farms and ages. The prevalence of rot, granulomas and horn separation was analysed at the animal level across farms. The prevalence of each claw disorder was calculated as a proportion (Dohoo et al. 2003):

$$P=\frac{a}{b} \times 100$$

where

a = the number of goats diagnosed with at least one case of a claw disorder in a population at a point in time

b = the number of goats within the herd at the time of hoof trimming

The annual incidence risk of claw disorders was estimated at the foot level. It was the sum of new claw disorders across all hoof trimming events for the 2019-2020 year divided by the average herd size of the farm (Dohoo et al. 2003). For example, the average herd size for farm A was 1,558, and the sum of new claw disorders between July 2019 and June 2020 was 4,223. Therefore, the annual incidence risk for that year for developing a claw disorder was 271%. Note that the number of new cases was measured between the first and last hoof trimming event, which was less than 365 days.

The incidence rate of claw disorders was calculated at the foot level across farms. It was defined as any new claw disorder at subsequent hoof trimming events. The foot incidence rates were calculated using the following formula (Dohoo et al. 2003):

$$I = \frac{\text{Number of new cases}}{\text{Sum of foot days at risk}}$$

$$\text{Days at risk} = c - 30\,(d) - 15(e)$$

Where

c = the number of days between each foot's first and last hoof trimming event.

d = the number of claw disorders present between each foot's first and last hoof trimming event.

e = the claw disorder status of each foot (presence/absence) at the last hoof trimming event.

The foot days at risk were calculated for each foot. It was the sum of days between herd entry and exit minus days in which they had a claw disorder present. The goats' herd entry and exit dates were their first and last hoof trimming records, respectively. If a goat had a claw disorder at hoof trimming, it would not contribute to the goat's time at risk for 30 days. Hoof trimming was on the day of diagnosis. It was assumed that this was, on average, the halfway point between when the claw disorder established itself and when it healed. If a claw disorder was present at the last hoof trimming events, it is unknown if it healed. These events would result in 15 days rather than 30 days being removed from the goat's days at risk. The total foot days at risk was the sum of all the individual foot days at risk.

The estimated number of days a claw disorder was present was calculated based on the following information on hoof growth rate and footrot recovery time from three sheep and two goat studies. These values were combined to estimate the average time a claw disorder healed that rounded to 30 days. For example, for horn separation, based on an average hoof length of 3.5 cm and an average growth rate of 4 mm/month, the average recovery from horn separation severity 2 and 1 would be 87.5 and 43.8 days, respectively. For footrot, recovery has been estimated to be, on average, between 5, 7, and 10 days from the three studies, Kaler et al. (2010b), Bitrus et al. (2017) and Smith et al. (2014). The duration of granulomas is unknown; however, it would likely fall within these values mentioned above.

The duration of claw disorders in the current study was calculated using the inverse of the cure rate (Tumwine et al. 2005).

$$D = \frac{1}{\text{cure rate}}$$

$$\text{Cure rate} = \frac{\text{Number of new cases}}{\text{Days at risk to be cured}}$$

$$\text{Days at risk to be cured} = f\text{-}g$$

Where days at risk to be cured is the number of days between the date of when the claw disorder was first recorded (f) minus the date of when the claw disorder was not present (g). The prevalence and incidence rate analysis' were carried out with R (R Core Team, 2021) data.table package (Dowle and Srinivasan, 2021). The 95% confidence intervals (CI) for incidence and cure rate (h) were calculated using the following equation (Dohoo et al. 2003):

$$95\%\ \text{CI} = h \pm 1.96 \times \sqrt{\frac{\text{annual rate per 100 feet}}{\text{sum of foot days at risk}}}$$

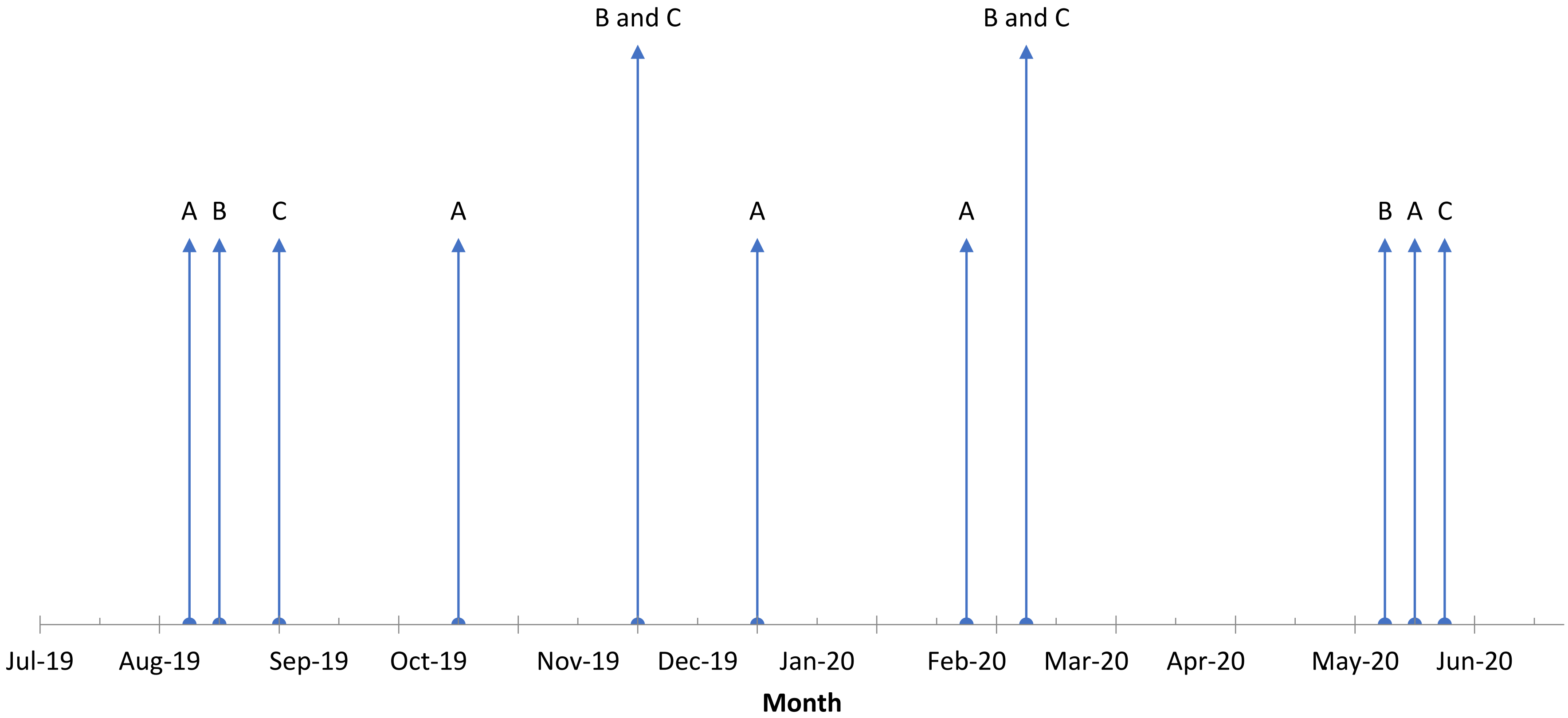


Figure 5.1. The timeline of hoof trimming events where claw disorder scoring occurred at farms A, B and C, located in Waikato, New Zealand.

5.4 Results

5.4.1 Descriptive results

The number of goat records collected during 2019-2020 differed between farms and hoof trimming events for each farm (Table 5.1). In total, there were 13,809 observations at the animal level. Most goats (>70%) from each farm had records from all hoof trimming events (Table 5.2). For calculating incidence rates, goats with one record were excluded from the analysis.

During the 2019-2020 season, within all farms, most goats were one- or two-year-olds (>40%; Figure 5.2). Farm C had the highest percentage (~ 28%) of one-year-olds within its herd. Farm A and B had a larger percentage of goats over the age of five, ~ 20 and ~ 17%, respectively, than Farm C, which only had ~ 14%.

Table 5.1. The number of goat records at each hoof trimming event for farms A, B and C between July 2019 and June 2020.

Hoof trimming event	Farm A	Farm B	Farm C
August 2019	1,454	765	802
October 2019	1,618	-	-
November 2019	-	753	795
December 2019	1,633	-	-
February 2020	1,590	740	776
May 2020	1,497	623	763

Table 5.2. The percentage of hoof trimming records per goat between July 2019 and June 2020 across farms A, B and C.

Number of records per goat	Farm A	Farm B	Farm C
1	2%	4%	3%
2	1%	3%	2%
3	5%	17%	7%
4	21%	76%	87%
5	72%	-	-

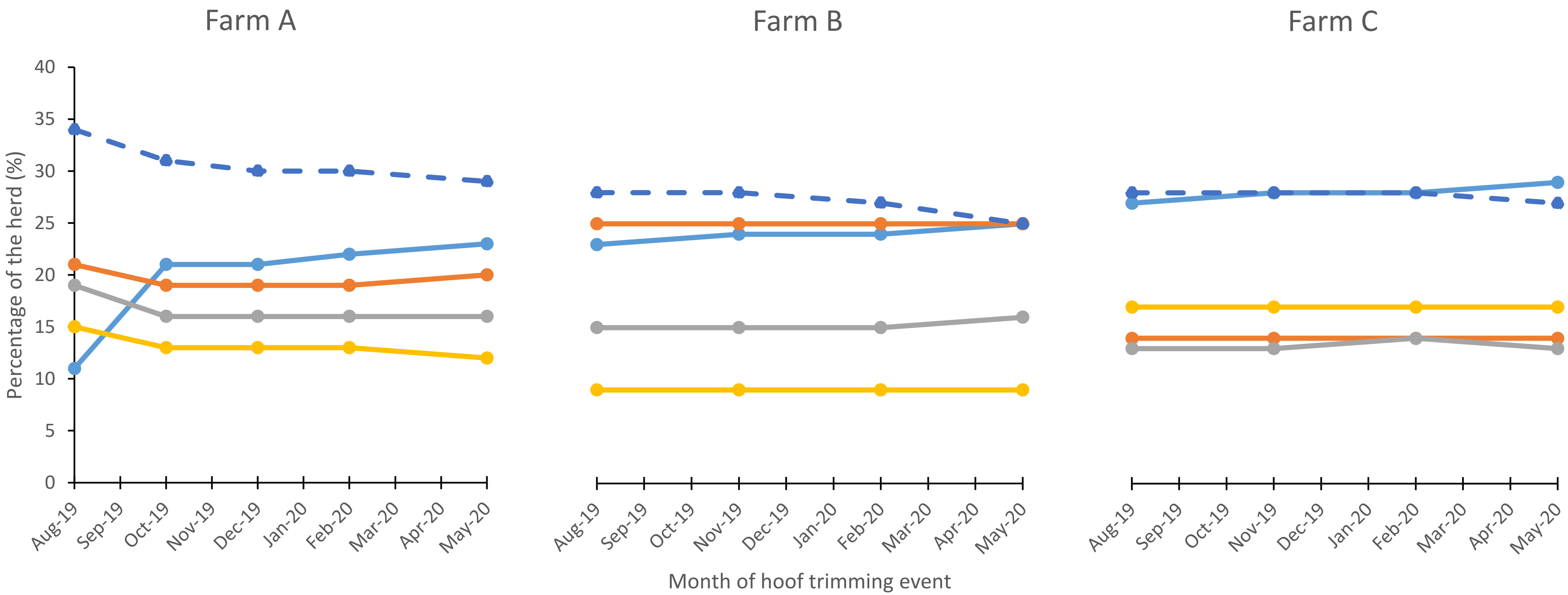


Figure 5.2. The herd age structure at each locomotion scoring event that was conducted during the 2019-2020 production year within three dairy goat farms in Waikato, New Zealand. One-year-olds (blue line), two-year-olds (orange line), three-year-olds (grey line), four-year-olds (yellow line), and five-year-olds or older (blue dotted line).

5.4.2 *Prevalence of claw disorders*

Across the 2019-2020 season, the prevalence of goats with at least one claw disorder record of either horn separation, granuloma, or rot is shown in Figures 5.3, 5.4 and 5.5. The prevalence changed depending on the farm and the age group of the animals. The distribution of type and severity of claw disorders also varied across the farms (Figure 5.3). Farm A's number of goats with claw disorders fluctuated throughout the year. The prevalence of claw disorders never went below 44%, and the highest prevalence of 65% was seen in December 2019. Farms B and C showed an incline at the beginning of the season, peaking in November before declining across the rest of the season. Farm B had the lowest percentage of goats with a claw disorder, while Farm C had the highest percentage of goats with at least one claw disorder. The change in the prevalence throughout the year suggests a seasonal or physiological aspect to the presence of claw disorders.

The prevalence of claw disorders was different between the age groups (Figure 5.4). In farms A and B, claw disorders had a higher prevalence in the older age groups (aged three and older), while in farm C, claw disorders had a higher prevalence among goats aged two and older. All farms showed a sharp increase in the percentage of one-year-olds with claw disorders, peaking between November and December 2019. The percentage of claw disorders within the herds decreased in February 2020. Upon observation, farms B and C claw disorders among one-year-olds decreased throughout the year (14 to 8% and 44 to 24%, respectively), whereas claw disorders in one-year-olds on farm A increased again towards the end of the year (34 to 40%). Overall, farm B had the lowest prevalence of claw disorders across all the age groups. This figure suggests a relationship between the goat age group and claw disorder prevalence.

The type and severity of claw disorders differed between farms (Figure 5.5). Across all farms, the most common claw disorder was horn separation severity 1 followed by horn separation severity 2. Rot, and to a smaller extent, granulomas, were claw disorders recorded mostly on farms A and B. Rot severity 3, was recorded only on farm A though this was a small percentage compared with the other claw disorders. Granulomas were mainly seen on farm A. They were present at a higher percentage than farms B and C.

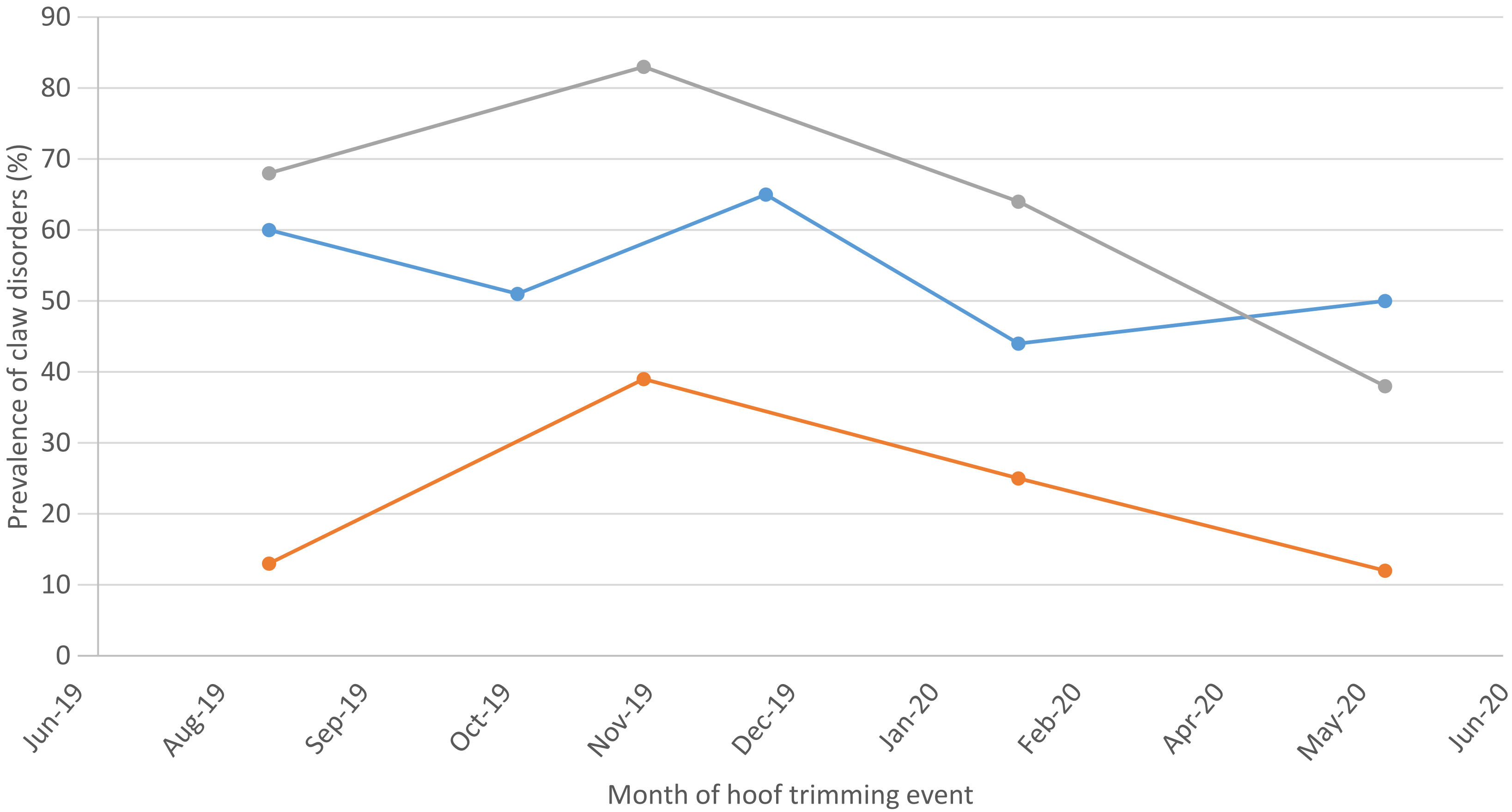


Figure 5.3. Prevalence of dairy goats with at least one record of horn separation, rot, or granuloma on three farms in Waikato, New Zealand, during the 2019-2020 production year. Farm A (blue line), farm B (orange line) and farm C (grey line).

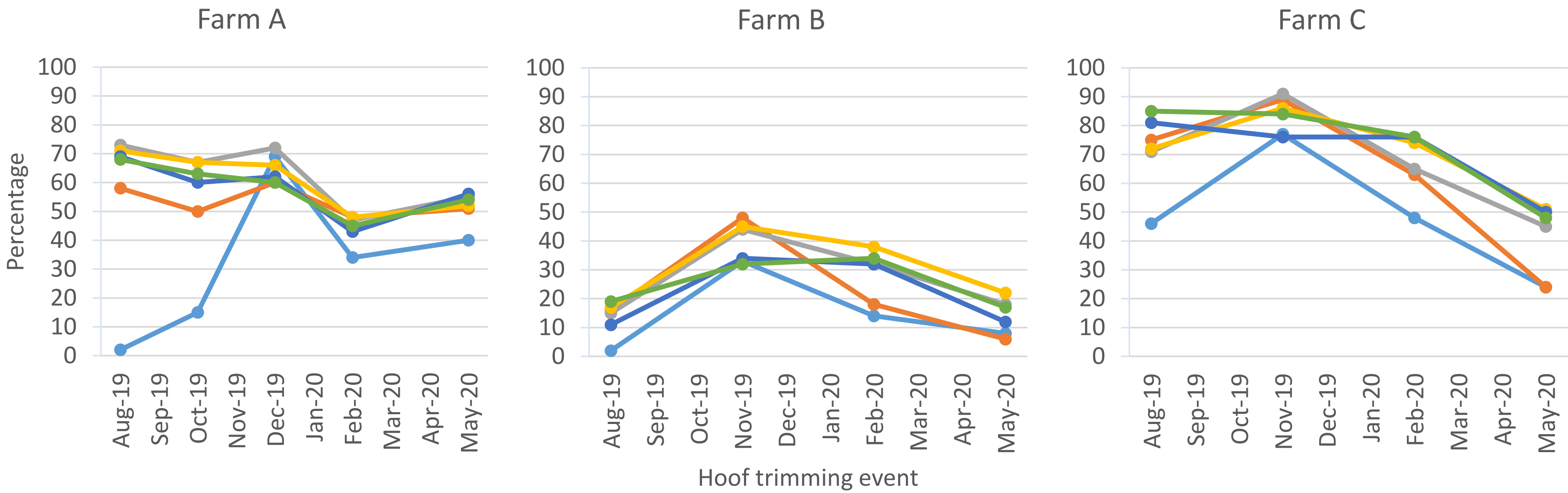


Figure 5.4. Prevalence of claw disorders within various age groups at hoof trimming events across the 2019-2020 production year from three dairy goat farms in Waikato, New Zealand. One-year-olds (light blue line), two-year-olds (orange line), three-year-olds (grey line), four-year-olds (yellow line), and five-year-olds (dark blue line) or older (green line).

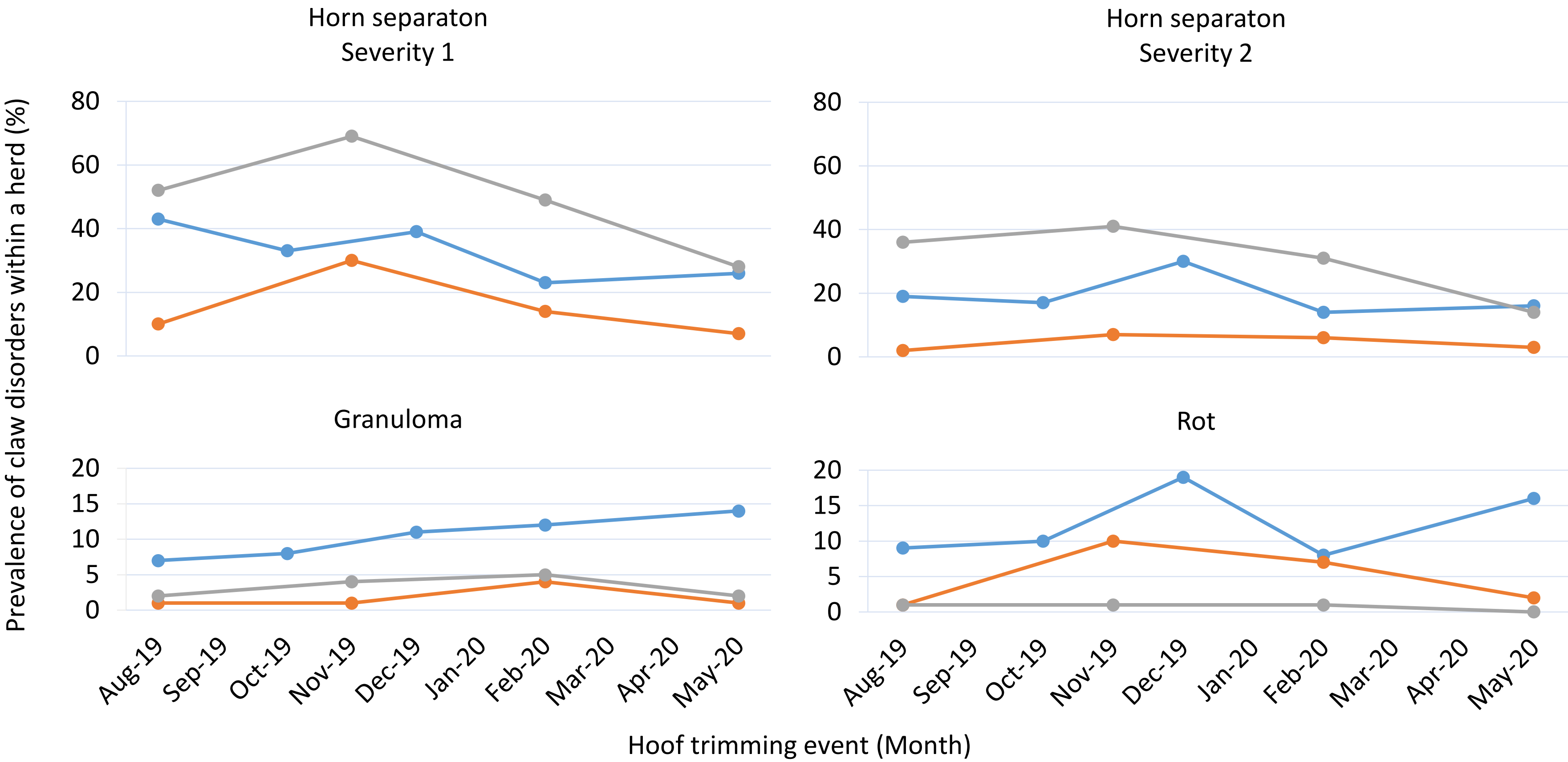


Figure 5.5. Prevalence of claw disorders at hoof trimming events across the 2019-2020 production year for three dairy goat farms in Waikato, New Zealand. Farm A (blue line), farm B (orange line), and farm C (grey line).

Farm A's highest percentage of granulomas was reported at the February and April 2020 hoof trimming sessions.

5.4.3 Incidence risk and rate of claw disorders

The annual incidence risk of claw disorders at the foot-level varied across farms (Table 5.3). The incidence risk for a foot to develop at least one claw disorder case - either horn separation, rot, or granulomas - was 271, 91, and 217% for farms A, B and C, respectively. The risk of developing horn separation was 225, 76, and 250% for farms A, B and C, respectively. The risk of developing rot was 62, 20, and 2.8% for farms A, B and C, respectively. The risk of developing a granuloma was 52, 7.6, and 12% for farms A, B and C, respectively.

The incidence rate of claw disorders was estimated at the foot level (Figure 5.6). Horn separation had the highest incidence rate across all farms compared with granuloma and rot claw disorders. In one year, farm C had incidence rates for horn separation over 100 and was interpreted as for every 100 feet there were 118 cases. The high number of cases reflects that some goats had multiple cases of horn separation events during the year.

A general trend showed higher incidence rates for claw disorders in the forefeet than in the hind feet. There was a difference (confidence intervals not overlapping) in the incidence rate of horn separation events between the fore and hind feet. There did not appear to be any discrimination between the front and back feet for granuloma claw disorders. For farm A, rot claw disorders appeared to have a higher incidence rate (confidence intervals not overlapping) in the forefeet than the hind feet (25 and 22 *vs.* 13 and 12 for left and right feet, respectively). Farm B appeared to have a higher incidence rate of rot on the right side (hind and forefeet) than on the left side (left hind and forefeet). For farm C, there was no trend for the rot incidence due to the lack of cases reported on the farm.

Table 5.3. The number, n, and percentage (in parenthesis) of goats with at least one claw disorder are further divided by either horn separation, rot, or granulomas at each hoof trimming event during the 2019-2020 year.

Hoof trimming event	Farm	Claw disorder				Herd size
		Horn separation	Rot	Granulomas	Total[1]	
August 2019	A	773 (53)	125 (9)	103 (7)	877 (60)	1,454
	B	83 (11)	8 (1)	11 (1)	100 (13)	765
	C	541 (67)	9 (1)	17 (2)	548 (68)	802
October 2019	A	703 (43)	166 (10)	127 (8)	831 (51)	1,618
November 2019	B	261 (35)	77 (10)	7 (1)	294 (39)	753
	C	650 (82)	8 (1)	29 (4)	359 (83)	795
December 2019	A	929 (57)	314 (19)	178 (57)	1,060 (65)	1,633
February 2020	A	546 (34)	122 (8)	188 (12)	694 (44)	1,590
	B	140 (19)	49 (7)	28 (4)	185 (25)	740
	C	487 (63)	4 (1)	29 (4)	500 (64)	776
May 2020	A	560 (37)	241 (16)	212 (14)	751 (50)	1,497
	B	60 (10)	10 (2)	9 (1)	76 (12)	623
	C	285 (37)	1 (0.1)	12 (2)	292 (38)	763

[1]Total = total number of goats with at least one claw disorder.

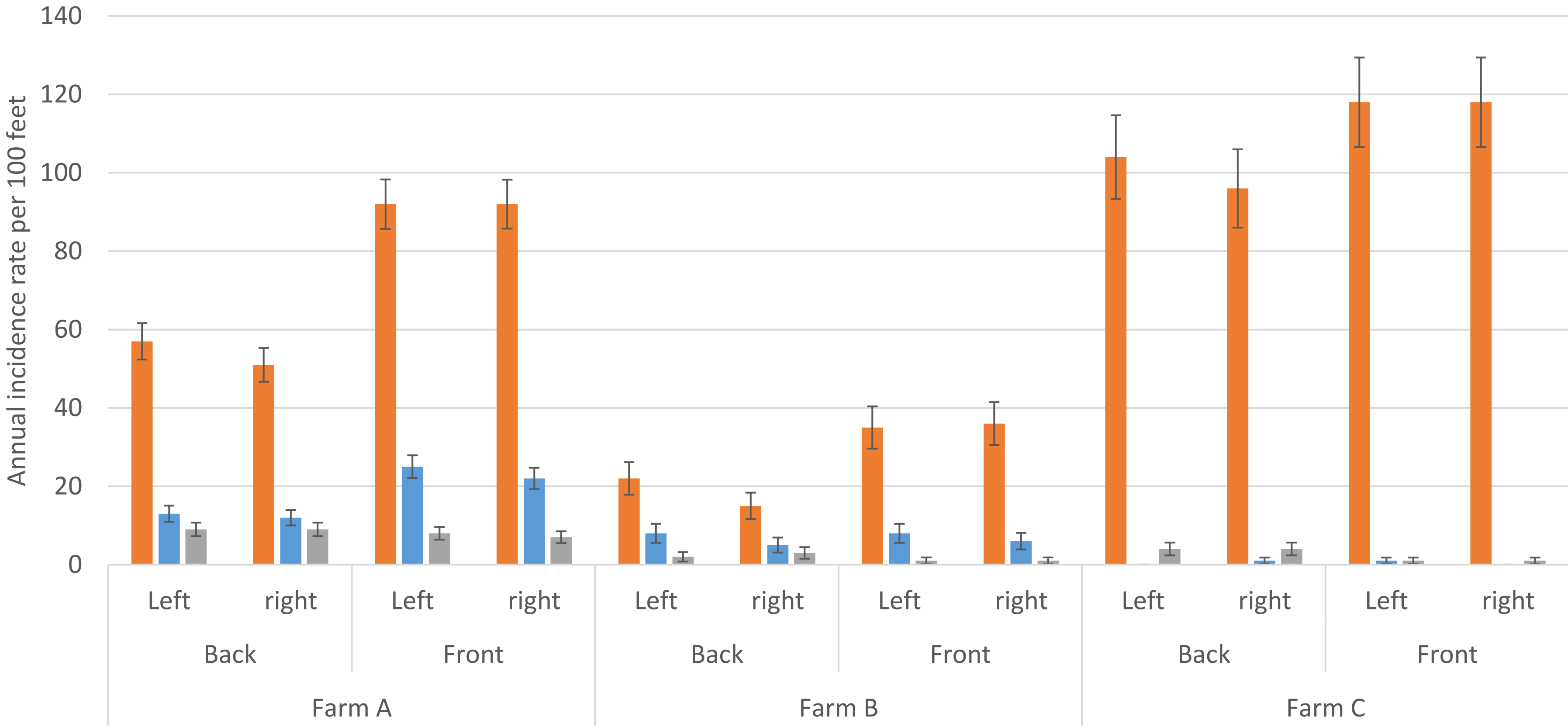


Figure 5.6. Annual foot-level incidence rate estimates over 100 feet-years with 95% CI based on the 2019-2020 production year, across farms A, B and C based within Waikato, New Zealand. Incidence rates are by claw disorder - horn separation (orange bar), rot (blue bar) and granuloma (grey bar) - and by location – back left foot, back right foot, front left foot, and front right foot.

5.4.4 Duration of claw disorders

The duration of the claw disorders varied across feet, farms and types of claw disorder (Figures 5.7, 5.8 and 5.9). Horn separation duration median ranged from 62 to 125 days, depending on the farm, with no apparent difference between the front and back feet (overlapping confidence intervals). The duration median of granulomas ranged from 86 to 125 days. For farms A and C, it appears that the granulomas lasted longer in the back feet than the front feet. The duration median for rot was between 52 to 119 days. There was no trend that rot lasted longer on the front feet than the back feet.

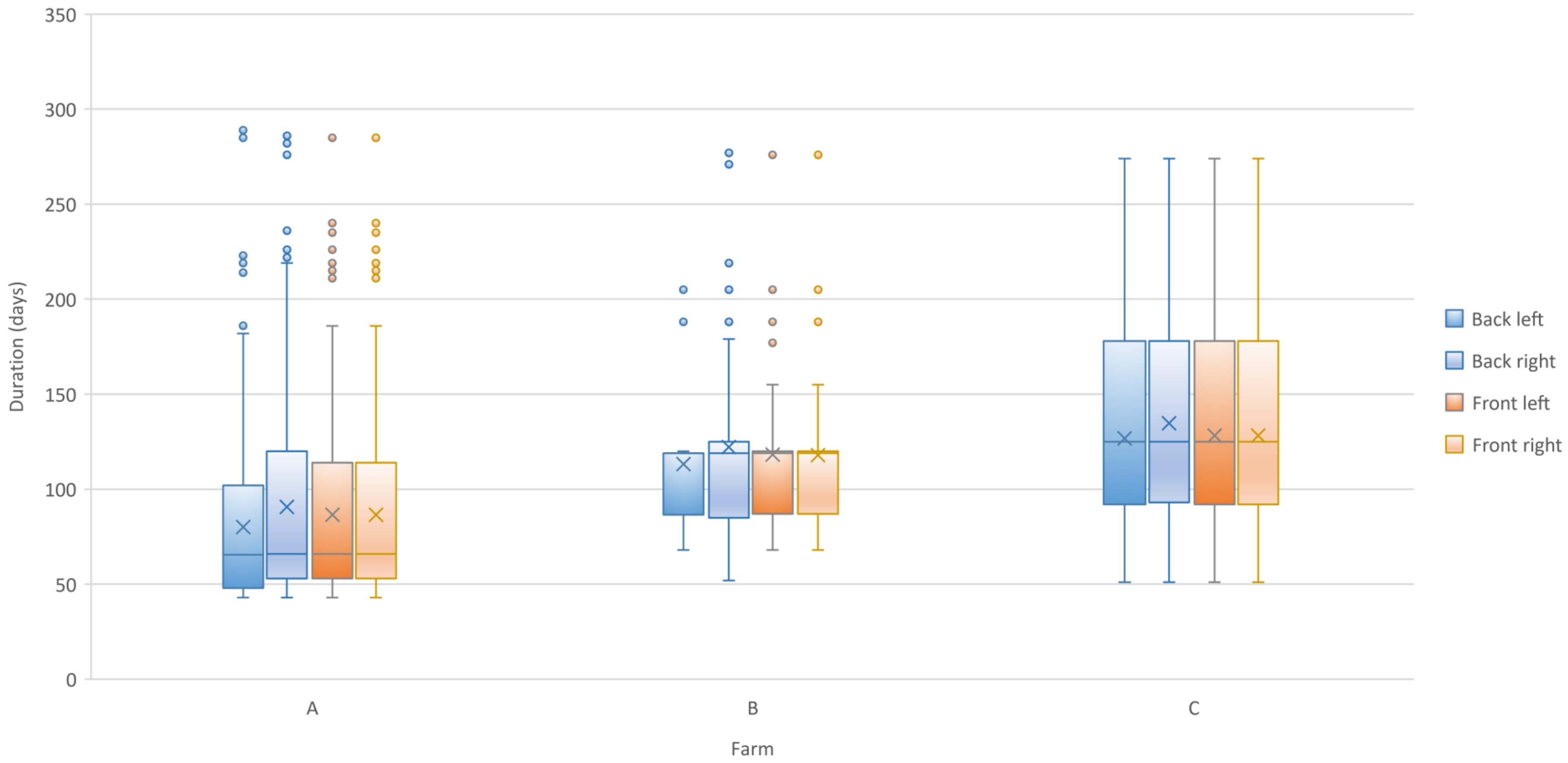


Figure 5.7. Estimation of the duration of horn separation claw disorders for the back left foot, back right foot, front left foot, and front right foot, based upon the 2019-2020 production year, across three dairy goat farms (A, B, and C) in Waikato, New Zealand. 'x' marks the mean duration.

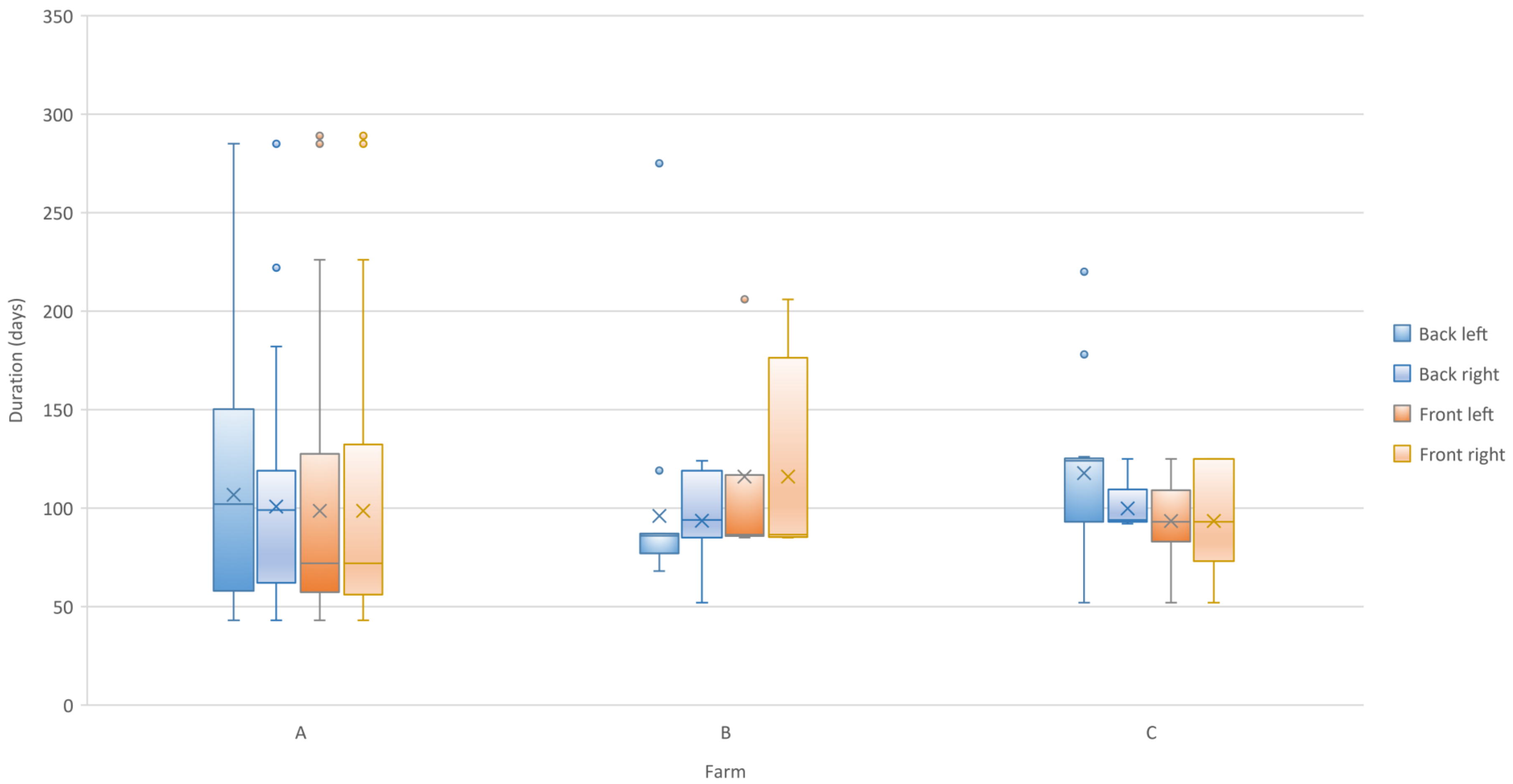


Figure 5.8. Estimation of the duration of granuloma claw disorders for the back left foot, back right foot, front left foot, and front right foot, based upon the 2019-2020 production year, across three dairy goat farms (A, B, and C) in Waikato, New Zealand. ‘x’ marks the mean duration.

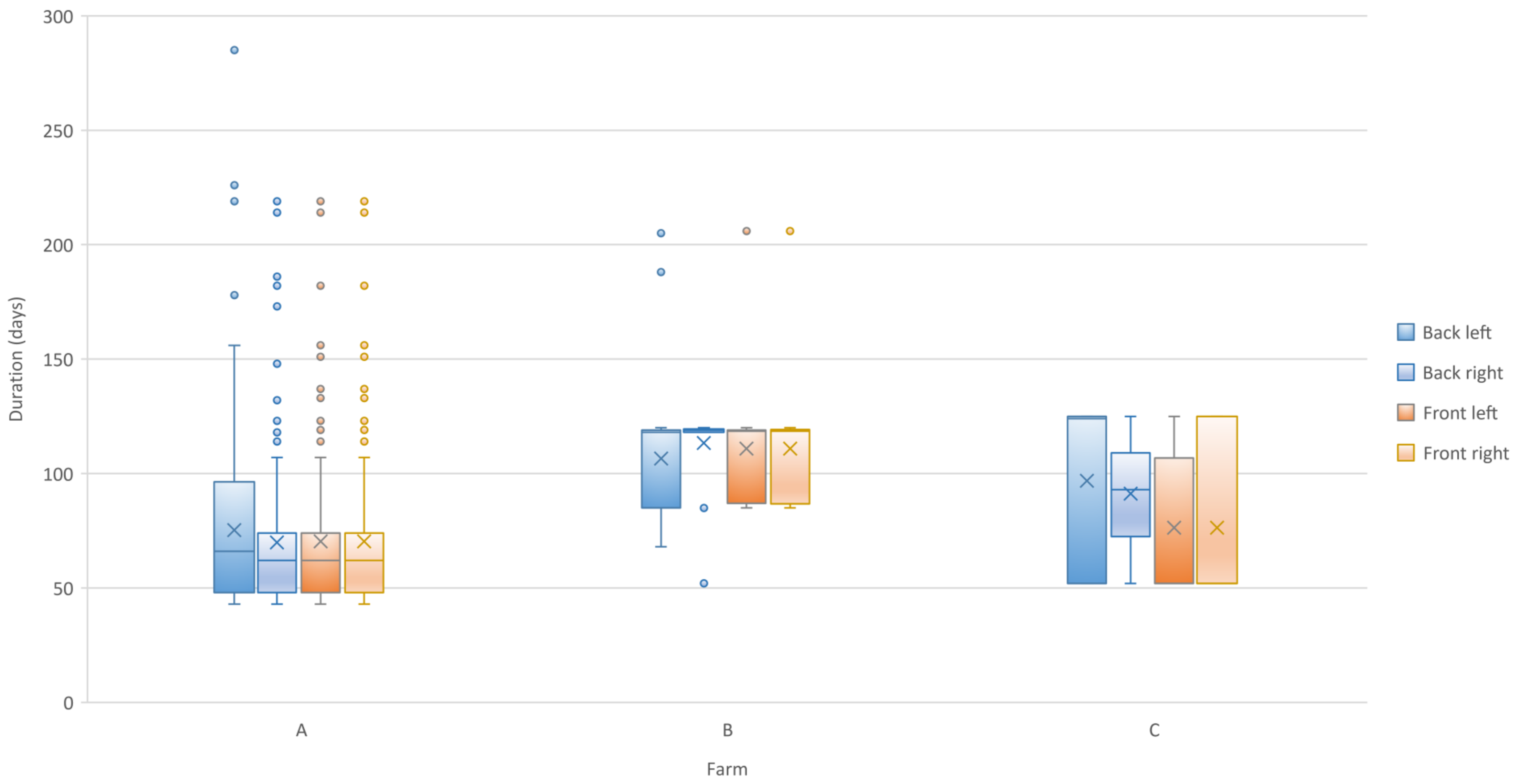


Figure 5.9. Estimation of the duration of rot claw disorders for the back left foot, back right foot, front left foot, and front right foot, based upon the 2019-2020 production year, across three dairy goat farms (A, B, and C) in Waikato, New Zealand. ‘x’ marks the mean duration.

5.5 Discussion

This study investigated dairy goat claw disorders on three commercial dairy goat farms in New Zealand. The farms were monitored over a season, and the claw health of the goats was evaluated during hoof trimming events.

5.5.1 Prevalence of claw disorders

All three farms had goats present with claw disorders during the 2019-2020 hoof trimming events. While the type and prevalence of claw disorders present differed between farms, some trends were similar, such as the possible influence of stage of production or season (difference in weather conditions). Few authors have reported the results of studies on the prevalence of a variety of claw disorders within commercial dairy goat herds (Chapter 2.4, Table 2.3); therefore, comparisons between the results of my thesis and past studies are limited.

The yearly average prevalence of claw disorders at the animal level for farms A, B and C were 22, 54, and 63%, respectively. Horn separation, granuloma, and rot were the most common claw disorders observed on the three farms. Other claw disorders present were sole haemorrhages, slippering, foreign particles, abscesses, laminitis and minor white line separation; however, they were observed in a smaller number of goats. Past studies have also observed the presence of similar claw disorders (Chapter 2.4). Overgrown claws were present within the current study's farms, though most claws were not considered severe (Sailer et al. 2021). Overgrown claws were recorded in previous dairy goat welfare studies, where it was reported that increased hoof trimming events decreased the prevalence of overgrown claws. Overgrown claws were uncommon in this current study, which could be explained by routine hoof trimming occurring at least four times a year. This number of hoof trimming events is more than the recommended routine hoof trimming twice a year (Battini et al. 2015). Due to the lack of reporting of rot, granulomas, and horn separation in these past welfare studies, overgrown claws could have been considered the only problem in dairy goat farms. The current study and a few others have reported that this is not the case, and that future welfare studies should consider other claw disorders when conducting their observations (Hill et al. 1997; Groenevelt et al. 2015 a, 2015b; Sailer et al. 2021).

Horn separation occurs as the outside claw horn separates itself from the white line of the sole or, more specifically, the laminar corium. Of the claw disorders, horn separation was the most common claw disorder observed at all farms. Horn separation was also the most common claw disorder in both studies by Hill et al. (1997) and Sailer et al. (2021). Hill et al. (1997) and Sailer et al. (2021) reported horn separation in 24.0-40.3% and 85.8-87.3% of goats examined, respectively. Our results fall between these results, despite being split by severity. In this study, there were severe cases of horn separation-horn capsule detachment- in combination with underlying rot and sometimes granulomas, most likely due to secondary infections. Many factors related to the causation of horn separation have been proposed. These will be discussed in a future chapter.

Rot and granulomas were the second or third most common claw disorders depending on the farm. While rot and granulomas were reported in Hill et al. (1997) prevalence study, none were reported in significant amounts in the study by Sailer et al. (2021). There was only one farm in the study of Hill et al. (1997) that had footrot (14.2%) and granulomas (3.9%) present. Although Hill et al. (1997) visually described footrot in their studies, some of the cases could have been digital dermatitis. Misclassification of rot in goats is due to digital dermatitis being visually similar to footrot. The only way to find the bacteria involved in the rot development is to complete a PCR analysis (Groenevelt et al. 2015a, 2015b; Sullivan et al. 2015; Crosby-Durrani et al. 2016). Many studies suggest that footrot in goats is different or that goats react differently to the presence of footrot in sheep and cows (Bennet et al. 2009; Ghimire et al. 2002; Hill et al. 1997). The theory that footrot is a different disease in goats was also suggested by Christodoulopoulos (2009), which reported that goat footrot is more similar to pig footrot. Additionally, it has been reported that infection of the footrot bacteria does not mean that lameness is a consequence (Knappe-Poindecker et al. 2015). Ghimire et al. (2002) suggested that footrot is less invasive in goats than sheep despite causing under-running claw disorders. In these cases, it could be that the footrot is within its subclinical phase or that goats could have developed a tolerance or a certain level of resistance to the infection, suggesting that there may be a genetic component.

Apart from Hill et al. (1997), there is little information about granulomas in dairy goats. Granulomas can be described as raspberry or cauliflower-like in appearance. An over-active immune response causes excessive granulation in wounds (Mulvaney et al. 2013). They can be found within or protruding from the claw (Hill et al. 1997). Hill et al. (1997) observed granulomas only up to 1 cm in size and located only in the sole. In the current study, some extreme cases of granulomas took up between 50 - 75% of the claw. Granulomas were also located across all areas of the claw. A reason for this difference between studies could be that the current study had sampled more goats and was able to see more variations in the appearance of granulomas. No cow or sheep studies have reported granulomas' prevalence as described in Hill et al. (1997). Toe granulomas are mentioned in sheep reports and are not mentioned anywhere else on the foot. It has been hypothesised that they are caused by excessive hoof trimming or follow rot left untreated (Annett et al. 2019). In dairy cows, granulomas are not often mentioned by themselves. Granulation was often described as granulation tissue linked to other claw disorders such as digital dermatitis, sole ulcers and white line fissure (Palmer et al. 2015; Shearer et al. 2015; Sadiq et al. 2021). Shearer et al. (2015) reported excessive granulation tissue in non-healing claw wounds. They also observed that claw wounds with excessive granulation were slower to heal (41-60 days) than a wound without this granulation (12-28 days). More research needs to be completed to understand the development of granulomas and how they should be treated appropriately in dairy goats.

The entry and exit of goats in the first and second half of the year affected the prevalence of claw disorders within each farm. Farm A observed a decrease in claw disorders from August 2019 to October 2019. This is most likely due to the dilution effect caused by the influx of a large number of one-year-old goats entering the herd before the October 2019 hoof trimming event. The one-year goats had no claw disorders upon entering the herd (results not shown), accounting for the lower percentage of claw disorders recorded in October 2019. This trend is not seen in farms B and C because all goats had kidded before the first hoof trimming event. The second half of the season shows the decline of claw disorders in farms B and C. The farmers had removed (sold or culled) older goats towards the end of the season to make room for new incoming one-year-old goats. Low production was the main reason for removing goats (results not shown). In the dairy cows and sheep industries, lame animals have been reported to have reduced milk production (Warnick et al. 2001, Green et al. 2002, Gelasakis et al. 2015). This meant some removed goats could have been lame due to chronic claw disorders. Removing these goats would reduce the farm's prevalence of claw disorders at that time of year.

The prevalence of claw disorders in farm A revealed a decline followed by an incline in claw disorders in the year's second half. As previously mentioned, a reason for the decline in the prevalence of claw disorders is the weather. The prevalence of claw disorders then seemed to increase from February 2020 to May 2020. Despite 100 goats leaving the herd within this timeframe, there was an increase in prevalence. A reason for this could be the increase in claw disorder prevalence in the group of one-year-old goats (coming up two-year-olds). Towards the end of the year, there was more intermingling between the age groups. On this farm, goats were not kept apart, and groups could mingle together, increasing the odds of pathogenic bacteria transmission between groups of goats.

Horn separation, rot, and granulomas were sometimes found together or in different combinations. A hypothesis could be that there is sometimes an interaction between them, creating a synergic effect, and increase the likelihood of lameness, and decreasing the animal's welfare. The relationship between each other will be expanded further in subsequent chapters.

5.5.2 Incidence of claw disorders

There have been no publications of incidence risks or rates of claw disorders within dairy goat or sheep farms. Comparisons can be made to dairy cow studies though there are limitations. This study focuses on the most common severe claw disorders observed on the three participating dairy goat farms - horn separation, rot and granulomas. Dairy cow studies focused on the claw disorder white line disease, and separate infectious disorders, digital dermatitis and footrot. Granulomas are not typical in dairy cow publications - they are not referred to in the ICAR claw health atlas (Egger-Danner et al.

2020), therefore, it is hard to compare the results from this study to dairy cow publications.

The annual incidence risk for claw disorders at the goat level varied from low (<10%) to high (>100%). Horn separation had the highest risk of developing across all the farms. The risk of a goat developing horn separation was over 100%, which indicated that a goat developed multiple cases of horn separation (same or different foot) between July 2019 and June 2020. This study's results were higher than those published in a dairy cow study (Sanders et al. 2009). Sanders et al. (2009) published an annual incidence risk of 4.8% for white line disease at the cow level. For this same study, there was no specific incidence risk for rot. It was instead classified as an infectious claw disorder within an 'Other' category, so it could not be compared with this current study. One reason the incidence risks for horn separation were higher in this study may be due to farm differences between how dairy goats and dairy cows are managed from a nutritional and environmental perspective.

The incidence rates for claw disorders at the foot level depended on the farm and claw disorder. Similar to the pattern in the prevalence study, farm C had the highest incidence rate for horn separation, and farm A had the highest incidence rates for rot and granulomas. For horn separation, the incidence rate was higher in the forefeet than in the hindfeet. This contradicts previous results in dairy cow literature and one study on sheep. There was a higher percentage of claw disorders in hind feet than forefeet in dairy cattle, and one sheep study reported more horn separation in the hind feet than the front feet (Somers and O'Grady, 2015; Solano et al. 2016; Best et al. 2021). An explanation for more claw disorders in the hind feet than the fore has been the uneven weight distribution across the claws within the hind and forelimb. It has been reported that 70-80% of the weight is placed on the lateral (outer) claws in the hind feet while the weight distribution between lateral and medial claws was more balanced in the forefeet (Amstel and Shearer, 2006; Somers and O'Grady, 2015; Solano et al. 2016). The distribution of weight across medial and lateral claws in dairy goats or sheep has not been investigated; therefore, this could be a factor with dairy goats. However, other factors, such as the environment, could be masking it and having a greater influence on claw disorder development.

One reason why there has been more horn separation in the forefeet than the hind feet in dairy goats within the current study could be due to moisture exposure. On the farms, the forefeet were exposed to more environmental moisture than the back feet. The water exposure is because of the fresh grass-fed to the goats at the feeding passages. As the goats eat, grass spills into their bedding, increasing the wetness of their bedding in front of them. Though not measured, the forefeet appeared to be standing in the damp bedding more than the hind feet. The increased absorption of moisture within the claw softens the claw horn. A weakened white line area has been associated with increased white line disease in dairy cows and horses (Barker et al. 2009; O'Grady and Burns, 2021).

5.5.3 Duration of claw disorders

The duration of claw disorders was estimated from the cure rate. This depended on the farm and whether it was the hind or forefoot affected. For farm A, granulomas appeared to take longer to heal than rot or horn separation, with the hindfeet taking longer to heal than the forefeet. Horn separation took the longest to heal for farms B and C, with no difference between the hind and forefeet. The duration of claw disorders has not been reported in goats. In sheep, a recent study reported some sheep (13.8% of their group) never recovered from white line disease or some degree of horn separation throughout their one-year observational study (Best et al. 2021). A review by Shearer et al. (2015) investigated a range of studies that estimated the time of claw disorder cure date in dairy cows. This study concluded that mild to moderate lesions took 21-30 days to heal, equivalent to severities 1 for horn separation and granulomas and severity 1 and 2 for rot. Severe lesions took 40-60 days to heal. In this study, the duration of claw disorders could have been affected by the type of treatment carried out by the farmers and the trimmers.

In the current study, the treatment of claw lesions used by the farmers and hoof trimmers was different for each claw disorder. Treatment information could not be recorded for individual goats. For horn separation, the trimmer cut away the loose dead horn. If there was underlying rot, an oxytetracycline antibiotic spray was used. If rot was found, the dead horn was cut away, and the lesion was sprayed with an oxytetracycline antibiotic spray. If the rot was severe, the lesion was bandaged with copper sulphate. Protruding granulomas were cut out if its root could be accessed. After being cut out, the wound was bandaged with copper sulphate if the bleeding was excessive (bleeding did not stop after a few seconds). Granulomas have also been known to be burned out. Both treatments were seen throughout this research, however, the technique to burn out the granulomas resulted in some goats showing signs of extreme pain (vocal demonstrations). Also, it was noted that applying copper sulphate to wounds also resulted in some goats demonstrating extreme pain. No pain relief or anaesthetics were used before or after treatment. Farmers occasionally used antibiotics and pain relief. The range of studies reviewed by Shearer et al. (2015) reported that foot blocks increased the recovery rate in dairy cattle. Foot blocks have not been used for treating claw disorders in dairy goats because there has been nothing commercially available in the size of a goat's claw. This should be further investigated. Alternative claw disorder treatments need to be more thoroughly investigated to increase claw disorder recovery and improve goat welfare.

The results of the current study may be partially explained by the type of calculation used for the duration. For example, because the calculation depended upon whether or not the goat had healed from a claw disorder from one hoof trimming event to a subsequent hoof trimming event, the number of consecutive claw disorders a goat had across the 2019-2020 year would affect this result (Appendix III, Figures 1-3). For example, farms A and C had a higher percentage of goats with consecutive records for horn separation than farm B, reflecting the higher duration of horn separation for farms A and C than farm B.

One limitation of the current study was that there are more animal records for farm A than for farms B and C for granulomas and rot claw disorder. This means that the duration results are not estimated precisely for farms B and C.

The farmers were asked to record claw disorders and their treatments between hoof trimming events however, this was not carried out consistently and could not be used. The alternative to this, was to use hoof trimming events though this had limitations. Calculating the duration of the claw disorder using hoof trimming events was based on whether the claw disorder was present at the next hoof trimming event. This calculation has limitations because there were three or four months between hoof trimming events, and information was taken at the foot level rather than the claw level. Due to the long period between hoof trimming events, the goat may have recovered from a claw disorder, such as horn separation, and subsequently developed horn separation again by the following hoof trimming event. In this study, this would have counted the goat as having one long horn separation event, therefore, the duration would have been overestimated.

Following the goats at the claw level rather than the foot level would be better for estimating the duration of claw disorders. For example, if there were horn separation on the lateral claw at one hoof trimming event and then on the medial claw at the following event, this would be classified as the claw disorder not being cured, and again, the duration would be overestimated. For better accuracy of claw disorder duration, a selection of a group of goats with a claw disorder should be followed more closely and at shorter intervals to understand the healing process of a claw disorder better.

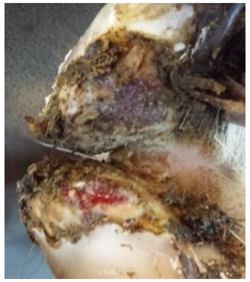
5.6 Conclusion

This was the first study conducted on commercial dairy goat farms in New Zealand, which describes the prevalence and incidence rate of claw disorders on three dairy goat farms. Results indicate that on these three farms, these two estimates change over time, farm, and age groups, but at any point in time, the prevalence was between 12 and 83%. The incidence risk and rate changed for different claw disorders and were different between farms. Horn separation was the most common problem on all farms and was generally endured for longer than rot and granulomas. This study suggests that claw disorders can potentially be a major problem for New Zealand dairy goats if they are associated with pain or production losses. More research is needed in this area of dairy goat farming to make inferences for the whole population of dairy goats on New Zealand commercial farmers, for farmers to better prevent, treat and manage claw disorders within their herd.

Appendix III

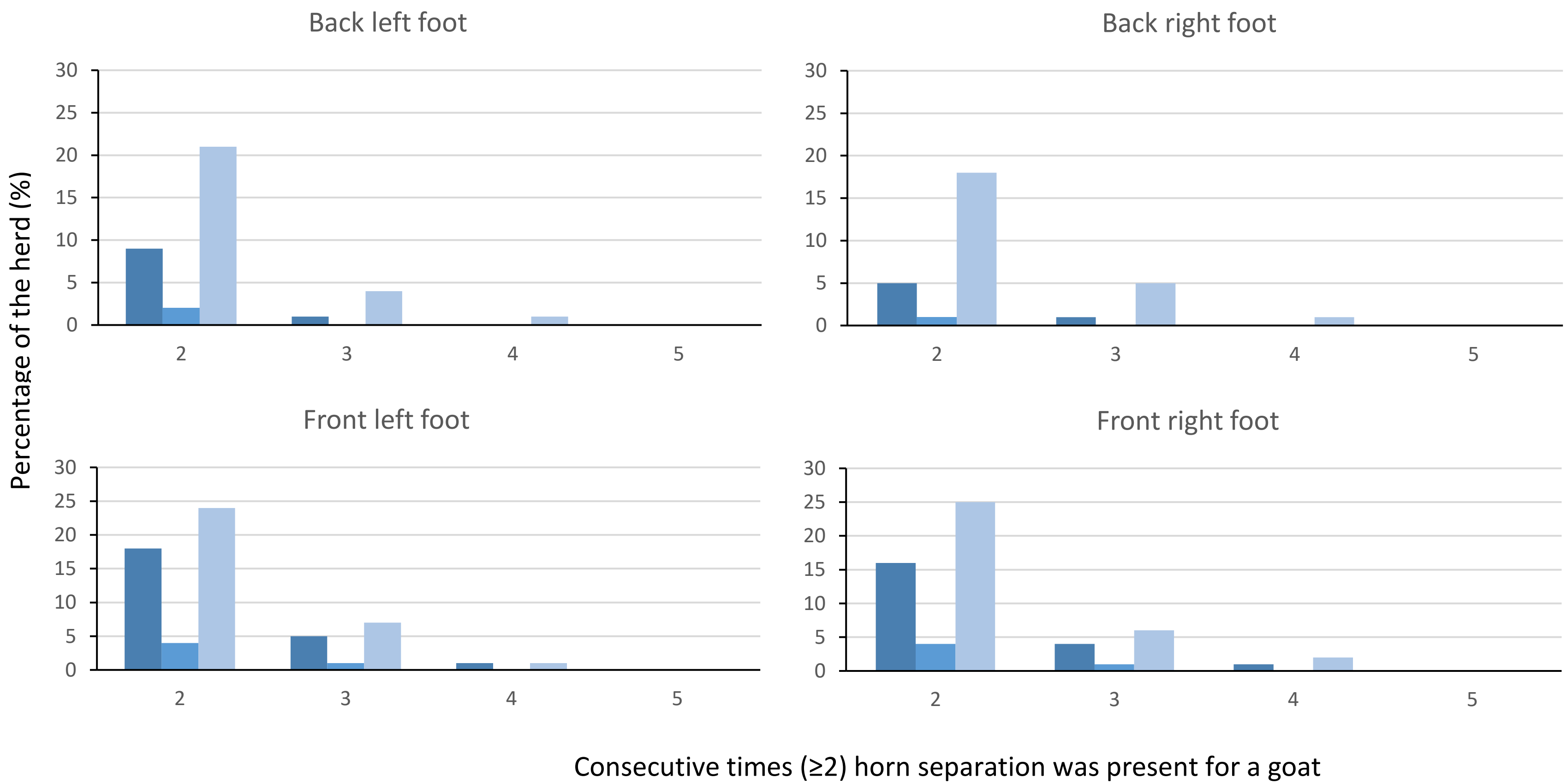
Supplementary information for Chapter 5

Appendix III Table 1. Images with written descriptions of claw disorders at different classes of severity observed in dairy goats on commercial farms during the 2019-2020 season.

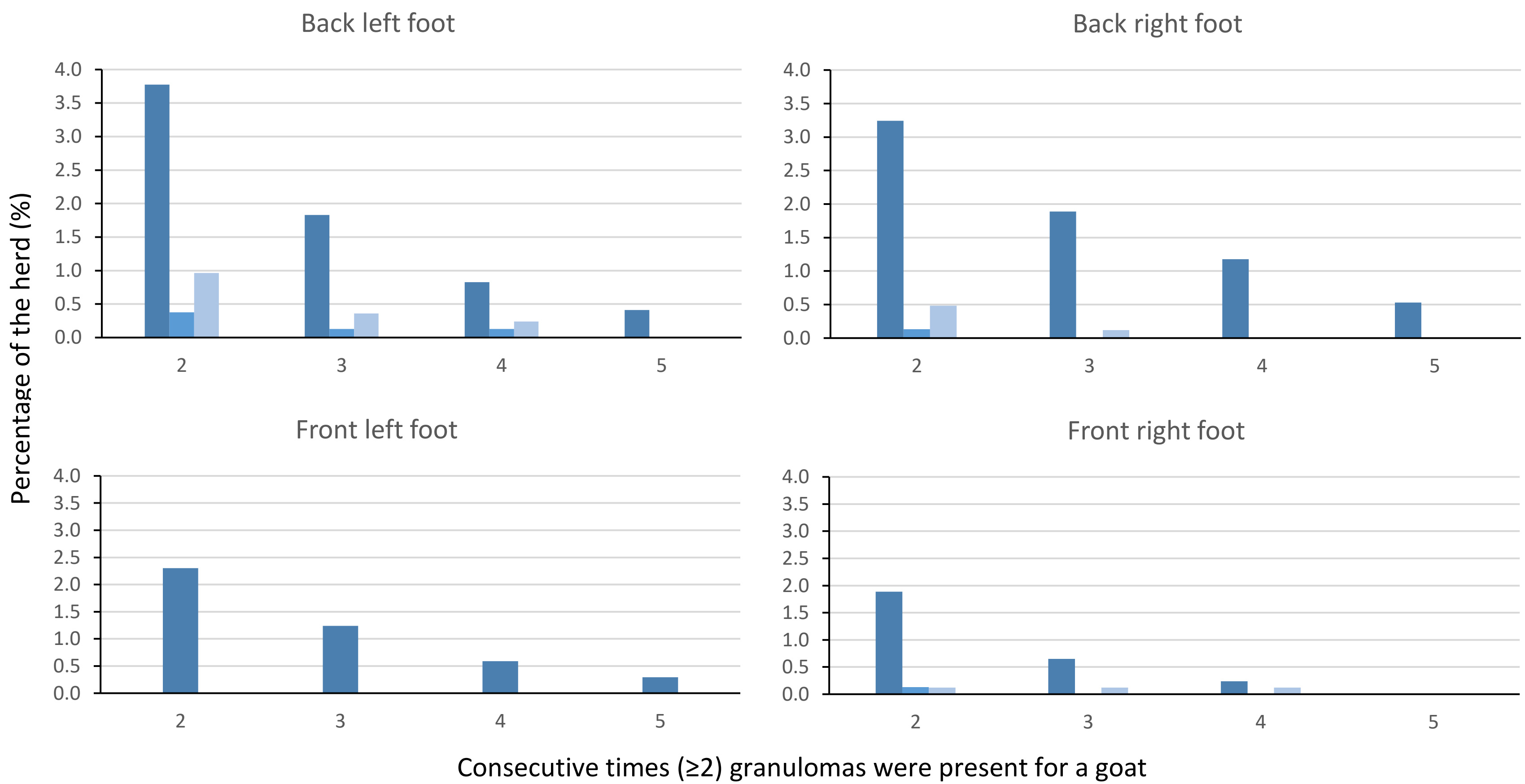
Claw Disorder	Severity 1	Severity 2	Severity 3
Rot	 Mildly damaged/misshapen sole/wall area of the digit, including surface rot (<=25%)	 Moderately damaged/misshapen sole/wall area of the digit (>25%	 Severely damaged/misshapen sole/wall area of the digit (>75%)
Horn separation (White line disease)	 Less than 50% of the wall needs to be cut away	 More than or equal to 50% of the wall needs to be cut away	

Appendix III Table 1 continued

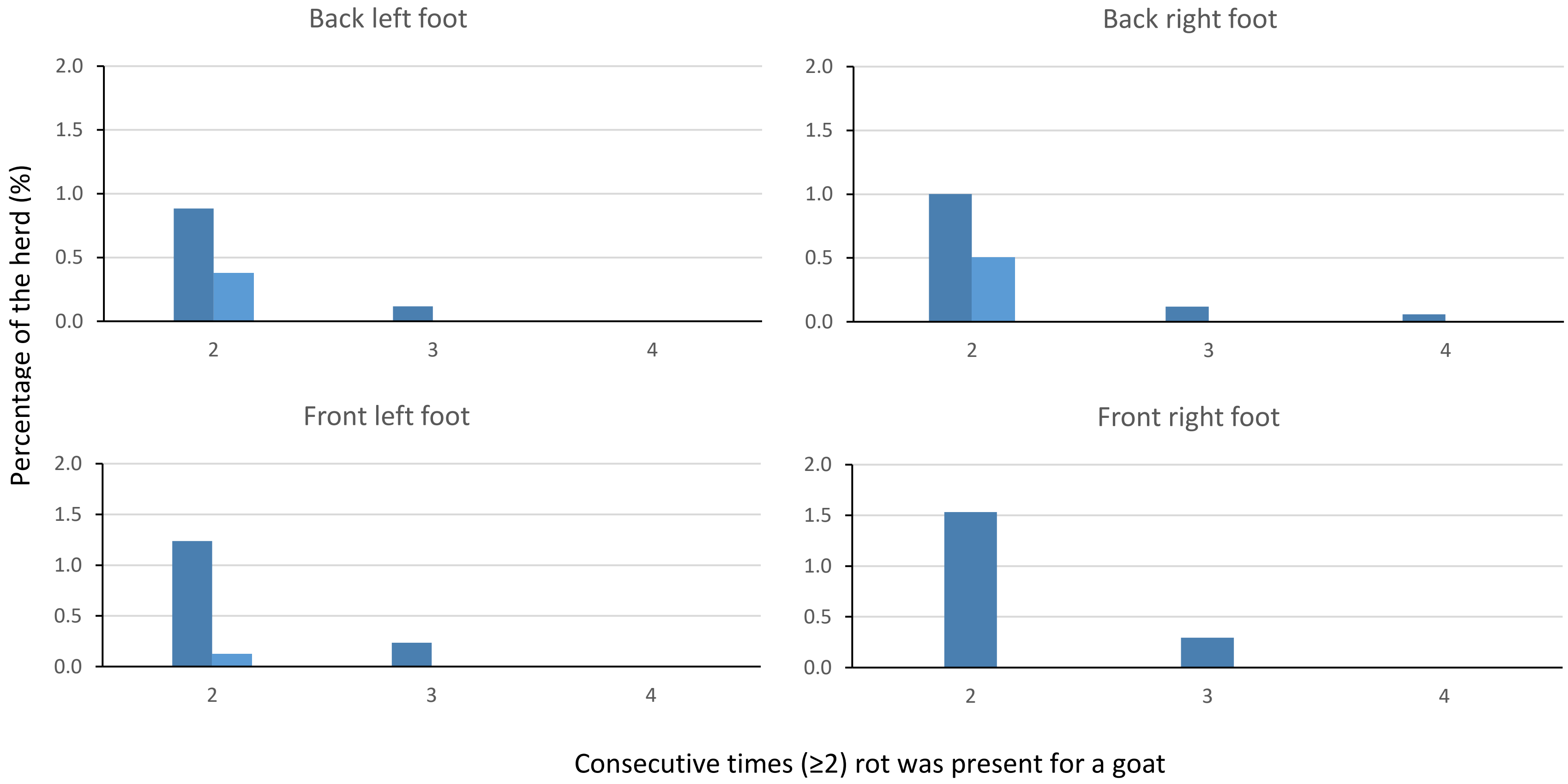
Claw Disorder	Severity 1	Severity 2	Severity 3
Granulomas	 Taking up less than 25% of the claw area	 Taking up more than or equal to 25% of the claw area	



Appendix III Figure 1. The percentage of goats, at the foot level, that had horn separation at consecutive hoof trimming events across farms A (dark blue), B (light blue) and C (lightest blue).



Appendix III Figure 2. The percentage of goats at the foot level that had granulomas at consecutive hoof trimming events across farms A (dark blue), B (light blue) and C (lightest blue).



Appendix III Figure 3. The percentage of goats at the foot level that had rot at consecutive hoof trimming events across farms A (dark blue) and B (light blue).

Chapter 6

Risk factors of claw disorders in dairy goats

6.1 Abstract

Claw disorders that cause lameness are a welfare problem on dairy goat farms. This study aimed to identify potential risk factors for developing claw disorders in dairy goat farms based in New Zealand. Three dairy goat farms in New Zealand participated in this study with claw disorder records taken during 4 or 5 hoof trimming events between July 2019 and June 2020. The main dataset contained 13,809 observations on 3,200 goats and was split into two datasets by lactation type- seasonal (≤305 days in milk) or extended (>305 days in milk) lactation. The prevalence (presence) and incidence rate (development) of three claw disorders- horn separation, rot or granuloma- were treated as dependent variables. Farm, age and foot were independent variables tested with prevalence and incidence rates. Season, stage of lactation, hoof trimmer, a previous case of claw disorder (horn separation, rot or granuloma) and a concurrent presence of claw disorder (horn separation, rot or granuloma) were included as risk factors for the prevalence of claw disorders.

This study achieved its goal of identifying some risk factors that increase or decrease the risk of claw disorders being present or developing in goats. At the foot level, farm, presence of a claw disorder at the previous hoof trimming, presence of concurrent claw disorders, age, and location were all associated with the prevalence of claw disorders. The strength and direction of the association differed between claw disorders. Farm, age and location were associated with the incidence rate of claw disorders. Horn separation appeared to be a more complex claw disorder compared with rot and granulomas, as there was more interaction between risk factors. The next step for this research is to expand the number of farms within the study to validate these results and identify other risk factors, such as season and stage of lactation, that were unable to be adequately assessed due to the small sample size of this study.

6.2 Introduction

Lameness is a broad topic; this study targets claw disorders causing lameness. In dairy goats, claw disorders associated with lameness have been linked with impaired welfare, reduced fertility, production and longevity (Eze, 2002; Christodoulopoulos, 2009). A lame dairy goat with low milk production and reduced fertility would increase its odds of being culled prematurely and thus reduce the expected income from dairy goat farming (Solis-Ramirez et al. 2011).

Claw disorders are caused by infectious diseases and non-infectious factors (Mathews, 2016). Pathogenic bacteria cause infectious claw diseases that colonise within the claw tissue when conditions are favourable and potentially lead to lameness. Infectious claw disorders identified as problematic in dairy goats are footrot and contagious caprine digital dermatitis (Mathews, 2016). As there is an interaction between infectious claw disorders, it can be challenging to identify the primary cause of the foot problem and resulting lameness (Beninger et al. 2018). Non-infectious diseases of the claw can develop for a variety of reasons. These variables include the climate, the animal's genetics, nutrition, environment, management, or a combination of the previously mentioned factors (Mathews, 2016). In some cases, non-infectious diseases can predispose the claw to infectious diseases (secondary infection). Additionally, not all claw disorders can cause lameness.

Previous studies have rarely discussed the risk of developing claw disorders in commercially managed dairy goat herds. One study reported that season could influence the presence of claw disorders, specifically overgrown claws, in dairy goats (Sailer et al. 2021). Other dairy goat studies have also suggested that the climate affected the prevalence of claw disorders (Eze, 2002; Christodoulopoulos, 2009). In dairy cattle and sheep studies, stage of lactation, season, type of flooring, nutrition, animal susceptibility, parity, and herd size are a few variables that have been identified with some claw disorders (Barker et al. 2009; Palmer and O'Connell, 2015; Gelasakis et al. 2019). The objective of this study was to identify risk factors that may be associated with the three main claw disorders, horn separation, rot and granulomas (identified in Chapter 3.3) in three commercial dairy goat farms in New Zealand.

6.3 Materials and methods

6.3.1 Study population

A full description of the study population is provided in Chapter 3.3. In brief, three dairy goat farms in Waikato, New Zealand, were enrolled in the study on a volunteer basis. There was a mixture of extended lactation and seasonal goats on the three farms.

Seasonal lactation goats had kidded between July and December 2019. Extended lactation goats were classified as goats that had been lactating for longer than 305-days as of July 2019. The goats were made up of pure- and cross-bred goats. On these farms, 12 to 83% of goats had at least one claw disorder at hoof trimming during the study period (Chapter 4).

Rainfall and temperature measurements near the farms were collected from the NIWA website[1] for the 2019-2020 season (Appendix II, Figure 1). There was high rainfall and low temperatures from July to August 2019. January 2020 and February 2020 were the driest and warmest months of the season.

6.3.2 Development of claw disorder scoring system

The hoof trimmers, the PhD candidate, and veterinarians developed the claw disorder scores, which are discussed in further detail in Chapter 5.3.2.

6.3.3 Claw disorder data collection

Data collection occurred during hoof trimming events between July 2019 and June (Figure 5.1). Depending on the farm, hoof trimming events took place 4-5 times a year. The information was recorded on a scoring sheet and entered into a Qualtrics database (Qualtrics. 20, Provo, UT). The data collection process was discussed in further detail in Chapter 4.

6.3.4 Data analysis

All claw disorders were recorded during the hoof trimming events, though only risk factors for rot, granulomas, and horn separation will be presented. The dataset was split into two depending on the type of lactation the goats were in, either seasonal (≥305 days in milk) or extended lactation (>305 days in milk). Definitions for prevalence and incidence rate were explained in more detail in Chapter 4.

For each dataset, three logistic regression models (for horn separation, rot, or granuloma) were built to identify risk factors associated with prevalence, with the

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[1]Station: Hamilton Ruakura; https://niwa.co.nz/climate/monthly

dependent variable being a binomial variable for the presence or absence of claw disorders.

The association of potential risk factors with the prevalence of a claw disorder was evaluated at the animal level and performed with a logistic regression model using the GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). The dependent variable was the presence or absence status of a specific claw disorder (horn separation, rot, or granuloma) at each hoof trimming event. The model included the fixed effects described in Table 6.1 and the random effect of animal to account for repeated measures on the same animal. The GLIMMIX procedure with a logit link function and the residual marginal pseudo-likelihood (RMPL) method were used to analyse and fit the model. While fitting the model, the residual dispersion was monitored, where a generalised chi-square statistic and the degrees of freedom close to one indicated that over-dispersion was not present (Schabenberger, 2005). The log estimate, standard errors, odds ratio, and 95% confidence intervals are presented. The differences between the means were adjusted with the Tukey correction.

The association of potential risk factors on the incidence rate of claw disorders was evaluated at the animal level. The incidence rate of claw disorders was the number of new cases between the first and last scoring event (between July 2019 and July 2020). The analysis was performed with a Poisson regression model using the GENMOD procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). To measure the model's goodness of fit, the Akaike Information Criterion (AIC) was used, where the lower the AIC, the better quality of the model. The model included an offset, the log-transformed sum of days at risk, to account for the effect of time. The risk factors variables, which were tested as risk factors for the dependent variables, are shown in Table 6.2. A Lagrange Multiplier test was used to determine if there was overdispersion within the models. If there was overdispersion, the negative binomial distribution was used as the alternative binomial distribution (Yang and Berdine, 2015). The differences between marginal means were adjusted with the Tukey correction.

Table 6.1. Independent variables that we considered as risk factors for the prevalence of claw disorders - either horn separation, rot, or granulomas in seasonal (≤305 days in milk) and extended (>305 days in milk) lactating goats from three farms located in Waikato, New Zealand.

Factor	Seasonal lactation goats	Extended lactation goats
Farm[1]	A, B, and C	A, B, and C
Age (years)	1, 2, 3, and 4+	2 and 3+
Season		Winter-Spring Summer-Autumn
Stage of lactation	Early (≤120 days) Late (>120 days)	
Hoof trimmer	A and B	A and B
Foot	Back left, back right, Front left, front right	Back left, back right, Front left, front right
A previous case of horn separation	Presence or absence	Presence or absence
A previous case of rot	Presence or absence	Presence or absence
A previous case of granuloma	Presence or absence	Presence or absence
Concurrent presence of a case of horn separation	Presence or absence	Presence or absence
Concurrent presence of a case of rot	Presence or absence	Presence or absence
Concurrent presence of a case of granuloma	Presence or absence	Presence or absence
Deviation from the median kidding date	Covariate	Not applied

[1]Note: for the analysis of rot, data from farm C were excluded, while for the analysis of granulomas, data from farm B were excluded because there were not enough observations for this analysis.

Table 6.2. Independent variables that we considered as risk factors for the incidence rate of claw disorders - either horn separation, rot, or granulomas in seasonal (≤305 days in milk) and extended (>305 days in milk) lactating goats from three farms located in Waikato, New Zealand.

Factor	Seasonal lactation goats	Extended lactation goats
Farm[1]	A, B, and C	A, B, and C
Age (years)	1, 2, 3, and 4+	2 and 3+
Foot	Back left, back right, Front left, front right	Back left, back right, Front left, front right
Deviation from the median kidding date	Number of days	Not applied

[1]Note: for the analysis of rot, data from farm C was excluded, while for the analysis of granulomas, data from farm B were excluded because there were not enough observations for this analysis.

6.4 Results

6.4.1 Descriptive results

After data editing, the dataset contained 13,809 observations at the animal level between July 2019 and June 2020. Table 6.3 shows the distribution of goats with at least one claw disorder from the hoof-trimmed goats. Farm A had the highest prevalence of rot and granulomas compared with farms B and C. Farm C had the highest prevalence of horn separation than farms A and B. November 2019 and December 2019 tended to have the highest levels of goats with at least one claw disorder.

Table 6.3. The number, n, and percentage (in parenthesis) of goats with at least one claw disorder. The dataset was divided by type of claw disorder- either horn separation, rot, or granulomas at each hoof trimming event during the 2019-2020 production year. The data were obtained from three farms located in Waikato, New Zealand. The herd size is the total number of goats assessed at each hoof trimming event.

		Claw disorder				
Hoof trimming event	Farm	Horn separation	Rot	Granulomas	Total[1]	Herd size
August 2019	A	773 (53%)	125 (9%)	103 (7%)	877 (60%)	1,454
	B	83 (11%)	8 (1%)	11 (1%)	100 (13%)	765
	C	541 (67%)	9 (1%)	17 (2%)	548 (68%)	802
October 2019	A	703 (43%)	166 (10%)	127 (8%)	831 (51%)	1,618
November 2019	B	261 (35%)	77 (10%)	7 (1%)	294 (39%)	753
	C	650 (82%)	8 (1%)	29 (4%)	359 (83%)	795
December 2019	A	929 (57%)	314 (19%)	178 (11%)	1,060 (65%)	1,633
February 2020	A	546 (34%)	122 (8%)	188 (12%)	694 (44%)	1,590
	B	140 (19%)	49 (7%)	28 (4%)	185 (25%)	740
	C	487 (63%)	4 (1%)	29 (4%)	500 (64%)	776
May 2020	A	560 (37%)	241 (16%)	212 (14%)	751 (50%)	1,497
	B	60 (10%)	10 (2%)	9 (1%)	76 (12%)	623
	C	285 (37%)	1 (0.1%)	12 (2%)	292 (38%)	763

[1]Total = total number of goats with at least one claw disorder.

6.4.2 Risk factors associated with claw disorders prevalence

The main factors that were significant to each model in increasing or decreasing the risk of a goat having either horn separation, rot or granulomas present are shown in Tables 6.4-6.9. The factors varied depending on whether the goats were classified as seasonal or extended lactation animals and depended on the claw disorder.

For seasonal lactation goats, across ages, stages of lactations and feet, the odds of horn separation being present in goats on farm C was significantly higher than for goats located within farms A and B (P-value <0.001). A previous granuloma case significantly decreased the odds of horn separation being present (OR = 0.52, 95% CI = [0.32 -0.83]). The concurrent presence of rot or rot and a granuloma increased the odds of having horn separation present at the same time by 19.2 and 5.16 times (P-value <0.001), respectively. The hoof trimmers only differed significantly in the back feet, where the odds of hoof trimmer A diagnosing horn separation were higher than hoof trimmer B (P-value <0.001). Overall, the odds of the front feet being diagnosed with horn separation by both hoof trimmers were higher than the back feet.

In extended lactation goats, the odds of horn separation present in goats on farm C were significantly higher than for goats on farms A and B (Table 6.5). The odds of horn separation being present were 8.60 times greater if rot was also present (95% CI = [7.20 -10.3]). Like seasonal goats, hoof trimmer A's odds of diagnosing horn separation were significantly higher than hoof trimmer B (OR = 0.78, 95% CI = [0.65 -0.92]), with no significant difference in the front feet.

Only two farms, A and B, were included in the analysis of factors associated with the presence of rot (Tables 6.6 and 6.7). In seasonal goats, having a previous case of granuloma increased the odds of rot being present by 4.60 (P-value <0.001). The odds of rot being present in three- and four-year-old or older goats were 3.16 and 2.26 times higher, respectively, than in one-year-old goats (P-value <0.001). The presence of both granuloma and horn separation increased the odds of rot also being present by 67.4 times (P-value <0.001). In extended lactation goats, having a previous case of either a granuloma, rot, or nick increased the odds of rot being present by 2.03, 2.36 and 1.65 times (P-value <0.001), respectively. The odds of rot being present increased with age, with three years old goats or older being 1.16 times more likely to present with rot than two-year-olds. There were significantly greater odds of rot being present in the front feet than the back feet on farm A (OR = 1.78, 95% CI = [1.36-2.33], although there is no significant difference for farm B. There are also significantly greater odds of rot being present in the Summer-Autumn on farm A than Winter-Spring (OR = 1.54, 95% CI = [1.22 -1.95]) with no significant difference on farm B.

Only two farms, A and C, were included in analysing risk factors associated with granulomas being present (Tables 6.8 and 6.9). For seasonal lactation goats, the odds of granulomas being present were higher for goats from farm A than on farm C (OR =0.55, 95% CI = [0.37-0.81]). The odds of granulomas being present were higher in the back feet than in the front feet (P-value <0.001). When rot was present, the odds of goats also having a granuloma present increased by 5.95 times (P-value <0.001). A previous case of a nick increased the odds of a granuloma being present by 1.86 (P-value =0.036). If a goat had a previous case of granuloma, or a previous case of horn separation and granuloma, the odds of a granuloma being present increased by 14.2 times or 3.28 times, respectively (P-value <0.001).

In the extended lactation goats on farm C, the odds of a granuloma being present on the back foot were higher than on the front foot (OR = 0.32, 95% CI = [0.11-0.91]). If only horn separation were present, the odds of granuloma also being present were lowered (OR = 0.70, 95% CI = [0.05-1.00]). When rot was present, the odds of a granuloma also being present increased by 3.79 times (P-value <0.001). A previous case of a nick increased the odds of a granuloma being present by 1.79 (P = 0.008). Meanwhile, having a previous case of rot, horn separation, granuloma, or the combination of these claw disorders also increased the odds of granuloma being present at the next hoof trimming event (OR = 1.44-76.2, 95% CI = [1.34-109]).

Table 6.4. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of horn separation in <u>seasonal lactation</u> dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Previous horn separation	Absence		-1.21 (0.16)	0.23 (0.03)	Reference		
	Presence		-1.12 (0.16)	0.25 (0.03)	1.09	0.99 -1.20	0.075
Previous granuloma	Absence		-0.83 (0.14)	0.30 (0.03)	Reference		
	Presence		-1.50 (0.24)	0.18 (0.04)	0.52	0.32 -0.83	0.006
Previous rot	Absence		-1.08 (0.14)	0.25 (0.03)	Reference		
	Presence		-1.24 (0.21)	0.22 (0.04)	0.85	0.61 -1.20	0.356
Previous nick	Absence		-1.16 (0.15)	0.24 (0.03)	Reference		
	Presence		-1.17 (0.18)	0.24 (0.03)	0.99	0.79 -1.25	0.947
Hoof trimmer x Foot	Back	A	-1.23 (0.16)	0.23 (0.03)	Reference		
	Back	B	-1.57 (0.16)	0.17 (0.02)	0.72	0.61 -0.84	<0.001
	Front	A	-0.94 (0.16)	0.28 (0.03)	1.35	1.14 -1.59	<0.001
	Front	B	-0.92 (0.16)	0.28 (0.03)	1.36	1.13 -1.64	<0.001

Table 6.4 continued

Predictor				Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Concurrent granuloma x concurrent rot	Concurrent granuloma	Concurrent rot						
	Absence	Absence		-2.28 (0.16)	0.09 (0.01)	Reference		
	Absence	Presence		0.67 (0.19)	0.66 (0.04)	19.22	14.1 -26.3	<0.001
	Presence	Absence		-2.41 (0.23)	0.08 (0.02)	0.88	0.53 -1.49	0.929
	Presence	Presence		-0.64 (0.31)	0.34 (0.07)	5.16	2.31 -11.5	<0.001
Farm x age x foot	Farm	Age	Foot					
	A	1	Back	-1.12 (0.17)	0.25 (0.03)	Reference		
	A	1	Front	-0.80 (0.17)	0.31 (0.04)	1.38	1.06 -1.80	0.003
	A	2	Back	-1.24 (0.20)	0.22 (0.03)	0.88	0.51 -1.54	1.000
	A	2	Front	-0.97 (0.19)	0.27 (0.04)	1.16	0.68 -1.98	1.000
	A	3	Back	-1.44 (0.21)	0.19 (0.03)	0.72	0.38 -1.39	0.984
	A	3	Front	-0.65 (0.20)	0.34 (0.05)	1.60	0.90 -2.87	0.328
	A	4+	Back	-1.50 (0.18)	0.18 (0.03)	0.69	0.43 -1.10	0.339
	A	4+	Front	-0.81 (0.17)	0.31 (0.04)	1.37	0.88 -2.12	0.602
	B	1	Back	-2.97 (0.24)	0.05 (0.01)	0.16	0.08 -0.32	<0.001
	B	1	Front	-2.14 (0.21)	0.10 (0.02)	0.36	0.21 -0.62	<0.001
	B	2	Back	-2.46 (0.22)	0.08 (0.02)	0.26	0.14 -0.50	<0.001
	B	2	Front	-1.73 (0.20)	0.15 (0.03)	0.54	0.32 -0.92	0.006
	B	3	Back	-2.34 (0.24)	0.09 (0.02)	0.30	0.14 -0.61	<.0001
	B	3	Front	-1.88 (0.22)	0.13 (0.03)	0.47	0.25 -0.88	0.003

Table 6.4 continued

Predictor				Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Farm x age x foot	Farm	Age	Foot					
	B	4+	Back	-2.65 (0.23)	0.07 (0.01)	0.22	0.11 -0.43	<0.001
	B	4+	Front	-1.75 (0.20)	0.15 (0.02)	0.53	0.32 -0.90	0.003
	C	1	Back	-0.59 (0.18)	0.36 (0.04)	1.70	1.09 -2.67	<0.001
	C	1	Front	-0.26 (0.18)	0.44 (0.04)	2.36	1.55 -3.60	<0.001
	C	2	Back	-0.22 (0.20)	0.45 (0.05)	2.46	1.47 -4.11	<0.001
	C	2	Front	0.02 (0.19)	0.51 (0.05)	3.14	1.91 -5.15	<0.001
	C	3	Back	-0.10 (0.19)	0.48 (0.05)	2.78	1.72 -4.49	<0.001
	C	3	Front	-0.09 (0.19)	0.48 (0.05)	2.80	1.75 -4.49	<0.001
	C	4+	Back	-0.17 (0.20)	0.46 (0.05)	2.58	1.53 -4.36	<0.001
	C	4+	Front	-0.10 (0.20)	0.48 (0.05)	2.78	1.66 -4.65	<0.001
Farm x age x SoL[1]	Farm	Age	SoL					
	A	1	Late	-0.86 (0.17)	0.30 (0.04)	Reference		
	A	1	Early	-1.07 (0.17)	0.26 (0.03)	0.81	0.63 -1.05	0.338
	A	2	Late	-1.16 (0.19)	0.24 (0.03)	0.74	0.45 -1.23	0.895
	A	2	Early	-1.06 (0.20)	0.26 (0.04)	0.82	0.47 -1.43	1.000
	A	3	Late	-1.11 (0.20)	0.25 (0.04)	0.78	0.44 -1.38	0.997
	A	3	Early	-0.99 (0.22)	0.27 (0.04)	0.88	0.46 -1.67	1.000
	A	4+	Late	-1.22 (0.17)	0.23 (0.03)	0.70	0.46 -1.06	0.228
	A	4+	Early	-1.09 (0.18)	0.25 (0.03)	0.79	0.51 -1.24	0.975

Table 6.4 continued

Predictor				Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Farm x age x SoL[1]	Farm	Age	SoL					
	B	1	Late	-2.92 (0.24)	0.05 (0.01)	0.13	0.06 -0.26	<0.001
	B	1	Early	-2.19 (0.20)	0.10 (0.02)	0.26	0.16 -0.45	<.0001
	B	2	Late	-2.76 (0.24)	0.06 (0.01)	0.15	0.07 -0.30	<0.001
	B	2	Early	-1.43 (0.19)	0.19 (0.03)	0.56	0.35 -0.90	0.002
	B	3	Late	-2.37 (0.24)	0.09 (0.02)	0.22	0.11 -0.46	<0.001
	B	3	Early	-1.84 (0.22)	0.14 (0.03)	0.37	0.20 -0.69	<.0001
	B	4+	Late	-2.21 (0.21)	0.10 (0.02)	0.26	0.14 -0.47	<0.001
	B	4+	Early	-2.18 (0.21)	0.10 (0.02)	0.27	0.15 -0.47	<.0001
	C	1	Late	-1.06 (0.19)	0.26 (0.04)	0.81	0.52 -1.29	0.995
	C	1	Early	0.21 (0.18)	0.55 (0.04)	2.91	1.97 -4.30	<0.001
	C	2	Late	-0.55 (0.21)	0.37 (0.05)	1.36	0.77 -2.39	0.951
	C	2	Early	0.35 (0.18)	0.59 (0.04)	3.34	2.17 -5.16	<0.001
	C	3	Late	-0.69 (0.19)	0.33 (0.04)	1.18	0.72 -1.92	1.000
	C	3	Early	0.51 (0.18)	0.62 (0.04)	3.90	2.53 -6.02	<0.001
	C	4+	Late	-0.48 (0.20)	0.38 (0.05)	1.46	0.85 -2.49	0.629
	C	4+	Early	0.21 (0.19)	0.55 (0.05)	2.90	1.79 -4.69	<0.001

Table 6.4 continued

Predictor	Farm	SoL	Foot	Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Farm x SoL[1] x foot	A	Late	Back	-1.34 (0.16)	0.21 (0.03)	Reference		
	A	Late	Front	-0.82 (0.16)	0.30 (0.03)	1.68	1.31 -2.16	<0.001
	A	Early	Back	-1.31 (0.17)	0.21 (0.03)	1.03	0.78 -1.37	1.000
	A	Early	Front	-0.79 (0.17)	0.31 (0.04)	1.74	1.29 -2.34	<0.001
	B	Late	Back	-2.88 (0.21)	0.05 (0.01)	0.22	0.13 -0.36	<0.001
	B	Late	Front	-2.25 (0.19)	0.09 (0.02)	0.40	0.27 -0.61	<0.001
	B	Early	Back	-2.33 (0.19)	0.09 (0.02)	0.37	0.25 -0.56	<.0001
	B	Early	Front	-1.50 (0.18)	0.18 (0.03)	0.86	0.61 -1.21	0.948
	C	Late	Back	-0.97 (0.18)	0.27 (0.04)	1.45	1.01 -2.07	<0.001
	C	Late	Front	-0.42 (0.17)	0.40 (0.04)	2.52	1.81 -3.51	<0.001
	C	Early	Back	0.43 (0.17)	0.61 (0.04)	5.90	4.39 -7.93	<0.001
	C	Early	Front	0.21 (0.17)	0.55 (0.04)	4.71	3.48 -6.37	<0.001
Deviation from the median kidding date		0.004 (0.002)				0.010		
Animal[2]				0.38 (0.03)				

[1]SoL = Stage of lactation

[2]Random effect of animal

Table 6.5. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of horn separation in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Age	2		-1.55 (0.15)	0.18 (0.02)	Reference		
	3+		-1.40 (0.13)	0.20 (0.02)	1.16	1.01 -1.33	0.036
Previous granuloma	Absence		-1.05 (0.12)	0.13 (0.02)	Reference		
	Presence		-1.90 (0.21)	0.26 (0.02)	0.43	0.29 -0.64	<0.001
Previous nick	Absence		-1.51 (0.13)	0.18 (0.02)	Reference		
	Presence		-1.44 (0.16)	0.19 (0.03)	1.07	0.88 -1.31	0.495
Concurrent granuloma	Absence		-1.27 (0.14)	0.22 (0.02)	Reference		
	Presence		-1.68 (0.17)	0.16 (0.02)	0.66	0.49 -0.90	0.007
Concurrent rot	Absence		-2.55 (0.14)	0.07 (0.01)	Reference		
	Presence		-0.40 (0.15)	0.40 (0.04)	8.60	7.20 -10.27	<0.001
Foot x Hoof trimmer	Back	A	-1.62 (0.15)	0.16 (0.02)	Reference		
	Back	B	-1.88 (0.14)	0.13 (0.02)	0.78	0.65 -0.92	<0.001
	Front	A	-1.19 (0.14)	0.23 (0.03)	1.54	1.23 -1.92	<0.001
	Front	B	-1.20 (0.15)	0.23 (0.03)	1.53	1.20 -1.96	<0.001

Table 6.5 continued

Predictor				Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Previous rot x Previous horn separation	Previous rot	Previous horn separation						
	Absence	Absence		-1.47 (0.13)	0.19 (0.02)	Reference		
	Presence	Absence		-1.57 (0.24)	0.17 (0.03)	1.66	1.47 -1.87	<0.001
	Absence	Presence		-0.97 (0.13)	0.27 (0.03)	0.91	0.53 -1.57	0.969
	Presence	Presence		-1.88 (0.21)	0.13 (0.02)	0.67	0.43 -1.04	0.090
Farm x Season x Foot	Farm	Season	Foot					
	A	Winter-Spring	Back	-1.49 (0.14)	0.18 (0.02)	Reference		
	A	Winter-Spring	Front	-0.62 (0.14)	0.35 (0.03)	2.37	1.89 -2.98	<0.001
	A	Summer-Autumn	Back	-1.94 (0.14)	0.13 (0.02)	0.64	0.50 -0.81	<0.001
	A	Summer-Autumn	Front	-1.35 (0.13)	0.21 (0.02)	1.14	0.91 -1.44	0.785
	B	Winter-Spring	Back	-3.23 (0.27)	0.04 (0.01)	0.18	0.08 -0.39	<0.001
	B	Winter-Spring	Front	-1.84 (0.19)	0.14 (0.02)	0.70	0.43 -1.14	0.426
	B	Summer-Autumn	Back	-2.74 (0.24)	0.06 (0.01)	0.29	0.14 -0.57	<0.001
	B	Summer-Autumn	Front	-2.89 (0.25)	0.05 (0.01)	0.25	0.12 -0.51	<0.001
	C	Winter-Spring	Back	-0.19 (0.15)	0.45 (0.04)	3.64	2.69 -4.91	<0.001
	C	Winter-Spring	Front	0.06 (0.15)	0.51 (0.04)	4.68	3.43 -6.37	<0.001
	C	Summer-Autumn	Back	-0.92 (0.16)	0.28 (0.03)	1.76	1.25 -2.46	<0.001
	C	Summer-Autumn	Front	-0.53 (0.16)	0.37 (0.04)	2.61	1.89 -3.61	<0.001
Animal[1]				0.35 (0.03)				

[1]Random effect of animal

Table 6.6. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of rot in seasonal lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Age	1	-2.27 (0.28)	0.09 (0.02)	Reference		
	2	-2.05 (0.28)	0.11 (0.03)	1.25	0.72 -2.18	0.734
	3	-1.12 (0.27)	0.25 (0.05)	3.16	1.83 -5.44	<0.001
	4+	-1.46 (0.25)	0.19 (0.04)	2.26	1.39 -3.68	<0.001
Foot	Back	-1.74 (0.25)	0.15 (0.03)	Reference		
	Front	-1.71 (0.25)	0.15 (0.03)	1.02	0.81 -1.29	0.849
Hoof trimmer	A	-1.73 (0.25)	0.15 (0.03)	Reference		
	B	-1.72 (0.24)	0.15 (0.03)	1.00	0.80 -1.25	0.982
Previous granuloma	Absence	-2.49 (0.23)	0.08 (0.02)	Reference		
	Presence	-0.96 (0.31)	0.28 (0.06)	4.60	2.72 -7.78	<0.001
Previous nick	Absence	-1.90 (0.18)	0.13 (0.02)	Reference		
	Presence	-1.54 (0.37)	0.18 (0.05)	1.43	0.76 -2.71	0.269

Table 6.6 continued

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Farm x SoL[1]	Farm	SoL					
	A	Late	-1.50 (0.23)	0.18 (0.03)	Reference		
	A	Early	-1.84 (0.26)	0.14 (0.03)	0.71	0.51 -0.99	0.039
	B	Late	-1.94 (0.28)	0.13 (0.03)	0.65	0.39 -1.08	0.124
	B	Early	-1.62 (0.28)	0.17 (0.04)	0.89	0.58 -1.37	0.892
Previous rot x previous horn separation	Previous rot	Previous horn separation					
	Absence	Absence	-1.86 (0.22)	0.13 (0.03)	Reference		
	Presence	Absence	-1.01 (0.37)	0.27 (0.07)	2.36	1.00 -5.60	0.052
	Absence	Presence	-1.58 (0.26)	0.17 (0.04)	1.33	0.90 -1.96	0.232
	Presence	Presence	-2.45 (0.45)	0.08 (0.03)	0.56	0.20 -1.59	0.481
Concurrent horn separation x concurrent granuloma	Concurrent horn separation	Concurrent granuloma					
	Absence	Absence	-4.10 (0.26)	0.02 (0.00)	Reference		
	Presence	Absence	-1.15 (0.26)	0.24 (0.05)	19.1	14.1 -26.0	<0.001
	Absence	Presence	-1.75 (0.28)	0.15 (0.04)	10.5	5.32 -20.7	<0.001
	Presence	Presence	0.11 (0.40)	0.53 (0.10)	67.4	26.3 -172.4	<0.001

Table 6.6 continued

Predictor	Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Deviation from the median kidding date	-0.004 (0.004)				0.233
Animal[2]		0.61 (0.12)			

[1]SoL = stage of lactation

[2]Random effect of animal

Table 6.7. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of rot in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Age	2	-1.90 (0.20)	0.13 (0.02)	Reference		
	3+	-1.50 (0.16)	0.18 (0.02)	1.16	1.01 -1.33	0.036
Hoof trimmer	A	-1.80 (0.18)	0.14 (0.02)	Reference		
	B	-1.60 (0.18)	0.17 (0.02)	1.22	1.01 -1.47	0.038
Previous horn separation	Absence	-1.63 (0.17)	0.16 (0.02)	Reference		
	Presence	-1.77 (0.19)	0.15 (0.02)	0.88	0.71 -1.09	0.229
Previous granuloma	Absence	-2.05 (0.17)	0.11 (0.02)	Reference		
	Presence	-1.35 (0.23)	0.21 (0.04)	2.03	1.33 -3.08	0.001
Previous rot	Absence	-2.13 (0.17)	0.11 (0.02)	Reference		
	Presence	-1.27 (0.21)	0.22 (0.04)	2.36	1.72 -3.24	<0.001
Previous nick	Absence	-1.95 (0.15)	0.12 (0.02)	Reference		
	Presence	-1.45 (0.24)	0.19 (0.04)	1.65	1.12 -2.41	0.011
Concurrent horn separation	Absence	-2.79 (0.17)	0.06 (0.01)	Reference		
	Presence	-0.61 (0.18)	0.35 (0.04)	8.79	7.39 -10.5	<0.001

Table 6.7 continued

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Concurrent granuloma	Absence		-2.43 (0.18)	0.08 (0.01)	Reference		
	Presence		-0.96 (0.20)	0.28 (0.04)	4.35	3.08 -6.14	<0.001
Farm x foot	Farm	Foot					
	A	Back	-1.85 (0.16)	0.14 (0.02)	Reference		
	A	Front	-1.27 (0.15)	0.22 (0.03)	1.78	1.36 -2.33	<0.001
	B	Back	-1.51 (0.25)	0.18 (0.04)	1.41	0.81 -2.44	0.388
	B	Front	-2.18 (0.30)	0.10 (0.03)	0.72	0.35 -1.46	0.623
Farm x season	Farm	Season					
	A	Winter-Spring	-1.77 (0.17)	0.15 (0.02)	Reference		
	A	Summer-Autumn	-1.34 (0.14)	0.21 (0.02)	1.54	1.22 -1.95	<0.001
	B	Winter-Spring	-1.71 (0.26)	0.15 (0.03)	1.06	0.60 -1.90	0.993
	B	Summer-Autumn	-1.98 (0.29)	0.12 (0.03)	0.82	0.42 -1.59	0.863
Animal[1]			0.27 (0.08)				

[1]Random effect of animal

Table 6.8. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of granuloma in seasonal lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Farm	A	-1.27 (0.24)	0.22 (0.04)	Reference		
	C	-1.88 (0.29)	0.13 (0.03)	0.55	0.37 -0.81	0.003
Age	1	-1.87 (0.30)	0.13 (0.03)	Reference		
	2	-1.20 (0.29)	0.23 (0.05)	1.95	0.99 -3.85	0.055
	3	-1.58 (0.30)	0.17 (0.04)	1.34	0.64 -2.80	0.738
	4+	-1.65 (0.27)	0.16 (0.04)	1.25	0.65 -2.40	0.812
Foot	Back	-1.22 (0.25)	0.23 (0.04)	Reference		
	Front	-1.93 (0.26)	0.13 (0.03)	0.49	0.35 -0.67	<0.001
Stage of lactation	Late	-1.56 (0.25)	0.17 (0.04)	Reference		
	Early	-1.59 (0.26)	0.17 (0.04)	0.98	0.74 -1.30	0.882
Hoof trimmer	A	-1.61 (0.26)	0.17 (0.04)	Reference		
	B	-1.54 (0.26)	0.18 (0.04)	1.07	0.78 -1.45	0.687
Previous nick	Absence	-1.88 (0.21)	0.13 (0.02)	Reference		
	Presence	-1.27 (0.35)	0.22 (0.06)	1.86	1.04 -3.32	0.036

Table 6.8 continued

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Concurrent horn separation	Absence		-1.41 (0.25)	0.20 (0.04)	Reference		
	Presence		-1.74 (0.27)	0.15 (0.03)	0.72	0.50 -1.06	0.093
Concurrent rot	Absence		-2.47 (0.24)	0.08 (0.02)	Reference		
	Presence		-0.68 (0.31)	0.34 (0.07)	5.95	3.69 -9.58	<0.001
Previous horn separation x previous granuloma	Previous horn separation	Previous granuloma					
	Absence	Absence	-2.55 (0.25)	0.07 (0.02)	Reference		
	Presence	Absence	-2.49 (0.25)	0.08 (0.02)	1.06	0.57 -1.97	0.994
	Absence	Presence	0.10 (0.37)	0.53 (0.09)	14.2	5.99 -33.5	<0.001
	Presence	Presence	-1.36 (0.49)	0.20 (0.08)	3.28	0.90 -11.9	0.084
Previous rot x previous granuloma	Previous rot	Previous granuloma					
	Absence	Absence	-3.72 (0.20)	0.02 (0.00)	Reference		
	Presence	Absence	-1.32 (0.30)	0.21 (0.05)	11.0	5.74 -21.1	<0.001
	Absence	Presence	-0.77 (0.32)	0.32 (0.07)	19.1	9.17 -39.9	<0.001
	Presence	Presence	-0.49 (0.55)	0.38 (0.13)	25.2	6.54 -97.0	<0.001

Table 6.8 continued

Predictor			Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Previous rot x previous horn separation	Previous rot	Previous horn separation					
	Absence	Absence	-2.14 (0.21)	0.11 (0.02)	Reference		
	Presence	Absence	-0.31 (0.41)	0.42 (0.10)	6.20	2.38 -16.2	<0.001
	Absence	Presence	-2.35 (0.31)	0.09 (0.02)	0.81	0.40 -1.7	0.869
	Presence	Presence	-1.50 (0.42)	0.18 (0.06)	1.89	0.70 -5.1	0.350
Deviation from the median kidding date		0.005 (0.005)			0.259		
Animal[1]				0.79 (0.17)			

[1]Random effect of animal

Table 6.9. The estimates, means, standard error (SE), odds ratio, and the 95% confidence interval of factors associated with the prevalence of granuloma in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)	Odds ratio	95% CI	P-value
Age	2	-1.26 (0.23)	0.22 (0.04)	Reference		
	3+	-1.42 (0.18)	0.20 (0.03)	0.86	0.66 -1.12	0.265
Season	Winter-Spring	-1.26 (0.21)	0.22 (0.04)	Reference		
	Summer-Autumn	-1.42 (0.19)	0.19 (0.03)	0.85	0.68 -1.05	0.129
Hoof trimmer	A	-1.45 (0.20)	0.19 (0.03)	Reference		
	B	-1.23 (0.20)	0.23 (0.04)	1.24	0.98 -1.58	0.077
Previous nick	Absence	-1.63 (0.17)	0.16 (0.02)	Reference		
	Presence	-1.05 (0.26)	0.26 (0.05)	1.79	1.17 -2.75	0.008
Concurrent horn separation	Absence	-1.13 (0.20)	0.24 (0.04)	Reference		
	Presence	-1.55 (0.22)	0.17 (0.03)	0.66	0.48 -0.89	0.007
Concurrent rot	Absence	-2.01 (0.19)	0.12 (0.02)	Reference		
	Presence	-0.67 (0.24)	0.34 (0.05)	3.79	2.66 -5.40	<0.001

Table 6.9 continued

Farm x foot	A	Back	-0.81 (0.18)	0.31 (0.04)	Reference		
	A	Front	-0.98 (0.18)	0.27 (0.03)	0.84	0.60 -1.18	0.549
	B	Back	-1.21 (0.25)	0.23 (0.04)	0.68	0.40 -1.14	0.216
	B	Front	-2.36 (0.40)	0.09 (0.03)	0.21	0.08 -0.57	<0.001
Previous rot x previous horn separation	Previous rot	Previous horn separation					
	Absence	Absence	-1.74 (0.18)	0.15 (0.02)	Reference		
	Presence	Absence	-0.88 (0.27)	0.29 (0.06)	2.38	1.34 -4.24	0.001
	Absence	Presence	-1.38 (0.22)	0.20 (0.03)	1.44	0.97 -2.14	0.080
	Presence	Presence	-1.36 (0.29)	0.20 (0.05)	1.47	0.79 -2.76	0.386
Previous rot x previous granuloma	Previous rot	Previous granuloma					
	Absence	Absence	-3.73 (0.18)	0.02 (0.004)	Reference		
	Presence	Absence	-1.91 (0.23)	0.13 (0.03)	6.19	3.85 -9.96	<0.001
	Absence	Presence	0.60 (0.21)	0.65 (0.05)	76.16	53.3 -108.9	<0.001
	Presence	Presence	-0.33 (0.35)	0.42 (0.09)	29.89	13.5 -66.4	<0.001
Animal[1]			0.31 (0.12)				

[1]Random effect of animal

6.4.3 Risk factors associated with claw disorders incidence rate

The risk factors associated with the incidence rate, or the development of claw disorders differed depending on the type of disorder (Tables 6.10-6.15). For seasonal lactation goats, the incidence rate of horn separation depended on the interaction between farm and age, and farm and foot. The incidence rate of horn separation on farm C was the highest compared with goats on farm B and farm A (OR= 0.24 and 0.69, P-value <0.001], respectively). In extended lactation goats, there were no interactions between predictor variables. The incidence rate of goats developing horn separation was the lowest on farm B (0.21 times lower than farm A; P-value <0.001) and the highest on farm C (1.49 times higher than farm A; P-value <0.001).

There were no interactions between factors for seasonal lactation goats for rot and granulomas, while there was one interaction term for the extended lactation goats (Tables 6.12-6.15). For seasonal and extended lactation goats, the incidence rate of rot on farm B was 0.42 (95% CI = [0.33 -0.53]) and 0.42 (95% CI = [0.30-0.59]) times lower than farm A, respectively. For seasonal lactation goats, the incidence rate of rot was highest in the three year old goats or older (P-value <0.001). For extended lactation goats, goats three years old or older were 1.5 times more likely to develop rot than two-year-olds (OR=1.50, 95% CI= [1.20-1.88]).

For granulomas in seasonal and extended lactation goats, the incidence rate of granuloma was 0.30 and 0.26 times lower on farm C than on farm A (P-value <0.001), respectively. In seasonal lactation goats, the incidence rate of granuloma in the front feet was lower than in the back feet (OR=0.48 and 0.43, 95% CI= [0.25-0.91 and 0.22-0.84]). In extended lactation goats, there did not appear to be any significant difference in the development of granulomas between the back and front feet on any of the farms.

Table 6.10. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of horn separation in seasonal lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor			Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A		-6.13 (0.03)	79.6 (2.63)	Reference		
	B		-7.19 (0.05)	27.4 (1.46)	0.34	0.30 -0.40	<0.001
	C		-5.76 (0.03)	115 (3.98)	1.45	1.30 -1.62	0.063
Age	1		-6.48 (0.04)	55.9 (2.23)	Reference		
	2		-6.33 (0.05)	64.9 (2.99)	1.16	0.99 -1.36	<0.001
	3		-6.19 (0.05)	74.9 (3.98)	1.34	1.13 -1.59	<0.001
	4+		-6.43 (0.05)	58.7 (2.85)			
Foot	Back left		-6.46 (0.05)	56.9 (2.66)	Reference		
	Back right		-6.67 (0.05)	46.4 (2.45)	0.82	0.68 -0.97	0.002
	Front left		-6.16 (0.04)	77.3 (3.10)	1.36	1.16 -1.58	0.943
	Front right		-6.15 (0.04)	78.0 (3.14)	1.37	1.17 -1.60	<0.001
Farm x age	Farm	Age					
	A	1	-6.05 (0.06)	86.1 (4.85)	Reference		
	A	2	-6.18 (0.08)	75.6 (5.69)	0.88	0.64 -1.21	<0.001
	A	3	-6.01 (0.09)	89.4 (7.59)	1.04	0.73 -1.47	1.000
	A	4+	-6.27 (0.05)	68.9 (3.80)	0.80	0.61 -1.05	0.982
	B	1	-7.41 (0.10)	22.0 (2.12)	0.26	0.18 -0.37	<0.001
	B	2	-6.95 (0.09)	35.0 (3.07)	0.41	0.29 -0.58	0.375

Table 6.10 continued

Predictor			Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm x age	B	3	-7.11 (0.11)	29.9 (3.43)	0.35	0.23 -0.54	0.998
	B	4+	-7.31 (0.10)	24.5 (2.52)	0.28	0.19 -0.42	0.273
	C	1	-5.99 (0.05)	91.8 (4.49)	1.07	0.83 -1.37	<0.001
	C	2	-5.87 (0.07)	103 (7.56)	1.20	0.88 -1.64	<0.001
	C	3	-5.45 (0.06)	157 (10.1)	1.83	1.37 -2.43	<0.001
	C	4+	-5.72 (0.08)	119 (9.82)	1.38	0.99 -1.93	<0.001
Farm x foot	Farm	Foot					
	A	Back left	-6.30 (0.06)	66.9 (4.16)	Reference		
	A	Back right	-6.45 (0.07)	57.7 (3.80)	0.86	0.25 -0.62	0.873
	A	Front left	-5.89 (0.05)	101 (5.44)	1.51	0.22 -0.49	<0.001
	A	Front right	-5.87 (0.05)	103 (5.51)	1.54	0.91 -1.63	<0.001
	B	Back left	-7.36 (0.11)	23.2 (2.52)	0.35	0.97 -1.92	<0.001
	B	Back right	-7.75 (0.13)	15.7 (2.01)	0.23	1.51 -2.87	<0.001
	B	Front left	-6.83 (0.09)	39.5 (3.39)	0.59	1.10 -2.27	<0.001
	B	Front right	-6.83 (0.09)	39.3 (3.39)	0.59	0.59 -1.22	<0.001
	C	Back left	-5.73 (0.07)	119 (7.74)	1.77	0.16 -0.37	<0.001
	C	Back right	-5.80 (0.07)	110 (7.34)	1.64	0.26 -0.58	<0.001
	C	Front left	-5.76 (0.06)	116 (7.41)	1.73	0.21 -0.53	<0.001
	C	Front right	-5.74 (0.06)	118 (7.48)	1.76	0.18 -0.42	<0.001
Deviation from the median kidding date[2]			0.002 (0.005)				0.689

[1]Cases per 100 goat-years.
[2]Based on the Wald's 95% confidence interval.

Table 6.11. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of horn separation in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A	-6.35 (0.03)	63.7 (2.08)	Reference		
	B	-7.65 (0.11)	17.4 (1.97)	0.27	0.36 -0.21	<0.001
	C	-5.85 (0.05)	105 (5.51)	1.65	1.87 -1.46	<0.001
Age	2	-6.64 (0.07)	47.5 (3.18)	Reference		
	3+	-6.59 (0.04)	50.2 (2.12)	1.06	1.19 -0.93	<0.001
Foot	Back left	-6.84 (0.06)	39.0 (2.48)	Reference		
	Back right	-6.90 (0.06)	36.6 (2.37)	0.94	1.13 -0.78	0.812
	Front left	-6.35 (0.06)	63.5 (3.69)	1.63	1.92 -1.38	<0.001
	Front right	-6.37 (0.06)	62.8 (3.65)	1.61	1.90 -1.36	<0.001

[1]Cases per 100 goat-years.

Table 6.12. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of rot in seasonal lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A	-7.78 (0.07)	1.50 (0.10)	Reference		
	B	-8.66 (0.11)	0.63 (0.06)	0.42	0.33 -0.53	<0.001
Age	1	-8.89 (0.13)	0.50 (0.06)	Reference		
	2	-8.43 (0.14)	0.79 (0.11)	1.59	0.96 -2.64	0.088
	3	-7.56 (0.12)	1.88 (0.22)	3.77	2.34 -6.08	<0.001
	4+	-8.00 (0.10)	1.20 (0.12)	2.42	1.56 -3.76	<0.001
Foot	Back left	-8.21 (0.11)	0.98 (0.11)	Reference		
	Back right	-8.59 (0.13)	0.67 (0.09)	0.68	0.45 -1.04	0.090
	Front left	-8.07 (0.10)	1.13 (0.12)	1.15	0.80 -1.66	0.754
	Front right	-8.00 (0.10)	1.20 (0.12)	1.23	0.86 -1.77	0.458
Deviation from the median kidding date[2]		-0.004 (0.003)				0.187

[1]Cases per 100 goat-years.

[2]Based on the Wald's 95% confidence interval.

Table 6.13. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of rot in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor			Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A		-7.68 (0.06)	16.9 (1.02)	Reference		
	B		-8.55 (0.17)	7.08 (1.24)	0.42	0.59 -0.30	<0.001
Age	2		-8.31 (0.13)	8.94 (1.17)	Reference		
	3+		-7.91 (0.09)	13.4 (1.20)	1.50	1.88 -1.20	<0.001
Foot	Back left		-8.04 (0.14)	11.7 (1.68)	Reference		
	Back right		-8.36 (0.19)	8.54 (1.61)	0.73	1.31 -0.40	0.512
	Front left		-7.81 (0.17)	14.7 (2.45)	1.26	2.17 -0.73	0.700
	Front right		-8.23 (0.21)	9.71 (2.04)	0.83	1.57 -0.44	0.875
Farm x foot	Farm	Foot					
	A	Back left	-8.09 (0.12)	11.2 (1.31)	Reference		
	A	Back right	-8.01 (0.11)	12.15 (1.39)	1.09	1.75 -0.68	0.999
	A	Front left	-7.15 (0.08)	28.7 (2.34)	2.57	3.85 -1.71	<0.001
	A	Front right	-7.45 (0.09)	21.1 (1.93)	1.89	2.89 -1.24	<0.001
	B	Back left	-7.99 (0.25)	12.3 (3.10)	1.10	2.53 -0.48	1.000
	B	Back right	-8.72 (0.36)	5.99 (2.12)	0.54	1.65 -0.17	0.701
	B	Front left	-8.48 (0.32)	7.59 (2.41)	0.68	1.88 -0.25	0.945
	B	Front right	-9.01 (0.41)	4.45 (1.83)	0.40	1.44 -0.11	0.374

[1]Cases per 100 goat-years.

Table 6.14. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of granulomas in seasonal lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A	-8.56 (0.10)	7.01 (0.69)	Reference		
	B	-9.76 (0.19)	2.12 (0.40)	0.30	0.45 -0.20	<0.001
Age	1	-9.48 (0.17)	2.77 (0.47)	Reference		
	2	-9.02 (0.20)	4.42 (0.88)	1.59	3.13 -0.81	0.293
	3	-9.00 (0.22)	4.49 (0.99)	1.62	3.34 -0.79	0.317
	4+	-9.13 (0.18)	3.94 (0.73)	1.42	2.69 -0.75	0.490
Foot	Back left	-8.76 (0.15)	5.69 (0.88)	Reference		
	Back right	-8.92 (0.16)	4.85 (0.77)	0.85	1.40 -0.52	0.842
	Front left	-9.42 (0.20)	2.96 (0.58)	0.52	0.92 -0.29	0.018
	Front right	-9.53 (0.21)	2.66 (0.55)	0.46	0.85 -0.25	0.006
Deviation from the median kidding date[2]		0.002 (0.005)				0.689

[1]Cases per 100 goat-years.

[2]Based on the Wald's 95% confidence interval.

Table 6.15. The estimates, standard error (SE), incidence rate ratio (IRR), and the 95% confidence interval of factors associated with the incidence rate of granulomas in extended lactation dairy goats on three commercial farms between August 2019-July 2020. Farms were located within Waikato, New Zealand.

Predictor		Estimate (SE)	Mean (SE)[1]	IRR	95% CI	P-value
Farm	A	-8.32 (0.06)	8.87 (0.55)	Reference		
	B	-9.67 (0.14)	2.30 (0.32)	0.26	0.34 -0.20	<0.001
Age	2	-8.96 (0.10)	4.71 (0.47)	Reference		
	3+	-9.04 (0.08)	4.34 (0.34)	0.92	1.07 -0.79	0.278
Foot	Back left	-8.94 (0.14)	4.78 (0.69)	Reference		
	Back right	-8.93 (0.14)	4.85 (0.69)	1.01	1.61 -0.64	1.000
	Front left	-8.91 (0.14)	4.93 (0.69)	1.03	1.62 -0.65	0.999
	Front right	-9.22 (0.07)	3.61 (0.27)	0.76	1.07 -0.54	0.156

[1]Cases per 100 goat-years.

6.5 Discussion

6.5.1 Risk factors associated with prevalence and incidence rate of claw disorders

The main risk factors that were significant with the claw disorders differed between seasonal and extended lactation. The probability of either horn separation, rot, and granuloma being present or developing was affected by farm, age, season, stage of lactation, hoof trimmers, and other prior or concurrent claw disorders. There were interactions between farm, age, season or stage of lactation, and foot, indicating a potentially complex relationship between claw disorders, environment, management, and physiological factors.

The presence of a previous claw disorder was generally associated with the increased risk of another claw disorder being present at the following hoof trimming event. Rot and granuloma present at the previous hoof trimming event increased the probability of rot or granuloma being present again. One explanation is that the claw disorder could be chronic, where the previous claw disorder had not healed by the next hoof trimming event. This trend has only been reported by Sanders et al. (2009). Information was collected on 2,100 cows over 3 ½ years. In that study, claw disorders classified under "Other" included claw disorders such as digital dermatitis and corkscrew claw. Also, claw disorders concurrent with the diagnosed claw disorder increased the hazards for thin soles, thin sole toe and heel ulcers, and white line disease. In the current study, previous and concurrent claw disorders affected the probability of another claw disorder being present on that same foot. This study is the first study that has been able to associate the non-infectious claw disorders, horn separation, and granulomas, with the infectious claw disorder, rot.

Anecdotally, farmers reported a progression of rot into a granuloma in some cases. In these situations, the management of claw disorders, such as prevention and treatment, should be investigated. Wilson-Welder et al. (2015) suggested that cattle's immune response to digital dermatitis can determine whether the wound is healed or becomes a chronic case. Shearer et al. (2015) also reported that the type of wound treatment affected the duration and outcome of the claw disorders. Genetics is another direction to determine the goat's resistance, tolerance or susceptibility to claw disorders or their potential response to treatment.

Despite no studies being published, one text reported hoof trimming injuries cause toe granulomas in sheep (Winter, 2011). The current study is the first to report the association between granulomas and hoof trimming injuries. Hoof trimming injury was defined by a nick, a laceration of the claw, which resulted in the blood outpour and was recorded at the foot level. The nick severity ranged from small, with minor bleeding (stopped bleeding within a minute), to large, with major bleeding, which was noted as a slice in the claw. The odds of a granuloma being present were 1.65-1.86 times greater than if no nick was made at the previous hoof trimming. Upon further examination of the seasonal and extended lactation datasets, of the 595 and 707 nicks recorded, only 20 and 40 prior nicks potentially (data were recorded at the foot, not claw level) resulted in a granuloma being present on the same foot at the next hoof trimming event. Therefore, the significance of these results should be taken with caution. In dairy goats, care should always be taken while trimming their feet, however, compared with a prior case of rot or granuloma, hoof trimming lacerations appear to be minor factors in causing granulomas.

6.5.2 Impact of the environment

It has been reported that excess moisture and faeces in the ground or bedding are favourable conditions for developing white line disease - horn separation - and the transmission of infectious pathogenic bacteria in dairy sheep and goats (Aguiar et al. 2011; Christodoulopoulos, 2009). The number of significant variables and the significant interactions within the model suggests that horn separation is more complex and depends on more environmental and management factors than rot or granulomas. Whereupon the possible effect of stage of lactation and season could be due to changes in the environment over the year. The current study reported that a wet spring coupled with the shortage of bedding – wood shavings – in the region meant that barns were more wet than usual and were not as clean. This can be seen with the increase in horn separation and rot observed on all farms during the November-December 2019 hoof trimming events and the observed effects of lactation stage and season. Farm C did not have an increase in rot present because it is possible that this farm does not have the virulent forms of bacteria present. There was a general decline in the claw disorders present over the summer months, which could mean that the barns may have been drier making conditions unfavourable for pathogenic bacteria and white line disease development. The duration of goats within a wet environment could also affect the prevalence of claw disorders.

Claw exposure to water has been linked to the increased softness of the hoof horn under extended periods of wet conditions. This is affected by the weather (Borderas et al. 2004). Cow claw horns were used to examine the rate of water uptake over time. Claw hardness decreased as water absorption increased. The water loss of the claw depended on the temperature, while water absorption was not dependent on temperature. At 20°C, it took 3 or 4 times longer for the claw to dry out when it took 1 hour to absorb 30% of the total water and 4 hours to absorb 50% of the total water (Borderas et al. 2004). It was also concluded that softer claws result in more severe claw disorders. This could be why the feet were softer for longer in the Winter while the feet could dry out quicker in the Summer. Dairy goats stood on a wet and dirty surface for up 1-2 hours, twice a day when they went to the milking parlour. Also, the bedding by the feeding passage was known to be wet most of the time throughout the year. Compared with overseas goat farms, New Zealand goats are generally fed grass, cut and carried to the goats. Overseas, goats are either grazed outdoors or fed forage, such as grass and maize silage, indoors (Morales et al. 2019; Prosser and Stafford, 2017). Goats housed indoors are sometimes fed fresh grass daily, which has a higher water content than forages such as grass silage (DairyNZ, 2021). The fresh grass makes the bedding by the feeding passage wetter, which may explain why horn separation was more prevalent on all farms compared with overseas studies. Dairy goat feet have smaller and thinner claws and a smaller surface area than cow claws. Therefore, it could be assumed that water absorption would occur quicker than what was seen in cows' claws. It could be hypothesised that this is attributed to the incidence rate of claw disorders than what may be seen on dairy cow farms. Management was also different between the three farms in this study and could have affected the prevalence of claw disorders within the herds.

The current study indicates that the prevalence of claw disorders has changed over time (Chapter 4). This was not reported in the study conducted by Sailer et al. 2021. They recorded claw disorders at two hoof trimming events, one in Spring and one in Autumn. Horn separation did not appear to differ between the seasons (85.8 and 87.3%, respectively). Other dairy goat studies did not indicate when their participating farms were sampled during the year, but suggested season was a potential risk factor for claw disorders (Eze, 2002; Anzunio et al. 2010). For example, Anzunio et al. (2010) took one recording from each farm over a few months (November 2004 and August 2005). It would be hard to compare the farms assessed at the sampling period's beginning, middle, and end of the sampling period. It also makes it hard to compare the prevalence levels between studies because each study would have a different sampling period. Another characteristic of these studies, including Sailer et al. (2021), is that the goats selected were a random subset of goats taken from the herd and, therefore, cannot be considered near the true prevalence. In the current study, by scoring goats at hoof trimming events, all the animals were evaluated, and all claw disorders were captured, whether lameness was present or not, which would disclose the true prevalence of claw disorders and this true prevalence would change over time.

Another reason for the lack of contrast between the two seasons in the study by Sailer et al. (2021) was the difference in the housing situation between Spring and Autumn. Dairy goats were housed indoors during the Spring and outdoors during the Autumn. In the current study, goats were housed undercover all year round though sometimes with access to an uncovered area. Sailer et al. (2021) reported no change in the prevalence of horn separation, which could indicate that the type of ground or bedding may not affect the prevalence of horn separation. In contrast, dairy cow studies reported infectious diseases- more specifically, digital dermatitis- as the most frequent claw disorder reported in herds primarily housed indoors (Somers et al. 2003; Solano et al. 2016). This is most likely due to different indoor conditions, with the environment being more likely to be drier due to different types of flooring and bedding being used, for example, straw or shavings are used in dairy goats and absorb more moisture from the environment compared with concrete that is used in dairy cows.

One Dutch dairy cow study reported that cows housed on straw had a higher risk of developing white line claw disorders than digital dermatitis (Somers et al. 2003). There was a higher prevalence of white line claw disorder in those herds than on concrete-type flooring. The authors thought the limited number of herds contributed to a potential bias in this result. The herds, which potentially distorted their results, did not trim regularly, and had steps going up to their feeding and milking ramp. These two factors may contribute to the irregular distribution of weight through specific areas of the claw. In the current study, two farms had feeding systems with no steps up to the feeding area, while the other farm had a conveyer belt system where the goats had to step up to get food. All farms had a ramp to the milking parlour from the barns. It is unclear what is causing the horn separation on the farms- whether it is multifactorial or caused by factors specific to each farm.

The weather, goat number and farm management changed over time. Weather information recorded from a nearby weather station indicated rainfall and temperature changed over the year (Appendix II, Figure 1). The number of goats in farm A increased significantly between August and December before declining over the last half of the year. This coincided with the influx of yearling does, which had kidded between these two events. Farm B goat numbers began to decline steadily before having a large decrease in the number of goats between March and May. This is due to the farmer culling goats in preparation for the next kidding season. Farm C goat numbers declined gradually throughout the season before May's last hoof trimming session. The management of goats on farm C changed slightly from February 2020 onwards. Zinc supplements were added to the diet, footmats with zinc sulphate were introduced twice daily, and water was removed from the milking parlour. These factors could have influenced the prevalence of claw disorders in dairy goats in each herd.

6.5.3 Impact of management

Other factors could have affected the prevalence of claw disorders, which have been investigated in dairy cattle, are the use of footmats, footbaths, and nutrition (Somers, 2005). These that have not yet been established in dairy goats. Improper use of footbaths and footmats can increase the risk of claw disorders such as digital dermatitis in dairy cattle (Somers, 2005). How footmats or baths should be used under dairy goat environments has not been determined. Interestingly, farm C, which had the least amount of rot, used disinfectant when cleaning out the barns, while the other two farms did not do this. Research needs to be completed surrounding how those factors may affect claw health in dairy goats.

All the goats were fed the same and were fed *ad libitum*. This could mean goats were eating more than needed, and they would be at risk for clinical or sub-clinical acidosis, which has been hypothesised to increase the risk of developing claw disorders, more specifically laminitis in cows (Abdela, 2016). A lack of minerals or amino acids can adversely affect the structure and integrity of the hoof wall (Langova et al. 2020). Nutrition on the three farms within the current study could not be investigated thoroughly. There could be unknown nutrient deficiencies that the farmer is unaware of, which could affect the goat's reaction to environmental factors such as moisture and pathogenic bacteria. A nutritional factor could explain why horn separation prevalence was higher on farm C than on farms A and B. Another factor could be a genetic predisposition to claw disorders.

6.5.4 Impact of physiological factors

Farm C was significantly more afflicted with horn separation than farms A and B, with early lactation significantly worse than late lactation for all ages. For most ages within farms B and C, horn separation was more likely to develop in early lactation than late lactation in seasonal goats. In dairy cattle, negative energy balance results in a reduced body condition score. It is associated with the mobilisation of fat reserves, including adipose tissue, within the digital cushion of the claw. Reduced thickness of the digital cushion reduces the shock absorption potential of the claw, which has been associated with sole ulcers and white line disease and thus increases the prevalence of lameness during this period (Raber et al. 2006; Green et al. 2014; Charfeddine and Perez-Cabal, 2017). The difference in stage of lactation was not apparent on farm A. A reason for this is that farm A may have other environment and management variables that may influence horn separation more than the stage of lactation.

The seasonal lactation dataset was divided by early and late lactation, though it could have been divided by season. The season could be considered a confounding variable in this situation. The stage of lactation was used in the model as the AIC was lower than the model that included season. The only way to separate these two variables would be to include goats kidding throughout the year to determine the effect of season on the development of horn separation and the effect of parturition on the development of horn separation. Sailer et al. (2021) and Hill et al. (1997) reported that it is unlikely that metabolic factors cause horn separation in dairy goats. It is unclear whether this referred to physiological changes due to parturition or diet-related influences. Parturition was proposed to be an important risk factor in developing claw disorders in dairy cows, including white line disease (Webster, 2002; Langova et al. 2020). There is no information regarding the metabolic differences in goats that are seasonally kidding compared with goats undergoing extended lactation. Extended lactation goats were fed the same diet as seasonal goats. Seasonal and extended lactation goats would have different energy requirements and physiological profiles, especially post-partum. Therefore, this could affect their tolerance, resistance, or susceptibility to claw disorders.

6.6 Conclusion

This was the first study conducted on commercial dairy goat farms in New Zealand, which examined risk factors for claw disorders in dairy goats. The prevalence of claw disorders changed over time and between age groups. Farm had a large effect on the incidence rate of all claw disorders, suggesting that management could be important in developing claw disorders. The concurrent or previous presence of other claw disorders was almost always a risk factor. Overall, this study revealed interactions between farm, age, season or stage of lactation, and foot, indicating a potentially complex relationship between claw disorders, environment, management and potentially physiological factors. From this study, the risk factors are, with the exception of the nicks, non-modifiable. Therefore, direct recommendations for prevention are unable to be made, however, it is still important to know which goats to pay attention to and how these claw disorders occur. More research is critically needed in this area on more farms of dairy goat farming.

Chapter 7

Association between lameness and claw disorders

7.1 Abstract

As reported in Chapters 3 and 4, lameness, the third most important health issue in dairy cows, is also a problem that dairy goat farmers face on their farms. This chapter investigated the relationship between claw disorders and locomotion scores in dairy goats. From three commercial dairy goat farms, 3,190 dairy goats were observed for claw disorders at hoof trimming events, while locomotion scoring took place close to or at herd testing events. The number of observations per goat varied depending on the farm and the number of opportunities to score the goats, ranging 4-5 times within a production year. Goats within the dataset were split into 1,805 seasonal lactation goats with 6,422 observations and 1,385 extended lactation goats with 5,552 observations. A logistic regression model evaluated the association between locomotion score and claw disorders whilst accounting for independent variables such as farm, age, and time. The claw disorders of interest were rot, granulomas, and horn separation. The dependent variable, clinical lameness, was derived from goats having a locomotion score of 3 and above on a 5-point scoring system. Rot and granulomas were associated with clinical lameness in seasonal and extended lactation goats. The odds of clinical lameness being diagnosed increased significantly (OR= 2.10-7.02) when rot or granulomas were present compared with when they were absent. Horn separation was associated with clinical lameness but only in seasonal lactation goats. These results indicate that claw disorders were important in causing clinical lameness and perhaps had the most severe implications on goat welfare. It also recommends future research avenues for finding treatments and preventions of common claw disorders in dairy goats on commercial farms, which have yet to be established in this area.

7.2 Introduction

Previous welfare studies have reported that lameness in goats is a common problem in many herds (Hill et al. 1997; Anzunio et al. 2010; Groenevelt et al. 2015a). Lameness can be defined as the impairment of normal locomotion due to pain caused by infectious diseases and non-infectious factors such as injury or claw disorders and can indicate poor claw health (Vieira et al. 2015; Mathews, 2016). Infectious claw diseases are caused by pathogenic bacteria or viruses that colonise on or within the goat's claw when the conditions are favourable and cause tissue damage. Non-infectious factors, such as management, environment, genetic factors, or a combination of the previously mentioned factors, are conditions that may affect the goat's life by predisposing the goat to lameness.

Several studies have looked at the proportion of lameness and claw disorders in subsets of dairy goats on commercial farms. The lameness prevalence ranged from 1.2 to 67% (Chapter 2.4, Table 2.2). Claw disorders that have been identified on commercial dairy goat farms are horn separation, overgrown claws, granulomas, digital dermatitis, footrot, abscesses, slippering, sole haemorrhages, claw deformations and foreign bodies (Hill et al. 1997; Anzuino et al. 2010; Sullivan et al. 2015; Groenevelt et al. 2015a; Crosby-Durrani et al. 2016; Ajuda et al. 2019; Hempstead et al. 2021; Sailer et al. 2021). There is little information on the relationship between lameness and claw disorders in dairy goats on commercial farms. Hill et al. (1997) reported that horn separation, abscesses and footrot were significantly associated with lameness. Digital dermatitis has also been known to cause lameness in dairy goats (Crosby-Durrani et al. 2016; Groenevelt et al. 2015a). The relationship between claw disorders and their severities with different locomotion scores is unknown. Identifying the most common claw disorders associated with lameness needs to be established to understand how to prevent it.

This study followed goats on three commercial dairy goat farms in New Zealand. The prevalence of lameness and claw disorders on these farms are reported in Chapters 3 and 5, respectively. The study of the three farms involved identified the most prevalent claw disorders were horn separation, rot, and granulomas. This chapter aims to identify which common claw disorders were significantly associated with clinical lameness and whether this differed between seasonal and extended lactation goats.

7.3 Materials and methods

7.3.1 Background information

Data collection was conducted on three farms based in Waikato, New Zealand. They were followed for one year, from July 2019 to June 2020. Further information on the farms is available in Chapters 3 and 5. The dairy goat breeds on the farms were a combination of Saanen, Toggenburg, Alpine breeds and their various crosses. All farms had a group of goats that kid seasonally, mainly between June and August, and all farms had a group of goats in extended lactation (goats lactating for more than 305 days). The goats were milked twice a day and were fed *ad libitum* with a combination of a total mixed ration and grass cut and carried from nearby paddocks (more details are explained in Chapter 3).

7.3.2 Data collection

A full description of the data collection process for locomotion scoring and hoof trimming events is reported in Chapters 3 and 5, respectively. In brief, locomotion and claw disorder scoring events were carried out 4-5 times a year. Lameness and claw disorders were scored at the animal level. One farm had five locomotion scoring and claw disorder scoring events, while the other two farms only had four events (Figure 7.1). A 5-point scale was used to score the locomotion of the goats using a method developed by Deeming et al. (2018). The 5-point scale locomotion scoring had five levels grading the goat's gait while walking, where- 0 was a normal gait, 1 was an uneven gait, 2 was a mildly lame gait, 3 was a moderately lame gait, and 4 was a severely lame gait. Scores 3 and 4 were classified as being clinically lame. As locomotion scoring was planned around herd testing (Chapter 6), the scoring occurred before or after hoof trimming events (Figure 7.1).

Claw disorders were recorded during hoof trimming events, which were within a few weeks of the locomotion scoring events. The claw disorders had three (horn separation, granuloma) or four (rot) severity levels where 0 was the absence of the claw disorder and 1, 2 or 3 was the severity of claw disorder (Chapter 5.3 for more details).

7.3.3 Data analysis

7.3.3.1 Prevalence of claw disorders by locomotion score

The dataset was divided into seasonal (≤305 days in milk) and extended (>305 days in milk) lactating goats. The respective datasets contained 1,805 seasonal lactation goats with 6,422 observations and 1,385 extended lactation goats with 5,552 observations. The claw disorders of interest were horn separation, rot and granulomas. Due to only a small number of goats with severity 3 rot, these scores were combined with the category, severity 2 rot. The prevalence of each claw disorder at each locomotion score was calculated as a proportion (Dohoo et al. 2003):

$$p = \frac{a}{n}$$

where

a = the number of goats with a claw disorder at a particular locomotion score

n = the total number of goats with that claw disorder

The 95% confidence intervals (CI) for the prevalence were calculated using the asymptotic method described in the following equation (Dohoo et al. 2003):

$$95\%\ CI = p \pm 1.96\sqrt{\frac{p\,(1-p)}{n}}$$

7.3.3.2 Association between claw disorders and lameness

The association between claw disorders and locomotion score was estimated with SAS (version 9.4, SAS Institute Inc., Cary, NC). Two datasets were used to create two models- one for the seasonal lactation goats and one for the extended lactation goats.

Using the PROC GLIMMIX, a logistic regression model was used with a binomial distribution with a logit link function to evaluate the association between clinical lameness (locomotion score ≥3) and the presence of claw disorders. The dependent variable was clinical lameness. The model included fixed effects, which are described in further detail below. They differed depending on the dataset that was used. For both datasets, a backwards stepwise approach to including or excluding independent variables was used. To measure the model's goodness of fit, the Akaike Information Criterion (AIC) was used, where the lower the AIC, the better quality of model.

The log estimate, standard errors, odds ratio, and 95% confidence intervals are presented. The differences between the means were adjusted with the Tukey correction. The final model follows:

$$y = \ln\left(\frac{p}{1-p}\right)$$

where **p** was the proportion of lame goats for each combination of variables.

For the seasonal lactation goats, the model included the fixed effects of farm, age and season, interaction between age and stage of lactation, claw disorders (granulomas, horn separation (severity 2) and rot), and days between hoof trimming and locomotion scoring events, and deviation from the kidding median date as covariates, and the random effects of goat and residual. The farm variable had three levels (A, B and C). The contemporary group, of age and stage of lactation, consisted of 8 levels and was the combination of age (1, 2, 3, ≥4) and stage of lactation (Early (≤120 days) or Late (>120 days). The claw disorders had two levels (absence or presence).

For extended lactation goats, the model included the fixed effects farm, age, season, interaction between age and season, and claw disorders (granulomas, horn separation (severity 2) and rot), and days between hoof trimming and locomotion scoring events, as a covariate, and the random effects of goat and residual. The farm variable had three levels (A, B or C). The contemporary group, of age and season, consisted of 4 levels and was the combination of age (2 and ≥3) and season (Autumn-Summer or Winter-Spring). The claw disorders had two levels (absence or presence).

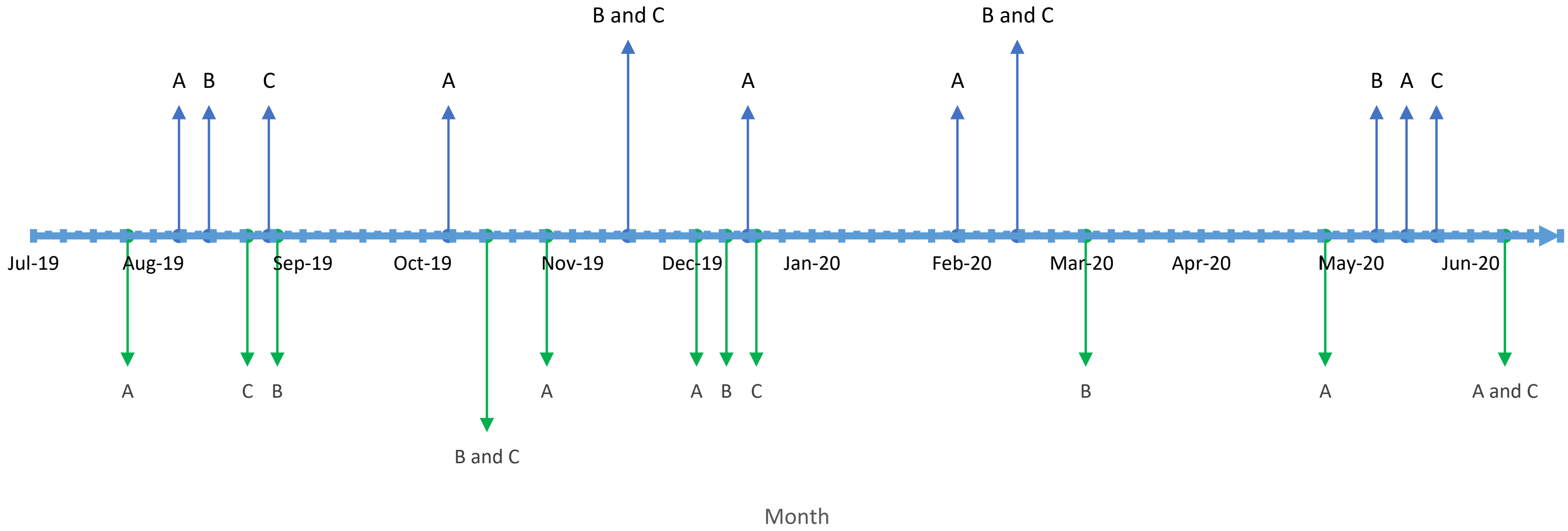

Figure 7.1. The distribution of hoof trimming (blue arrows, above axis) and locomotion scoring (green arrows, below axis) events on farms A, B and C, located in Waikato, New Zealand, occurring between July 2019 and June 2020.

7.4 Results

7.4.1 Prevalence of claw disorders at various locomotion scores

For seasonal and extended lactation goats, the distribution of claw disorders across different locomotion scores is presented in Figures 7.2-7.5. A higher percentage of goats with rot or granulomas had locomotion scores of 3 or 4 than those with horn separation. Goats with granulomas had the highest percentage of goats diagnosed as clinically lame, where 42 and 59% of goats with a granuloma close to the locomotion scoring event were diagnosed as clinically lame. Some goats, 8.10% of seasonal and 17.2% extended lactation goats, were lame though they had no horn separation, rot or granulomas present. The correlations between the claw disorders (Tables 7.1 and 7.2) were low and, in some cases, insignificant. These trends were similar for seasonal and extended lactation goats.

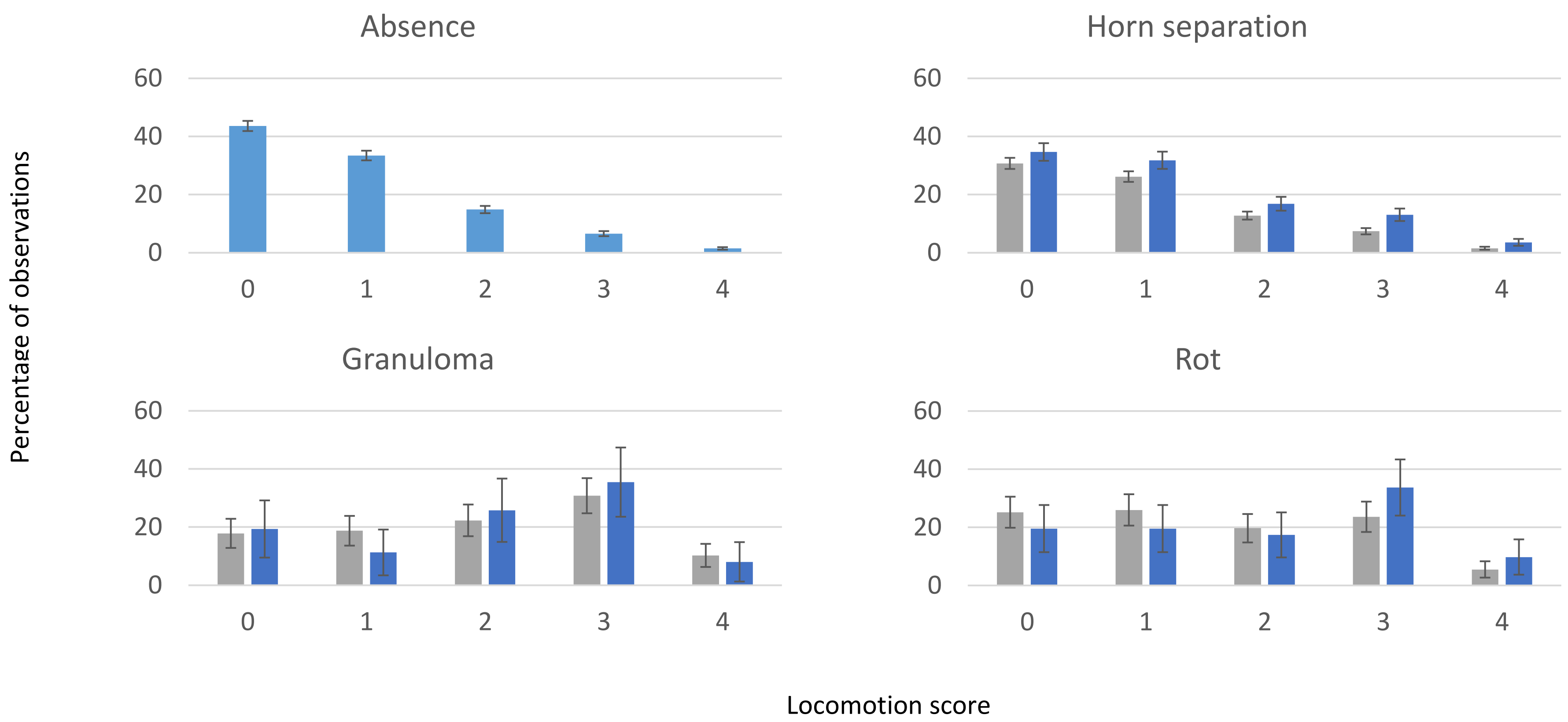

Figure 7.2. Distribution of locomotion scoring severities (0-4) on three New Zealand dairy goat farms within the 2019-2020 production year in seasonal lactation dairy goats. The absence (light blue) or presence of horn separation, granuloma and rot displayed by severity 1 (grey) and 2 (dark blue) were spread across the locomotion scores. Locomotion scores presented as 0-normal gait; 1-uneven gait; 2-mildy lame; 3- moderately lame; 4- severely lame.

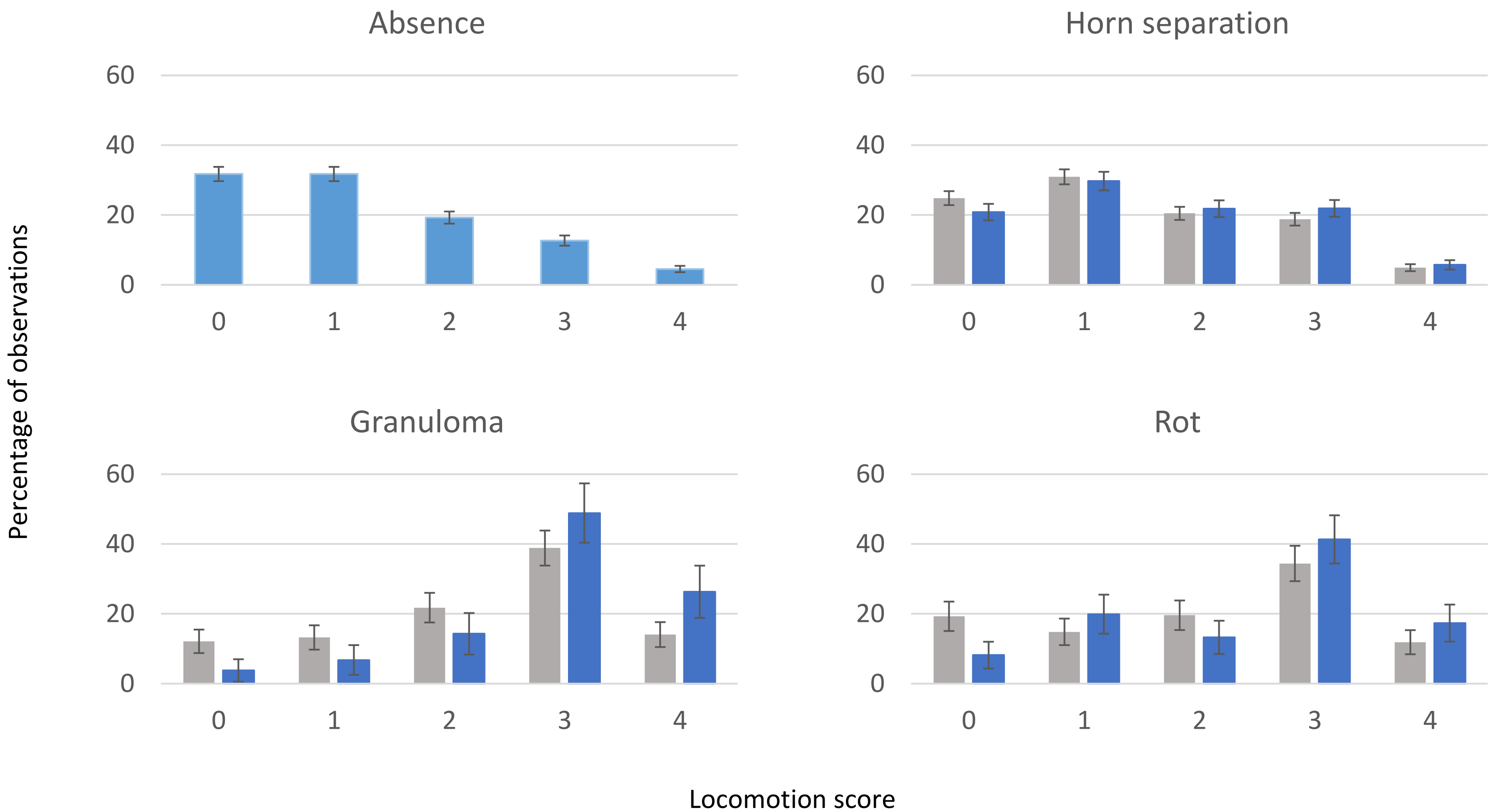

Figure 7.3. Distribution of locomotion scoring severities (0-4) on three New Zealand dairy goat farms within the 2019-2020 production year in extended lactation dairy goats. The absence (light blue) or presence of horn separation, granuloma and rot displayed by severity 1 (grey) and 2 (dark blue) were spread across the locomotion scores. Locomotion scores presented as 0-normal gait; 1-uneven gait; 2-mildy lame; 3- moderately lame; 4- severely lame.

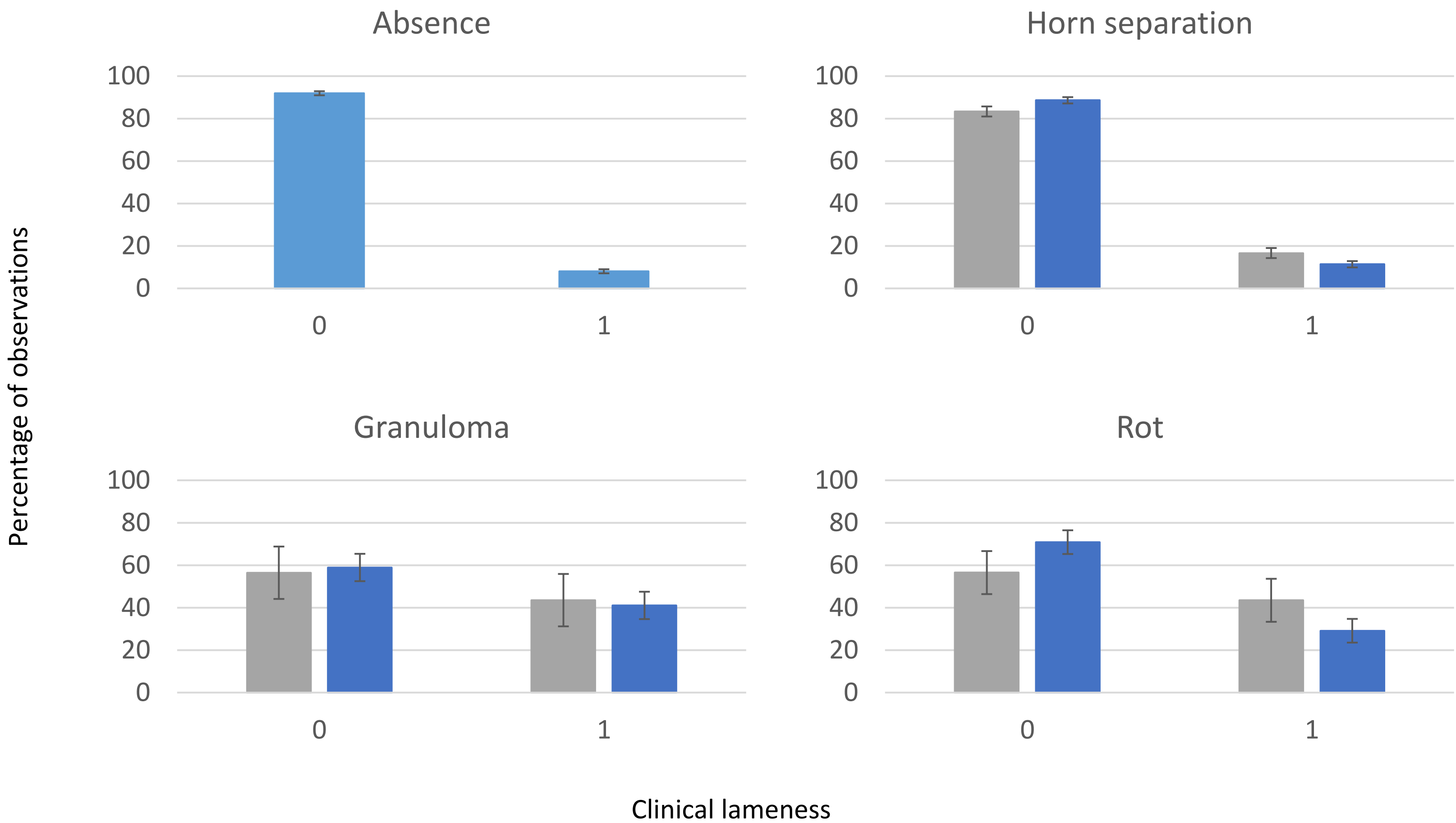

Figure 7.4. Distribution of clinical lameness cases (locomotion scores 3 or 4) on three New Zealand dairy goat farms within the 2019-2020 production year in seasonal lactation dairy goats. The absence (light blue) or presence of horn separation, granuloma and rot displayed by severity 1 (grey) and 2 (dark blue) were spread across the locomotion scores. Locomotion scores presented as 0-normal gait/uneven gait/mildly lame; 1-moderately/severely lame.

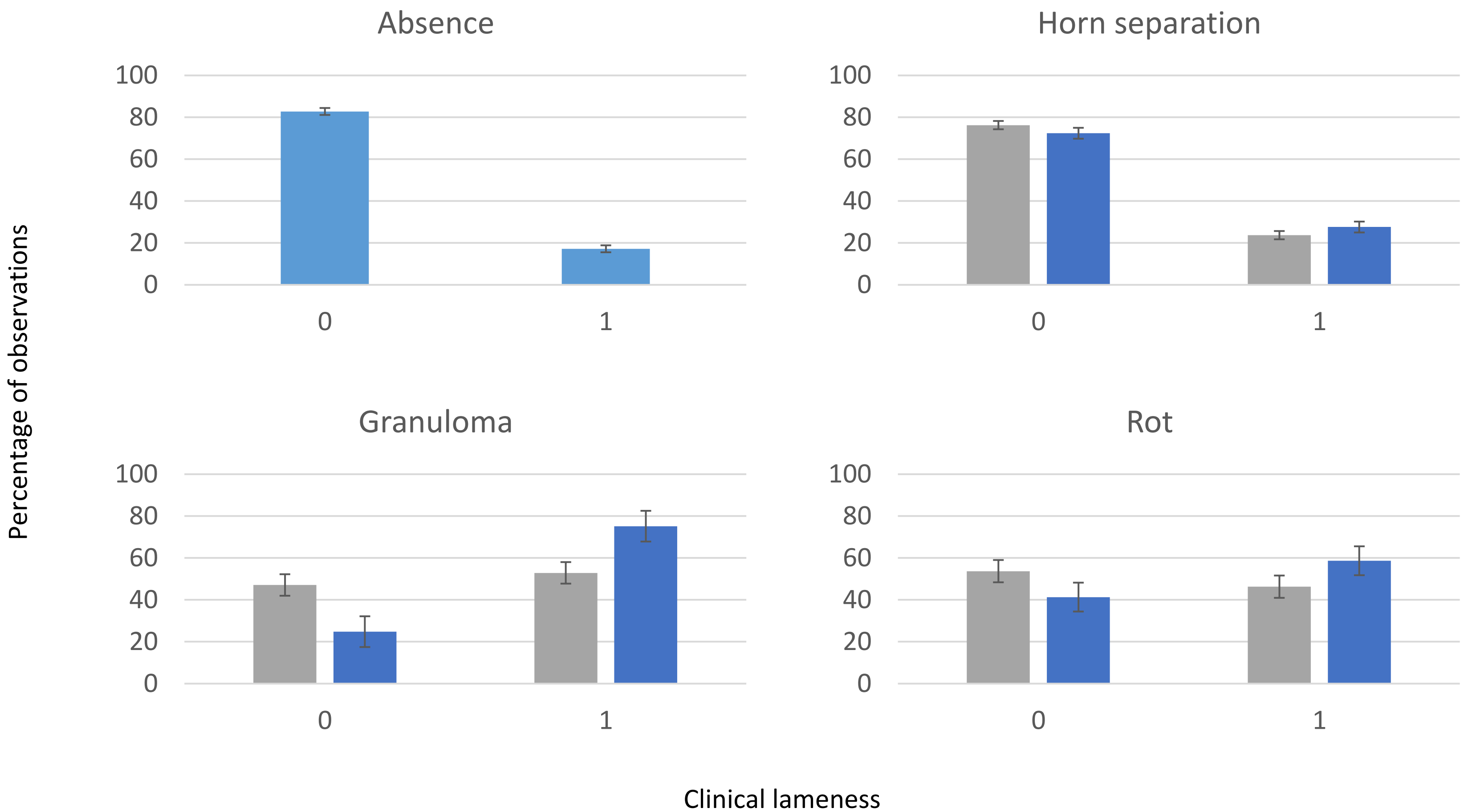

Figure 7.5. Distribution of clinical lameness cases (locomotion scores 3 or 4) on three New Zealand dairy goat farms within the 2019-2020 production year in extended lactation dairy goats. The absence (light blue) or presence of horn separation, granuloma and rot displayed by severity 1 (grey) and 2 (dark blue) were spread across the locomotion scores. Locomotion scores presented as 0-normal gait/uneven gait/mildly lame; 1- moderately/severely lame.

Table 7.1. Estimates of Pearson's correlation coefficients between claw disorders in seasonal lactation goats at the animal level from three dairy goat farms in New Zealand. The first row is the coefficient (in bold), the second row is the P-value testing for a difference from 0.

Claw disorder		Horn Separation		Granuloma		Rot
	Severity	1	2	1	2	1
Horn Separation	1	**1.000**				
	2	**0.061**				
		<0.0001				
Granuloma	1	**-0.026**	**-0.008**			
		0.053	0.541			
	2	**-0.035**	**0.001**	**-0.018**		
		0.009	0.954	0.176		
Rot	1	**0.042**	**0.185**	**0.078**	**0.028**	
		0.002	<0.0001	<0.0001	0.035	
	2	**-0.010**	**0.147**	**0.038**	**0.022**	**0.008**
		0.472	<0.0001	0.004	0.098	0.556

Table 7.2. Estimates of Pearson's correlation coefficients between claw disorders in extended lactation goats at the animal level from three dairy goat farms in New Zealand. The first row is the coefficient (in bold), the second row is the P-value testing for a difference from 0.

Claw disorder		Horn Separation		Granuloma		Rot
	Severity	1	2	1	2	1
Horn Separation	1	**1.000**				
	2	**0.149**				
		<0.0001				
Granuloma	1	**-0.004**	**0.028**			
		0.764	0.023			
	2	**0.023**	**0.008**	**0.004**		
		0.062	0.526	0.731		
Rot	1	**0.044**	**0.220**	**0.122**	**0.059**	
		<0.001	<0.0001	<0.0001	<0.0001	
	2	**0.013**	**0.161**	**0.035**	**0.074**	**0.046**
		0.304	<0.0001	0.005	<0.0001	<0.001

7.4.2 Association between claw disorders and clinical lameness

Rot and granulomas, regardless of severity, were significantly associated with clinical lameness for seasonal and extended lactation goats (Tables 7.3 and 7.4, Figures 7.6 and 7.7). Horn separation was not significantly associated with clinical lameness for seasonally lactating goats (data not shown). However, when horn separation was split into severity 1 and 2, horn separation, severity 2, was significantly associated with clinical lameness when granulomas were also present. For the full model results, including any interactions between the claw disorders on clinical lameness, refer to Appendix IV, Tables 1 and 2. For seasonal goats, the presence of granulomas or rot significantly increased the probability of lameness to varying degrees (Table 7.3). The odds of a goat being clinically lame significantly increased if rot was present (OR=2.35, 95% CI [1.73-3.20]). The presence of granuloma, horn separation of severity 2, or both, significantly increased the odds of clinical lameness by 7.02, 1.70 and 3.63 times, respectively (95% CI = 1.21-11.2). For extended lactation goats, only the presence of rot and granulomas were significantly associated with clinical lameness. The presence of granuloma, rot, or both, increased the odds of clinical lameness by 5.94, 3.94, and 6.62 times, respectively (95% CI = 2.83-12.3).

Table 7.3. The estimates, standard errors (SE), odds ratio (OR) and 95% confidence intervals (CI) for the association between claw disorders and clinical lameness (locomotion score ≥3) in seasonal lactation goats, while accounting for the interaction between farm, age and stage of lactation.

Predictor			Estimate (SE)	OR	95% CI	P-value
Horn separation (severity 2)		Absence	Reference			
		Presence	-0.06 (0.19)	0.94	0.65 -1.36	0.74
Granuloma		Absence	Reference			
		Presence	1.35 (0.19)	3.87	2.65 -5.64	<0.001
Rot		Absence	Reference			
		Presence	0.86 (0.16)	2.35	1.73 -3.20	<0.001
Horn separation (severity 2) x Granuloma	Horn separation (severity 2)	Granuloma				
	Absence	Absence	Reference			
	Presence	Absence	0.53 (0.13)	1.70	1.21 -2.40	<0.001
	Absence	Presence	1.95 (0.18)	7.02	4.42 -11.2	<0.001
	Presence	Presence	1.29 (0.32)	3.63	1.58 -8.35	<0.001

Table 7.4. The estimates, standard errors (SE), odds ratio (OR) and 95% confidence intervals (CI) for the association between claw disorders and clinical lameness (locomotion score ≥3) in extended lactation goats, while accounting for farm, age and season.

Predictor			Estimate (SE)	OR	95% CI	P-value
Horn separation (severity 2)		Absence				
		Presence	0.03 (0.10)	1.03	0.85 -1.26	0.74
Granuloma		Absence				
		Presence	1.15 (0.15)	3.16	2.35 -4.24	<0.001
Rot		Absence				
		Presence	0.74 (0.15)	2.10	1.57 -2.80	<0.001
Granuloma x rot	Granuloma	Rot				
	Absence	Absence				
	Presence	Absence	1.78 (0.14)	5.94	4.14 -8.54	<0.001
	Absence	Presence	1.37 (0.13)	3.94	2.83 -5.49	<0.001
	Presence	Presence	1.89 (0.24)	6.62	3.57 -12.3	<0.001

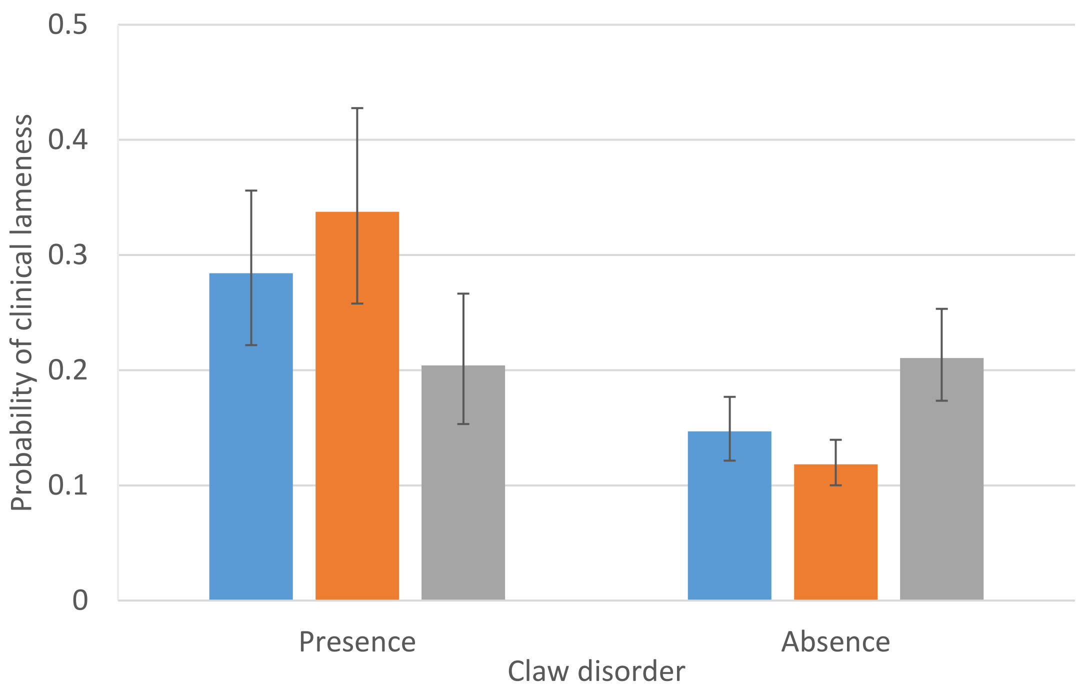

Figure 7.6. The predicted probability of clinical lameness (locomotion scores 3 or 4) being diagnosed in seasonal lactation goats on three New Zealand farms in the presence or absence of rot (blue), granulomas (orange) or horn separation, severity 2 (grey) after accounting for farm, age and stage of lactation within the 2019-2020 production year.

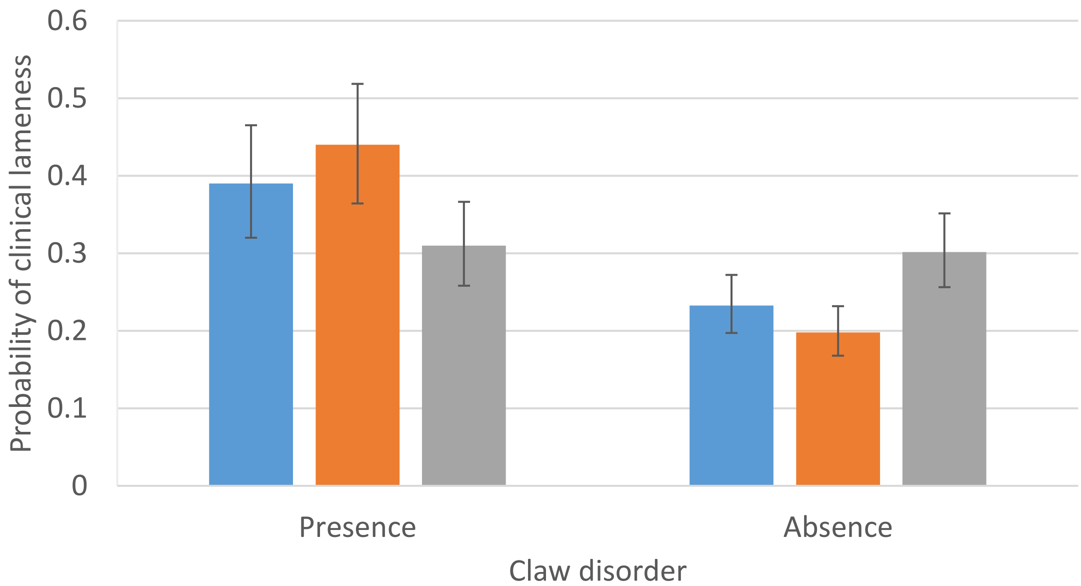

Figure 7.7. The predicted probability of clinical lameness (locomotion scores 3 or 4) being diagnosed in extended lactation goats in the presence or absence of rot (blue), granulomas (orange) or horn separation, severity 2 (grey) after accounting for farm, age and season within the 2019-2020 year.

7.5 Discussion

In seasonal and extended lactation goats, rot and granulomas were significantly associated with clinical lameness while accounting for other variables such as farm and age. Only horn separation (severity 2) was not significantly associated with clinical lameness in extended lactation goats. The current study agrees with the findings reported by Hill et al. (1997), where there was a relationship between horn separation, rot (visually identified as footrot), and granulomas with lameness. Though it was not mentioned in Hill et al. (1997)'s research, it was assumed that they were only studying goats in seasonal lactation based on literature that first reported this practice to be present in commercial farms in the year 2000 within the Netherlands (Schuiling et al. 2007). The current study validates Hill et al. (1997) research and expands upon the past study to include extended lactation goats, where horn separation was not significantly associated with clinical lameness.

The lack of correlations between claw disorders diagnosed simultaneously indicates that their causes are independent of each other (Manske et al. 2002). Claw disorders were independent of one another when presenting simultaneously, though the results in Chapter 6 indicated that a goat with a previous claw disorder could predispose to another. For example, having a previous case of rot was associated with a granuloma developing in the future. It is unclear what conditions caused some claw disorders to heal while others become more severe or progress into other claw disorders. This could further predict the likelihood of the goat being lame in the future.

There are similarities between claw disorders causing lameness in dairy goats and dairy cows housed indoors and outdoors. The claw disorders causing lameness differed between dairy cows housed indoors or outdoors. In dairy cows housed indoors, sole ulcers, interdigital inflammation, double sole, and moderate to severe digital dermatitis cases were identified as causing clinical lameness (Tadich et al. 2010). The most common lameness-causing claw disorders for dairy cows managed outdoors were sole injuries, such as haemorrhages and white line disease (Chesterton et al. 2008; Somers and O'Grady, 2015). The difference between dairy goats and cow claw disorders is that foot granulomas have not been reported as a problem on cow farms, regardless of their housing type.

Housing management could explain some similarities between claw disorder-causing lameness in dairy goats and cows (Solis-Ramirez et al. 2011; Brakenrig, 2017). The housing of dairy goats is the combination of conditions between dairy cows housed indoors or outdoors. Dairy goats are housed on soft ground, similar to cows housed outdoors though the stocking density in the barn would be similar to dairy cows housed indoors. A higher stocking rate would mean that the hygiene of the barns would be an important factor for controlling infectious claw disorders such as footrot and digital dermatitis that have been reported in dairy cows housed indoors. Like dairy cows housed outdoors, haemorrhages of the foot and white line diseases were also present in dairy goats. However, only severe cases of white line disease, referred to as severity two horn separation, were associated with lameness. Sole haemorrhages were present though not common. Therefore, they were not analysed alongside lameness records because this chapter focuses on more common claw disorders previously reported in Chapter 5. Therefore, they could still be associated with lameness.

Despite different production systems, claw disorders appear to be more similar between dairy goats and sheep than dairy cows and dairy goats. Generally, the current study agrees with the results reported in previous sheep studies. In sheep, interdigital dermatitis, footrot, severe cases of horn separation or a combination of the claw disorders have been associated with lameness (Angell et al. 2014; Winter et al. 2015, Best et al. 2021; Moschovas et al. 2021). Similar to these studies, in sheep, minor cases of white line disease were documented as not being associated with lameness, while more moderate to severe cases of white line disease that develop into an abscess have been reported alongside lameness (Winter and Arsenos, 2009; Gelasakis et al. 2015). Footrot, digital dermatitis and pedal joint abscess were also associated with lameness in dairy sheep (Gelasakis et al. 2015; Gelasakis et al. 2013). In sheep studies, toe granulomas have been identified as a claw disorder, though not associated with lameness.

This study reported goats with a locomotion score of 0 or 1 (normal or uneven gait) with a claw disorder. There was a higher percentage of goats with horn separation than granuloma or rot with a locomotion score of 0 or 1. Although the association was insignificant, goats with severity 2 horn separation had a higher locomotion score (2, 3 and 4) than those with severity 1. Tadich et al. (2010) reported lameness occurring if a claw disorder disrupts the sensitive laminae. This is recorded in seasonal goats of the current study, where the probability of being clinically lame increased significantly when horn separation was observed with granuloma. Despite some claw disorders not causing lameness, they could indicate underlying animal health problems, such as an unbalanced diet or a diet deficient in minerals such as zinc or biotin (Langova et al. 2020). Following minor claw disorders could shed light on how claw disorders may develop into more severe claw disorders that cause clinical lameness. Less severe claw disorders, such as horn separation, could impact the goat's welfare in other ways and should be the focus of further research.

Some goats classified as lame or clinically lame (a locomotion score greater than one) were not diagnosed with either horn separation, rot, or granulomas. There are a few reasons that could explain this. Firstly, the days between hoof trimming and locomotion scoring events ranged from 86 days before the locomotion scoring event to 74 days after the locomotion scoring event. These large differences between events could mean that a) goats could have developed a claw disorder or b) goats could have healed from a claw disorder between hoof trimming and locomotion scoring events. Depending on their claw disorder diagnosis, these goats could have ended up with a lower or higher locomotion score than what may have been true at the time of locomotion scoring. To understand the impact of hoof trimming on goats, locomotion and claw disorder scoring events should be investigated together in future studies on dairy goats. The second reason for identifying lameness without horn separation, rot or a granuloma present was that the goat could have had another claw disorder at the hoof trimming event, classified under "other", or presence of an injury above the foot. The "other" category included minority claw disorders observed within the herd, such as widening of the white line, toe abscesses, overgrown claws, sole haemorrhaging, false floors. Some claw disorders, such as abscesses, have been known to cause lameness in dairy goats (Hill et al. 1997). Lastly, some goats could have had abnormal leg conformation or an injury higher in the limb rather than the foot. Injuries unrelated to the foot were not recorded because they were considered out of the scope of this study.

7.6 Conclusion

Regardless of severity, rot and granulomas were strongly associated with clinical lameness in seasonal and extended lactation dairy goats. Only severe horn separation was associated with clinical lameness in seasonal lactation dairy goats. Further, some goats presenting with claw disorders may not be clinically lame. This study indicates potential research opportunities in establishing targeted prevention and treatment strategies to reduce the amount of claw disorder-causing clinical lameness within herds on commercial dairy goat farms.

Appendix IV

Supplementary information for Chapter 7

Appendix IV Table 1. The fixed and random effects estimates, standard errors, degrees of freedom (DF), t- and P-value for seasonal lactation goats for the association between claw disorders and clinical lameness (locomotion score ≥3).

Effect			Estimate	Standard error	DF	t-value	P-value
Intercept			-2.42	0.18	1775	-13.3	<0.001
Farm	A		0.41	0.17	3754	2.44	0.015
	B		0.37	0.17	3754	2.21	0.027
	C		0.00	.	.	.	.
Stage of lactation x age	Stage of lactation	Age					
	Early	1	-0.33	0.18	3754	-1.77	0.077
	Late	1	-1.03	0.20	3754	-5.14	<0.001
	Early	2	-1.24	0.24	3754	-5.07	<0.001
	Late	2	-0.90	0.21	3754	-4.19	<0.001
	Early	3	-0.22	0.21	3754	-1.07	0.29
	Late	3	-0.13	0.19	3754	-0.70	0.48
	Early	≥4	0.12	0.15	3754	0.79	0.43
	Late	≥4	0.00	.	.	.	.
Rot	Presence		0.86	0.16	3754	5.46	<0.001
	Absence		0.00				

Appendix IV Table 1. continued

Effect			Estimate	Standard error	DF	t-value	P-value
Horn separation (severity 2)	Presence		0.53	0.13	3754	4.02	<0.001
	Absence		0.00	.	.	.	.
Granuloma	Presence		1.95	0.18	3754	10.8	<0.001
	Absence		0.00	.	.	.	.
Horn separation (severity 2) x granuloma	Horn separation (severity 2)	Granuloma					
	Presence	Presence	-1.19	0.37	3754	-3.25	0.001
	Presence	Absence	0	.	.	.	.
	Absence	Presence	0	.	.	.	.
	Absence	Absence	0	.	.	.	.
Date difference[1]			-0.00261	0.001365	3754	-1.91	0.056
Deviation from the median kidding date			0.00699	0.003357	3754	2.08	0.037
Animal[2]			0.83	0.12			

[1]The difference, in days, between the locomotion scoring and claw disorder scoring dates.
[2]Random effect of animal.

Appendix IV Table 2. The fixed and random effects estimates, standard errors, degrees of freedom (DF), t- and P-value for extended lactation goats for the association between claw disorders and clinical lameness (locomotion score ≥3).

Effect			Estimate	Standard error	DF	t-value	P-value
Intercept			-1.39	0.08	1359	-16.4	<0.001
Farm	B		-0.68	0.18	3403	-3.79	<0.001
	C		-0.50	0.14	3403	-3.57	<0.001
	A		0.00	.	.	.	.
Season x age	Season	Age					
	Summer-Autumn	2	-0.42	0.17	3403	-2.38	0.017
	Winter-Spring	2	-0.93	0.18	3403	-5.20	<0.001
	Summer-Autumn	≥3	0.04	0.09	3403	0.49	0.627
	Winter-Spring	≥3	0.00	.	.	.	.
Horn separation (severity2)	Absence		0.03	0.10	3403	0.34	0.737
	Presence		0.00	.	.	.	.
Granuloma	Absence		1.78	0.14	3403	12.64	<0.001
	Presence		0.00	.	.	.	.

Appendix IV Table 2. continued

Effect			Estimate	Standard error	DF	t-value	P-value
Rot	Absence		1.37	0.13	3403	10.62	<0.001
	Presence		0.00	.	.	.	.
Granuloma x Rot	Granuloma	Rot					
	Presence	Presence	-1.26	0.29	3403	-4.41	<0.001
	Presence	Absence	0.00	.	.	.	.
	Absence	Presence	0.00	.	.	.	.
	Absence	Absence	0.00	.	.	.	.
Date difference[1]			0.0005	0.0011	3403	0.45	0.650
Animal[2]			1.02	0.11			

[1]The difference, in days, between the locomotion scoring and claw disorder scoring dates.

[2]Random effect of animal.

Chapter 8

The effect of lameness on milk production of dairy goats

8.1 Abstract

The objective of this study was to evaluate the effects of clinical lameness on milk yield in dairy goats. In total, 10,318 test-day records were collected from 3,190 goats on three farms in Waikato, New Zealand, from July 2019 to June 2020. Two farms had four herd test events, while one had five. The dataset was split into two groups of goats depending on the type of lactation: seasonal lactation (≤305 days in milk) and extended lactation goats (>305 days in milk). Dependent variables were daily yields of milk, fat, protein and lactose, percentages of fat, protein and lactose, and somatic cell score. Mixed linear models analysing the seasonal lactation data included fixed effects of stage of lactation (early and late), parity (1, 2, 3 and ≥4), clinical lameness (yes/no) or lameness severity score (0, 1, 2, 3, 4), deviation from the median kidding date, time between locomotion scoring and milk testing, estimated breeding value, and random intercepts of farm-herd test day and animal. The mixed linear model of the extended lactation data set was the same but did not include the stage of lactation, deviation from the median kidding date or estimated breeding value. Clinically lame goats (scored 3 or 4) produced 2.63% (3.86 *vs.* 3.74 kg) and 4.66% (3.20 *vs.* 3.05 kg) less milk in the seasonal and extended lactation data, respectively. For severely lame goats (score 4 only), there was a 7.10% (3.83 *vs.* 3.56 kg) and 8.56% (3.23 *vs.* 2.95 kg) reduction in daily milk yield for seasonal and extended lactation goats, respectively. The differences in the milk characteristics between lame and non-lame goats ranged from 0.22 to 9.50%, depending on the lameness score and lactation type. For seasonal lactation goats, the average daily protein (121 *vs.* 117 g) and lactose (172 *vs.* 167 g) yields significantly decreased when the goats were clinically lame. In extended lactation goats, clinically lame goats had a significant decrease in the average fat (104 *vs.* 100 g), protein (104 *vs.* 99.6 g), and lactose yields (141 *vs.* 135 g). Despite differences not being significantly different for other milk characteristics, dairy goats that were severely lame were different from goats walking normally. The potential average daily milk income lost for the farmer was estimated to be between NZD 26-104 per goat. This study established the impact of lameness on milk production and annual income loss in dairy goats on three commercial farms.

8.2 Introduction

Animal welfare issues on dairy goat farms, such as lameness, have increasingly been highlighted within past welfare studies conducted on international goat farms (Anzunio et al. 2010; Muri et al. 2013; Hempstead et al. 2021). Lameness in dairy goats has been largely overlooked in the past. The within-herd prevalence of lameness was quantified on some European commercial dairy goat farms, ranging from 1.7 to 67% over the last 20 years (Hill et al. 1997; Anzunio et al. 2010; Groenevelt et al. 2015a). Despite the large variation in prevalence between studies, lameness on commercial farms is a global problem. This problem must be addressed to improve farm animal welfare and production efficiency. Increased productivity and animal efficiency would improve resource utilisation due to future competition over scarce resources (Bastida and Juste, 2011).

Lameness has been known to cause economic consequences for farmers and has been extensively researched in sheep (Nieuwhof and Bishop, 2005; Lovatt, 2015) and dairy cattle (Archer et al. 2010; Dolecheck and Bewley, 2018; Alvergnas et al. 2019) but not dairy goats. This is likely due to the relatively smaller size of the industry. For example, lameness is the second most costly animal health problem in dairy cattle after mastitis (Cha et al. 2010). In the New Zealand dairy cattle industry, lameness was estimated to cost farmers around NZD 94 per cow (Tranter and Morris, 1991). This study was over 30 years ago, so the cost will likely be higher. A USA study estimated that digital dermatitis and white line disease cost farmers USD 64 (NZD 94) and USD 152 (NZD 240), respectively (Dolecheck et al. 2019). In sheep, footrot, an infectious cause of lameness, is the second most costly health problem after gastrointestinal parasites. In New Zealand, it has cost the industry an estimated NZD 9 million per year (Nieuwhof and Bishop, 2005). In a more recent British study, the management of lameness costs farmers between £3.90 - 6.35 (NZD 7.45-12.1) depending on the lameness prevalence within the herd (Winter and Green, 2017). These costs give a rough idea of lameness's impact on each industry. Dairy goats are housed and managed differently from dairy cows and sheep, therefore, it is unknown how lameness may impact farmers economically.

Literature on the effects of lameness in dairy goats and sheep is scarce. Though not yet quantified, the consequences of lameness reported for dairy goats are reduced milk yield, fertility and longevity (Eze, 2002; Christodoulopoulos, 2009; Soli-Ramirez et al. 2011). Lameness in dairy sheep was also significantly associated with a reduction in milk yield (Gelasakis et al. 2015). Additionally, Gelasakis et al. (2015) reported that the effect of lameness in high-yielding sheep was associated with greater milk losses than in control sheep. In analogy to dairy cows and dairy sheep, in the present study, it was hypothesised that the milk yield of dairy goats was negatively affected by lameness and claw disorders (Barkema et al. 1994; Gelasakis et al. 2010). To date, no studies have analysed the association between milk production and lameness in dairy goats. This study aims to evaluate the effect of lameness on milk production and milk characteristics and the potential economic effect on three commercial farms based in New Zealand.

8.3 Materials and methods

8.3.1 Data collection

Data collection consisted of records from 3,190 goats from three farms based in Waikato, New Zealand. The goats within the three farms were a combination of Saanen, Toggenburg, Alpine breeds, and various crosses, which was generic to the New Zealand goat industry (Scholtens et al. 2017). As the goat breed was not accurately recorded, the goat breed was not included in the analyses. Goats were housed in semi-indoor conditions and were kidded once a year. Seasonal lactation goats kidded between June and August 2019 (≤305 days in milk). Farmers also had a group of goats undergoing extended lactations (>305 days in milk). Extended lactation goats were not bred at seasonal breeding periods or had not conceived but were retained in the herd and were continuously milked for prolonged periods. Milk production information was taken from MINDApro™ (LIC Corporation Limited, Hamilton, New Zealand).

Both groups of goats were housed and managed the same. Goats were milked twice a day and fed *ad libitum* with a total mixed ration and fresh grass cut and carried from nearby paddocks. A supplementary concentrate meal was given in the milking parlour. Locomotion analysis was carried out 4-5 times a year within a couple of weeks of herd testing and hoof trimming. More information on the data collection has been described in Chapters 3 and 5.

8.3.2 Statistical analysis

The primary dataset was split by type of lactation, seasonal and extended lactation goats. The seasonal lactation dataset comprised 1,782 goats with 6,368 test-day records. The extended lactation goats' dataset comprised 1,363 goats with 5,479 test-day records. Univariate linear models were conducted using SAS (version 9.4, SAS Institute Inc., Cary, NC) to determine which variables were significantly associated with test-day milk production characteristics. The dependent variables included daily yields of milk, fat, protein, and lactose; concentrations of fat, protein, and lactose; fat-to-protein ratio and milk income. The somatic cell score was calculated as average log2 (somatic cell count/1000). The evaluated milk income assumed a payment for the producers of $19 per kg of goat milk solids (GMS), where GMS was the sum of fat, protein, and lactose yields.

The independent variable of interest was clinical lameness (0/1) or lameness score (0 to 4). Other independent variables and covariates included in the model for seasonal and extended lactation groups of goats are presented in Table 8.1.

There were two differences in the variables used within the model for the extended lactation goats compared with seasonal lactation goats. Firstly, within the extended lactation group of goats, there was considerable variation in lactation lengths (ranging from 272 to 3,738 days in milk at the first test-day event). Because of this, season was used as a factor rather than the stage of lactation. Season had two levels, Winter-Spring (June 2019-November 2019) and Summer-Autumn (December 2019-May 2020). Secondly, the deviation from the median kidding date was omitted from the model. The effect of the kidding date was excluded because the deviation from the median kidding date in this group ranged from days to years, therefore, its effect was considered to be low and not important in this analysis

The random effects of the farm-herd test date, animal and residual were assumed with zero means and variances σ_f^2, σ_a^2 and σ_e^2, respectively. A repeated effect with a serial autocorrelation was considered however, there were 3-4 months between herd-testing, and therefore, the serial auto-correlation was assumed to be low.

The mixed models were run using the MIXED procedure from SAS. A backwards stepwise approach to including or excluding independent variables was used. Interactions terms were omitted if they did not significantly contribute to the regression model. Significant interaction terms are presented in Table 8.2. Only the main effects are provided in the results section; interaction effects, if any, are presented in Appendix V, Tables 1-4. The marginal means for each fixed effect level were used for multiple comparisons with adjustment by the Tukey-Kramer method (Rafter et al. 2002).

A hypothetical scenario of one herd of 1,000 goats illustrated daily milk income at the different prevalence levels of severe lameness. The following equation was used:

Income lost = 1,000 x (percentage of goats severely lame) x (difference in milk income)

Where:

Difference in milk income =
(average income from goats with a locomotion score of 0)
minus
(average income from goats with a locomotion score of 4)

Table 8.1. Independent variables that were included in the analysis of variance for milk production characteristics in seasonal (≤305 days in milk) and extended (>305 days in milk) lactation goats from three farms (A, B, and C) located in Waikato, New Zealand.

Variable	Fixed or random	Seasonal dataset	Extended dataset
Parity	Fixed	1, 2, 3, 4+	1, 2, 3+
Stage of lactation	Fixed	Early lactation, ≤120 days Late lactation, >120 days	-
Season	Fixed	-	Winter-Spring Summer-Autumn
Deviation from the median kidding date	Fixed	Covariate	-
Estimated breeding values [1]	Fixed	Covariate	Covariate
Date difference between locomotion scoring and test-day event	Fixed	Covariate	Covariate
Farm–herd test day	Random	A, 5 herd test-days B, 4 herd test-days C, 3 herd test-days[2]	A, 5 herd test-days B, 4 herd test-days C, 4 herd test-days
Animal	Random		
Residual	Random		

[1]This excluded estimated breeding values for milk lactose concentration and yield because no values have been estimated for these milk characteristics.

[2]Due to the Covid-19 pandemic, the last herd test was delayed until June 2020. By this time, the farmer had dried the seasonal lactation goats off in preparation for the next production year and was not present at the fourth herd test.

Table 8.2. Significant independent variable interactions were included in the analysis of variance for milk production characteristics in seasonal (≤305 days in milk) and extended (>305 days in milk) lactation goats from three farms located in Waikato, New Zealand.

	Seasonal lactation		Extended lactation
Dependent variable	Clinical lameness	Lameness score	Lameness score
Daily yield			
Milk (kg)	Parity and stage of lactation	Parity and stage of lactation	Lameness score and parity
Fat (g)	Parity and stage of lactation	Parity and stage of lactation	Lameness score and parity
Protein (g)	Parity and stage of lactation	Parity and stage of lactation	Lameness score and parity
Lactose (g)	Parity and stage of lactation	Parity and stage of lactation	Lameness score and parity
Concentration (%)			
Fat	Parity and stage of lactation	Parity and stage of lactation	
Protein	Parity and stage of lactation	Parity and stage of lactation	
Lactose	Parity and stage of lactation	Parity and stage of lactation	
Fat: protein ratio		Lameness score and stage of lactation	
Somatic cell score[1]		Parity and stage of lactation	
Milk income ($/day)[2]	Parity and stage of lactation	Parity and stage of lactation	Lameness score and parity

[1]Somatic cell score = average $\log_2$ (somatic cell count).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

8.4 Results

The percentage of the goats across parity, locomotion score, and clinical lameness was stratified by type of lactation, seasonal or extended lactation, as shown in Table 8.3. Most seasonally lactating goats (66%) were of parity 1 or 2. Most extended lactation goats had given birth only once before entering the continuous lactating group. Across the 2019-2020 production year, 24.4% and 46.3% of seasonal and extended lactation goats were clinically lame at least once, respectively.

Seasonal and extended lactation goats differed in average milk production yields (Table 8.4). Average milk characteristics were higher for seasonal lactation goats than extended lactation goats except for fat and protein percentages and somatic cell counts.

Table 8.3. Percentages of goats by parity and clinical lameness status (locomotion score 3 or 4) for seasonal (≤305 days in milk) and extended (>305 days in milk) lactation groups from three farms in New Zealand during the production season of 2019-2020.

Variable	Seasonal goats (n=1,782)	Extended goats (n= 1,363)
Parity 1	41.4%	60.1%
Parity 2	24.3%	18.1%
Parity 3	17.8%	12.5%
Parity 4+	16.5%	9.40%
Goats clinically lame	24.4%	46.3%

Table 8.4. Descriptive statistics of daily milk characteristics by seasonal (≤305 days in milk) and extended (>305 days in milk) lactation groups on three farms in New Zealand during the 2019-2020 production season.

Variable (per test day)	Seasonally lactating goats (n=1,782)		Extended lactation goats (n= 1,363)	
	Mean	Standard deviation	Mean	Standard deviation
Daily yields				
Milk (kg)	3.75	1.13	3.14	0.99
Fat (g)	117	39.0	103	32.9
Protein (g)	118	35.3	103	30.9
Lactose (g)	170	53.4	140	45.1
Concentration (%)				
Protein	3.17	0.34	3.32	0.34
Fat	3.14	0.55	3.31	0.58
Lactose	4.54	0.27	4.47	0.29
Fat to protein ratio	0.995	0.17	1.000	0.16
Somatic cell score[1]	9.50	1.42	10.0	1.15
Milk income ($/kg)[2]	7.70	2.34	6.57	1.99

[1]Somatic cell score = average $\log_2$ (somatic cell count/1000).

[2]Milk income is calculated as $19 per kg of goat solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

8.4.1 Effect of lameness on daily milk yield and composition

For seasonally lactating goats, milk and lactose yields, but not fat and protein yields, were significantly different between goats diagnosed as clinically and not clinically lame (Table 8.5). Clinically lame goats produced 2.63% less milk and 2.59% less lactose than goats defined as not clinically lame. The consequent effect of these reductions was that the milk income of clinically lame goats was reduced by 2.12%.

When milk production and characteristics were associated with locomotion scores of seasonal lactation goats, the greatest reduction was between goats with a normal gait, which scored 0, and goats defined as severely lame, which scored 4 (Tables 8.6 and 8.7). The reduction in milk, protein, and lactose yield was significant (P-value <0.05). Milk yield reduced by 7.10%, protein yield decreased by 8.11%, lactose yield decreased by 7.53%, and milk income reduced by 5.93%.

For extended lactation goats, clinically lame goats had a significantly (P-value <0.05) reduced daily milk (0.15 kg), fat (3.43 g), protein (4.32 g), and lactose (5.99 g) yields than goats not clinically lame (Table 8.8). The reduction was between 3.30 and 4.66%. The average milk income was reduced by 3.74% ($ 0.25 per kg of GMS) for each clinically lame goat.

When analysing locomotion scores, all milk characteristics were significantly reduced for goats with severe (score 4) locomotion impairment compared with goats with a normal gait (Tables 8.9 and 8.10). There was a reduction of 8.56% (0.28 kg) for milk, 4.59% (4.77 g) for fat, 8.26% (8.65 g) for protein, and 7.05% (10.1 g) for lactose yields. Consequently, the average milk income was reduced by 6.10% ($ 0.40 per kg of GMS).

Table 8.5. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in seasonal lactation goats classified by clinical lameness status at the test-day on three farms based in New Zealand during the 2019-2020 production year.

Test day milk characteristic	Scores 0-2 (not clinical)			Scores 3 and 4 (clinical)		
	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields						
Milk (kg)	3.84[a]	0.099	3.64-4.03	3.74[b]	0.104	3.53-3.94
Fat (g)	121[a]	3.29	114-127	120[a]	3.49	113-127
Protein (g)	121[a]	3.34	114-128	117[b]	3.47	110-124
Lactose (g)	172[a]	7.07	158-186	167[b]	7.21	153-182
Concentrations (%)						
Fat	3.16[a]	0.072	3.02-3.30	3.27[b]	0.074	3.13-3.42
Protein	3.17[a]	0.042	3.09-3.25	3.17[a]	0.043	3.08-3.25
Lactose	4.53[a]	0.035	4.46-4.60	4.56[b]	0.035	4.49-4.63
Fat: Protein ratio	1.00[a]	0.023	0.95-1.04	1.04[b]	0.024	0.99-1.08
Somatic cell score[1]	9.55[a]	0.130	9.30-9.81	9.60[a]	0.137	9.33-9.87
Milk income ($)[2]	7.78[a]	0.306	7.18-8.38	7.61[b]	0.312	7.00-8.23

[1]Somatic cell score = average $\log_2$ (somatic cell count/1000).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Table 8.6. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in seasonal lactation goats were classified by locomotion score on the test-day on three farms based in New Zealand during the 2019-2020 production year.

Test day milk	Score 0			Score 1			Score 2		
characteristic	Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields									
Milk (kg)	3.83[a]	0.101	3.63-4.03	3.84[a]	0.101	3.65-4.04	3.78[a]	0.103	3.65-4.05
Fat (g)	120[a]	3.33	113-126	121[a]	3.34	114-127	122[a]	3.42	115-128
Protein (g)	121[a]	3.37	114-127	121[a]	3.38	114-128	121[a]	3.43	114-128
Lactose (g)	170[a]	7.10	157-184	173[a]	7.11	159-187	173[a]	7.16	159-187
Concentrations (%)									
Fat	3.15[a]	0.072	3.00-3.29	3.16[a]	0.072	3.02-3.30	3.18[ab]	0.073	3.04-3.33
Protein	3.18[a]	0.042	3.09-3.26	3.17[a]	0.042	3.09-3.25	3.17[a]	0.042	3.09-3.25
Lactose	4.52[a]	0.035	4.46-4.59	4.52[a]	0.035	4.45-4.59	4.54[ab]	0.035	4.47-4.61
Fat: Protein ratio	0.99[a]	0.023	0.95-1.04	1.00[a]	0.023	0.96-1.05	1.00[ab]	0.023	0.96-1.05
Somatic cell score[1]	9.54[a]	0.132	9.29-9.80	9.58[a]	0.132	9.32-9.84	9.52[a]	0.135	9.26-9.79
Milk income ($)[2]	7.77[a]	0.307	7.11-8.31	7.82[a]	0.307	7.21-8.42	7.84[a]	0.310	7.23-8.45

[1]Somatic cell score = average $\log_2$ (somatic cell count/1000).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Table 8.7. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in seasonal lactation goats were classified by locomotion score on the test-day on three farms based in New Zealand during the 2019-2020 production year (continued).

Test day milk characteristic	Score 3			Score 4		
	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields						
Milk (kg)	3.78[a]	0.106	3.58-3.99	3.56[b]	0.121	3.32-3.80
Fat (g)	120[a]	3.54	113-127	119[a]	4.19	111-127
Protein (g)	118[a]	3.51	112-125	111[b]	3.96	103-119
Lactose (g)	170[a]	7.25	156-184	158[b]	7.77	142-173
Concentrations (%)						
Fat	3.24[b]	0.075	3.10-3.39	3.40[c]	0.082	3.24-3.56
Protein	3.17[a]	0.043	3.08-3.25	3.16[a]	0.047	3.07-3.25
Lactose	4.56[b]	0.036	4.49-4.63	4.58[b]	0.038	4.50-4.65
Fat: Protein ratio	1.02[b]	0.024	0.98-1.07	1.09[c]	0.026	1.04-1.14
Somatic cell score[1]	9.56[a]	0.139	9.28-9.83	9.76[a]	0.162	9.45-10.1
Milk income ($)[2]	7.70[a]	0.314	7.09-8.32	7.25[b]	0.337	6.59-7.91

[1]Somatic cell score = average $\log_2$ (somatic cell count/1000).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Table 8.8. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in extended lactation goats classified by clinical lameness status on the test-day on three farms based in New Zealand during the 2019-2020 production year.

Test day milk characteristic	Scores 0-2 (not clinical)			Scores 3 and 4 (clinical)		
	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields						
Milk (kg)	3.20[a]	0.089	3.03-3.38	3.05[b]	0.091	2.88-3.23
Fat (g)	104[a]	2.79	98-109	100[b]	2.87	95-106
Protein (g)	104[a]	2.83	98-109	99.6[b]	2.89	94-105
Lactose (g)	141[a]	4.97	132-151	135[b]	5.04	126-145
Concentrations (%)						
Fat	3.27[a]	0.060	3.15-3.39	3.35[b]	0.061	3.23-3.47
Protein	3.27[a]	0.033	3.20-3.33	3.30[b]	0.033	3.23-3.36
Lactose	4.47[a]	0.019	4.43-4.50	4.48[b]	0.019	4.44-4.52
Fat: Protein ratio	1.01[a]	0.018	0.97-1.04	1.02[b]	0.018	0.98-1.06
Somatic cell score[1]	10.0[a]	0.078	9.85-10.2	10.1[a]	0.082	9.89-10.2
Milk income ($)[2]	6.59[a]	0.217	6.16-7.01	6.34[b]	0.220	5.91-6.77

[1]Somatic cell score = average $\log_2$ (somatic cell score/1000).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Table 8.9. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in extended lactation goats were classified by locomotion scores on the test-day on three farms based in New Zealand during the 2019-2020 production year.

Test day milk characteristic	Scores 0			Scores 1			Scores 2		
	Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields									
Milk (kg)	3.23[a]	0.092	3.05-3.41	3.19[a]	0.091	3.01-3.37	3.20[a]	0.092	3.02-3.38
Fat (g)	104[ab]	2.89	98.1-109	103[ab]	2.84	97.5-109	105[a]	2.88	99.0-110
Protein (g)	105[a]	2.92	99.1-111	103[ab]	2.88	97.8-109	104[ab]	2.91	98.1-110
Lactose (g)	143[a]	5.06	132.6-152	141[a]	5.02	131-151	141[a]	5.05	131-151
Concentrations (%)									
Fat	3.27[ab]	0.062	3.15-3.39	3.26[a]	0.061	3.14-3.38	3.28[ab]	0.062	3.16-3.40
Protein	3.27[a]	0.028	3.21-3.32	3.27 [a]	0.028	3.22-3.33	3.27[ab]	0.029	3.22-3.33
Lactose	4.46[a]	0.019	4.43-4.50	4.47[a]	0.019	4.43-4.51	4.47[a]	0.019	4.43-4.50
Fat: Protein ratio	1.00[a]	0.018	0.97-1.04	1.00[a]	0.018	0.97-1.04	1.01[a]	0.018	0.97-1.05
Somatic cell score[1]	9.98[a]	0.081	9.82-10.14	10.0[a]	0.080	9.86-10.2	10.0[a]	0.081	9.85-10.2
Milk income ($)[2]	6.63[a]	0.221	6.19-7.06	6.56[ab]	0.219	6.14-6.99	6.57[ab]	0.220	6.14-7.00

[1]Somatic cell score = average $\log_2$ (somatic cell count).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Table 8.10. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition in extended lactation goats were classified by locomotion scores on the test-day on three farms based in New Zealand during the 2019-2020 production year (continued).

Test day milk characteristic	Scores 3			Scores 4		
	Mean	SE	95% CI	Mean	SE	95% CI
Daily yields						
Milk (kg)	3.08[b]	0.093	2.89-3.26	2.95[c]	0.102	2.75-3.15
Fat (g)	101[ab]	2.94	95.4-107	99.0[b]	3.30	92.5-105
Protein (g)	101 [ab]	2.96	94.8-106	96.1[c]	3.24	89.8-102
Lactose (g)	136[b]	5.10	126-146	132[b]	5.44	122-143
Concentrations (%)						
Fat	3.32[b]	0.062	3.20-3.44	3.44[c]	0.065	3.31-3.57
Protein	3.30[bc]	0.029	3.24-3.35	3.32 [c]	0.030	3.26-3.38
Lactose	4.48 [ab]	0.019	4.44-4.51	4.50[b]	0.021	4.46-4.54
Fat: Protein ratio	1.01[a]	0.019	0.98-1.05	1.04[b]	0.019	1.00-1.08
Somatic cell score[1]	10.0[a]	0.083	9.87-10.2	10.1[a]	0.093	9.96-10.3
Milk income ($)[2]	6.38[bc]	0.223	5.94-6.81	6.22[c]	0.238	5.75-6.69

[1]Somatic cell score = average $\log_2$ (somatic cell count).

[2]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

When severe lameness was present within a herd, the reduction of milk income depended on whether the goats were in seasonal or extended lactation (Figure 8.1). As the percentage of goats with severe lameness within the herd increased, the daily loss of income was higher, regardless of seasonal (NZD 26 *vs.* 104 per day per goat) or extended lactation goats (NZD 20 *vs.* 78 per day per goat). The cost of severe lameness (score of 4) was higher in seasonal goats than in extended lactation goats.

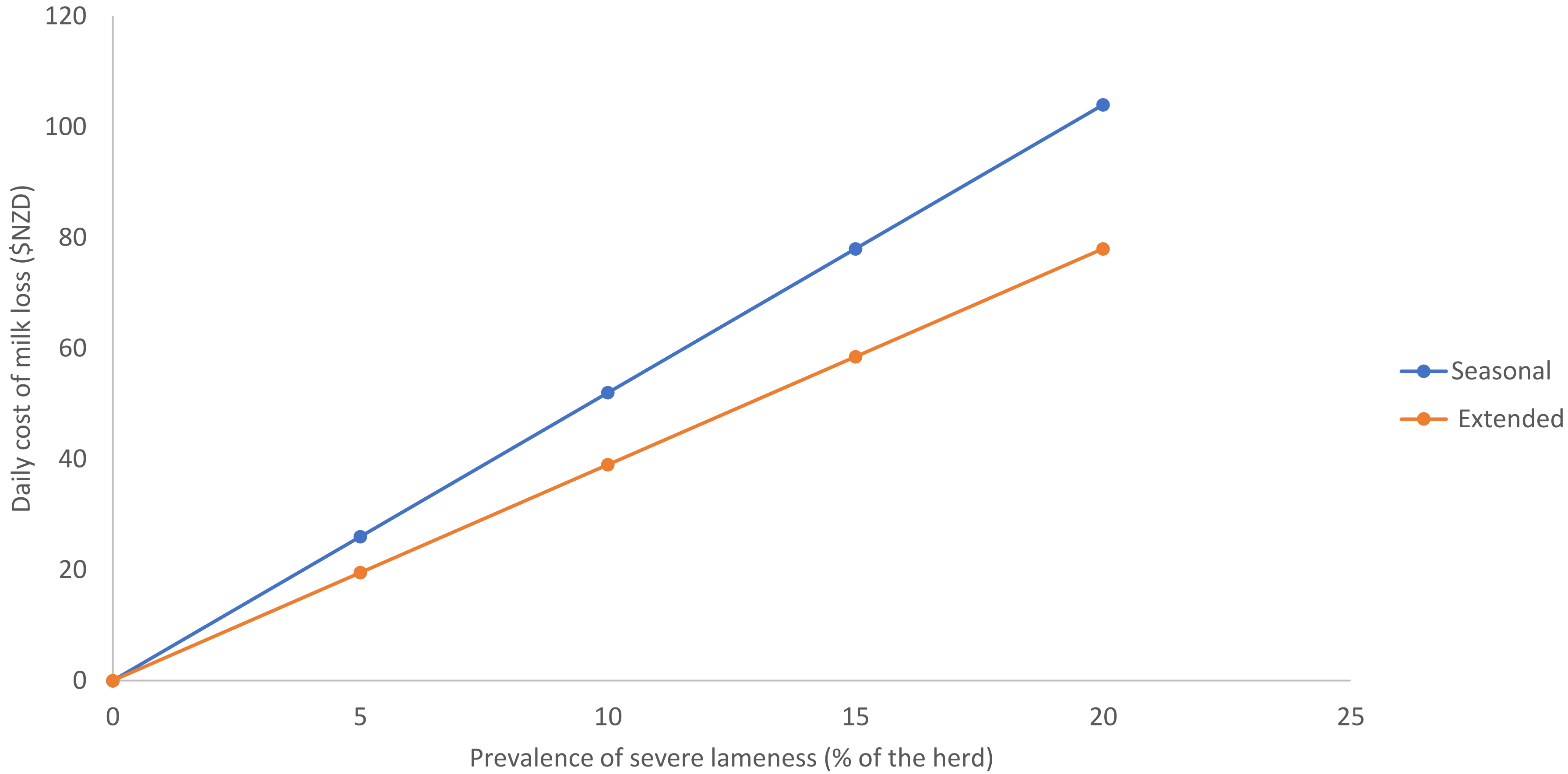

Figure 8.1. The average daily loss of income due to a reduction in goat milk solids (GMS) at different prevalence levels of severe lameness (locomotion score 4) is based on a farm with 1,000 goats and income from the sale of GMS at a farm gate price of NZD 19/kg. Note that these averages did not account for the duration of lameness.

8.5 Discussion

The average milk production yields for the study farms were within the range of what was previously reported in New Zealand (Morris et al. 2006; Solis-Ramirez et al. 2011; Scholtens et al. 2019). Milk component concentrations also fell within the range of national (Scholtens et al. 2019) and international studies (Vacca et al. 2018; Laučienė et al. 2021). Variations were most likely due to management and environmental factors (Castaneda-Bustos et al. 2014; Scholtens et al. 2019).

This study has highlighted that clinically lame goats, regardless of lactation type, had significantly lower milk production than goats that were not clinically lame. The impact of lameness on milk production differed from dairy sheep and cow studies. Assuming that locomotion scoring was on the day of diagnosis, the estimated daily reduction of milk yield in clinically lame seasonal and extended lactation dairy goats was 2.63 and 4.66%, respectively. The total annual loss for a herd would depend on the average prevalence of clinical lameness and the average duration of the clinical lameness. In dairy sheep, the daily milk yield was reduced between 10.8 and 35.8%, depending on when lameness was diagnosed (Gelasakis et al. 2015). Gelasakis et al. (2015) reported that lameness affected milk production though the effect depended on the time of diagnosis during a lameness episode. A 10.8, 32.5 and 35.8% reduction was recorded two weeks before, during the week, and one week after the lameness diagnosis in those sheep, respectively. The present study did not relate the relative loss to the time of diagnosis. Instead, the estimated milk reduction applied to an 'average day' of lameness throughout the season.

In dairy cattle, reduced milk yields in lame cows have been reported (Enting et al. 1997; Hernandez et al. 2002; Bicalho et al. 2008). Similar to this study, dairy cows' daily milk yield loss was between 0.82 – 11.1% (Enting et al. 1997; Kocak and Ekiz, 2006; Bicalho et al. 2008). Over an entire lactation (305 days), milk yield reduction was between 2.38-9.92%, depending on the cause of lameness (Hernandez et al. 2002). In dairy cows, reduced milk yields were apparent for up to four months before and five months after diagnosis (Warnick et al. 2001; Green et al. 2002). Another study on dairy cows reported that lame cows had a reduced test-day milk yield up to eight months after diagnosis (Archer et al. 2010). In contrast, there are reports that lame cows had higher production than healthy cows before the onset of lameness (Green et al. 2002; Hernandez et al. 2002). This would imply that high production predisposed cows to lameness. Due to only one milk test-day event occurring around the time of the locomotion scoring in the current study, the impact of milk lost for a goat over one lameness event should be investigated further in dairy goats to study the relationship between lameness duration and milk production. Additionally, it would be important to determine if high genetic merit goats had an increased risk of becoming lame.

There was a significant effect of severe lameness (score 4) on milk production and milk yield regardless of lactation type. This is a function of the duration and severity of a case of lameness, where the longer the goat was left untreated, the more severe and painful the conditions were. As Gelasakis et al. (2015) suggested in their study on lame sheep, lame goats were probably less able to compete for high quality and quantity of feed despite the goats having had ample headspace at the feeding passage (330 mm per head). Like cows, a goat in pain may have drifted lower in the herd's hierarchy and were outcompeted by non-lame goats when the ration is fed out (Yunta et al. 2012). Alternatively, inflammatory factors could negatively impact the goat's appetite and reduce milk production (Gelasakis et al. 2015).

The reduction in milk production of severely lame goats was comparable to milk production loss in mildly to severely lame cows (Green et al. 2002). A possible reason for a relatively lower loss in goats was that they were housed indoors on soft bedding all year and could lie down next to the feeding passage to graze while being fed. This might be explored further by comparing the time spent lying down between lame and non-lame goats. Thus, lame goats might find it easier to meet their daily nutritional needs, unlike dairy cows or sheep that usually graze outside for all or part of the year. Also, cows housed indoors would still have to walk to and stand at the feeding passage, while goats do not have to if they do not want to it.

The present study is the first to distinguish between seasonal and extended lactation goats and their response to lameness. The reduction in milk production was higher in the extended lactation goats than in seasonal lactation goats; however, the reduction in income of clinical lameness to the farmer was higher in seasonal lactation goats. Clinically and severely lame goats in seasonal lactations had a reduction of 2.63 and 7.10%, respectively, in average milk production compared with non-clinically lame goats and goats with a normal gait. The milk production of clinically and severely lame goats in extended lactation reduced on average by 4.66 and 8.56%, respectively. Little is known about the physiological differences between seasonal and extended lactation goats, and some underlying factors could differentiate the goat's response to lameness. Another reason extended lactation goats had a higher milk yield reduction could be farm management factors. For example, due to seasonal goats being used for breeding, the farmer could prioritise the treatment of seasonal goats above extended lactation goats. Delaying treatment could increase the severity of lameness. More investigation needs to determine whether this difference is physiological or because of management.

Lameness on UK commercial dairy goat farms does not appear to be a priority for most farmers (Anzunio et al. 2019). The farmer survey of that study reported that kidding health, Johne's disease, tuberculosis, and nutrition were more important production limiting factors than lameness. Lameness appeared less important to farmers because they generally underestimated their herd's lameness prevalence and tended to accept mild lameness within their farm as an unavoidable phenomenon (Anzunio et al. 2010; Wynands et al. 2021). Because the costs of lameness may not always be directly observed, farmers may often be unaware of the full extent of the economic impact associated with lameness (Wynands et al. 2021).

When the farm gate price for milk is relatively high, farmers may tend to accept the costs due to lameness. In our estimates, milk income was substantially reduced when goats were clinically lame and furthermore when the goats were severely lame. Farmers within the study incurred regular management costs for preventing or treating lameness, including hoof trimming, feed supplements, footbath supplies and direct costs, such as farm labour and treatment. Unlike dairy cow farmers, it is uncommon for commercial dairy goat farmers to call a veterinarian to treat individual goats for lameness. These factors need to be accounted for when undertaking an economic analysis of lameness on farms, which would be the next step forward after this study. Therefore, depending on the incidence rate of lameness per year, the cause and type of lameness, the number of treatments required, the number of herd trimmings and other prevention strategies, the cost of lameness for farmers will vary substantially. The resulting financial burden can severely impact the farmer's production costs and subsequent profits.

8.6 Conclusion

This is the first study that quantifies the effects of lameness on milk production in dairy goats on commercial farms. Milk production was significantly affected, where severe lameness resulted in a 7.10% loss of milk production for seasonally lactating goats and 8.56% for goats in extended lactation. Other milk characteristics significantly affected by severe lameness were fat, protein, and lactose concentrations. At a relatively high prevalence of severe lameness, a reduction in milk incomes can have grave impacts on the economic efficiency of a dairy goat farm.

Appendix V

Supplementary information for Chapter 8

Appendix V Table 1. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition for independent variables that had a significant interaction with locomotion scores in <u>seasonal lactation</u> goats classified by locomotion scores at the test-day on three farms based in New Zealand during the 2019-2020 production year.

Milk characteristics		Stage of lactation	Score 0			Score 1			Score 2		
			Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Fat: protein ratio	Locomotion score		0.99^{a}	0.023	0.95-1.04	1.00^{a}	0.023	0.96-1.05	1.00^{ab}	0.023	0.96-1.05
	Stage of lactation x locomotion score	Early	1.00^{a}	0.024	0.96-1.05	1.02^{a}	0.024	0.97-1.07	1.02^{a}	0.024	0.97-1.06
		Late	0.98^{a}	0.024	0.93-1.03	0.98^{ac}	0.024	0.94-1.03	0.99^{ab}	0.024	0.94-1.04

^{a,b,c}Means with different superscripts within the same row are significantly different (P-value <0.05).

Appendix V Table 2. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition for independent variables that had a significant interaction with locomotion scores in <u>seasonal lactation</u> goats classified by locomotion scores at the test-day on three farms based in New Zealand during the 2019-2020 production year (continued).

Milk characteristics		Stage of lactation	Score 3			Score 4		
			Mean	SE	95% CI	Mean	SE	95% CI
Fat: protein ratio	Locomotion score		1.02^{b}	0.024	0.98-1.07	1.09^{c}	0.026	1.04-1.14
	Stage of lactation x locomotion score	Early	1.03^{a}	0.025	0.98-1.08	1.14^{b}	0.030	1.08-1.20
		Late	1.02^{b}	0.025	0.97-1.07	1.03^{bc}	0.028	0.98-1.08

^{a,b,c}Means with different superscripts within the same row are significantly different (P-value <0.05).

Appendix V Table 3. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition for independent variables that had a significant interaction with locomotion score in extended lactation goats classified by locomotion scores at the test-day on three farms based in New Zealand during the 2019-2020 production year.

Milk characteristics		Parity	Score 0			Score 1			Score 2		
			Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Milk (kg)	Locomotion score		3.23[a]	0.092	3.05-3.41	3.19[a]	0.091	3.01-3.37	3.20[a]	0.092	3.02-3.38
	Parity x	1	2.96[a]	0.094	2.78-3.14	2.98[a]	0.093	2.80-3.17	2.92[ab]	0.095	2.73-3.10
	locomotion score	2	3.27[a]	0.107	3.06-3.48	3.22[a]	0.102	3.02-3.42	3.14[a]	0.105	2.94-3.35
		3	3.45[a]	0.106	3.25-3.66	3.37[a]	0.103	3.17-3.57	3.55[a]	0.106	3.35-3.76
Fat (g)	Locomotion score		104[ab]	2.89	98.1-109	103[ab]	2.84	97.5-109	105[a]	2.88	99.0-110
	Parity x	1	99.0[a]	2.94	93.2-105	99.3[a]	2.93	93.5-105	97.1[ab]	3.00	91.2-103
	locomotion score	2	104 [a]	3.48	97.0-111	104[a]	3.28	97.7-111	103[a]	3.38	96.0-109
		3	109 [a]	3.42	102-115	106[a]	3.30	99.4-112	114[a]	3.43	108-121
Protein (g)	Locomotion score		105[a]	2.92	99.1-111	103[ab]	2.88	97.8-109	104[ab]	2.91	98.1-110
	Parity x	1	97.5[a]	2.97	91.6-103	98.3[a]	2.96	92.5-104	96.1[a]	3.01	90.2-102
	locomotion score	2	106[a]	3.41	98.9-112	104[a]	3.25	97.9-111	101[a]	3.33	94.8-108
		3	111[a]	3.35	104.7-118	108[a]	3.26	101.5-114	114[a]	3.37	107.5-121
Lactose (g)	Locomotion score		143[a]	5.06	132.6-152	141[a]	5.02	131.1-151	141[a]	5.05	130.9-151
	Parity x	1	130[a]	5.15	119.8-140	131[a]	5.14	121.2-141	128[a]	5.20	117.7-138
	locomotion score	2	149[a]	5.78	137.2-160	145[a]	5.59	134.2-156	142[a]	5.72	130.7-153
		3	149[a]	5.62	138.1-160	146[a]	5.51	135.4-157	153[a]	5.58	141.7-164
Milk income ($/day)	Locomotion score		6.63[a]	0.221	6.19-7.06	6.56[ab]	0.219	6.14-6.99	6.57[ab]	0.220	6.14-7.00
	Parity x	1	6.17[a]	0.225	5.73-6.61	6.21[a]	0.224	5.77-6.65	6.06[a]	0.227	5.61-6.50
	locomotion score	2	6.89[a]	0.253	6.39-7.38	6.77[a]	0.245	6.29-7.25	6.62[a]	0.251	6.13-7.11
		3	6.82[a]	0.246	6.34-7.31	6.71[a]	0.241	6.24-7.19	7.03[a]	0.244	6.55-7.51

[1]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.
[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Appendix V Table 4. Marginal means (Mean), standard errors (SE), and 95% confidence intervals (CI) of daily milk yields and composition for independent variables that had a significant interaction with locomotion score in extended lactation goats classified by locomotion scores at the test-day on three farms based in New Zealand during the 2019-2020 production year (continued).

Milk characteristics			Score 3			Score 4		
			Mean	SE	95% CI	Mean	SE	95% CI
Milk (kg)	Locomotion score		3.08[b]	0.093	2.89-3.26	2.95[c]	0.102	2.75-3.15
	Parity x	1	2.86[b]	0.095	2.68-3.05	2.65[c]	0.102	2.45-2.85
	locomotion score	2	3.06[a]	0.111	2.84-3.27	3.04[a]	0.135	2.77-3.30
		3	3.31[a]	0.111	3.10-3.53	3.17[a]	0.139	2.90-3.45
Fat (g)	Locomotion score		101[ab]	2.94	95.4-107	99.0[b]	3.30	92.5-105
	Parity x	1	95.6[ab]	3.00	89.7-102	91.9[ab]	3.31	85.4-98
	locomotion score	2	100[a]	3.61	93.1-107	100[a]	4.59	91.1-109
		3	108[a]	3.63	101-115	105[a]	4.74	95.7-114
Protein (g)	Locomotion score		101[b]	2.96	94.8-106	96.1[c]	3.24	89.8-102
	Parity x	1	94.3[a]	3.01	88.4-100	88.3[b]	3.25	81.9-95
	locomotion score	2	100[a]	3.51	93.0-107	98.1[a]	4.31	89.6-107
		3	108[a]	3.52	100.8-115	102[a]	4.43	93.4-111
Lactose (g)	Locomotion score		136[b]	5.10	126.1-146	132[b]	5.44	121.8-143
	Parity x	1	126[a]	5.20	115.3-136	118[b]	5.50	106.8-128
	locomotion score	2	140[a]	5.94	128.8-152	142[a]	6.96	128.0-155
		3	142[a]	5.74	131.0-154	138[a]	6.96	124.5-152
Milk income ($/day)[1]	Locomotion score		6.38[bc]	0.223	5.94-6.81	6.22[c]	0.238	5.75-6.69
	Parity x	1	5.96[ab]	0.227	5.51-6.40	5.65[b]	0.241	5.18-6.12
	locomotion score	2	6.56[a]	0.261	6.04-7.07	6.59[a]	0.307	5.99-7.19
		3	6.62[a]	0.251	6.12-7.11	6.43[a]	0.307	5.83-7.03

[1]Milk income is calculated as $19 per kg of goat milk solids (GMS), where GMS are the sum of fat, protein, and lactose yields.

[a,b,c]Means with different superscripts within the same row are significantly different (P-value <0.05).

Chapter 9

The genetic parameters of milk, and occurrence and susceptibility of lameness and claw disorders in dairy goats

9.1 Abstract

Lameness and claw disorders are important animal welfare aspects in dairy goats, where knowledge of foot problems is limited. This study aimed to determine the genetic parameters of the occurrence and susceptibility of clinical lameness and selected claw disorders in dairy goats. Three farms within the Waikato region of New Zealand were a part of this study. Information on pedigree, lameness, claw disorders, and milk production was collected from June 2019-July 2020. The dataset contained 1,638 does, the progeny of 174 sires and 1,231 dams. The occurrence of clinical lameness or claw disorders was defined as one of the events present at least once over the lactation period. Susceptibility of clinical lameness or claw disorders was defined as the number of times the goat was diagnosed as having one of the events present divided by the number of times they were assessed during the lactation. Clinical lameness was defined as having a locomotion score equal to or greater than three. Claw disorders included in the analysis were horn separation, rot and granuloma. The genetic parameters (heritability, genetic and phenotypic variances, and covariances) were estimated by Restricted Maximum Likelihood models. A single-trait animal model was used to estimate the heritability, while the bivariate model was used to estimate the correlations. The heritability (h^2) estimates for lameness occurrence and susceptibility were 0.07 and 0.13, respectively, and the h^2 estimates of claw disorder susceptibilities ranged from 0.02 to 0.23. The genotypic correlations ranged from weak to very strong between lameness and milk production traits (-0.94 to 0.84) and weak to moderate correlations (0.23 to 0.84) between claw disorder and milk production traits. This study reports genetic variation for the occurrence and susceptibility of lameness and claw disorders in dairy goats. The results indicate that lameness and claw disorders can be reduced using breeding if these traits are included in a selection index that considers the genetic correlation between lameness and claw disorders and milk production traits. Both aspects need to be further investigated using a larger cohort of animals to verify these results.

9.2 Introduction

The previous chapters have reported results of the prevalence of claw disorders and clinical lameness on three dairy goat farms in New Zealand. Similar to information reported in studies published overseas, clinical lameness and claw disorders have become welfare issues. Literature across dairy cows and sheep research studies has identified causal factors that can be split into three categories: management, environment, and genetics (Solano et al. 2015; Heringstad et al. 2018). However, there are many complex interactions among these causative factors. Management factors include nutrition and flooring. Environmental factors include the presence of bacteria and seasonal weather changes. Changes in both variables, such as floor/bedding surfaces, to reduce lameness in a herd could be seen as short-term solutions. At the same time, breeding can be treated as a long-term solution (Bicalho and Oikonomou, 2013).

Selective breeding has been investigated as a long-term option to reduce the prevalence of lameness and claw disorders within dairy cattle and sheep (Connington et al. 2010; Chesnais et al. 2016; Heringstad et al. 2018). Heringstad et al. (2018) did an extensive review of the genetics of claw health (infectious and non-infectious claw disorders) in dairy cattle. Overall, it was reported that across studies, claw disorders had low to moderate (0.01-0.39) heritabilities. Grouping the claw disorders as one claw health trait or grouping based on aetiology resulted in higher estimates for heritabilities. Heritabilities for lameness and claw disorders were low, 0.02-0.34. When lameness was treated as an ordinal trait (1-5 score), it had higher heritability (h^2) estimates than when lameness was used as a presence/absence trait (0.08-015 *vs.* 0.02-0.04, respectively).

Heringstad et al. (2018) also identified genetic and phenotypic correlations in lameness and claw disorder traits. A moderate genetic correlation (0.55) between claw disorders in the front and hind legs has been reported. This means that claw disorders in the front and hind legs could be considered different traits. Within a lactation, it has been suggested that claw disorders and lameness should be classified as different traits depending on the cow's stage of lactation. A few studies have reported that both infectious and non-infectious claw disorders have moderate to high genetic correlation ranging across the stage of lactation from -0.40 to 0.98 (Heringstad et al. 2018). This suggests that, depending on the claw disorder, the claw disorder could be treated as one or multiple traits within one lactation and across parities.

A few studies have reported the heritability of claw disorders and lameness in sheep. Studies investigating footrot in lambs (8-9 months old) reported heritabilities between 0.03-0.41 when an occurrence recording system was used (Nieuwhof et al. 2008; Skerman et al. 1988; Raadsma et al. 1994). Conington et al. (2010) studied the prevalence of white line disease or "Shelly hoof" and reported heritabilities between 0.09-0.33. The h^2 estimates of the prevalence of white line disease were higher than the h^2 estimates for the number of feet affected traits (0.15-0.33 *vs.* 0.09-0.29, respectively). O'Brien et al. (2017) analysed lameness in various breeds of ewes and lambs and reported an overall heritability for lameness between 0.06 and 0.12. Despite heritability studies in sheep, none have reported genetic or phenotypic correlations between different claw disorders or between claw disorder and lameness traits.

After an extensive search, only one study referenced genetics in the occurrence of lameness and claw disorders in dairy goats. Hill et al. (1997) reported that the incidence of horn separation was random and, therefore, most likely caused by external factors rather than genetic factors. Despite Hill et al. (1997) observation that there has been no previous evidence of lameness and claw disorders being heritable in dairy goats, evidence in sheep and dairy cow studies suggests otherwise, therefore, heritability should be investigated in dairy goats.

Before the collection of phenotypes, the traits need to be defined. It is common in dairy cattle and sheep to present lameness and claw disorders as a binomial or ordinal trait. Using these definitions at the lactation level (rather than test-day level) cannot capture the incidence rate (number of new cases) over time. Similar to Nieuwhof et al. (2008), susceptibility was investigated in addition to having two ordinal traits: one for lameness and one for claw disorders. In this study, susceptibility has been defined as the number of times a goat was diagnosed with clinical lameness or a claw disorder (horn separation, rot, or granuloma) over the number of times the goat was observed.

Currently, the Dairy Goat Cooperative (NZ) Ltd, manages the genetic evaluation of dairy goats twice a year for lactation yields of milk, fat, protein and lactose and average somatic cell score (SCS). Exploration of including selection against occurrence and susceptibility of lameness and claw disorder requires estimating the following genetic parameters: variance and covariances, heritabilities and genetic and phenotypic correlations between production traits, and occurrence of lameness and claw disorders. Therefore, the objective of this study was to estimate the genetic parameters (genetic variances and covariances, heritability, and genetic and phenotypic correlations) for the occurrence and susceptibility of lameness and claw disorders and milk production and composition traits in dairy goats.

9.3 Methodology

9.3.1 Data

Data were collected from three dairy goat farms in Waikato, New Zealand, for one year, from June 2019 to June 2020. For more details on each farm, refer to Chapter 3.3. The dataset was split into seasonal (≤305 days) and extended (>305 days in milk) lactating groups. Only seasonal lactation goats were used to predict the heritability of milk genetic parameters because only partial lactation information was available for extended lactation goats.

The final dataset of seasonal goats contained 1,638 does with observations. The pedigree included 174 sires and 1,231 dams, spanning one generation. Of the does, 3% had no information on the sire or dams, 83% had both records of the sire and the dam, 14% had only information on the dam, and 0.1% had only sire information.

There were a few crossovers of sires between farms, where farm A shared one sire with farm B and three sires with farm C. There was one sire shared between farms B and C. The goat breeds present on the three farms consisted mainly of Saanen crosses with other breeds such as Toggenburg, Alpine and Nubian (Scholtens et al. 2017). Despite many crosses within the herd, heterosis was not estimated as the data input for the breed information of the animal, sire and dam was not precisely recorded within the pedigree.

9.3.2 Milk trait characteristics

An orthogonal polynomial model of order 3 was used to predict the total yields of milk, protein, fat, and lactose to 270 days. Traditionally, 305 days are used to calculate total yields, however, because of the timing of the herd tests for the three farms in this study, 270 days were used instead. For example, many goats on farms B and C had less than 270 days of milk for their last herd test. Farm B had four herd tests, with their last herd test in March 2020. This meant that this farm herd's maximum days in milk were 259 days. The Covid-19 pandemic disrupted farm C's last herd test, which had to be rescheduled for June 2020. By this time, many seasonal goats had been dried off in preparation for the next kidding season. The last herd test for these seasonal goats was in December 2019. Therefore, for 88.8% of the goats, the maximum days in milk was 178. The long intervals between herd tests meant that using a test-day interval method to calculate the total yields would also provide less accurate results (McDaniel, 1968). An alternative prediction tool, the Legendre polynomial model, was used instead as random regression models are more robust under circumstances where there are unequal days between herd tests (McGill et al. 2014), and polynomials have previously been used to model lactation curves in dairy goats (Silva et al. 2013; Brito et al. 2018).

Aside from calculating total production yields, milk concentrations and ratios were also calculated. The lactation milk fat, protein, and lactose percentages were calculated by taking the respective total lactation yields and dividing by the total milk yield, times by 100. Milk protein-to-fat ratio (P:F), milk protein-to-lactose ratio (P:L), and the milk lactose-to-milk fat and protein ratio (L:(F+P)) was calculated from the total yields for the respective milk characteristics.

9.3.3 Lameness and claw disorder trait definitions

Locomotion and claw disorder scoring events were carried out five times for farm A and four times for farms B and C. More information on the logistics of the locomotion and claw disorder scoring events is reported in Chapters 3 and 5. This study established two clinical lameness traits and five claw disorder traits. Lameness was scored using a 5-point locomotion scale developed by Deeming et al. (2018). In brief, the scores were defined as 0-normal, 1- uneven, 2-mildly lame, 3-moderately lame, and 4-severely lame. A goat was classified as clinically lame if its locomotion was scored as a three or a four. The clinical lameness traits were susceptibility (continuous variable) and occurrence (binomial variable). Clinical lameness susceptibility was the number of times the goat was clinically lame (scored 3 or 4) over the total number of times they were scored between July 2019 and June 2020. Clinical lameness occurrence was given a binomial score (presence or absence) if the goat had been diagnosed as being clinically lame at least once across the production year.

Three claw disorders were selected to focus on - horn separation, rot, and granulomas. Horn separation was defined as a severe form of white line disease. Horn separation of severity 2 was another trait that was included and was defined as the separation of the white line region that separated from more than half of the hoof wall. This extra category was included because horn separation, severity 2, was also associated with clinical lameness, according to results completed in Chapter 7. Rot was defined as the combination of digital dermatitis and footrot. Granulomas were cherry-like tissue growths protruding from the claw. Each claw disorder was classified as present or absent at each hoof trimming event. The five claw disorder traits estimated were horn separation susceptibility, horn separation susceptibility (severity 2), rot susceptibility, granuloma susceptibility, and claw disorder occurrence. Claw disorder (horn separation, rot, and granuloma) susceptibility was calculated by the number of times the goat was diagnosed as having one of these disorders over the total number of times the hoof trimmer assessed the goat between July 2019 and June 2020. Claw disorder occurrence was the binomial score given (presence or absence) if the goat had at least one case of horn separation or rot or granuloma.

9.3.4 Models to estimate genetic parameters

The genetic parameters (heritability, genetic and phenotypic variances, and covariances) were estimated by Restricted Maximum Likelihood models using ASReml version 4 (Gilmour et al. 2015). The milk production traits, lameness, and claw disorder susceptibility were treated as continuous variables, while lameness and claw disorder occurrence traits were treated as binary variables. This study classified the occurrence as a binary trait and susceptibility as a continuous trait. Both classifications of the traits were assumed to have a normal distribution for both animal and residual variances.

A single-trait animal model was used to estimate the heritability, while the bivariate model was used to estimate the correlations. The single trait animal model was represented as:

$$\mathbf{y}=\mathbf{Xb} + \mathbf{Za} + \mathbf{e}$$

Where **y** is the vector of phenotypic observations from measured goats based on one trait, **b** is the vector of fixed effects for goats, **a** is the vector of random animal effects, and **e** is the vector of random residual errors, **X** is the incidence matrix for the fixed effects and **Z** is the incidence matrix combining observations with the respective animals.

Fixed effects included in the vector **b** consisted of farm, parity, and deviation from the median kidding date as a covariate. The bivariate animal model was represented as:

$$\begin{bmatrix}\mathbf{y_1}\\\mathbf{y_2}\end{bmatrix}=\begin{bmatrix}\mathbf{X_1} & 0\\0 & \mathbf{X_2}\end{bmatrix}\begin{bmatrix}\mathbf{b_1}\\\mathbf{b_2}\end{bmatrix}+\begin{bmatrix}\mathbf{Z_1} & 0\\0 & \mathbf{Z_2}\end{bmatrix}\begin{bmatrix}\mathbf{a_1}\\\mathbf{a_2}\end{bmatrix}+\begin{bmatrix}\mathbf{e_1}\\\mathbf{e_2}\end{bmatrix}$$

Where $\mathbf{y_1}$ and $\mathbf{y_2}$ are the vectors of phenotypic observations from measured goats based on the two traits of interest, $\mathbf{b_1}$ and $\mathbf{b_2}$ are the vectors of fixed effects for goats, $\mathbf{a_1}$ and $\mathbf{a_2}$ are the vectors of random animal effects, and $\mathbf{e_1}$ and $\mathbf{e_2}$ are the vectors of random residual errors, **X** is the incidence matrix for the fixed effects and **Z** is the incidence matrix for the additive genetic effects. Fixed effects included were farm and parity. Additive genetic effects consist of the additive genetic relationships between animals. The distribution properties of the variance-covariance elements for traits used in the model for the random additive genetic effect and the random residual effect is as follows:

$$\text{var}\begin{bmatrix}a_1\\a_2\end{bmatrix}=\begin{bmatrix}\mathbf{A}\sigma^2_{a1} & \mathbf{A}\sigma_{a12}\\\mathbf{A}\sigma_{a21} & \mathbf{A}\sigma^2_{a2}\end{bmatrix}$$

and

$$\text{var}\begin{bmatrix}e_1\\e_2\end{bmatrix}=\begin{bmatrix}\mathbf{I}\sigma^2_{e1} & \mathbf{I}\sigma_{e12}\\\mathbf{I}\sigma_{e12} & \mathbf{I}\sigma^2_{e2}\end{bmatrix}$$

For the random genetic effects aspect of the model, A is the relationship matrix among the animals, and σ^2_{a1}, σ^2_{a2} and σ_{a12} are the (co)variance components for the traits of interest. For the random residual effects aspect of the model, **I** is the identity matrix (where the order is equal to the number of observations), and σ^2_{e1}, σ^2_{e2} and σ_{e12} are the error (co)variance components for the traits of interest.

Heritability for a trait was estimated with the following equation:

$$h^2 = \frac{\sigma^2_a}{\sigma^2_p}$$

A single trait model was used to estimate the heritability, where heritability is the proportion of phenotypic (σ^2_p) variance explained by animal additive genetic (σ^2_a) variance within a given population (Lush, 1954; Dempster and Lerner, 1950). Phenotypic variance is the sum of genetic and environmental variances within the population. Low, moderate and high heritabilities are defined as h^2 estimates between 0-0.10, 0.10-0.60, and 0.60-1.00, respectively (Robinson et al. 1949).

A bivariate model was used to estimate the phenotypic and genotypic correlations to identify relationships between two traits. Phenotypic and genotypic correlations were defined by the following equations:

Phenotypic correlation (r_P)

$$r_p = \frac{\sigma_{p12}}{(\sigma_{p1} \times \sigma_{p2})}$$

Genotypic correlation (r_G)

$$r_G = \frac{\sigma_{a12}}{(\sigma_{a1} \times \sigma_{a2})}$$

Where σ_{p12} and σ_{a12} are the phenotypic and genotypic covariance between two traits, σ_{p1} and σ_{a1} are the phenotypic and genotypic standard deviations for trait one, and σ_{p2} and σ_{a2} are the phenotypic and genotypic standard deviations for trait one. Weak, moderate and strong correlations were defined as estimates between 0.30-0.50, 0.50-0.70, and 0.70-1.00, respectively.

9.4 Results

9.4.1 Descriptive statistics

Descriptive statistics are presented in Table 9.1. The lactational (270 days) averages for fat and protein yields were 31.0 and 30.9 kg, with average fat and protein percentages of 3.19 and 3.18%, respectively. The lactose yield and percentage were higher than fat and protein at 44.4 kg and 4.54%, respectively. Averages for lameness susceptibility and occurrence had high standard deviations. The averages for claw disorder traits ranged from low to high, 0.04-0.80, with relatively high standard deviations. The coefficient of variations for lactation length and milk characteristics ranged from low to moderate, while they were high for lameness and claw disorder traits.

Table 9.1. Descriptive statistics[1] for milk production, lameness, and claw disorder traits in dairy goats from three farms taken between July 2019 and June 2020 production year within New Zealand.

Trait	N	Average	SD	Min	Max	CV
Lactation length (days)	1637	257	67.5	33.0	350	26.2
Total yields (kg; 270 days)						
Milk	1637	978	228	442	1718	23.3
Fat	1637	31.0	6.99	13.9	54.3	22.6
Protein	1637	30.9	6.76	13.7	53.9	21.9
Lactose	1637	44.4	10.5	19.8	79.4	23.5
Somatic cell score[2]	1637	9.48	1.12	5.98	13.1	11.8
Milk component concentrations (%)						
Fat	1637	3.19	0.36	1.91	4.37	11.4
Protein	1637	3.18	0.23	2.47	4.08	7.31
Lactose	1637	4.54	0.18	3.62	5.14	3.93
Milk ratios[3]						
Protein:fat	1637	1.01	0.11	0.74	1.49	10.8
Protein:lactose	1637	0.70	0.05	0.53	0.96	7.46
Lactose: fat+protein	1637	0.72	0.06	0.56	0.93	7.83
Clinical lameness						
Susceptibility	1625	0.09	0.18	0.00	1.00	208
Occurrence	1637	0.24	0.42	0.00	1.00	180
Claw disorders						
Horn sep. sus ($x10^3$)[4]	1637	0.43	0.32	0.00	1.00	75.3
Horn sep. sus.2 ($x10^3$)[4]	1637	0.18	0.23	0.00	1.00	127
Rot susceptibility	1637	0.05	0.13	0.00	1.00	244
Granuloma susceptibility	1637	0.04	0.15	0.00	1.00	338
Occurrence	1637	0.80	0.40	0.00	1.00	50.0

[1]N = number of records, SD = standard deviation, Min = minimum value, Max = maximum values, CV = coefficient of variation.

[2]Somatic cell score = average $\log_2$(somatic cell count).

[3]Ratios were calculated using milk component concentrations (%).

[4]Horn sep. sus = horn separation susceptibility; Horn sep. sus.2 = horn separation susceptibility severity 2.

9.4.2 Genetic parameters

Estimates of variance components and heritabilities for the different traits are presented in Table 9.2. The heritabilities for milk production traits ranged from 0.24-0.80. Meanwhile, heritabilities for lameness and claw disorder traits ranged from 0.07-0.13 and 0.02-0.23, respectively.

Tables 9.3 and 9.4 present the estimates for the genetic and phenotypic correlations. Generally, if there was a relationship, the genetic correlations among milking traits were positive and the strength varied from moderate to very strong (0.62-0.97). There were a few exceptions. Firstly, the weak positive correlation between somatic cell score and the P:F. Secondly, there were strong negative correlations between L:(F+P) with protein percentage and between L:(F+P) with P:L. Lastly, there were moderate negative correlations between P:L and fat percentage, between P:L and milk yield, and between fat yield and the P:F.

There were five strong to very strong positive genetic correlations among claw disorder traits and between lameness and claw disorder traits. The correlations were between horn susceptibility and claw disorder occurrence, between granuloma susceptibility and rot susceptibility and lameness occurrence, between rot susceptibility and lameness and lastly, between rot susceptibility and lameness occurrence.

Generally, the genotypic correlations between lameness and claw disorder traits and milk traits ranged from none to weak, with some exceptions. There was a very strong correlation between lameness occurrence and fat percentage. There was also a very strong negative correlation between lameness occurrence and lactose percentage. Rot and granulomas had weak to very strong correlations with milk production yield traits. Horn separation susceptibility and horn separation susceptibility of severity 2, had weak and moderate correlations with milk concentration traits, respectively. There were also weak correlations between lactose percentage and granuloma susceptibility and claw disorder occurrence.

Generally, the phenotypic correlations between milk production traits were positively strong or very strong relationships. The two exceptions were between L:(F+P) and milk protein percentage and between L:(F+P) and P:L, where the strong correlations were negative.

There were only three strong correlations between the lameness and claw disorder traits. There was one very strong correlation between lameness susceptibility and lameness occurrence, one moderate correlation between horn separation susceptibility and claw disorder occurrence, and lastly, one weak correlation between the two horn separation traits.

Overall, there were no strong phenotypic correlations between lameness and claw disorder traits with milk traits. There was only a moderate correlation between milk protein percentage and lameness occurrence. There were also weak correlations between lameness occurrence and milk fat and lactose content, between lameness susceptibility and total fat yield, and between horn separation susceptibility and milk protein percentage and horn separation (severity 2) and milk lactose percentage.

Table 9.2. Estimates of additive genetic and residual variances, heritability, and the corresponding standard errors in parenthesis for milk production, lameness, and claw disorder traits in dairy goats from three farms taken between July 2019 and June 2020 production year within New Zealand.

Traits	Additive genetic variance	Residual variance	Heritability
Total yields (kg; 270 days)			
Milk	8508 (2035)	24206 (1914)	0.26 (0.06)
Fat	8.93 (1.95)	23.9 (1.84)	0.27 (0.06)
Protein	6.24 (1.53)	19.6 (1.47)	0.24 (0.06)
Lactose	19.3 (4.40)	50.3 (4.10)	0.28 (0.06)
Somatic cell score[1]	0.28 (0.06)	0.31 (0.07)	0.80 (0.07)
Milk component concentrations (%)			
Fat ($x10^4$)	0.05 (0.01)	0.07 (0.01)	0.56 (0.06)
Protein ($x10^4$)	0.03 (0.00)	0.02 (0.00)	0.69 (0.06)
Lactose ($x10^4$)	0.02 (0.00)	0.01 (0.00)	0.63 (0.06)
Milk ratios[2]			
Protein:fat ($x10^3$)	3.92 (0.63)	5.57 (0.53)	0.56 (0.06)
Protein:lactose ($x10^3$)	1.77 (0.20)	0.86 (0.15)	0.67 (0.06)
Lactose:fat+protein ($x10^3$)	1.82 (0.22)	1.20 (0.17)	0.60 (0.06)
Clinical lameness			
Susceptibility ($x10^3$)	4.03 (1.76)	26.4 (1.84)	0.13 (0.06)
Occurrence ($x10^3$)	0.01 (0.01)	0.15 (0.01)	0.07 (0.05)
Claw disorders			
Horn sep. sus. ($x10^3$)[3]	0.02 (0.00)	0.05 (0.00)	0.23 (0.06)
Horn sep. sus. 2 ($x10^3$)[3]	0.01 (0.00)	0.03 (0.00)	0.22 (0.06)
Rot susceptibility ($x10^3$)	1.84 (0.71)	12.1 (0.77)	0.13 (0.05)
Granuloma susceptibility ($x10^3$)	0.45 (0.82)	21.1 (1.08)	0.02 (0.04)
Occurrence ($x10^3$)	0.01 (0.01)	0.11 (0.01)	0.11 (0.05)

[1]Somatic cell score = average log_2(somatic cell count).

[2]Ratios were calculated using milk component concentrations (%).

[3]Horn sep. sus = horn separation susceptibility; Horn sep. sus. 2 = horn separation susceptibility severity 2.

Table 9.3. Estimates of phenotypic (above) and genetic (below) correlations and standard errors (in parentheses) for milk production, lameness, and claw disorder traits in dairy goats from three farms taken between July 2019 and June 2020 production year within New Zealand.

	Trait	1	2	3	4	5	6	7
1	Milk yield		0.81 (0.01)	0.91 (0.00)	0.98 (0.00)	-0.18 (0.03)	0.15 (0.08)	-0.20 (0.05)
2	Fat yield	0.62 (0.09)		0.86 (0.01)	0.83 (0.01)	-0.23 (0.02)	0.31 (0.02)	-0.06 (0.05)
3	Protein yield	0.79 (0.05)	0.74 (0.06)		0.92 (0.00)	-0.14 (0.03)	-0.06 (0.05)	0.09 (0.05)
4	Lactose yield	0.94 (0.01)	0.70 (0.07)	-		-0.23 (0.02)	-0.15 (0.05)	-0.18 (0.05)
5	Somatic cell score[1]	0.26 (0.17)	0.17 (-0.01)	-0.01 (0.15)	0.15 (0.33)		-0.10 (0.04)	0.14 (0.26)
6	Fat percentage	-	0.43 (0.11)	-0.05 (0.20)	-0.17 (0.20)	-0.49 (0.24)		-0.12 (0.32)
7	Protein percentage	-0.21 (0.22)	-0.03 (0.20)	-0.06 (0.25)	-0.18 (0.22)	0.07 (0.11)	0.26 (0.44)	
8	Lactose percentage	-	0.00 (0.11)	0.44 (0.13)	0.00 (0.11)	-0.06 (0.29)	0.28 (0.18)	0.08 (0.18)
9	Protein:fat ratio[2]	0.07 (0.13)	-0.56 (0.10)	0.13 (0.13)	-0.03 (0.13)	0.35 (0.12)	-0.22 (0.44)	-0.23 (0.12)
10	Protein:lactose ratio[2]	-0.53 (0.09)	-0.19 (0.11)	-	-0.42 (0.23)	0.23 (0.10)	-0.59 (0.23)	0.87 (0.02)
11	Lactose:fat+protein ratio[2]	0.55 (0.09)	-0.12 (0.12)	-	0.56 (0.08)	-0.05 (0.12)	-0.44 (3.83)	-0.77 (0.03)
12	Lameness susceptibility	0.09 (0.21)	-0.11 (0.20)	0.16 (0.21)	0.09 (0.21)	0.26 (0.20)	-	0.11 (0.14)
13	Lameness occurrence	0.07 (0.26)	-0.07 (0.24)	0.14 (0.26)	0.10 (0.25)	0.43 (0.24)	0.75 (0.12)	-
14	Horn sep. sus. [3]	0.05 (0.03)	0.10 (0.18)	0.08 (0.18)	0.10 (0.18)	0.07 (0.17)	-0.04 (0.13)	0.37 (0.12)
15	Horn sep. sus. 2[3]	0.07 (0.18)	0.06 (0.17)	-0.05 (0.18)	0.10 (0.18)	0.06 (0.17)	-0.40 (0.15)	0.34 (0.09)
16	Rot susceptibility	0.31 (0.22)	0.14 (0.20)	0.41 (0.22)	0.31 (0.22)	-0.02 (0.20)	0.20 (0.08)	0.08 (0.15)
17	Granuloma susceptibility	0.52 (0.42)	0.63 (0.48)	0.84 (0.49)	0.63 (0.46)	-0.07 (0.35)	0.00 (0.38)	-0.25 (0.27)
18	Claw disorder occurrence	-0.08 (0.23)	0.07 (0.23)	-0.10 (0.23)	0.02 (0.24)	-0.19 (0.22)	0.05 (0.17)	0.18 (0.09)

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Table 9.4. Estimates of phenotypic (above) and genetic (below) correlations and standard errors (in parentheses) for milk production, lameness, and claw disorder traits in dairy goats from three farms taken between July 2019 and June 2020 production year within New Zealand (continued).

	Trait	8	9	10	11	12	13	14
1	Milk yield	0.21 (0.19)	0.00 (0.03)	-0.42 (0.02)	0.42 (0.02)	-0.05 (0.03)	-0.02 (0.03)	0.05 (0.03)
2	Fat yield	-0.03 (0.05)	-0.46 (0.20)	-0.21 (0.03)	-0.08 (0.03)	-0.45 (0.03)	-0.03 (0.03)	0.07 (0.03)
3	Protein yield	0.16 (0.04)	0.04 (0.26)	-0.10 (0.02)	0.12 (0.02)	0.07 (0.03)	-0.03 (0.03)	0.07 (0.03)
4	Lactose yield	-0.03 (0.05)	-0.05 (0.03)	-0.14 (0.08)	0.44 (0.02)	-0.05 (0.03)	-0.02 (0.03)	0.06 (0.03)
5	Somatic cell score[1]	0.03 (0.05)	0.21 (0.02)	0.28 (0.02)	-0.14 (0.03)	0.05 (0.03)	0.05 (0.03)	0.03 (0.03)
6	Fat percentage	0.32 (0.06)	-0.14 (0.09)	0.08 (0.04)	-0.50 (0.23)	-0.19 (0.06)	0.37 (0.08)	0.03 (0.03)
7	Protein percentage	-0.02 (0.08)	0.08 (0.04)	0.85 (0.01)	-0.72 (0.01)	0.02 (0.03)	0.55 (0.21)	0.39 (0.03)
8	Lactose percentage		-0.23 (0.03)	-0.32 (0.03)	-0.18 (0.04)	-0.19 (0.07)	-0.34 (0.04)	0.07 (0.03)
9	Protein:fat ratio[2]	-0.31 (0.09)		0.25 (0.03)	0.38 (0.02)	-0.01 (0.03)	0.01 (0.03)	-0.02 (0.03)
10	Protein:lactose ratio[2]	-0.27 (0.07)	0.25 (0.09)		-0.80 (0.01)	0.01 (0.03)	0.00 (0.03)	-0.01 (0.03)
11	Lactose:fat+protein ratio[2]	-0.01 (0.16)	0.28 (0.09)	-0.86 (0.02)		-0.02 (0.03)	0.01 (0.03)	0.00 (0.03)
12	Lameness susceptibility	-	0.32 (0.17)	0.10 (0.15)	0.09 (0.15)		0.84 (0.07)	0.01 (0.03)
13	Lameness occurrence	-0.94 (0.03)	0.22 (0.20)	0.11 (0.18)	0.02 (0.19)	-		0.00 (0.03)
14	Horn sep. sus. [3]	0.15 (0.13)	0.00 (0.14)	-0.05 (0.13)	0.06 (0.13)	0.18 (0.22)	0.22 (0.28)	
15	Horn sep. sus. 2[3]	-	-0.12 (0.15)	-0.22 (0.13)	0.14 (0.13)	0.36 (0.21)	0.23 (1.45)	0.63 (0.12)
16	Rot susceptibility	0.07 (0.15)	0.17 (0.17)	0.04 (0.15)	0.01 (0.15)	0.70 (0.22)	0.97 (0.25)	0.11 (0.21)
17	Granuloma susceptibility	0.27 (0.24)	0.07 (0.30)	0.25 (0.27)	-0.19 (0.28)	0.68 (0.39)	0.95 (0.25)	0.40 (0.40)
18	Claw disorder occurrence	0.06 (0.27)	-0.22 (0.19)	-0.19 (0.17)	0.09 (0.17)	-0.32 (0.27)	-0.28 (0.31)	0.92 (0.13)

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Table 9.5. Estimates of phenotypic (above) and genetic (below) correlations and standard errors (in parentheses) for milk production, lameness, and claw disorder traits in dairy goats from three farms taken between July 2019 and June 2020 production year within New Zealand (continued).

	Trait	15	16	17	18
1	Milk yield	0.02 (0.03)	0.00 (0.03)	-0.01 (0.02)	-0.05 (0.03)
2	Fat yield	0.02 (0.03)	0.01 (0.03)	0.00 (0.02)	-0.01 (0.03)
3	Protein yield	0.02 (0.03)	0.02 (0.03)	-0.01 (0.02)	-0.03 (0.03)
4	Lactose yield	0.03 (0.03)	0.01 (0.03)	-0.01 (0.02)	-0.04 (0.03)
5	Somatic cell score[1]	0.01 (0.03)	-0.02 (0.03)	0.01 (0.03)	-0.03 (0.03)
6	Fat percentage	0.10 (0.04)	0.16 (0.04)	-0.03 (0.04)	0.16 (0.05)
7	Protein percentage	0.20 (0.04)	0.04 (0.03)	0.03 (0.03)	0.06 (0.03)
8	Lactose percentage	0.39 (0.03)	0.05 (0.26)	0.03 (0.01)	0.29 (0.11)
9	Protein:fat ratio[2]	0.00 (0.03)	0.01 (0.03)	-0.02 (0.03)	-0.06 (0.03)
10	Protein:lactose ratio[2]	-0.04 (0.03)	0.01 (0.03)	0.00 (0.03)	0.01 (0.03)
11	Lactose:fat+protein ratio[2]	0.03 (0.03)	-0.01 (0.03)	-0.01 (0.03)	-0.05 (0.03)
12	Lameness susceptibility	0.06 (0.03)	0.26 (0.02)	0.29 (0.02)	0.03 (0.03)
13	Lameness occurrence	0.06 (0.13)	0.22 (0.02)	0.23 (0.02)	0.05 (0.02)
14	Horn sep. sus. [3]	0.49 (0.02)	0.21 (0.02)	0.03 (0.02)	0.57 (0.02)
15	Horn sep. sus. 2[3]		0.24 (0.02)	0.03 (0.02)	0.25 (0.02)
16	Rot susceptibility	0.02 (0.22)		0.26 (0.02)	0.20 (0.02)
17	Granuloma susceptibility	0.49 (0.39)	0.92 (0.48)		0.09 (0.02)
18	Claw disorder occurrence	0.45 (0.21)	-0.02 (0.29)	0.02 (0.49)	

Where '-' represents any non-estimable relationship.

[1]Somatic cell score = average $\log_2$(somatic cell count).

[2]Ratios were calculated using percentages.

[3]Horn sep. sus = horn separation susceptibility; Horn sep. sus. 2 = horn separation susceptibility severity 2.

9.5 Discussion

9.5.1 Heritability estimates

The results from this study indicate that lameness susceptibility, horn separation susceptibility and rot susceptibility could be included in breeding programs as a tool to improve animal welfare on commercial dairy goat farms. This study also reported the heritability of lameness susceptibility (a continuous trait) was better than having lameness as a binomial or ordinal trait. Previous studies have reported lameness traits as a binary trait (similar to the occurrence trait in this study) or as an ordinal trait. In dairy cows, the heritability of lameness as a binary trait has ranged from 0.01 to 0.04 using either a linear or threshold model. In contrast, the heritability of lameness as an ordinal trait has ranged from 0.03-0.15 (Heringstad et al. 2018). The results in the current study were consistent with the study of Weber et al. (2013), which also used a 5-point locomotion scale and classified clinical lameness as a locomotion score ≥3. Heritability of lameness prevalence was 0.08 and 0.15 when using a linear and threshold model, respectively, similar to this current study's 0.07 and 0.13 for lameness occurrence as a binary trait and lameness susceptibility as a continuous trait, respectively. When modelling binary or ordinal traits, threshold models can account for multiple cases over time, while linear models cannot (Heringstad et al. 2018). Clinical lameness susceptibility had a higher heritability than clinical lameness occurrence. As susceptibility within this study considers multiple cases over a specific time period, it could explain why these heritabilities were similar to the results reported that used threshold models.

Another factor that may explain the higher h^2 estimate for clinical lameness susceptibility than the h^2 estimate for clinical lameness occurrence is that the calculation of lameness susceptibility includes a degree of the permanent environment effect. The permanent environment is the environment the goat would share with itself at multiple data collection time points (Kruuk and Hadfield, 2007). For example, the barn is the same barn the goat is housed in when data is collected over multiple locomotion scoring events. Lameness susceptibility captures the variation in the environment, such as the changes in bedding conditions, wet *vs.* dry. Lameness occurrence does not account for this effect, as this captures one measurement across one production period (July 2019-June 2020).

As a trait defined by this study, claw disorder susceptibility has not been reported in any other study, dairy cows or otherwise. Horn separation susceptibility had the highest h^2 estimate, while the estimate for granuloma susceptibility was the lowest. Compared with dairy cows, in the current study, horn separation could be comparable to severe white line disease, and rot, including digital dermatitis. The h^2 estimates for white line disease and digital dermatitis were higher in this study than those published in dairy cattle. An extensive review published heritabilities for claw disorders in dairy cows, which were defined by a binary variable - presence or absence. White line disease had estimates between 0.01-0.10, while digital dermatitis had estimates between 0.01-0.09 (Heringstad et al. 2018). The differences in h^2 estimates of the two claw disorders could be due to the different definitions of claw disorders. Horn separation is a more severe form of white line disease; therefore, the phenotype would be better defined, easier and more accurately recorded than white line disease. The more accurately recorded the phenotype is, the higher the heritability (Schöpke et al. 2015). Rot in this study was broadly defined. It encompassed digital dermatitis and footrot because they are similar in their appearance in goats (Groenevelt et al. 2015). Due to digital dermatitis appearing differently in cows than goats, perhaps the goat's genetic response is different from cows.

More in line with this study’s estimates were the heritabilities for "shelly hoof" or horn separation and footrot in sheep. Heritability estimates for horn separation have been reported to be between 0.03 and 0.61 (Connington et al. 2010). For footrot, estimates have been between 0.09 and 0.33 (Raadsma et al. 1994; Skerman et al. 1998; Nieuwhof et al. 2008). These figures varied depending on the animal's age (lamb or ewes), breed (Mule or Blackface ewes), number of feet scored, and the type of model used (threshold or linear). One of the traits defined by Nieuwhof et al. (2008) had a similar definition to rot susceptibility in this study - they combined and then averaged the footrot scores for mules and ewes across four events. For this trait and using a linear model, they had a heritability between 0.13-0.19 with standard errors of 0.09-0.10, which is consistent with the results for rot susceptibility within this study (0.13). Nieuwhof et al. (2008) reported that the h^2 estimate increased to 0.21-0.23 when the number of affected feet was considered. They also reported that when multiple scores were accounted for over a number of events, the heritabilities were higher than if only one score was considered (Nieuwhof et al. 2008). Age, breed, and the number of feet affected were not investigated within this study though it would be interesting to determine whether claw disorders should be considered separate traits by, for example, number of feet, in dairy goats.

Heritability estimates reported in this study indicate underlying genetic variations for phenotypic traits within dairy goats. Consistent with previous studies, milk production traits in this study suggest a genetic variation. This is the first study to report h^2 estimates for lameness and claw disorder traits in dairy goats and depicts genetic variation within lameness and claw disorder traits which is a novel insight into goat health. This study suggests including lameness and claw disorders in dairy goat breeding programs within commercial dairy goat farms.

9.5.2 Correlations

Currently, clinical lameness and claw disorder traits are not considered in breeding programs for the genetic improvement of dairy goats. One important aspect of introducing them into the breeding program is how the trait is phenotypically and genetically related to other measured traits. The phenotypic correlation between lameness susceptibility and clinical lameness occurrence was strongly positive (0.84), indicating that these two traits are related. However, the genetic correlation was not estimable, which may be due to a reduced number of observations. The genetic correlations between clinical lameness occurrence and susceptibility and between rot and granulomas were positively strong (though relatively high standard errors were also noted to be present), while the phenotypic correlations were weak. Strong genetic correlations indicate that if there is genetic selection against lameness, there will also be genetic selection against rot and granulomas. Weber et al. (2013) reported relatively higher genetic correlations between lameness and claw disorders (including and excluding digital dermatitis) (0.60-0.95) which was in line with results from the current study. The inclusion of digital dermatitis decreased the genetic correlation with lameness, which is the opposite in the current study where digital dermatitis (falling under rot) had a very strong relationship with clinical lameness. This suggests that digital dermatitis in cows may differ from digital dermatitis in dairy goats, which is supported by Groenevelt et al. (2017). The strong genetic correlations estimated in this study between lameness and claw disorders indicate that lameness can be used as an indicator trait rot and granulomas.

This study reported weak phenotypic correlations between claw disorders. The exception was between all horn separation and the most severe horn separation cases. The weak genetic correlation, strong phenotypic correlation indicates that the environment is important in the presence of horn separation. This makes sense as overall horn separation comprises of severe horn separation.

There were underlying genetic correlations, varying in strength, between the claw disorders. Despite a high standard error, the strongest genetic relationship was between rot and granuloma. This phenotypic association was also recognised in Chapter 7. The mechanisms behind granuloma development are currently unknown. A low heritability of granulomas suggests that these occur due to environmental factors. Winter (2011) suggests granulomas were related to trimming injuries, although results from this study suggest this may not be entirely true. In the current study, the relationship between granulomas and hoof trimming injuries was unclear. An alternative explanation could be an indirect genetic element to granuloma development, which may be triggered by rot development as the heritability for granulomas is low (0.02) while for rot it is moderate (0.13). There was only a very low correlation between horn separation (a severe form of white line disease) and rot (encompassing digital dermatitis and footrot) susceptibility. These were in line with previous research completed in dairy cows on the closest claw disorder traits of digital dermatitis and white line disease, where genetic correlations ranged from -0.33 to 0.08 (Heringstad et al. 2018).

One important aspect of a breeding program for the genetic improvement of dairy goats is how health traits, such as lameness and claw disorders, are phenotypically and genetically related to milk production traits. Unlike previous dairy cattle studies, there was little correlation between lameness and milk yield – less than 0.10 *vs.* 0.17-0.44 (Pryce et al. 1997; König et al. 2008). In this study, clinical lameness susceptibility had a weak negative phenotypic correlation with milk fat percentage and a weak positive genotypic correlation with protein-to-fat ratio. This is good because it indicates selection against lameness will only have a small effect, if any, on the goats' milk production and its components.

The genetic correlation between the occurrence of clinical lameness and fat percentage was moderately positive (0.75). A reason could be the goat's change in fat percentage as a result of metabolic problems, such as acidosis, which has been reported in dairy cattle (de Vries and Veerkamp, 2000). Fat percentage has been linked to negative energy balance, sub-acute ruminal acidosis (SARA) and ruminal acidosis in dairy cattle (de Vries and Veerkamp, 2000). Negative energy balance has indirectly been associated with the increased risk of lameness through loss of body condition (Collard et al. 2000; Huxley et al. 2013). Milk fat depression has been linked with subacute ruminal acidosis in cows (Plaizier et al. 2008). The production of endotoxins is a consequence of acidosis, which has been associated with lameness-causing-laminitis (Plaizier et al. 2008; Eckel and Ametaj, 2020). Therefore, in dairy goats, feed management practices that increase fat percentage or the P:F could indirectly lead to SARA or acidosis could increase lameness within the herd. The results from this study also indicate that milk fat percentage could be a predictor trait for lameness, where, within the breeding goal, selecting goats with higher estimated breeding values for fat percentage could indirectly select goats more susceptible to clinical lameness.

The opposite could be true for the lactose percentage. There was a strong genetic correlation between occurrence of clinical lameness and lactose percentage (-0.94).

Perhaps, lactose percentage shares some underlying biological mechanisms relating to the health status and potentially the immune system within dairy goats, as it has been suggested in dairy cows (Ingvartsen et al. 2013; Costa et al. 2019a). In dairy cows, some studies have reported a negative association between lactose percentage and mastitis (Ebrahimie et al. 2018; Costa et al. 2019b). Though not a strong genetic relationship between lameness occurrence and lactose percentage in this study, in dairy cows, one study observed moderate and weak relationships between lactose yield and mastitis (0.52) and ketosis (0.42), respectively (Costa et al. 2019b). As suggested by Ingvartsen et al. (2013), it could be the effects of genotype, nutrition, time, and management that can affect the immune system via the metabolic pathway, which increases the animal's susceptibility to disease, in this case, lameness. The current study suggests that lactose percentage may be an important indicator of lameness occurrence within a lactation, and this relationship should be further investigated with a larger dataset to validate these results, however, as there is no literature to refer to, this aspect needs to be verified to obtain a better understanding of how milk lactose may be related to lameness. Other health traits and the relationship with lactose should also be explored in the future.

Claw disorders have very weak phenotypic correlations and weak to moderate genetic correlations with milk production traits. Horn separation traits were negatively correlated with fat percentage and positively correlated with lactose percentage. Rot and granuloma susceptibility were positively correlated with milk yield traits. By taking these values with caution, it could be inferred that genetic selection for higher yields of production traits may increase the goat's genetic susceptibility to rot and granulomas, while genetic selection for higher concentrations of fat percentage could increase the goat's genetic susceptibility to horn separation. Estimates of genetic correlation between claw disorders and production traits are few in dairy cattle. Depending on the model, Koening et al. (2005) and König et al. (2008) reported genetic correlations between digital dermatitis and milk yield of 0.07-0.24, which was similar to the values reported in this study (0.31). They also reported correlations of 0.17-0.28 between hoof wall disorders and milk yield, which were higher estimates than this study (0.05-0.07). Gernand et al. (2012) reported weak genetic correlations between digital dermatitis and protein yield, fat and protein percentages (-0.11 to 0.05) which, considering the higher standard error, was still lower than the values calculated in this study (0.08-0.41). From the limited number of studies published, the relationship between milk production traits and claw disorder traits in dairy goats is still unclear. Based on dairy cow studies, there is a negative relationship between production traits and claw health, and this study tends to agree with this though further investigation, with a larger cohort of animals, is needed in goats before conclusions can be made to determine underlying genetic factors.

Phenotypic and genetic correlations can predict the outcome of one trait by the results based on another different trait, i.e. if selecting trait A will adversely affect trait B. The information becomes useful if the desired trait is hard to measure (too costly or time-consuming, or both), i.e., measuring an indirect trait would increase selection efficiency (Isik, 2009). This is possible because the two traits may share genes or are linked together to be inherited together. Establishing relationships between traits also determines how breeding goals may adversely affect traits.

9.5.3 Limitations to this study

9.5.3.1 Data collection limitations

One of this study's limitations is the limited number of observations available. Many observations need to be collected on the phenotypes of interest to estimate accurate and reliable genetic parameters (reducing the standard errors). The current methodology for measuring lameness and claw disorders in dairy goats is time-consuming. Locomotion scoring would ideally need to be completed objectively and routinely. Introducing cameras that can record this information automatically would help the farmers immensely. An incentive also needs to be included for farmers and hoof trimmers to record all this information. The farmers would invest in equipment and additional services from the hoof trimmer. Dairy goat hoof trimmers and farmers cannot be expected to record this information without reliable technology, preferably designed for dairy goats.

Hoof trimmers and veterinarians also need to be involved in this technology development as they routinely trim goat feet and have knowledge of many claw disorders. One study on dairy cattle reported that to improve lameness management in farms, the communication between farmers, hoof trimmers, and veterinarians needs to be improved (Wayward et al. 2021). There is a lack of knowledge within this area of dairy goats in all three types of personnel. At the moment, everything is taught through word of mouth because there are no courses for the dairy goat farmers or hoof trimmers to take that would be relevant to them. Trimming a goat's foot is different from trimming a cow's foot. Getting everyone involved to share knowledge and create a universal understanding of claw disorders in dairy goats would be worthwhile.

9.5.3.2 Statistical limitations

It would be important to run a multivariate analysis rather than a bivariate analysis to investigate various trait combinations in one model to evaluate covariances when modelled together. This requires more herds with genetic links among the sires. This would not be possible until artificial insemination is widely used within the dairy goat population of New Zealand.

Another approach to estimating heritabilities and variances is using threshold models rather than linear ones. Past literature has presented heritabilities of lameness and claw disorders traits in sheep and dairy cattle using either threshold or linear models (Nieuwhof et al. 2008; Connington et al. 2010; Heringstad et al. 2018). Genetic and environmental variances can be obtained using linear models and liability-threshold models. Threshold models can be better used when the trait of interest is binomial or ordinal, though with a potentially underlying continuous phenotype and a low heritability (Dempster and Lerner, 1950). It is based on the probability of a phenotype being expressed depending on environmental or genetic conditions being met. However, depending on the information available and the trait being used, there may not be much difference between the results of the two models (Varona et al. 1999). As linear models (using either restricted maximum likelihood or least-squares) are simple and more widely used to estimate genetic parameters, it was chosen to model this study's estimates (Varona et al. 1999; Raadsma et al. 1994). Heringstad et al. (2018) explained that, unlike linear models, thresholds could hold time accountable when there are repeated measures for individuals on ordinal variables. The use of threshold models may be better used for the two binomial traits in this study when test-day level (to account for repeated measures over time) with the threshold model rather than as one trait over one lactation using a linear model.

There are two alternatives to the current model which could be used to analyse lameness and claw disorder traits in the future. Firstly, including breed and, subsequently, the heterosis effect. There are significant differences in milk production traits in different dairy goat breeds (Garcia-Peniche et al. 2012) and heterosis has been known to significantly affect milk production traits (Scholtens et al. 2019). In dairy cows, sheep and meat goats, breed was a risk factor in developing lameness and claw disorders (Connington et al. 2010; Browning et al. 2011; Chawala et al. 2013). Therefore, heterosis should be included in the model to capture variation associated with breed. To do this reliability, data input of the breeds by the farmers needs to be accurate, which is challenging to achieve when only a pedigree is available.

Secondly, investigate the heritabilities of claw disorder and lameness traits at the test-day level. As with genetic parameters for milk production traits that have been reported to change over the lactation (Swalve, 1995), this could also be the case for the genetic parameters of claw disorders and lameness. In dairy cattle, test-day milk yield has been associated with claw disorders (Koening et al. 2008). It could be good to establish whether claw disorders and/or lameness traits are more heritable at the test-day level rather than at the lactation level.

9.5.3.3 Future breeding limitations

This study is the first of its kind in dairy goats. It creates the foundation for future research on genetic parameters of health traits besides somatic cell score (related to mastitis). The objective would be to eventually include lameness and claw disorder traits to reduce lameness and claw disorders prevalence in herds and improve animal welfare in dairy goats. To include these traits in the breeding goal or selection index for dairy goats, the economic values and weights need to be estimated (Byrne et al. 2016). The model to estimate the economic value for the occurrence of clinical lameness and claw disorders need to include direct and indirect costs. Indirect costs, such as additional farm labour, should be included as these are also important because, as discussed in Chapter 8, the direct costs, such as milk production, are not significantly affected until severe lameness has been reached. The indirect costs may vary depending on the prevalence of lameness and the causes of lameness (which affect the duration of lameness) on the farm. The economic weights derived from the influence of other traits, such as milk production traits, on claw disorders and lameness needs to be included at this stage. Finally, using the economic weight and including the desired gains value would establish a selection index for the breeding goal. The desired gains approach would capture costs that may not be monetary, such as animal welfare, and add value to the trait.

Improving claw health through genetics creates permanent gains (Heringstad et al. 2018). Due to the low heritability of health traits, many observations are needed to produce reliable genetic evaluations. Agreeing on the definition of traits is important to be universally understood and have phenotypes accurately recorded.

9.6 Conclusion

This study has reported estimates of genetic parameters for claw disorder and lameness traits in dairy goats. These results suggest selecting against clinical lameness, horn separation, and rot susceptibility can be possible. There are weak to strong genetic and phenotypic correlations between lameness and claw disorders traits with milk fat and lactose. More work needs to be completed on the relationship between these traits to determine the underlying biological relationships, and assign appropriate economic weights if they are to be included in the breeding goal and selection index. Before this can be done, investing in better technology for dairy goat farmers and hoof trimmers to collect information on lameness and claw disorders is the next step forward.

Chapter 10

General discussion and conclusion

10.1 Main results summary

This study investigated lameness, specifically clinical lameness, and claw disorders, specifically rot, granulomas, and horn separation, in dairy goats on three farms in New Zealand. The prevalence of clinical lameness and claw disorders changed over time, with the highest prevalence occurring between November and December 2019. The average prevalence for farms A, B and C were 23, 12, and 10%, respectively. The annual incidence rate of animal-level clinical lameness for farms A, B and C were 104, 56, and 55 cases per 100 goat-years across one year. The duration of clinical lameness cases depended on the farm and ranged from 34 to 321 days. This study suggests that claw disorders seen on these three goat farms are likely to be present throughout dairy goat farms in New Zealand because the incidence rate is high, therefore, the probability of finding a farm without lameness is likely zero. Horn separation was the major problem on all three farms. The incidence rate for the claw disorders paralleled the prevalence results, where horn separation had the highest incidence rates (57-118 cases per 100 foot-years) across all farms compared with rot and granulomas. Granulomas were estimated to take the longest to recover from, where the median depended on the farm and ranged from 86-125 days.

The relationship between clinical lameness and claw disorders was investigated. The animal-level risk factors in this study that were associated with clinical lameness and claw disorders were age, farm, stage of lactation or season, and a previous case of clinical lameness or claw disorder. Rot and granulomas were strongly associated with clinical lameness, while horn separation was not. The relationship between milk production and clinical lameness was investigated. The average reduction in daily milk yield ranged from 2.63 to 4.66% (0.15-0.27 kg) and reduced more at higher lameness severities, with severe lameness (locomotion score 4) had the highest daily production losses of 7.10% and 8.56%. We could not determine the reduction duration due to a lack of data. The genetic evaluation of clinical lameness and claw disorder suggests that these traits are heritable. The heritability of clinical lameness and claw disorder traits ranged from 0.02 to 0.23 and should be investigated further to include them in future breeding goals.

10.2 What was unknown before this study

The Dairy Goat Co-operative (NZ) Ltd suggested lameness was a problem faced by commercial dairy goat farmers in New Zealand. There was no information on the level of lameness, the causes of lameness, or the impact of lameness on goat welfare, production and the environment. Some information from overseas studies indicates that lameness prevalence varied across countries and between farms. Claw disorders known to cause lameness in dairy goats were less understood, with limited studies publishing the different types, and prevalence of claw disorders present within dairy goat farms. While the information on the risk factors of lameness and claw disorders has been vast in dairy cow studies, nothing has been published on the effects of lameness on milk production and its characteristics. In addition, there has been no information on the genetic evaluation of lameness and claw disorders in dairy goats. Other aspects need to be investigated further to understand lameness and claw disorders within dairy goat herds.

10.3 Logistical challenges of researching lameness on commercial dairy goat farms

At the beginning of this research, there were a number of goals that this study wanted to achieve. However, some could not be achieved due to logistical reasons, limited resources, and limited time. One aspect of this study was to evaluate how lameness and claw disorder prevalence changed over time. It was decided to stop at the end of the first year because the manual recording of claw disorders and video-based lameness scoring was very time-consuming for the limited timeframe of a PhD. Having data for a second year would have allowed looking at the change of clinical lameness and claw disorders over time (either by stage of lactation or by season).

Evaluating the locomotion of the goats in the videos took longer than initially thought. Goats were analysed by one scorer, with goats being videoed twice at one scoring event. Unless the goat had severe lameness, most goats were viewed multiple times to ensure that the scorer had what they thought was the appropriate locomotion score. Generally, the lower the score, the more time was taken to establish the locomotion score. Going forward with future research, the alternatives would be to have more than one scorer scoring the videos or implement objective methods to measure locomotion scoring.

There were two considerations when planning the timing of locomotion events. One scenario was to plan locomotion scoring events a week before claw disorder scoring events. This may have given more precise results in the association between lameness and claw disorders. This was attempted at one farm, however for logistic reasons, the number of goats scored was less than if the locomotion scoring event was completed at the herd test, because the locomotion scoring event used occurred simultaneously with milking events. By having the locomotion scoring session at the herd testing, there was less disruption to the farmer's daily milking routine compared with when it is done under the 'normal' milking session. Therefore, the second scenario, having the locomotion scoring event at herd testing was better for this project.

This study originally presented information on all claw disorders observed within the herds during routine hoof trimming events. Information on all claw disorders present was initially collected, however, within the pilot study, three major, more severe, claw disorders appeared to stand out from all of the others- these were horn separation, granulomas and rot. The focus of the claw disorder aspect of the study was changed to presenting more information on these three claw disorders.

The original concept was to investigate the effect of lameness on milk production and present a lactation curve, as published by Gelaskis et al. (2015), which reported a deviation of milk production between lame and non-lame dairy goats. There were two reasons why this did not occur. Firstly, Gelaskis et al. (2015) had more records per goat than this study where milk yield was recorded daily and then averaged over 7-days, whereas in this study, goats had, at the most, four or five records per goat. This is because there were only four or five herd tests taken (where locomotion scoring was undertaken at the same time) and they were also taken with inconsistent time points (out of the farmer's control). Secondly, due to having one to five time points per goat, a non-linear lactation curve had to be estimated for each goat based on the goat's days in milk. There was not enough time within this research study to thoroughly investigate which curve would be the most appropriate fit (B-splines, Legendre polynomials, etc.), which would have different estimates of total lactation milk yields (Brito et al. 2017) and it would be unclear which curves would be better to estimate the lactation curves for lame and non-lame goats. In addition, having goats in extended lactation (≥305 days in milk) made estimating the lactation curve in dairy goats more complicated because looking at a lactation beyond 305 days using test-day data in milk has not been previously investigated. This was also made harder by not having information on the prior milk production, at the beginning of their lactation, prior to this study.

10.4 Relevance and added knowledge from this thesis

At the beginning of this research, no method was published to measure claw disorders and locomotion on large commercial dairy goat farms. Researching three farms rather than 50 farms allowed us to establish the logistics of this project. This research had to create, modify and validate scoring systems for claw disorders that could be used for our circumstances, and to modify and validate the locomotion scoring system already established by Deeming et al. (2018).

When conducting the locomotion and claw disorder scoring, several logistical difficulties were discovered and differed from farm to farm (Table 10.1). For example, for locomotion scoring, two farms had rotary milking parlours, while the third had a herringbone rapid exit milking parlour. The difference was that the rotary system released 1-3 goats simultaneously, while the herringbone system released 40 goats simultaneously. Bearing in mind the point of the research was to reduce the impact we had on the farmer's schedule, the problems encountered and resolved are in Table 10.1. There were some exceptions to some of the problems that could be improved for future research. Firstly, the presence of yearling goats on the farm. If locomotion scoring occurs at milking, it appeared that it would be best done a couple of months after the last of the young goats have kidded. This was because it takes time for the young goats to become accustomed to the milking parlour system, where an older goat walks out of the milking parlour and back towards the barn, whereas the new or yearly goats initially clump around the milking parlour exit and obstruct other goats exiting. In August 2019, not many young goats could be scored; in October 2019, the young goats walked better, and hence more goats were scored. Secondly, the 'man-made' race (Figure 10.1) created on farm B was not ideal for scoring the goat's locomotion because it took a while for the goats to get used to it. Also, if one goat stopped, it created a backlog of goats, resulting in goats not being about to walk forward freely. An improvement would be to have a race to create a bottleneck (to decrease the number of goats going back to the barn at one time) and then film the goats further down the race, where it was wider, as they walked back towards the barn. This would have them walking more freely with fewer goats obstructing each other.

Figure 10.1. During the locomotion scoring event on farm B, a 'man-made' race was needed and created out of farm gates.

Despite the obstacles in the locomotion scoring event set-up, this research validated the scoring system created by Deeming et al. (2018) but with some suggestions. Firstly, awareness around goats with multiple claw disorders across more than one foot. As further discussed in chapter 10, the current scoring system was developed to fit goats that may have a problem in one foot or limb (despite the description suggesting “one or more legs may be affected”). Goats with potentially multiple problems may not have shown a limp. Instead, they may show shuffling behaviour or shortened stride. Therefore, the defining ‘limp’, which classifies a lame goat, should rectify another term that includes goats with multiple limb problems in the scoring system. Secondly, goose-stepping severity should be better defined. No references or videos have been referencing goose-stepping severity anywhere before this study. The only terms used with goose-stepping are in text and generic terms such as moderate and severe goose-stepping. Therefore, this study had to create its definition whereupon it used the lateral angle of the front legs in reference to the ground as an indication of severity, i.e. roughly between 90˚ and 45˚ was moderate and less than 45˚ angle to the ground was severe. Thirdly, perhaps when designing an objective system for goats, it can use the accumulative symptom effect to assign a severity score. For example, if it has symptoms a) and b) it is a score 2, but if it has a score a) and b) and c) then it is a score 3.

Table 10.1. The logistical issues that arose when designing the locomotion and claw disorder scoring events across all of the farms.

	Issue	Problems	Solution
Farms A and C (rotary)	During 'normal' milking events the rotary was rotating very fast.	• The goats were coming off fast which meant that there was more obstruction from other goats as they walked past the camera which meant that less goats could be scored. • The rotary was going too fast for us to spray the numbers on the back of the goats.	• Conducting the locomotion scoring event during herd tests. The rotary is slowed down enough at these events.
	During 'normal' milking events on farm A, they run about 1000 goats as one herd.	• There were only 400 stencils made, therefore we had multiple colours and numbered the goats over three milking events. Unfortunately, by the time videoing occurred the spray paint was becoming unreadable	• By conducting the event at herd tests, farm A kept the goats in groups overnight. This meant that we had enough stencils for each goat and only needed one stencilling event rather than three.
Farm B (40 bale aside)	Release of 40 goats at one time	• A lot of obstruction from other goats	• Created a race, using gates which meant they had to go back to the barn in single file.

Table 10.1. continued

	Issue	Problems	Solution
Farm B (40 bale aside)	Locomotion scoring was done after the herd test	• There were too many people in a small herringbone pit for the herd test and this research was to be conducted at the same time.	• The experiment was carried out a day after the farmer’s last herd test.
	Lighting	• Where the exit race was there was limited lighting. This was a problem for morning milking events (that started off in the dark) which meant goats could not be seen on the cameras.	• Filmed two afternoon milking events rather than a morning and an afternoon event.
All farms	Deeming et al. (2018) used live scoring however in this research this could not be done	• Standing too close to the goats (to identify the goats) interrupted their ‘normal’ walking gait. If you interrupt the goats’ ‘normal’ routine their demeanour changes. • In Deeming et al. (2018) they scored one goat at a time through a race. On commercial farms, this is not possible.	• Using a camera to record the goats captured most goats

Table 10.1. continued

	Issue	Problems	Solution
All farms	Young goats (their first kidding)	• Young goats at the beginning of the season are not used to the normal routines of the farm. They are more energetic, and were more likely to hang around the milking parlour, which obstructed other goats from walking freely.	• Unable to resolve this problem. After a couple of months, the young goats were better and walking back to the barns 'nicely'.
	Identifying goats	• Identifying goats was a problem because their herd ID (attached to their ear) was too small to be seen on the camera	• Using stencils to spray the number on the goat's rump was quicker, easier and more accurate, than spraying a number freehand. • The stencil number corresponded to the goat's EID
	EID Numbering	• The lack of goats with EID because they had been lost	• Not necessarily resolved but it was better if the farmer kept up to date with making sure EIDs were all present before the herd test.

The claw disorder scoring system was not as effective as it was anticipated. This is evident in the claw disorder scoring inter-and intra-reliability scores. Ideally, the reliability scores should be strong, or be above 0.8 (McHugh, 2012), however, this was not the case for this study, with some reliability scores being only fair (0.37). According to the hoof trimmers, the pictures were sometimes unclear and they struggled to correctly identify the claw disorder's severity. One way to improve this is to use live scoring rather than pictures. Though as discussed in Foddai et al. (2012), it may have been difficult to find the required number of claw disorders for each score, at one time point. The second alternative could be to use videos rather than photos or a combination of both, as in Foddai et al. (2012). It was initially thought that photos would be sufficient to analyse the reliability of the claw disorder scores, however, this was not true for this study. We would have liked to have used an already validated scoring system for all claw disorders for this study. However, there was none available for horn separation and granulomas in either sheep or dairy cattle. Following this, it would be important to establish and validate important claw disorders observed in dairy goats so that further research on their prevalence within the herd is consistent.

The current study carried out a large-scale collection of information on lameness and claw disorders within dairy goat farms. This study has been the first to research entire herds and has successfully followed the herds over a long period of time (one production year). The successfulness of collecting a large number of records has enabled the quantification of lameness and claw disorders on three New Zealand dairy goat farms. The logistics were extensive, however, with the investment of new technology within this area, the amount of labour input could be reduced. For example, the use of technology when locomotion scoring the animals would greatly reduce the amount of time and subjectiveness of locomotion scoring if artificial intelligence was used to assess the goat's locomotion, for example, a pressure-sensing walkway system tested by Rifkin et al. (2019).

Another challenging aspect of this study was the multidisciplinary research (combination of epidemiology and genetics). This thesis highlighted the interchangeable use of terminologies such as prevalence, incidence rate, occurrence and susceptibility in published literature. For example, Chawala et al. (2013) and Gernand et al. (2012) use the term incidence for what is presented in this thesis as prevalence (reporting results for a point in time), according to standard epidemiology terminology (Dohoo et al. 2003). Despite these terms being used completely differently within the current study, published studies used prevalence, incidence, and occurrence and susceptibility interchangeably. This sometimes made interpreting their results difficult in relation to the results within this study.

10.5 Recommendations for the industry

10.5.1 Industry-wide burden of lameness

There is currently no information on the realistic, acceptable level of lameness on farms, in New Zealand or internationally, for dairy goats or any other species. The European Union has a comprehensive approach that farms must abide by legally. Farmers must "take all reasonable steps to ensure the welfare of animals under their care and ensure that those animals are not caused any unnecessary pain, suffering or injury" (EU Council Directive, 98/58/EC). In New Zealand, under the Animal Welfare Act 1999, s 11, there is an "Obligation to alleviate pain or distress of ill or injured animals". A possible exception to this is lameness caused by conformation abnormalities. As the farmers within this study are a part of the DGC, it is mandated that they have a lameness management plan in place and follow the national animal welfare advisory committee guidelines (Smith, personal communication). From the results of three farms, having an entire herd free of lameness is unrealistic for farmers. A herd maximum lameness percentage threshold or standard should be considered and monitored within the industry to give farmers an achievable goal for their herd health, however, farmers should always be working towards zero cases of lameness or claw disorders within their herds.

10.5.2 Routine monitoring of lameness on the farm

Monitoring the industry would be difficult to be carried out, especially when there is no reliable management system for the dairy goat farmers to use. Current management systems, such as MINDA, are designed for dairy cow farmers; anecdotally because of this, they are unsuitable for how dairy goats are managed and are subsequently too expensive to be used by all dairy goat farmers. Complementary to using management systems, electronic ID should be compulsory for all commercial dairy goat farmers. Similar to NAIT in New Zealand dairy cows, the electronic ID allows for movement monitoring of goats across all farms, which is particularly important for disease surveillance and control purposes but can also be used by farmers to record individual production and health data. Further recording would also allow for monitoring sick goats and reoccurring sick goats. Electronic IDs and in combination with a suitable management system may make it a lot easier and less labour-intensive to keep track of sick animals within a large herd.

Electronic IDs would enable technology to be used by hoof trimmers to record claw disorders that they find, along with enabling a more straightforward method of keeping track of sick animals for the farmer. With investment and the development of a claw disorder management system, goat hoof trimmers could record claw disorders for individual goats during regular hoof trimming sessions. This vital veterinary information would be important for the validation of this study. Additionally, the information could help farmers, veterinaries and scientists better understand claw disorders in dairy goats through the continuous monitoring of claw disorders. The introduction of regular claw disorder monitoring would enable the establishment of a claw health index that could be included in the farmer’s breeding goal. The claw health index could assign one value which incorporates the major claw disorders in dairy goats, including claw conformation. The aim would be a long-term solution to reducing claw disorders and, subsequently lameness caused by claw disorders, in dairy goats.

10.5.3 Lameness treatment and prevention

Farmers were asked to record health problems and treatments related to lameness. The farmers were provided with health sheets to complete, however, this was only completed on two farms and the records were inconsistent, therefore, this research could not obtain more accurate information on the incidence rate of lameness or claw disorders. There were a few reasons the farmers were inconsistent with their recording treatment information. Firstly, it had to be done manually with a piece of paper rather than with technology. Having a hoof trimming application on their phone would make it easier to record claw disorders and treatments, and because farmers usually have their phones on them, they would be less likely to forget to bring a folder and pen hoof treatments. Additionally, the farmers would be less likely to incorrectly record the animal identification number. Secondly, the farmers would treat one goat multiple times for the same problem. According to the farmers, this is difficult to record using the manual system. Lastly, the farmer's motivation to record the information. Due to the manual nature of recording the information, the farmer would be less inclined to record it, especially if they had a lot of goats to treat at one time (20 or 30 goats to treat). Sometimes the farmers were too busy to record the information. Due to treatments not being recorded consistently, this research could not calculate the true cost of lameness and claw disorders to dairy goat farmers. It was only able to obtain one aspect of the cost of lameness to the farmer through their loss of income.

Literature on the treatment of specific claw disorders, such as granulomas, is limited in dairy goats. Treatments have not been researched, and the current method of treatment in New Zealand has stemmed from word of mouth between farmers and hoof trimmers. Copper sulphate and topical antibiotic spray are predominantly used on the three farms to treat a wide range of claw disorders. The most painful treatment is the burning out of granulomas. While this treatment was not undertaken during this study, granulomas were instead cut out, the burning out of granulomas was occurring on other farms according to hoof trimmers. The PhD student conducting this research had been present as the procedure was done during separate visits to farms not included in this study. From the experience of the PhD student, using copper sulphate, the cutting out or burning out of granulomas was also generally painful for the goat. As consumer awareness of farming and procedures on farm is increasing these treatments' costs and benefits should be further investigated.

10.6 Limitations to this study

Before this study, there had been no large locomotion and claw disorder studies, therefore, the logistics of doing this were unknown. Within this study, a pilot stage developed the skills and tools required to apply on a larger scale. There are a few limitations to this study. These include some aspects of data collection, assessment of risk factors, the use of test-day yields and genomics to establish genetic relationships with lameness and claw disorders between animals.

One limitation of this study was the small number of farms included. This study only had three farms participating. This represents roughly 3% of dairy goat farms in New Zealand, therefore, for some information, results cannot be extrapolated to the broader population. Due to the low number of farms, farm-level risk factors such as herd size could not be established. However, due to the large number of animals included in the study, animal-level risk factors, such as age, could be evaluated across the farms. The small number of farms included in this study enabled us to establish the project's logistics. The next step would be to assess farm-level risk factors by including a large number of farms within the study.

Only non-modifiable risk factors for lameness and claw disorders could be assessed on the three dairy goat farms. Non-modifiable factors, such as farm and goat's age, are factors that the farmer cannot change. As a result, this study cannot make direct recommendations for prevention practices based on this. These risk factors are still important to know because it informs the farmers which 'at risk goats' they can direct their attention to within the herd. The next in the research is to include more farms in the analysis and include more modifiable risk factors such as the use of footmats and footbaths, wet conditions of the farms. One way to do this would be to conduct a survey or cross-sectional study. These factors would give the farmers more information on preventing claw disorders and subsequent lameness, which they could apply within their herd.

Due to time-constraints, the current study could not establish the lactation curves of lame and non-lame dairy goats. Various models have been used to model the lactation curve of seasonal goats (Fernandez et al. 2002; Brito et al. 2017; Scholtens et al. 2019). For dairy goats, the models, such as Wood's lactation curve, B-splines, and Legendre polynomials have been used to estimate the total milk yield over lactation (Brito et al. 2018; Rojo-Rubio et al. 2016). As of yet, only a few studies have modelled the lactation curves for extended lactation goats (Salama et al. 2005; Douhard et al. 2013). However, these studies have only followed goats that had been lactating for no more than two years. Many extended lactation goats in the current study had been lactating continuously for more than two years, even up to nine years. It is unclear how their constant lactation over multiple years affected their lactation curve and how multiple lactation curves should be modelled and compared between seasons. Following this development, modelling how lameness and claw disorders may affect the lactation curve of extended and seasonal lactation goats and, subsequently, their overall production across one or multiple lactations.

During the calculation of the heritabilities of claw disorders and lameness events, a couple of aspects were unable to be studied within the current scope of this study. Firstly, the effects of heterosis, as touched upon in Chapter 9, heterosis effects were unable to be estimated within this study. According to Scholtens et al. (2019), the goats are predominantly comprised of Saanen and Saanen cross-breeds in New Zealand. Due to potential inaccuracies of breeding records from farmers, this was omitted from the analysis and knowledge could have been lost because of this. Future analysis should try to have accurate breed records to estimate heterosis effects on lameness and claw disorder susceptibility. Secondly, due to the decision to investigate lameness and claw disorder susceptibility across the entire lactation, the effects of the stage of lactation were able to be investigated. Though it was unclear what the effects of the stage of lactation were in the current study, any future studies that can have access to many herds may be able to clarify its relationship with lameness and claw disorder susceptibility. Considering heterosis and stage of lactation may change the h^2 estimates. Additionally, heterosis and stage of lactation are effects included in the estimation of breeding values for claw health, therefore, these values may be affected if they are not taken into account.

Genomic selection is already used in dairy cows to estimate breeding values for cows and bulls. It uses genetics and phenotype to estimate breeding values, rather than only using phenotypes and traditional pedigree to assign breeding values. Genomic selection uses genetic markers, such as single nucleotide polymorphisms (SNP), corresponding to phenotypic traits. The advantages indicate that generation intervals are shorter when using genomic selection than in traditional breeding programs. There are also high accuracies (correlation between true and estimated breeding values) of animal’s breeding value from birth rather than the traditional breeding method, which needs years before reliable breeding values can be established on cows and bulls. If there were sufficient phenotypic records of lameness and claw disorders in dairy goats, along with genetic information from the respective goats, there is a potential to identify genetic markers that are associated with lameness and claw disorders. This could allow farmers to make alternative decisions on the selection of goats at birth that the farmer would like to breed from in the future.

10.7 Future considerations (due to current limitations)

This study provided the information to suggest that lameness and claw disorders are both frequent and production limiting problems on New Zealand dairy goat farms. This study was an exploratory analysis and the foundation for future research in this area. More areas to conduct research in are three avenues that have been identified to be the next stage – identifying more risk factors, causes, and treatments of claw disorders.

10.7.1 Identifying other risk factors

In addition to more research on treatments of claw disorders, more research is needed on the risk factors and preventions of claw disorders, and subsequently lameness ,within the herd. Risk factors that should be further investigated are animal-level factors, such as body condition score and herd-level risk factors, such as barn conditions. These should be undertaken to include more herds within the study. Doing a principal component analysis (PCA) to understand how risk factors may be related to each other would be an alternative method to visualise these relationships. Preventions that should be further investigated are footbaths and minerals, such as biotin. In order to investigate the treatments and preventions of claw disorders, and subsequent lameness, the cooperation of veterinarians, farmers, hoof trimmers, and industry parties is needed. One idea is to establish a lameness management plan as part of herd health planning. A plan would include lameness and claw disorder treatments and prevention, which should be a requirement for farmers. This should be reviewed with their veterinaries annually to determine the prevalence of lameness and the causes over the year and determine what is working and needs to be improved.

The logistics of obtaining goat-level information on claw disorders have been established. To develop a more representative understanding, more herds need to be included in the study to identify other risk factors. In saying this, introducing technology such as applications designed for goat hoof trimmers to record claw disorders would make obtaining information more manageable. This study has identified some potential factors associated with claw disorders which can be used as the basis for future studies. Other factors that should be investigated are genetic merit, reproduction, nutrition, body condition score and type of bacteria present. The logistical process must be in place as information on these factors is not routinely collected. Secondly, research into claw disorders treatments in dairy goats needs to be established, as they are currently not many affordable options available to farmers and hoof trimmers. Educating farmers and hoof trimmers about goat feet is also recommended, as it was observed to be lacking in this study.

Genetic merit for milk production should also be investigated further in dairy goats to determine if it is a risk factor for the development of lameness. In dairy cows and sheep, it has been hypothesised that animals of higher genetic merit for milk production were more susceptible to lameness events (Green et al. 2014). One proposal is to do a case-control study which could follow goats of high and low genetic merit for milk production, though an alternative is to do a retrospective study, which compares the prevalence or incidence rate of lameness in high genetic merit dairy goats compared with low genetic merit goats. Each type of research would assess how and to what extent genetic merit for milk production is related to lameness susceptibility in dairy goats.

One aspect of this study was to look at the genetic origins of lameness and claw disorders. One aim was to undergo a genome-wide association study to investigate genomic regions that may be associated with lameness or specific claw disorders. The aim was to genotype the dairy goats participating in the study. This would also serve as a confirmation of parentage. Another aim was to determine the estimated breeding values of the bucks and does. This was unable to be achieved during this project and would still be useful to do in the future to identify regions within the genome or breeding values which are particular risk factors that may predispose goats to specific claw disorders.

10.7.2 Identifying more causes of claw disorders

Previous studies have suggested that digital dermatitis and footrot cause lameness in dairy goats. Our study was unable to ascertain whether the rot observed was footrot or digital dermatitis. Groenevelt et al. (2017) reported both claw disorders are similar in appearance, and only PCR analysis can confirm which bacteria may be causing the infection. Following our study, due to the prevalence of rot on all farms to varying levels, it would be important to determine which bacteria was causing it. This would help the direction of future work, such as the development of potential vaccines or breeding to specifically target the bacteria of interest, which have been demonstrated to be a common control method of footrot in sheep (Raadsma and Egerton, 2013), to aid farmers in the reduction of rot claw disorders in dairy goats.

Though it was not a part of the original plan of this thesis, the research conducted two additional experiments. Both experiments focused on the bacteria causing the rot reported on all the farms, but mostly on farms A and B. The first study was a pilot study investigating all the types of bacteria present within rot on three goats and exploring two sampling techniques used to acquire the bacteria. The second experiment was a case-control study. Thirty-five goats with rot were swabbed. These swabs were sent away for PCR analysis to confirm and quantify the type of bacteria present to obtain information on the causation of rot. These two aspects of my study are currently ongoing. Preliminary results suggest that *Treponema spp*, was the predominant species present within the rot lesions over *D.nodous* and *F.necrophorum*.

10.8 General conclusion

The thesis has established that lameness and claw disorders occurred frequently and reduced milk productivity on all three investigated dairy goat farms. This study has created a good foundation for future research in dairy goats raised on commercial farms, nationally and internationally.

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Appendix VI

Validation of locomotion and claw disorder scoring in dairy goats

1.1 Introduction

Lameness and claw disorders are welfare issues in ruminant species farmed for milk production, including dairy goats. To measure lameness, the gait of a walking goat is given a locomotion score which indicates the relative comfort or discomforts the goat may be experiencing while it is walking. The locomotion scoring system uses a score to identify whether a limp is present and, if it is present, its severity. To measure claw disorders, the claw lesions are viewed and scored based on several visual factors, such as lesion size, presence of a pungent odour, or signs of animal discomfort. Claw disorders are then given a score to indicate the severity of the lesion present or, in some cases, the stage of the disease (Somers et al. 2005). The main goal of a claw disorder and lameness scoring system is for their wide-spread use by many observers to establish a benchmark for reliable industry standards across time and countries (Kofler et al. 2022). One way to measure the reliability is to use intra- and inter-observer reliability. This is where scores from observers are compared to themselves across time (intra-observer reliability) and between different observers (inter-observer reliability).

For lameness, multiple four-point locomotion scoring systems have been developed for goats (Flower and Weary, 2006; Anzunio et al. 2010; Deeming et al. 2018). Deeming et al. (2018) compared the four-point scoring system to a newly developed 5-point scoring system, which incorporated an unevenness score. Incorporating an unevenness score in the locomotion system captured goats that presented with a gait that deviated from normal but did not show a limp, for example, swinging out of one hind limb as it walked or having a shortened stride. The intra-observer reliability was high between scorers for both scoring systems (weighted kappa = 0.96-1.00). The inter-observer reliability was also high (weighted kappa = 0.90 to 1.00) when training was given. Though the assessment was completed under a controlled environment, i.e. one goat was scored at a time with no other goats present, it is unclear how the 5-point scoring system would perform under on-farm conditions.

To date, there is limited information on claw disorders scoring systems used in dairy goats. There has been no scoring system specifically designed for measuring the severity of white line horn separation or granulomas in goats, cattle, or sheep. Non-specific lesion severity has been scored in dairy goats (Groenevelt et al. 2015b). A scoring system has been established for footrot in sheep (Foddai et al. 2012), and there is an M-stage scoring system for digital dermatitis in dairy cows (Vanhoudt et al. 2019). As reported by Groenevelt et al. (2017), although “rot” in dairy goats can be either footrot or digital dermatitis due to its clinical presentation of the claw disorder, it is not like sheep or cows, therefore, their scoring systems do not particularly apply to dairy goats. Therefore, the aim of this study is to develop and validate a new claw disorder system to specifically identify the presence and severity of common claw disorders in dairy goats in New Zealand. In addition, the lameness and claw disorder scoring systems were further assessed to obtain more information on the locomotion and claw disorder scoring system's performance in a commercial farming environment.

1.2 Methodology

1.2.1 Validation of the locomotion scoring

The intra- and inter-observer reliability were estimated to quantify any scoring bias when locomotion scoring. Where the intra-observer reliability measured the agreement within the scores of one observer, which were taken at two different time points - the inter-observer measured the agreement between the scores of two different observers (Hayen et al. 2007).

The inter-observer reliability between two scorers was undertaken to ensure that the observer scored correctly using the Deeming et al. (2018) descriptions (Appendix VI, Table 1). Scorer 1 was the PhD student, while scorer 2 was one of the developers of the 5-point scoring system. The difference between this study and Deeming et al. (2018) is that the scale is from 0 to 4 rather than 1 to 5. To increase the intra-observer reliability, training videos were obtained from Deeming et al. (2018) and watched before each scoring session (Kaler et al. 2009). There were no training videos on goose-stepping, therefore, the observers had to rely on the written description to differentiate between the goats with moderate and severe high goose-stepping.

To create the validation dataset (the farm reference videos), a video segment showing at least 60 goats (which were selected randomly) was extracted from each farm and taken from the first locomotion scoring event. The farm reference videos made up roughly 3.7%, 7.8%, and 7.1% of goats across farms A, B, and C, respectively. Although roughly 60 goats were viewed on the video, the goats that were included in the analysis must have been scored by both observers 1 and 2.

The validation dataset was stratified by farm first before measuring the reliabilities between observer's scores using SAS (version 9.4, SAS Institute Inc., Cary, NC). The inter- and intra-observer reliabilities used Cohen's weighted kappa (κ_w; Dohoo et al. 2013) to measure the degree of the agreement due to the ordinal scoring system used to score locomotion. The weighted kappa considers partial agreement between scores that are considered close together on the numerical scale (Dohoo et al. 2013).

To compare and validate the results with Deeming et al. (2018), this study also looked at the inter- and intra-observer reliability of the 4-point scoring system. The 4-point scoring system combined the groups of scores, 0 and 1. The weighted kappa was interpreted using the following scale established by Landis and Koch (1977) (0 = poor; 0.01–0.20 = slight; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = substantial; 0.81–1.00 = almost perfect).

1.2.1 Validation of claw disorder scoring

The two hoof trimmers scored the pictures at the beginning and end of the experimental period. The scores were analysed using SAS (version 9.4, SAS Institute Inc., Cary, NC). The kappa statistic was calculated overall across all three claw disorders between the two scorers and between the two time points for each scorer. The kappa statistic was interpreted following the scale formed by Landis and Koch (1977) as described above.

1.2.2 Specificity and sensitivity of the claw disorder scoring

The claw disorder scoring system was developed during a pilot study that was conducted on farm A. The scoring system was developed using past literature (Foddei et al. 2012), the Dairy Goat Co-operative vet consultant, and the hoof trimmers. The resultant scoring system is described in Appendix VI, Table 2. The claw disorders- rot, granulomas, and white line horn separation- were photographed. Five pictures were taken of each claw disorder at different severities to validate the claw disorder scoring system. In total, 35 pictures were taken and used as a reference.

At the time of classification, these pictures were considered true positives. Under the assumption that these were true, the sensitivity (identification (presence/absence) of the correct claw disorder) and specificity (identification of healthy foot or absence of claw disorder) were calculated for each hoof trimmer (the scorers) at the beginning and the end of the project. Sensitivity was calculated as the proportion of feet with claw disorders correctly detected as having a claw disorder. Specificity was calculated as the proportion of healthy feet correctly detected as having no claw disorders (Dohoo et al. 2003). The lower and upper confidence intervals ($P_{lower/upper}$) for specificity and sensitivity were calculated using the following equations (Fleiss, 2003):

$$P_{Lower} = \frac{(2np + Z_{\alpha/2}^2 - 1) - Z_{\alpha/2}\sqrt{Z_{\alpha/2}^2 - \left(2 + \frac{1}{n}\right) + 4p(nq+1)}}{2(n + Z_{\alpha/2}^2)}$$

$$P_{Upper} = \frac{(2np + Z_{\alpha/2}^2 + 1) + Z_{\alpha/2}\sqrt{Z_{\alpha/2}^2 + \left(2 - \frac{1}{n}\right) + 4p(nq-1)}}{2(n + Z_{\alpha/2}^2)}$$

Where:

n = sample size

p = the estimates of the confidence intervals for specificity and sensitivity.

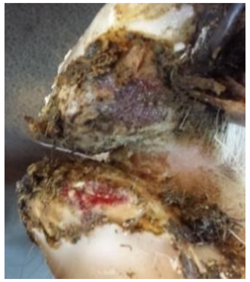
q = 1-p

$Z_{\alpha/2}$ = is the standard normal distribution for the 95% confidence interval (type I error).

Appendix VI Table 1. Locomotion scoring strategy used to measure lameness in dairy goats. Adapted from Deeming et al. (2018).

Severity score	Label	Clinically lame	Limping	Gait description	Modifications
0	Normal/not lame	No	No	Moving forward with even strides where hooves track up. Weight-bearing and no apparent head nodding.	
1	Uneven gait	No	Uneven	Moving forward with shorter strides where hooves do not track up. Weight-bearing, and having an absent head nodding, however, have joints that may show stiffness.	
2	Mildly lame	No	Yes	Moving forward with shorter strides where hooves do not track up. One or more legs/feet may be affected. Weight-bearing, and having an absent head nodding however may show a mild limp.	
3	Moderately lame	Yes	Yes	Reluctant to move forward and may display a moderate limp. One or more legs could be affected and may display moderate goose-stepping.	
4	Severely lame	Yes	Yes	Walking on the knees. Refusal to bear any weight on one foot. Severe limping or goose-stepping.	If there is no limp though they are walking forward and weight-bearing reluctantly. Multiple feet involved.

Appendix VI Table 2. Images with written descriptions of claw disorders at different classes of severity in dairy goats on commercial farms during the 2019-2020 season.

Claw Disorder	Severity 1	Severity 2	Severity 3
Rot	 Mildly damaged/misshapen sole/wall area of the digit, including surface rot (<=25%)	 Moderately damaged/misshapen sole/wall area of the digit (>25% and 75%)	 Severely damaged/misshapen sole/wall area of the digit (>75%)
Horn separation (White line disease)	 Less than 50% of the wall needs to be cut away	 More than or equal to 50% of the wall needs to be cut away	

Appendix VI Table 2. continued

Claw Disorder	Severity 1	Severity 2	Severity 3
Granulomas	 Taking up less than 25% of the claw area	 Taking up more than or equal to 25% of the claw area	

1.3 Results

1.3.1 Validation of the locomotion scores

The intra- and inter-observer reliability were calculated for the 4- and 5-point scoring systems (Appendix VI, Tables 3 and 4, respectively). Overall, for the intra- and inter-observer reliability, the scores were higher using the 4-point scoring system (0.80 and 0.82, respectively) than the 5-point scoring system (0.74 and 0.73, respectively). Across farms, the intra-observer reliability ranged between 0.60 and 0.86 (moderate to almost perfect), while the inter-observer reliability ranged from 0.69 to 0.84. Across both point systems, farm B had the highest inter-observer reliability scores, while farm A had the highest intra-observer reliability scores.

1.3.2 Validation of the claw disorder scoring

The inter and intra-observer reliability for scoring (0 to 3) and identifying (presence/absence) the claw disorders are shown in Appendix VI, Tables 5 and 6, and Appendix VI, Tables 7 and 8, respectively. Inter-observer reliability was moderate overall at the beginning and end of the experiment (0.42 and 0.59, respectively). For scoring the claw disorders, the inter-reliability was substantial at the beginning but only fair at the end, 0.61 and 0.37, respectively, while intra-reliability was substantial. For identifying the claw disorders, the intra-observer reliability was higher than the inter-observer reliability, with hoof trimmer 1 and 2 having substantial agreements between their beginning and end scores (0.81 and 0.71, respectively).

1.3.3 Specificity and Sensitivity of the claw disorder scoring

The sensitivity for detecting claw disorders (presence/absence) was between 50 and 100% (Appendix VI, Table 9). The specificity for the detection of claw disorders was between 85 and 100%.

Appendix VI Table 3. Inter and intra-observer reliability of locomotion scores assigned to goats by the two observers, and their 95% confidence intervals (CI), from three farms when using the five-point scoring system (0 =normal; 1=uneven gait; 2=mildly lame; 3= moderately lame; 4= severely lame).

Farm	Inter-observer reliability			Intra-observer reliability		
	No. of goats	Weighted kappa	95% CI	No. of goats	Weighted kappa	95% CI
A	47	0.69	0.56-0.82	49	0.81	0.71-0.91
B	40	0.75	0.59-0.90	43	0.60	0.41-0.79
C	50	0.70	0.58-0.82	51	0.75	0.64-0.85
Overall	137	0.73	0.65-0.80	143	0.74	0.67-0.81

Appendix VI Table 4. Inter and intra-observer reliability of locomotion scores assigned to goats by the two observers, and their 95% confidence intervals (CI), from three farms when using the four-point scoring system (0 =normal and uneven gait; 2=mildly lame; 3= moderately lame; 4= severely lame).

Farm	Inter-observer reliability			Intra-observer reliability		
	No. of goats	Weighted kappa	95% CI	No. of goats	Weighted kappa	95% CI
A	47	0.80	0.67-0.93	49	0.86	0.77-0.96
B	40	0.84	0.68-1.00	43	0.68	0.45-0.90
C	50	0.79	0.67-0.91	51	0.78	0.66-0.90
Overall	137	0.82	0.75-0.89	143	0.80	0.73-0.87

Appendix VI Table 5. Overall inter-observer reliability Cohen’s kappa scores, standard errors (SE), P-value and confidence intervals for agreement between hoof trimmers 1 and 2 for scoring (normal; severity 1; severity 2; severity 3) the claw disorders horn separation, granulomas and rot at the beginning and end of the experimental period.

	Kappa	SE	P value	95% Confidence interval
Beginning	0.61	0.06	<0.001	0.47-0.75
End	0.37	0.06	<0.001	0.22-0.52

Appendix VI Table 6. Overall intra-observer reliability Cohen's kappa scores, standard errors (SE) for hoof trimmers 1 and 2 for scoring (normal; severity 1; severity 2; severity 3) the claw disorders horn separation, granulomas and rot.

	Kappa	SE	P value	95% Confidence interval
Hoof trimmer 1	0.79	0.06	<0.001	0.68-0.90
Hoof trimmer 2	0.68	0.07	<0.001	0.56-0.81

Appendix VI Table 7. Overall inter-observer reliability Cohen’s kappa scores, standard errors (SE), P-value and confidence intervals for agreement between hoof trimmers 1 and 2 for identifying (presence or absence) the claw disorders horn separation, granulomas and rot at the beginning and end of the experimental period.

	Kappa	SE	P value	95% Confidence interval
Beginning	0.59	0.07	<0.001	0.44-0.74
End	0.42	0.07	<0.001	0.26-0.58

Appendix VI Table 8. Overall intra-observer reliability Cohen's kappa scores, standard errors (SE) for hoof trimmers 1 and 2 for identifying (presence or absence) the claw disorders horn separation, granulomas and rot.

	Kappa	SE	P value	95% Confidence interval
Hoof trimmer 1	0.81	0.07	<0.001	0.69-0.91
Hoof trimmer 2	0.71	0.07	<0.001	0.58-0.84

Appendix VI Table 9. Sensitivity and specificity and the 95% confidence intervals (in parenthesis) for hoof trimmers 1 and 2 for identifying the claw disorders horn separation, granulomas and rot.

		Granuloma		Horn separation		Rot	
		Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
Beginning	Hoof trimmer 1	90 (43-100)	98 (90-100)	100 (53-100)	97 (88-99)	89 (57-99)	98 (89-100)
	Hoof trimmer 2	70 (27-94)	100 (93-100)	100 (53-100)	85 (74-92)	100 (71-100)	93 (82-97)
End	Hoof trimmer 1	80 (35-98)	98 (90-100)	100 (53-100)	97 (88-99)	94 (64-100)	98 (89-100)
	Hoof trimmer 2	50 (15-85)	98 (90-100)	100 (53-100)	97 (88-99)	100 (71-100)	98 (89-100)

1.4 Discussion

1.4.1 Validation of the locomotion scores

The 4-point and 5-point scales used generally had a substantial agreement between scorers and between scores taken across time. Based on the chi-square test results, there was no observer bias between the scores when the 4-point or 5-point scale system was used.

The 4-point scoring system proved more reliable than the 5-point scoring system based on the higher kappa scores. Compared with Deeming et al. (2018), the inter-observer reliability of the scores for the 5-point scoring system in this study was lower (0.90-1.00 *vs.* 0.69-0.75, respectively). No inter-observer reliability scores were reported for the 4-point scoring system. For intra-observer reliability, Deeming et al. (2018) reported higher reliability for both scoring systems than this study (1.00 *vs.* 0.68-0.86 and 0.96 *vs.* 0.60-0.81, respectively). In agreement with the results of this study, the 4-point scoring system was more reliable than the 5-point scoring system. For intra- and inter-observer reliability, most of the differences were deviations by 1 score and occurred between 0 and 1 scores or 1 and 2 scores. This shows the challenge of differentiating between normal, uneven gaits, and mild lameness. The difficulty of differentiating between low scores was also noted by a couple of other authors investigating lameness in cows and sheep (Winckler and Willen, 2001; Kaler et al. 2009). In this study, there were nine months between the beginning and end scores. The intra-observer reliability had a substantial agreement between the two-time points meaning that there was little difference between the scores and that the risk of measurement bias for the lameness outcome did not change between the beginning and the end of the project.

The imperfect intra-observer agreement was mostly due to differences by 1 score between the beginning and the end of the project. During this study, the reference videos of score category 3 contained goats that varied in severity. A potential issue came with the interpretation of reluctance and when the goat showed head nodding. On the high end of the scale of score 3, the goats showed a greater reluctance to bear weight while walking forward but still bore weight. On the lower scale of 3, goats were limping, head nodding, walking forward reluctantly and bearing weight reluctantly. Head nodding was the principal difference between scores 2 and 3. It may be interesting to change the terminology for score 4 for weight-bearing to unwillingness or severe reluctance to bear weight rather than being unable to bear weight. It might be helpful to differentiate this score in the future as this may compromise studies investigating factors affecting lameness severity or severity of lameness affecting production traits such as milk yield.

1.4.2 Validation of the claw disorder scoring

On average, the intra-observer reliabilities and inter-observer reliability for identifying claw disorders were substantial and moderate, respectively. Compared with other studies, the reliabilities are similar to past studies (Holzhauer et al. 2005; Foddai et al. 2012; Phythain et al. 2016; Vanhoudt et al. 2019; Van Riet et al. 2020). Holzhauer et al. (2005) investigated the presence and absence of claw disorders on dairy cow farms. The agreement between hoof trimmers varied from 0.1 to 0.7 depending on claw disorder. Agreement of digital dermatitis scores varied between observers (0.40 to 0.60), while for white line disease, agreements were less than 0.40. Holzhauer et al. (2005) suggested that live training rather than classroom training improves reliability. This study used live training to establish claw disorders and their severities. This may have helped consistencies with scores in real life, however, for scoring the photographs, the results did not appear to differ much from Holzhauer et al. (2005)

Vanhoudt et al. (2019) used the M-scoring system in cows to measure the severity of digital dermatitis. Across all severities, the inter-observer reliabilities were moderate (0.48), ranging from 0.61 to 0.99. Vanhoudt et al. (2019) also reviewed other past studies with inter-observer reliabilities between 0.41 and 0.85. This scoring system has been established within the industry for over 20 years (Greenough et al. 2008). The scoring system has had time to be critiqued and refined by many experts, while the scoring systems in the present study are newly developed and probably need to be reviewed and further refined. A higher inter-observational agreement is needed before it can be used generally internationally (Vanhoudt et al. 2019).

Van Riet et al. (2020) investigated claw disorders in sows. They used 80 photographs. Intra-observer reliability for claw disorders was, on average, 0.77 (0.35 to 0.84), while the inter-observer reliability was, on average, 0.68 (0.64-0.89). The familiarity with the scores, the testing conditions, and the number of animals within a testing session may have impacted the agreement. This study suggested extra training sessions to improve their reliability. The authors also suggested that observers could have assigned a higher score to prevent the possibility of missing existing lesions, which may have also happened for the hoof trimmers in this study.

Phythain et al. (2016) reported high inter-observer reliability for claw disorders in sheep. The observers were mostly experienced or trained with a background in animal or veterinary science. There was one-day training session that they had undertaken. Only the presence or absence of claw disorders was established. Agreement varied between 66.7 and 96.7%. White line disease had the lowest agreement (66.7), while footrot, digital dermatitis and toe granulomas had the highest 96.7%.

Foddai et al. (2012) used sheep to investigate claw disorder scoring reliabilities. They used photographs, videos and post-mortem (live) scoring. A 5-point scoring system scale was used that was developed by Egerton and Roberts (1971). The scoring was different within Foddai et al. (2012), where the inter-observer scoring sessions 1 and 2 were conducted within a couple of hours of each hour (despite being randomised in the following scoring session). In the current study, the amount of time between the scoring sessions was 9 months rather than 2 hours which could explain why the inter-observer reliabilities were lower in this study than Foddai et al. (2012). Photographs could be scored more consistently, while videos and post-mortem were more real-life, though more exposed to unnecessary errors.

Across sheep and dairy cow studies, within the discussions, the quality of information and training of the observers. There is also a discrepancy between photographs (2D), videos (3D) and manual (4D) scoring. All three methods have their advantages and disadvantages. For example, there is more observational control over photographs than videos and even more so than live scoring. Live scoring may have more observational errors (i.e., light differences). The disadvantage of photographs is the lack of visibility.

Although the advantage of live scoring is this is closer to real-life circumstances (van Riet et al. 2020). In this current study, photographs were used, however, there may have been a lack of visibility for the hoof trimmer scoring the pictures. Some pictures may not have been of the highest quality (they were taken with an android phone) and were not taken on the same day. Therefore, the visibility may have been impacted by the environment, such as the light. Another thought is implementing virtual reality technology to have a more controlled environment but a standardised technique to score the claw disorders.

In this study and under these circumstances, a combination of photographs and videos (concurrently) should be used to measure inter-and intra-observer reliability. When live scoring is carried out, more points of view are obtained and having the senses of touch and smell and the ability to manipulate the claws helps diagnose the claw disorder and its severity. It was decided within this thesis that a binary variable for rot and granuloma be used in the analysis of risk factors and heritability for claw disorders and the heritability because the reliability was higher when these scores were dichotomised.

In this study, the hoof trimmers had very limited knowledge of theory, i.e. they had not been educated at a school like dairy cattle trimmers are required to do. This is very normal in the dairy goat industry. The hoof trimmers are trained on the job by previous hoof trimmers that have taught themselves or have trimmed their own goats. This may mean they need further training before being used in further research to obtain consistent results.

1.4.3 Specificity and sensitivity of the claw disorder scoring

One of the study's aims was to analyse the accuracy of detecting claw disorders in dairy goats. The interpretation of claw disorder sensitivity and specificity results are as follows:

We can say with 95% confidence that the sensitivity for granulomas for hoof trimmer 1 is between 43 and 100%. For example, the probability of a granuloma being correctly diagnosed by hoof trimmer 1 is between 43 and 100%.

We can say with 95% confidence that the specificity for granulomas is between 89.8 and 99.7%. For example, the probability of a claw disorder without granuloma being reported negative for a granuloma by hoof trimmer 1 is between 90 and 100%.

The sensitivities and specificities of horn separation and rot were high. Despite high values, there were also large confidence intervals which a low sample size could explain. There were no previous studies for comparison for the claw disorder horn separation, but there were similar studies for rot, and digital dermatitis in dairy cows.

In this study, the figures are slightly higher, however, the 95% confidence interval was larger than past studies that analysed the accuracy of the M-scoring systems for digital dermatitis dairy cattle (M0- absence versus M1 to M4). Reulen et al. (2011) reported specificities and sensitivities between 0.67 to 0.92 and 0.79 to 0.94, respectively. Solano et al. (2017) reported sensitivities and specificities of 0.92 and 0.88. A reason for high figures and large confidence intervals could be the lower number of samples within the study. In this study, 35 pictures (or 35 feet) were taken of the lesions, whereas Reulen et al. (2011) and Solano et al. (2017) had larger sample sizes of 484 and 6991, respectively. Higher figures could be due to controlled conditions that the scorers would be under compared to the live scoring reported to be carried out in Reulen et al. (2011) and Solano et al. (2017). As pictures rather than live-scoring were used to score accuracy, fewer variables could contribute to bias, such as variable light conditions. To increase the precision of the sensitivity and specificity estimates, more feet need to be analysed in dairy goats. Furthermore, more studies are needed to validate the results of horn separation and rot in dairy goats.

The accuracy of detecting granulomas was lower than rot and horn separation. This is likely due to less severe granulomas looking like a nick (caused by the hoof trimmers accidentally trimming too low). Sometimes it was hard to photograph the granulomas due to the blood generated when the hoof trimmers came across them in real life. Therefore, when it came to identifying and scoring them in the picture, the hoof trimmer thought it was a nick rather than a granuloma. Live scoring would be more appropriate for these types of claw disorders.

1.5 Conclusion

The locomotion scoring had a substantial agreement between scorers and between scores over time. This study validated the 5-point scoring system that can be implemented on commercial dairy goat farms. The claw disorder scoring system needs to be further validated and perhaps refined before it can be used as an international scoring system.

Curriculum Vitae

Natasha Jaques was born in New Zealand, however, she has had the opportunity to live, work and study abroad. Before she left overseas, she was a regional representative that played hockey at a national level. She has a broad professional and academic background encompassing field and laboratory work. She started her Bachelor of Science (Technology), majoring in Biology, at the University of Waikato in 2010. As a requirement of the degree, internships were carried out at the Environmental Science and Research (ESR) and Lallemand Inc. The first internship was at ESR based in Christchurch, New Zealand, from November 2012 to February 2013 and investigated the inhibition of Listeria monocytes using bacteriophage. The second internship was at Lallemand, based in Montreal, Canada, from January 2014 to December 2014, and investigated glutathione production from yeast in the genetic improvement division. After this internship, she graduated with her Bachelor's degree and travelled to The Netherlands to work on a dairy goat farm, Geitenfarm de Houtsberg. Alongside this work, she was accepted into Wageningen University. She graduated from Wageningen in 2016 with a Master of Animal Science, specialising in Animal Nutrition and Animal Breeding and Genetics. After three and half years, she moved back to New Zealand to start her PhD in Animal Science at Massey University under Nicolas Lopez-Villalobos. Her PhD investigated lameness in dairy goats, with her research findings contributing to the development of the OmniEye camera system, an early lameness detection tool in dairy cattle, led by Greg Peyroux.

By the end of her PhD, she will have seven chapters ready to be published, with results from a side project also lined up to be published after her PhD. Upon completing her PhD, she wants to find a job that works closely with farmers. Her goal is to help farmers to increase the robustness of their livestock through improvements in their management and efficiency through the uptake of technology, breeding and genetics. She has a scientific background that has enabled her to have a large set of skills ranging from laboratory and field work to analysis and documentation. She has extensive knowledge of data collection, management, and analysis. She has also shown that she can manage projects and people.

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Natasha Jaques
Name/title of Primary Supervisor:	Nicolas Lopez-Villalobos
Name of Research Output and full reference:	
Prevalence and incidence rate of clinical lameness in New Zealand dairy goats	
In which Chapter is the Manuscript /Published work:	3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition	
For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Animal Science and Production	
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Date:	
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Name of candidate:	Natasha Jaques
Name/title of Primary Supervisor:	Nicolas Lopez-Villalobos
Name of Research Output and full reference:	
The Effect of Lameness on Milk Production of Dairy Goats; Animals 2023, 13(11), 1728; https://doi.org/10.3390/ani13111728	
In which Chapter is the Manuscript /Published work:	Chapter 8
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition	
For manuscripts intended for publication please indicate target journal:	
Candidate's Signature:	Natasha Jaques Digitally signed by Natasha Jaques Date: 2023.05.31 20:27:26 +12'00'
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Name of candidate:	Natasha Jaques
Name/title of Primary Supervisor:	Nicolas Lopez-Villalobos
Name of Research Output and full reference:	
Estimates of Genetic Parameters for Milk, the Occurrence of and Susceptibility to Clinical Lameness and Claw Disorders in Dairy Goats; Animals (Basel). 2023 Apr; 13(8): 1374. Published online 2023 Apr 17. doi: 10.3390/ani13081374	
In which Chapter is the Manuscript /Published work:	Chapter 9
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition	
For manuscripts intended for publication please indicate target journal:	
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