Evaluation of claw health of dairy cattle housed in dirt lot vs free stall in TMR systems in the central region of South Africa

by

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Declaration

I, Nokuthula Lorraine Mhlongo, hereby declare that this dissertation, submitted for the MSc (Agric) Animal Science: Production Physiology and Product quality degree at the University of Pretoria, is my own work and has not previous been submitted by me for a degree at any other institution.

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Abstract

Claw health is arguably an important factor in dairy cow welfare. Evaluation is important as an early indicator of lameness in dairy cattle. In South Africa, information on claw lesions is not routinely collected and not yet included in genetic evaluations. The study aimed to evaluate the claw health of dairy cattle housed in dirt lot vs free stall under the TMR systems in the central regions of South Africa. The current study evaluated data 10 commercial dairy farms having a dirt lot or, free stall system. Data were collected by professional claw trimmers from January 2011 to May 2018. The scored claw disorders included heel erosion (**E**), digital dermatitis (**DD**), foot rot (**F**), hairy attack (**HA**), axial fissure (**AX**), sole ulcer (**U**), toe ulcer (**TU**), white line (**WL**), sole fracture (**SF**) and corkscrew (**C**). The edited data were statistically analysed for all lesions with years, infectious vs non-infectious, season, dirt lot vs free-stall as variables and season by housing interactions. A significance test after chi-square testing was also performed. The overall prevalence rate for all the lesions among trimmed cows was the highest in 2017 (30%) and 2016 (28%), compared to 2014 (17%), 2015 (18%) and 2018 (7%). The occurrence of infectious (59%) lesions ($P < 0.001$) was higher compared to non-infectious (41%) across years in all farms. Digital dermatitis (53%), E (35%) and C (41%) were the most frequent lesions ($P < 0.001$), reported in 70 to 80% of the total herds, while other lesions were relatively low. Heel erosion was significantly influenced by free stall farms, while DD was not influenced by housing systems ($P > 0.002$). Similarly, C was also not influenced by housing systems ($P > 0.002$). Heel erosion was significantly influenced ($P < 0.001$) by Autumn and Spring, with profound effects marked in Spring (8.4%). Summer and free stalls interactions significantly influenced E ($P < 0.001$). The current study suggests that seasons and housing type have notable effects on the prevalence of claw lesions. The findings indicate that different lesion types having significantly different risk factors, which will require intervention and specific management for ensuring claw health.

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List of Abbreviations

AX	Axial fissure
DD	Digital dermatitis
CHD	Claw horn disorders
E	Heel erosion
F	Foot root
HA	Hairy attack
ICAR	International Claw health Atlas
TMR	Total Mixed Rations
WL	While line
SF	Sole fracture
SU	Sole ulcer
C(C)	Corkscrew claw
h^2	Heritability
LM	Linear Model
TM	Threshold Model
DM	Dry Matter
QAC	Quaternary ammonium-based commercial footbath product
CuSO4	Copper sulphate
N	Norwegian breed
F	Friesian breed
CaM	Calmodium
ID	Inter digital dermatitis
HHE	Heel horn erosion
HFA	Axial horn fissure
HFH	Horizontal horn fissure
HFV	Vertical horn fissure
IH	Interdigital hyperplasia
IP	Interdigital phlegmon
SHD	Sole hemorrhage diffused
SHC	Sole hemorrhage circumscribed
TN	Toe necrosis
TS	Thin sole
WLF	White line fissure

WLA	White line abscess
AC	Asymmetric claws
CD	Concave dorsal wall
DS	Double sole
SC	Scissor claws
SW	Swelling of coronet or bulb
BU	Bulb ulcer

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Chapter 1: Introduction

1.1. Introduction to the South African industry

In South Africa (SA), dairy production is the fifth-largest agricultural industry, providing a sustainable living for over 1 961 milk producers across the country (Department of Agriculture, 2017). Holstein, Jersey, Guernsey, and Ayrshire are the four major milk producing breeds in the country (Department of Agriculture, 2017). The industry has approximately 640 000 cows in milk which produces approximately 3 253 000 tons of milk per annum (Lactodata, 2018). The majority of the producers are situated in the Western Cape, Eastern Cape, KwaZulu - Natal, and the Free state. In the past decade, the South African dairy industry has undergone changes including increasing consumer's demands, adoption of new technologies and economic pressures. Production has also shifted to the climatically milder coastal regions. The number of milk producers has decreased by more than 60%, with only 1 364 producers remaining in January 2018, down from 3 551 in January 2009 (Lactodata, 2018). Despite a decrease in the number of producers, average herd sizes have increased (Lactodata, 2018). The production of milk tends to fluctuate, but an increase of 26% from 2 587 000 tons to 3 253 000 tons has been reported due to the pressure for higher efficiency (Lactodata, 2018). Similarly, this trend of a decline in the number of producers, an increase in herd sizes and milk yield have also been reported for global dairy production (Barkema *et al.*, 2015). The increase in herd size is driven by economies of scale aimed at maintaining profitability (Wilson, 2011; Bernard, 2019). The emphasis on the intensity of production, unfortunately, holds potential negative implications for the health and welfare of dairy cows as well as on the production and management systems.

Worldwide cows are managed under different housing and management systems (Cook & Nordlund, 2009). In regions with good warmer climates cows are kept on pasture grazing systems, and in zero-grazing (TMR) systems in areas where grazing is not most proficient (Haskell *et al.*, 2006; Cook & Nordlund, 2009). In some countries producers with high producing cows, do move their cows from pasture to housing during the winter months (Haskell *et al.*, 2006). In South Africa, dairy cows are reared and managed under two common production systems namely: Grazing (pasture) and Total Mixed Ration (TMR) systems) (Theron & Mostert, 2009; Abin *et al.*, 2018). These two systems vary from keeping the cows on pasture or/and housing throughout the year respectively. There are two common types of TMR systems, namely; free stall and dirt lot housing systems. Due to the increase in herd sizes, land availability, the decrease in quality of forage, and climatic changes (Briginshaw *et al.*, 2016), a number of producers have shifted from the traditional system to TMR systems. Hence, TMR is the most predominant system used by the majority of the dairy producers situated in the central regions of South Africa. This system is associated with higher profitability (Robertson & Wilson, 2007, 2008, 2009), due to improved milk yield, high concentrate feed as well as larger herd size (higher stocking rate) especially in free stalls, since free stalls can accommodate a larger number of dairy cows (Barkema *et al.*, 2015). Despite the benefits of this system, it has been associated with decreased health and an increase in welfare problems of dairy cows (Sanders *et al.*, 2009; von Keyserlingk *et al.*, 2012). A number of studies have reported the effect of various management and housing practices indicating the consequences of a cow leg injury and resultant lameness (Gomez & Cook, 2010; Andreasen & Forkman, 2012; Allen *et al.*, 2015; Chen *et al.*, 2017). Lameness is considered as the most important welfare problem because of its high prevalence in herds throughout the world and its weakening effects on longevity (Huxley, 2012; Weigele *et al.*, 2018). Claw lesions may result from infectious diseases and lesions caused by disruptions of the horn of the claws (claw disorders) (von Keyserlingk *et al.*, 2009).

Claw lesions are the most common causes of lameness. The most commonly reported claw disorders involve different types of dermatitis, heel horn erosion, sole ulcers, hemorrhages and different types of white-line disorders (Bicalho *et al.*, 2007; Thomas *et al.*, 2015). Claw lesions developments are influenced by genetic and non - genetic factors. This includes factors such as nutrition, hormonal changes, external trauma, individual genetics, claw management, housing and infectious agents (Barker *et al.*, 2010; Becker *et al.*, 2014; Heringstad *et al.*, 2018). Management factors such as biosecurity measures also play an important role in claw management. This includes the use of disinfectants, isolation of sick animals, restricting movement within the herd, environmental sources as well as farm and external equipment and the quarantining of newly purchased cows. Higher practices of biosecurity have been reported to improve animal health, productivity and economic losses (Sarrazin *et al.*, 2014; Laanen *et al.*, 2013). However, proper biosecurity measures are not practiced efficiently in dairy farms, resulting in increased outbreaks of claw diseases (Sayers *et al.*, 2013). Stall or barn hygiene is also reported as a management factor associated with lesion development in floors that are not frequently cleaned (Cook & Nordlund, 2009).

Nutrition plays a vital role in claw health, as an inadequate supply of nutrients may result in claws that are not strong and more prone to lesion development (Muelling, 2009; Bauer *et al.*, 2018). Genetic factors such as the breed, genetic selection, and accurate recording also have been correlated with lameness (Baird *et al.*, 2009; Chapinal *et al.*, 2013b; Ring *et al.*, 2018). For example, constant selection for improved milk production without considering claw traits has been negatively reported to have an influence on claw health (Kougioumtzis *et al.*, 2011). In addition, insufficient records on claw lesions decrease the opportunity of selection against claw lesions. These factors contribute to increased incidences of claw lesions, resulting in cows that are lame (Heringstad *et al.*, 2018).

Claw lesion and resulting lameness also causes significant economic losses in terms of reduction in reproductive efficiency, milk production and increase in culling rates (Machado *et al.*, 2010; Tadich *et al.*, 2010; Walker *et al.*, 2010; Huxley, 2013). In terms of reproduction performance, lameness has a major negative impact on the fertility of the affected cows. In an affected cow, the process of insemination is delayed with a lower chance of a successful pregnancy. Cows suffering from pain associated with lameness change their behaviour to reduce discomfort (Whay *et al.*, 2008). This also influences milk yield because of the cows' inability to walk and stand in the milking parlour. Literature indicates that high milk-producing cows are associated with a high prevalence of claw disorders (Huxley, 2013) and studies show that certain breeds are at a higher risk as compared to others (Baird *et al.*, 2009). In addition, claw quality has an influence on the chances of cows suffering from claw lesions (Borders, 2004). High claw quality provides the opportunity for increased longevity and lifetime performance (Distl *et al.*, 1990) of a dairy cow.

Claw health in dairy cattle has received a considerable amount of attention over the past decade with increased awareness of the importance of claw health monitoring and recording in countries such Mexico, Netherlands, Germany and United Kingdom (Horseman *et al.*, 2013; Charfeddine & Pérez-Cabal, 2017; Bryant *et al.*, 2018). Dairy farmers aim to have strong and healthy cows that are able to produce milk efficiently. In essence, the evaluation of claw health can, therefore, be an early indicator of lameness in South African dairy cattle. Preventive measures and strategies for a number of claw disorders are currently available to minimize lameness in dairy herds. These include hoof trimming and recording of these traits (Speijers *et al.,* 2012).

In South Africa, hoof trimming is performed by private companies such as DairySmid Trimming Association. DairySmid Trimming Association is the most predominant trimming private company, available commercially to the local producers in the central regions of South Africa(Personal communication; van Zyl, 2018. Hoof trimmer and consultant. riaan@dairysmid.com). DairySmid has been recording a number of claw traits, aimed at promoting improved claw health and longevity through claw trimming and recording, following the internationally recognized Zinpro lameness assessment tools (DairySmid, 2016; Larson *et al.*, 2014). In European countries, ICAR guidelines are applied for claw evaluations and recording. The ICAR is an internationally recognized recording system focusing on a range of important traits in dairy cattle including fertility and udder health (Egger-Danner *et al.*, 2015). However, more recently ICAR prioritised feet and legs and developed a national claw health atlas. The developed national claw health atlas is aimed at promoting early detection of claw lesions through improved claw recording and evaluation of dairy cattle (Egger-Danner *et al.*, 2015).

Despite the availability of different hoof trimming and potential for recording claw traits (claws, legs, and linear traits), in South African accurate recording of these traits remain difficult and costly to measure. In the national milk recording scheme in South Africa, claw traits are not recorded. Due to the low interest in recording, claw lesions are also not part of an official recording and no automated systems are available for claw recording. As a result, data is limited to farmers making use of routine trimming by professional trimmers. In addition, cows with severe claw disorders require treatment from a professionally trained hoof specialist, which is quite expensive and contributes to excessive production costs. Consequently, information on lameness is not collected routinely in South Africa and is not included in current genetic evaluations. Furthermore, foot disorders and lameness are highly important welfare problems in dairy farming that are currently underestimated, which may lead to other health problems and reduced longevity. Hence, there is a need for an investigation on dairy claw health in SA dairy herds to add to the present knowledge and provide reference data for claw traits.

1.2. **The aim of the study**

In South Africa, national recording of claw lesions is very low, the data is limited to producers making use of routine trimming by professional trimmers. Furthermore, no automated systems claw records are available. The aim of the current study was to evaluate the claw health of dairy cattle housed in dirt lot vs free-stall TMR systems in the central regions of South Africa.

To achieve this, aim the following objectives were set:

1. To collect claw lesion data obtained from professional claw trimmers and create a database.
2. To statistically analyse the available claw lesion data from farmers in the central regions.
3. To compare the lesion data of two selected producers with the ICAR claw Health Atlas.

Chapter 2: literature review

2.1. **Introduction**

In dairy production, longevity is highly desirable, defined as production over the lifetime of the animal (van Pelt *et al.*, 2015). An increase in the production life or lifespan of a dairy cow is a major determinant of the overall profitability of a dairy farm (Sewalem *et al.*, 2008; Ahlman *et al.*, 2011). Efficient milk production depends on the health status of the cow. Claw health and quality are primary aspects associated with lameness (Laursen *et al.*, 2009) and a significant welfare issue in dairy cows. The major lameness incidents arise from claw lesions (Randall *et al.*, 2018), which are influenced by a number of different risk factors. The risk factors include management and production systems, environmental factors, individual cow and genetic factors (Barker *et al.*, 2010; Randall *et al.*, 2018). The aim of this review was to discuss relevant scientific literature to describe claw health and quality as well as different factors contributing to the development of claw disorders on dairy cows housed under TMR systems.

2.2. **Claw anatomy with regard to lesion development**

A healthy claw in dairy cattle is an important component of the animal's well-being and productivity. The quality and health of the claw depend on the anatomy, arrangement and the physiology of its internal structures (Figure 2.1) (Greenough, 2007). The internal functional structures of the horn include the epidermis of the wall of the corium, dermo-epidermal junction, dermis, and digital cushions. The claw epidermis is divided into dead and living epidermal cells (Figure 2.1), situated in the horn layer as well as in the basal and spiny layers respectively (van Amstel & Shearer, 2006; Greenough, 2007). The basement membrane has a regulatory function and is positioned between the epidermis and dermis (corium) (van Amstel & Shearer, 2006; Greenough, 2007). The dermis (corium) has nerves and blood vessels located underneath the epidermis. It plays an important role in the process of keratinization during horn formation by supplying the epidermis with nutrients such as vitamins, minerals, and trace elements (Mülling *et al.*, 1999). The dermis also has an additional support and suspension role to the pedal bone provided through the collagen, elastin, and proteoglycans (van Amstel & Shearer, 2006).

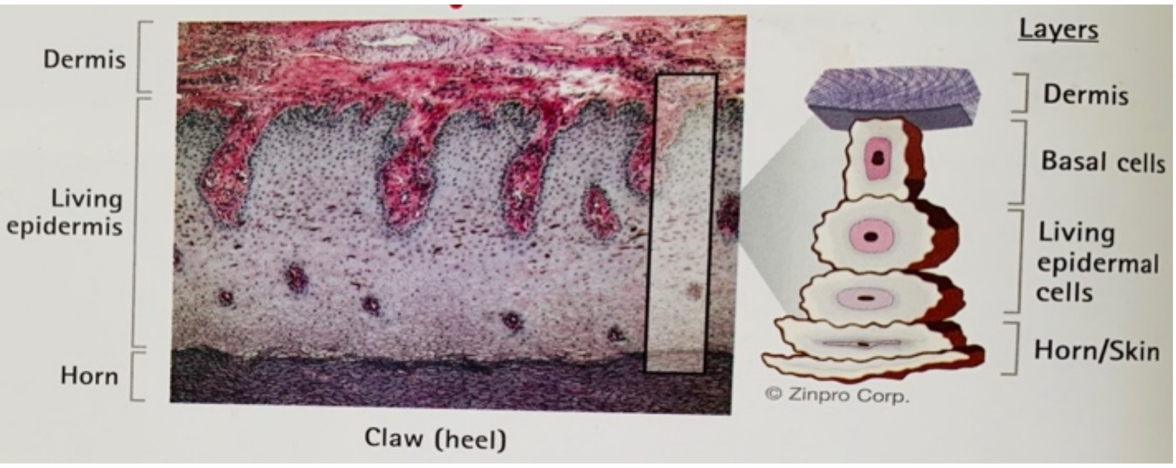

Figure 2.1. The epidermis of claw and skin (Larson *et al*., 2014).

The digital cushion is situated below the pedal bone filled with a greater proportion of adipose fat (Oikonomou *et al.*, 2014)**.** The digital cushion (Figure 2.2) is one of the key support structures inside the claw capsule responsible for shock absorption related to locomotion to the pedal bone and subsequent distribution of weight between the inner and outer claws (Oikonomou *et al.*, 2014; Newsome *et al.*, 2016, 2017). The pedal bone is located inside the claw capsule, responsible for the prevention of excessive pressures on the sensitive dermis and active horn producing epidermis (Figure 2.2) (van Amstel & Shearer, 2006). The connective tissue, such as the collagen fibres, are responsible for the function of the suspensory apparatus, which is to the hold pedal bone on a stable position inside the claw capsule (van Amstel & Shearer, 2006).

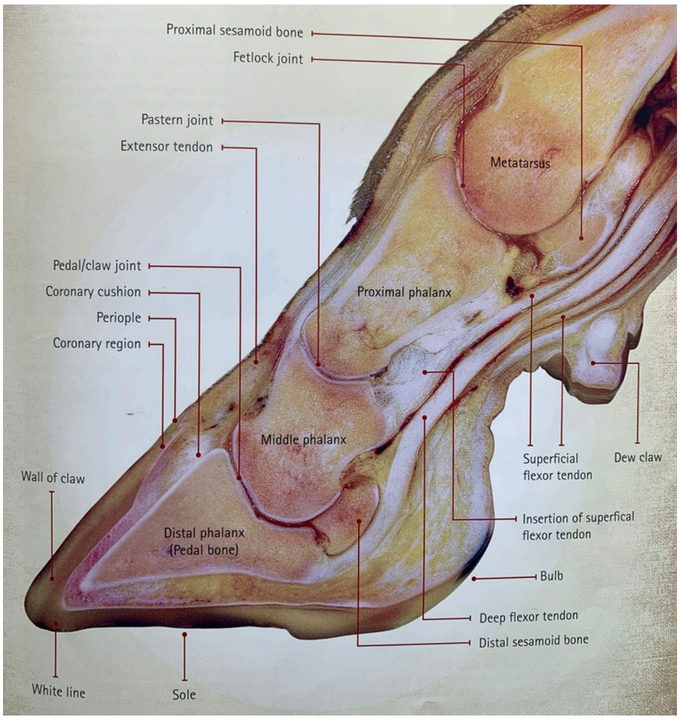

Figure 2.2. The anatomy of the inner claw (Larson *et al*., 2014).

Briefly, claw horn is formed through an active process of keratinization, proliferation, and cornification occurring in different areas of the horn (coronary, laminar, sole and heel regions) (Vermunt & Greenough, 1995; Hoblet, 2000). During these processes, keratin proteins and intercellular cementing substance are synthesized by the living epidermis cells in the basal layer (Hoblet, 2000). The synthesized keratin proteins are high in cysteine content, responsible for the chemical and mechanical horn stability (Lean *et al.*, 2013). The intercellular cementing substance comprises of glycoproteins and complex lipids, which provides mechanical horn stability and helps with keeping normal hydration of the horn (Hoblet, 2000). Furthermore, lipids contribute to the intercellular cementing substance responsible for cell to cell adhesion, resulting in mechanical horn stability (Hoblet, 2000; Lean *et al.*, 2013). Any disturbance in this process may lead to the destruction of the claw horn integrity and quality resulting in claw lesion development. Key structures such as the digital cushions, pedal bone as well as the collagen play an important role in the pathogenesis of hoof and claw lesions (van Amstel & Shearer, 2006; Newsome *et al.*, 2016, 2017).

Good quality collagen fibers of the connective tissues are responsible for the function of the suspensory apparatus which are of great importance. During calving, the connective tissue undergoes changes due to metabolic and hormonal fluctuations (Tarlton *et al.*, 2002; Chapinal *et al.*, 2009a). These fluctuations are thought to have an influence on the stability of the pedal bone. The pedal bone becomes dislocated resulting in the sinking, rotating and tilting that causes trauma on the epidermis and dermis of the claw (Lischer *et al.*, 2002; Tarlton *et al.*, 2002). Damage caused by the subsequent pressure on the soft living tissues between the horn and the pedal results in claw horn disruption (Newsome *et al.*, 2016). The condition leads to the development of lesions such as hemorrhage, with sole ulcers occurring in more severe cases (Mülling & Lischer, 2002; Winkler & Margerison, 2012). A significant relationship between claw conformation and digital dermatitis has been reported (Gomez *et al.*, 2015). Digital dermatitis has also been reported to cause significant milk losses (Faust *et al.*, 2001; Pavlenko *et al.*, 2011). Heel erosion is another problematic infectious lesion following digital dermatitis, also associated with milk losses and lameness (Green *et al.*, 2010).

2.3. **Claw lesions**

Claw health can be defined as the absence of claw lesions (Laursen *et al.*, 2009), resulting from the disruptions of the horn (claw disorders). The disorders are classified according to their aetiology, namely: infectious and non-infectious lesions. Infectious lesions include different types of digital dermatitis, interdigital dermatitis, foot rot and heel erosion (Evans *et al.*, 2009; Buch *et al.*, 2011). Non-infectious lesions develop on the sole of the horn, affecting claw horn and targeting specific regions of the sole as illustrated in the diagram showing claw zones in figure 2.3. The most commonly reported lesions are a sole ulcer, toe ulcer, sole hemorrhage, and white line disease.

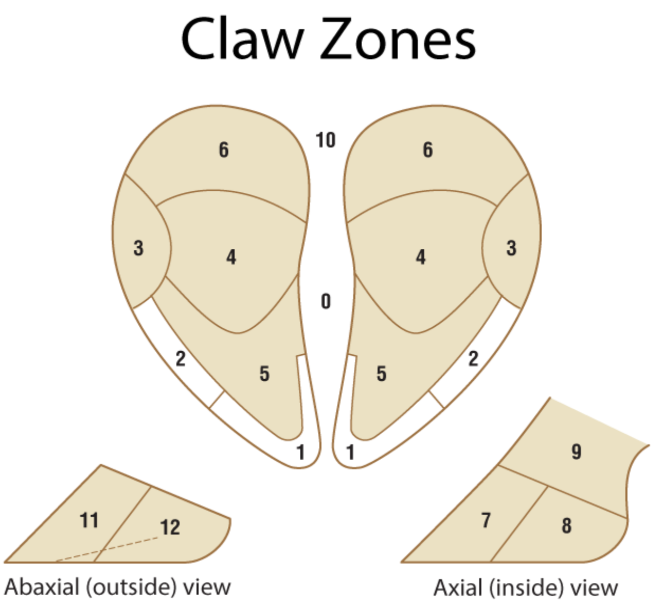

Figure 2.3. Classification of claw zones (Larson *et al.*, 2014).

Among the infectious lesions (Table 2.1), digital dermatitis (DD) is the most problematic disease affecting about 70 to 94% of dairy herds worldwide (Cramer *et al.*, 2008; Elliott & Alt, 2009; Solano *et al.*, 2016). It has also been associated with production losses, fertility and claws locomotion (Holzhauer *et al.*, 2008; Gomez *et al.*, 2015; Jacobs *et al.*, 2017). Digital dermatitis causes pain to the animal and can last for a longer period, with a possibility of re-occurrence over time (Döpfer, 2009; Bruijnis *et al.*, 2012). It causes changes in claw conformation that stimulates the occurrence of other infectious foot lesions (Gomez *et al.*, 2015). Heel erosion is the most prevalent lesion in Norwegian dairy herds following digital dermatitis with 34.8% and 22.1% of the incidences reported on problematic and controlled herds respectively (Knappe-Poindecker *et al.*, 2013). Heel erosion has been associated with higher incidences of lameness due to the poor quality horn as a result of reduced claw hardness and a compromised horn heel, as it is responsible for bearing weight (Frankena *et al.*, 2009; Knappe-Poindecker *et al.*, 2013). Foot rot is often reported as the most frequent lesion, causing about 90% of lameness incidences in sheep in Great Britain (Kaler & Green, 2008, 2009). However, about 40 % of cases of foot rot have been reported in dairy cattle in the first 30 days after calving (Metre, 2017). The occurrence of this lesion has been correlated to hygiene management in dairy herds (Metre, 2017), resulting in decreased feed intake and immediate milk loss. Furthermore, foot rot may result in the formation of abnormal heels or other lesions such as digital dermatitis and ulcerative interdigital lesion (Shearer, 2009).

Table 2.1. Description of infectious and non-infectious claw lesions adapted from (Larson *et al*., 2014; Egger-Danner *et al*., 2015).

Name of lesion type	Description (symptoms)
Heel erosion (E)	Severe bulb erosion, occurring as V-shaped in severe cases and may also extend to the corium. Uneven weight bearing due to a damaged horn. As the problem continues the heel becomes sore. Zone affected: 6.
Foot rot	Tipping toes, symmetrical and painful swellings of the foot, lower leg and dew claw. Zone affected: 9
Digital dermatitis (DD)	It occurs on the skin just above or below the horn or the skin in between the digits of the claws. Causing painful bright- red or black circular sores or ulcerations. Affected cows are lame. Zone affected: 9, 10.
Axial fissure (AF)	Vertical crack or groove in the inner claws parallel to front claw surface. Bleeding may be an indicator for this lesion. Results into mild or severe lameness. Zones affected: 11, 12.
Sole ulcer (SU)	It occurs at a sole heel outside hind claws, exposing fresh or necrotic corium. Zone affected: 4
White line (WL)	It is a void that occurs in the junction between the sole and the wall in mild cases. In severe cases, abscesses form, at the heel-sole-wall juncture. Zones affected: 1, 2, 3
Toe ulcer (TU)	Black mark, blood stain and/or rupture in white line or sole at the toe caused by rotation of pedal bone within the claw pressing down on the sole or thin soles. Zones affected: 1
Cork crew (C)	Rapid irregular growth of the claw with rotation. Sole displaced inward and rear. Causes difficulty in walking. Zones affected: 7
Sole haemorrhage (H)	Appears as a light to dark red coloration at the sole. Zones affected: 4,5,6
Sole fracture	Separated sole and bulb, exposed corium and heel fracture. Zone affected: 4,5.

The most prevalent non-infectious lesions (sole ulcer, toe ulcer, sole hemorrhage, and white line disease (Table 2.1) cause constant pain and lameness and represents over 65% of all lesions diagnosed in visually lame cows and represents the largest source of economic losses amongst the several lameness related diseases (Bicalho *et al.*, 2007). The most prevalent lesions in this category on dairy farms are sole ulcers and white line lesions. Sole ulcers occur mostly in the lateral claw of the rear foot, affecting both claws with high chances of re-occurrence (Shearer & van Amstel, 2017). Sole ulcers are a result of the poor claw quality production, resulting from inappropriate weight distribution throughout the claw horn (Oikonomou *et al.*, 2013; Nuss, 2014). Similarly, weight distribution has also been associated with the development of sole ulcers as a result of enhanced horn growth (Shearer & van Amstel, 2017). In a study by Kehler & Sohrt, (2000), sole ulcers were also associated with claw permanent displacement and a compressed corium. Other authors have correlated the composition and thickness of the digital cushion with sole ulcers (Bicalho *et al.*, 2008). A sole ulcer may also arise from other claw lesions such as white line, hemorrhage and interdigital hyperplasia (Holzhauer *et al.*, 2008). Furthermore reduced fertility, poor locomotion scores and higher incidences of milk fever has been associated with sole ulcers (Sogstad *et al.*, 2006; Tadich *et al.*, 2010; Amory *et al.*, 2008).

White-line lesions usually occur within the white line horn in the form of an abscess that results in pain and lameness (Shearer & van Amstel, 2017). This lesion has been associated with a thinner digital cushion, where the sensitive tissues are not usually protected resulting in increased forces that lead to white line bruises (Bicalho *et al.*, 2009; Green *et al.*, 2014). Similarly, Bicalho *et al.*, (2009) correlated reduced thickness of the digital cushion as a result of low body condition score with the incidence of the white line. On the other hand, Greenough, (2007) related white line separation with a compressed and expended digital cushion as a risk factor leading to white line lesions. A white line may also be influenced by increased forces transferred on the laminar of the dermis due to physical stresses linked with weight bearing (Shearer & van Amstel, 2017). Other claw lesions such as hemorrhages, corkscrew claw, toe ulcer, and axial fissures also underlay white-line diseases (Kujala *et al.*, 2010; Newsome *et al.*, 2016). Larson *et al.*, (2014) associated axial fissures and sole fracture lesions with environmental factors such as walking surfaces, nutrition and increased standing times. Hemorrhage lesions are a result of damaged sensitive tissues caused by excessive weight-bearing in a claw (Mülling & Lischer, 2002; Winkler & Margerison, 2012). They are also associated with milk losses. It has been related to thin digital cushion in a study conducted by (Newsome *et al.*, 2017) in the United kingdom.

Corkscrew is a genetic lesion usually affecting the outer claw of any claw on the hind legs, growing in an inward direction towards the rear legs in a spiral shape (van Amstel, 2017). The occurrence of this lesion has been associated with the changes in the pedal bone due to increased weight-bearing and subsequent rotation (van Amstel, 2017). The occurrence of this lesion has been reported to be a risk factor for other lesion development such as white lines, sole hemorrhage, and a sole ulcer (van Amstel, 2017). Resulting in increased lameness, which has been correlated with milk losses. Corkscrew was theorized to have the potential to complicate the selection criteria (Myburgh, 2014). Since overgrown claws involve trimming which may require to be included in the selection criteria as an additional factor (Myburgh, 2014). Toe ulcers are inflammation and infection occurring at the tip of the toe as a result of mechanical damage to the toe tip (Table 2.1). In severe cases, it may lead to necrosis of the digital cushion and pedal bone. Solano *et al.*, (2016) reported that cows suffering from hemorrhages, white line, and toe ulcers are to be at risk for sole ulcers, and resulting in more cases of increased lameness in dairy cows.

Lameness results in discomfort and pain at the cow's leg level but mostly at the hoof claw level (Archer *et al.*, 2010a). Animals in pain show behavioral signs such as a decrease in mobility or a change in behavior to reduce discomfort. Reduction in feed intake, milking production and reproduction associated with lameness due to discomfort and changes in behavior have been reported (Archer *et al.*, 2010b; Chapinal *et al.*, 2009b; Huxley, 2013). In a study by Miguel-Pacheco *et al.*, (2014) feed intake periods for lame cows were significantly shorter compared to those of non-lame or healthy cows. Similar findings have been reported by other authors (Bach *et al.*, 2007; González *et al.*, 2008; Gomez & Cook, 2010), where shorter feed intake periods was associated with lame cows. Lame cows are often not willing to walk to the milking and feeding station due to pain. As a result, cow tends to reduce their discomfort by spending more time lying down (Ito *et al.*, 2010) and modifying gaits to be able to access food and water. However, in a study by (Cook *et al.*, 2008) lame cows were observed to spend most of their time standing.

Studies have also been conducted on the impacts of lameness on milk yield in dairy cows in which high milk production have been reported to be a significant risk factor for lameness (Bicalho *et al.*, 2008; Green *et al.*, 2010; Huxley, 2013). Manske, (2002b) found that 72% of the cows in a Swedish study with either one or more lesions did not result in apparent lameness although changes in locomotion were apparent resulting from increased susceptibility to more severe claw lesions. Conversely, Tadich *et al.*, (2010) did not find any association between increasing locomotion scores and other claw disorders (white line, hemorrhage and sole ulcer). In terms of reproduction performance, lameness has a major negative impact on the fertility of the affected cows (Walker *et al.*, 2008, 2010). Affected cows delay the process of insemination and have a lower chance of pregnancy. Sole ulcers and resultant lameness have also been linked with longer calving intervals, longer intervals from calving to first service and the highest chances of failure to conceive in matured cows (Sogstad *et al.*, 2006).

2.4. **Non-genetic factors**

The quality of the claw and lameness is influenced by non-genetic and genetic factors. These include environmental factors such as housing systems, walking surface, nutrition, season and management. Genetic factors are risks factors that can be controlled and managed without compromising the needs of the animals and at the same time protecting the claw integrity from these risks factors. Genetic factors include breed, claw shape, and size. In addition, the management factors associated with increased chances of lameness include not treating cows in time. Factors that affect the reduction of the incidence of the condition are also influenced by the perceptions and attitudes of farmers on the farms. Leach *et al*. (2012) reported that farmers often placed low importance on lameness control compared with other health issues such as mastitis, which the authors suggest that it could be due to the cost element attached and availability of improved recording systems and control facilities.

2.4.1. **Production systems and walking surfaces**

Dairy cattle are managed under different housing and management systems in a range of different climates worldwide including South Africa (Nigel *et al*., 2009). The choice for an appropriate housing system is dependent on the region, herd size, availability of land, climate, and whether the housing system is cost-effective or efficient (Bewley *et al*., 2017). The chosen housing system should provide good comfort, easy access to water and food, and the cow should remain productive (Bewley *et al*., 2017). In South Africa, there are two commonly used production systems in dairy farming which include: pasture grazing system and Total Mixed Ration (TMR) (Theron & Mostert, 2009; Abin *et al.*, 2018). Pasture-based husbandry is practiced in mostly in the southern regions of South Africa, where historically the rainfall was more reliable for all-year-round high-quality grass /legume pastures where grazing could be cultivated. In pasture grazing systems, cows are kept on pasture and allowed to graze throughout the year and are provided with supplements to boost their nutritional requirement (Cook & Nordlund, 2009). This system is known to generate cow comfort associated with improved claw health, locomotion scores, as well as reduced clinical lameness (Olmos *et al.*, 2009). Challenges with this system are primarily during the warmer and rainy weather whereby the cows are exposed to muddy conditions and are more likely to suffer from heat stress. These conditions have been reported to be risk factors for claw diseases resulting in lameness (Bewley *et al.*, 2017; Endres, 2017).

Total Mixed Ration is a predominant system used by the majority of the dairy producers situated in the central regions of South Africa (Abin *et al.*, 2018) and cows are kept in a stall or barn permanently protected from inclement weather, provided with balanced ration, and not allowed to graze at all. Dairy cows are housed under a different range of TMR systems such as free-stall, dirt-lot, composed-pack barns, as well as conventional bedded-pack worldwide (Fjeldaas *et al.*, 2011; Chapinal *et al.*, 2013a; Bewley *et al.*, 2017). However, in South Africa, free stall and dirt lot are the only two commonly used housing systems (Muller *et al.*, 1996; Webb & Erasmus, 2013). In free stall systems, cattle are housed in a confined housing system that has an artificial flooring surface, a resting base and a neck rail to restrict the animal from standing too far forward in stalls (Bewley *et al.*, 2017). The type of bedding used in these systems includes composted or dried separated manure solids (green solid), sand, rubber, and mattress (Bewley *et al.*, 2017). The walking surfaces are mainly hard solid concrete floors in the walking alleys. Walking and lying surfaces play an important role in the development of claw lesions resulting in lameness (Endres, 2017). Uncomfortable free stalls have been related to increased standing, low lying periods, and increased time perching, resulting in claw lesions (Bicalho & Oikonomou, 2013).

Gomez & Cook, (2010) found reduced standing hours when cows were housed in stalls with deep sand beds, suggesting that sand bedded stalls provide good comfort, thus encouraging lying periods. Andreasen & Forkman, (2012) associated low lameness incidences with cows housed on sand bedded stalls, and resulting in increased milk production compared to those that were exposed to mattress bedding. Rushen & De Passillé, (2006) found a lower number of strides, slipping as well as shorter walking time on walkways than on concrete. Rubber floors were associated with improved gait on cows with sole ulcers (Flower *et al.*, 2007). The stall design has been reported to be a risk factor for lameness (Cook & Nordlund, 2009). Dippel *et al.*, (2009) reported a significant relationship between the presence of short neck rails and the prevalence of lameness. On the other hand, Tucker *et al.*, (2006) associated the presence of brisket rail or board in stalls with reduced lying time, thus the higher lameness risks. More recently, Westin *et al.*, (2016) revealed a significant interaction between lameness incidences and the stall average width. Several authors explained several properties of different stall designs related to high incidences of claw lesions or lameness cases. However, a study by Leonard *et al.*, (1994) conducted 25 years ago clearly explained the impact of stalls design on lameness. These authors reported increased perching periods, decreased lying time and higher lameness incidences in free stalls with concrete surface and restrictive dividers compared to free stalls with minimal restrictive dividers and softer surfaces in heifers 2 months after calving.

In dry lot systems, cows are kept in open dirt corrals equipped with concrete pad in the feed bunk (Chen *et al.*, 2017)**.** Usually, with this system, a resting area with shelter is provided for the cattle rest during hot and rainy days (USDA, 2010; Chen *et al.*, 2017). However, the shelter provided for the cattle kept under the system is less as compared to the indoor housing and therefore cattle more likely to be exposed to severe rainy and hot weather (Chen *et al.*, 2017). When cows are exposed to such hot weather tend to suffer from heat stress and spend more time standing trying to cool off their body (Allen *et al.*, 2015). Cooling resources may also be provided in such farms such as shade, drinking water, and sprayed water to assist the cattle to cope with the heat load (USDA, 2010). Understanding the way dirt lot is designed this cooling resources might not be sufficient enough in mitigating the problem especially when cows are constantly exposed to such weather conditions. Both heat stress and prolonged standing hours have a negative impact on claw lesions development. During heat stress, weaker claws are produced due to the mechanical changes inside the claws horn (Shearer & van Amstel, 2017). Resulting in a higher prevalence of white line, sole ulcer and toe ulcer lesions (DeFrain *et al.*, 2013). Rainy weather is also correlated to claw lesion development due to exposure of the cow's claw to muddy conditions and wet walking surfaces (Metre, 2017). Cow's claws exposed to such conditions usually leads to their claw horns becoming softer and wearing off resulting in a higher susceptibility to claw lesions (Borderas *et al.*, 2004; Popescu *et al.*, 2010).

Highly moisturized conditions also appear to be an important risk factor for infectious diseases (Berry, 2006). Wet skin of the horn is more likely to develop digit infections. The association between wet skin and digits infection was also reported by other authors in the United States (DeFrain *et al.*, 2013; Chen *et al.*, 2017; Metre, 2017), where they associated infectious lesions such as foot rot, digital dermatitis and heel erosion with warm and wet conditions. Despite the disadvantages, dirt lot has a positive implication on the claw health and lameness of cattle (USDA, 2010). The walking surfaces in dirt lots are usually sand, providing a comfortable walking surface that allows for natural locomotion by providing enough friction. However, there are limited studies conducted to support this theory in dirt lot housing systems. The use of sand bedding has been reported (Gomez & Cook, 2010) to encourage lying activities in dairy cows, hence the positive implication on claw health (USDA, 2010). Comparing the two housing systems, their importance as risk factors for claw lesion development and resulting lameness are reflected in several studies. This is supported by the higher incidence of claw lesions reported in free stalls compared to dirt lot dairies. Rearing cows on dirt lot has been reported to improve claw health as compared to keeping cows indoors (USDA, 2010; Chen *et al.*, 2017). Incidences of lameness and lesions are less frequent in dirt lots as compared to cows in TMR systems (De Vries *et al.*, 2015). Dirt-lot provides comfortable standing and lying surfaces. Access to suitable or comfortable standing surfaces has been associated with improved claw health (Endres, 2017). Conversely, more prevalence of dermatitis has also been associated with farms with muddier corrals in dirt lots (Chen *et al.*, 2017).

Housing systems such as free stalls barns are also designed in such a way that they restrict the animal from lying or walking (Endres, 2017). In such systems, cows spend most of their time standing mostly on hard or concrete surfaces which result in the development of claw lesions and resulting lameness (Solano *et al.*, 2016). Furthermore, studies by Barberg *et al.*, 2007; Ito *et al.*, (2010) showed that cows in sand concrete floors were associated with less damage to joints. This was attributed to the fact that stall with sand bedding has good drainage as compared to solid floors, which prevent exposure of the cows to wet floors (urine) and liquid manure. Studies have shown a reduction in lying time on cows that were exposed to rain and wind (Webster *et al.*, 2008; Schütz *et al.*, 2010). Cows are more likely to be exposed to such weather conditions during the rainy and dry season. However, the effect of season on the development of claw lesions has not been well studied. Shearer *et al.*, (2006) and Sanders *et al.*, (2009) reported high incidences of thin sole ulcer, sole ulcer, and white line in summer and autumn for toe ulcer in the South-Eastern United States. Conversely, Laven & Lawrence, (2006) reported higher white line lesion prevalence during winter in the United Kingdom. However, seasonality differences between the two countries could have contributed to the finding differences. Similarly, Defrain *et al.*, (2013) found a higher occurrence of non-infectious claw lesions during and after summer as well as infectious claw lesions during the winter season in the United States. Laven & Lawrence, (2006) also found significantly higher foot rot prevalence compared to digital dermatitis in summer.

2.4.2. **Hygiene**

Infectious hoof disorders such as dermatitis, foot rot, and heel erosion are linked to the hygiene, where general management plays a role in the development and spread of these lesions (Chapinal *et al.*, 2010a; Evans *et al.*, 2016; Metre, 2017). The nature of the walking surface and floor wetness are common factors reported in the literature (Chapinal *et al.*, 2010b, 2013a; Metre, 2017). Highly moisturized conditions with low oxygen pressures are risk factors for infectious lesions (Berry, 2006). The skin of the hoof and horn exposed to highly moisturized environmental conditions is more likely to develop feet and digits infections (Berry, 2006).

Surface hygiene is a major factor that may worsen infectious hoof disorders (Knappe-Poindecker *et al.*, 2013). As a result, regular cleaning may keep the environment clean, while minimizing the incidents of infectious lesions. In a study conducted by Doerfler *et al.*, (2017) shorter cleaning intervals improved hygiene and reduced the accumulation of liquid manure and infectious claw lesions. Similarly, Yaylak *et al.*, (2010) and DeVries *et al.*, (2012) associated shorter cleaning intervals with decreased manure on walkways. Damaged and softer hooves are more prone to pathogenic agents while dryer walkways sustain stronger and harder hooves that are more resistance to claw disease pathogens (Borderas *et al.*, 2004; Popescu *et al.*, 2010).

Footbaths are the most commonly used method to control infectious claw disorders (Jacobs *et al.*, 2017) to maintain a healthy environment for dairy cows. However, poorly managed footbaths may increase the spread of diseases such as digital dermatitis (Smith *et al.*, 2014). Solutions that are kept for a period longer than the recommended time, may become weaker and less effective, and may also act as a medium for the spread of a pathogen within the herds (Smith *et al.*, 2014).

The use of footbaths solutions varies with different farmers as the substances used are detrimental to the animals, handlers, and environment. Copper Sulphate ($CuSO_4$) for example is a standard compound used in footbath solutions by the industry to treat infectious diseases such as digital dermatitis (Cook *et al.*, 2012; Logue *et al.*, 2012; Speijers *et al.*, 2012), followed by formalin (Solano *et al.*, 2015).

Copper sulphate has been reported to be harmful to the environment when it reaches the soil and to the cow itself (Smith *et al.*, 2014). Regardless of its negative effects, copper sulphate has been considered to be the most effective solution to eliminate dermatitis within a short period (Cook *et al.*, 2012; Logue *et al.*, 2012; Speijers *et al.*, 2012; Jacobs *et al.*, 2017). In a study by Speijers *et al.*, (2012) copper sulphate (5%) used on a weekly basis eliminated the high prevalence of digital dermatitis. Fjeldaas *et al.*, 2014 associated copper sulphate with improved heel erosion and digital dermatitis occurrence. Fjeldaas *et al.*, (2014) also found harder claw horns on cows that were dipped in copper sulphate and had softer claws when they were exposed to water. This could suggest that copper sulphate eliminates infectious diseases without compromising claw quality. However, the copper sulphate was ineffective in a solution compromised of 20% manure.

Formalin has been associated with undesirable characteristics, such as toxins that may lead to cancer (Doane & Sarenbo, 2014). Other harmless systems have been implemented such as the use of automated water flushing in an attempt to mitigate digital dermatitis by washing the hind feet (Thomsen *et al.*, 2012). However, this system did not reduce the disease prevalence although claws were cleaned effectively. Other compounds such as organic and inorganic compounds have been used in footbaths to eliminate infectious claw lesions. Capion et al., (2018) found 73%, 71% and 62% healing rates for the inorganic acid solution, salicylic acid, and inorganic acid powder respectively. Similarly, salicylic acid was also associated with higher improved rates for digital dermatitis than chlortetracycline spray (Schultz & Capion, 2013). The finding thus suggests that footbath is the most effective means to control and manage infectious lesions.

General management factors such as auctions are also a potential source of infection and contribute to the spread of various infectious claw diseases. A study by Hulek *et al.*, (2010) found 12.1% prevalence of digital dermatitis in first lactation cows at the Australian auction centre. It was suggested by the authors that when buying breeding stock, thorough examination for digital dermatitis and overall claw health is a necessity. Therefore, biosecurity measures must be followed, and animals must be tested upon arrival and quarantined for two weeks until proven clean. As a result, the introduction of various management strategies has been recommended which includes footbaths and biosecurity programs in dairy herds (Solano *et al.*, 2017).

2.4.3. **Nutrition**

Nutritional management has been reported as a factor influencing claw health and plays a vital role in claw horn development (Lean *et al.*, 2013). Good nutrition is important for the development of a robust claw horn and a healthy hoof that can withstand harsh environmental conditions (Muelling, 2009; Bauer *et al.*, 2018). The claw consists of a water-soluble protein known as keratin, generated through the process of keratinization of keratinocytes and membrane coating material in the epidermis (Hoblet, 2000). Biotin is the most important vitamin involved in the process of keratinization as it is responsible for the integrity and formation of the claw horn. A deficiency in biotin may result in the formation of soft and weaker claw horns that are prone to lesion development. Lameness can cause a radical decline in biotin reserves which may result in decreased keratinization and intercellular cementing substance production of the claw horn (Tomlinson *et al.*, 2008). Several studies have found that feeding supplemental biotin of 10 to 20 mg results in a reduction in claw lesions such as sole hemorrhages, white line separation and sole ulcers (Hedges *et al.*, 2001; Lean & Rabiee, 2011). It has also been shown that biotin supplementation can improve hoof health under stressful conditions (Lean *et al.*, 2013). On the other hand, Chen *et al.*, (2012) did not find any significant differences between the hardness of the claw and moisture content with biotin supplement concentrations of 20 and 40 mg per day.

Vitamin A, D, and E also play an important role in the quality and structure of the keratinized tissues (Lean *et al.*, 2013). Vitamin A is significant for during the process of cell keratinization, while vitamin D forms part of the significant calcium metabolism regulators (Lean *et al.*, 2013). Vitamin E is responsible for the lipid-rich cellular membrane maintenance in the intercellular cementing substance of horn tissue (Lean *et al.*, 2013). Feeding high amounts of feeds rich in readily fermentable carbohydrates may result in ruminal acidosis (Bramley *et al.*, 2008; Golder *et al.*, 2012), which has been associated with higher production of volatile fatty acids and lactic acids causing a decline in ruminal ph. Low ruminal ph has been associated with laminitis, lameness and metabolic acidosis (Lean *et al.*, 2000, 2013). Feeding grass, as well as fructose, has been reported to reduce ruminal ph and increase volatile fatty acid and lactic acid concentrations (Golder *et al.*, 2012). Similarly, Nagaraja & Titgemeyer, (2007) suggested high amounts of grains supplied in an extremely fermentable form may lead to acute acidosis. Furthermore, lower consumption of neutral detergent fiber, as well as high consumption of non-fiber carbohydrates, has been associated with herds with a higher prevalence of cows with acidosis than herds with lower incidences (Bramley *et al.*, 2008). In addition to high carbohydrates diets, some studies have reported that high amounts of rapidly degradable protein may encourage the risks of laminitis and acidosis (Lean *et al.*, 2013). Increased prevalence and time intervals of lameness have been reported in cows fed with higher levels of crude proteins.

As highlighted in a study by Lean *et al.*, (2013) high protein diets were also associated with higher poor locomotion scores, outer toe length as well as the frequency and length of lameness incidences. Low dry matter percentage (25% DM) has also been reported to trigger the development of claw lesion rather than a high dry matter (60%) diet (Offer *et al.*, 2003).

Minerals such as Zinc (Zn), Manganese (Mn), Copper (Cu), Cobalt (Co), Selenium (Se), Zinc (Zn), Calcium (Ca) and Sulphur (S) affect claw integrity (Table 5.1). Claw horn integrity involves the physiological structure, protective and biochemical function of the healthy claw (Bauer *et al.*, 2018). Therefore, it is important that minerals are supplied correctly to support a smooth keratinization process (Muelling, 2009). During keratinization, Zn is required to act as a catalyst to activate Zn metalloenzymes, which are fundamentals for differentiation of keratinocytes (Lean *et al.*, 2013; Bauer *et al.*, 2018). Zinc also plays a vital role in the production of structural proteins as well as enzymes (Cu/Zn superoxide dismutase) which inhibits lipid peroxidation. Likewise, it regulates binding proteins (Calmodulin (CaM)) which carries and binds calcium ions into the cytosol of keratinizing cells, the last important step in the formation of keratinocytes (Lean *et al.*, 2013). Insufficient supply of Zn may result in producing poor horn tissues thereby increasing the chances of claw diseases and resulting lameness. Belge *et al.*, (2004) found notably lower blood Zn levels in cows infected with chronic laminitis compared with scores obtained from sound cows. Similar to Zn, Copper (Cu) activates a number of enzymes including Cu/Zn superoxide dismutase as well as cytochrome-c and thiol oxidase (Lean *et al.*, 2013). Thiol oxidase is responsible for the development of chemical bonds among keratin filaments, which provide the keratinized horn cells with rigidity and structural strength. Effects of Cu deficiency are reviewed in studies by (Muelling, 2009; Lean *et al.*, 2013), which included cows that are more prone to foot rot, heel cracks, sole abscesses as well as the production of compromised horn tissue.

Table 2.2. Important minerals required for horn formation and integrity adopted from Lean *et al.*, (2013).

Micro - mineral	Macro - mineral	Role
Cobalt (Co)		An important component for vitamin B-12
Copper (Cu)		Act as a catalyst during keratinization
Manganese (Mn)		Act as a catalyst during keratinization
Selenium (Se)	Calcium (Ca)	Responsible for horn production, protection and maintenance
Zinc (Zn)		Act as a catalyst during keratinization
	Sulphur (S)	Responsible for horn quality

Cobalt deficiency results in vitamin B12 deficiency associated with decreased energy and protein metabolism, while Manganese has an indirect influence on the keratinization process, acting as a catalyst for enzymes (pyruvate carboxylase) responsible for energy production. The role of other important minerals such as calcium and selenium has been reviewed in a study by (Muelling, 2009), indicating that calcium is responsible for horn production, by a process that is mainly controlled in the epidermis by the calcium concentration. Inadequate provision of calcium caused by hypocalcemia may compromise the quality of the claw horn. Selenium may add value (protection and maintenance) to the intercellular cementing substance. An oversupply of selenium has been shown to result in soft and unstable horns (Combs, 2000). Soft horns and resulting lameness have been associated with an inadequate supply of Sulphur comprising of amino acids (Lean *et al.*, 2013).

2.4.4. **Genetic factors**

Recording or reporting claw lesions is crucial for improved management and selection against lesions. The availability of lesions data for individual cows may enable the producers to inspect, identify and treat lesions as well as track changes over time (Cramer *et al.*, 2008; Chapinal *et al.*, 2009b; Heringstad *et al.*, 2018). There are different types of recording systems available in dairy cattle, which are used for collecting and reporting specific foot or lameness lesions information. This includes claw or hoof trimming data, veterinary diagnosis data and automated data collection systems (Heringstad *et al.*, 2018). However, hoof trimming data is the most commonly claw recording systems in the central regions of South Africa. The claw trimming data is usually generated through various claw lesion associations such as DairySmid Trimming Association in South Africa and ICAR claw health Atlas recording systems in European countries (Egger-Danner *et al.*, 2015; DairySmid, 2016).

DairySmid trimming and the Hoof Trimmers' Association are the most common South African recording private companies, commercially available to local producers. However, DairySmid Trimming Association is mainly used by those producers that are situated in the central regions of South Africa. DairySmid uses lameness assessment tools developed by Zinpro which are also internationally recognized as guidelines to classify and assess risk factors for lameness in dairy cows (Larson *et al.*, 2014). It provides full descriptions and claw zones of different claw traits (14 important claw lesions) to guide with efficient assessments and recording during trimming by trained trimmers (Larson *et al.*, 2014). This also includes lesion classification categories according to their aetiology. In addition, locomotion scoring is part of the assessment tool used to detect the presence of claw disorders. It is based on observation of the cow when standing, walking, as well as, the posture. However, visual observation can be laborious and time-consuming since it requires observation of individual cows while standing and walking (Potterton *et al.*, 2012: García-muñoz *et al.*, 2017). Yet, recording of these diseases may enable early detection of claw disorders to help producers, trimmers, as well as, veterinarians to observe and compare the incidences of lameness.

ICAR is an internationally recognized recording system developed to promote the development and improvement of performance recording and genetic evaluation of livestock (Egger-Danner *et al.*, 2015). It is a new claw health evaluation procedure in South Africa, but common in other countries such as New Zealand, Germany, and Italy (Bryant *et al.*, 2018). ICAR is focusing on a range of important traits in dairy cattle including fertility, udders, and health (Egger-Danner *et al.*, 2015). However, more recently ICAR prioritised feet and legs as well as claw health traits and developed recording practices. Together with the international recognized claw experts (Egger-Danner *et al.*, 2015), ICAR developed and published a claw health atlas in 2015 which consists of 27 clearly described claw lesions to aid in accurate lesion identification and recording high quality-data experts (Egger-Danner *et al.*, 2015). The atlas is projected to improve early detection of claw health disorders through improved claw recording and evaluation of dairy cattle.

Studies have demonstrated genetic improvement can be achieved through data recorded by claw trimmers (Häggman & Juga, 2013; van Pelt *et al.*, 2015; Heringstad *et al.*, 2018). However, to perform genetic evaluations data is required to estimate genetic parameters including heritability and correlations. Although claw health lesions have low heritability, breeding for increased claw health may improve claw health in the long run (Bicalho & Oikonomou, 2013). Low heritability on lameness, other claw disorders, and locomotion have been reported, with heritability values varying between low (0.01) to moderate (0.20). The heritability of individual claw data recorded by claw trimmers ranged from 0.002 to 0.2 (Table 2.3), indicating that the traits are lowly to moderately heritable. However, a higher heritability ranging from 0.19 to 0.52 was reported in a study by Schöpke *et al.*, (2015) where better clinical status definitions were used. The study illustrated that higher heritability can be achieved on a more accurately recorded data.

Table 2.3. Heritability estimates(h^2) for traits recorded by trimmers adopted from Heringstad *et al.*, (2018).

Claw traits	h^2	Reference	Model[1]
Individual traits			
Digital dermatitis	0.20	Ødegård *et al.*, (2013)	TM
	0.02	Pérez-Cabal & Charfeddine, (2015)	LM
	0.20	Ødegård *et al.*, (2013)	TM
Heel erosion	0.03	Buch *et al.*, (2011)	LM
	0.09	Ødegård *et al.*, (2013)	TM
Hemorrhage	0.04	Johansson *et al.*, (2011)	LM
	0.07	Ødegård *et al.*, (2013)	TM
Sole ulcer	0.04	van der Spek *et al.*, (2013)	LM
	0.018	Ødegård *et al.*, (2013)	TM
White line	0.02	Pérez-Cabal & Charfeddine, (2015)	LM
	0.09	Gernand *et al.*, (2012)	TM
Cork screw	0.02	Johansson *et al.*, (2011)	LM
	0.23	Ødegård *et al.*, (2013)	TM
Toe ulcer	0.02	Malchiodi *et al.*, (2017)	TM
	0.002	Malchiodi *et al.*, (2017)	LM
Grouped traits			
Infectious	0.11	Dhakal *et al.*, (2015)	TM
Non-infectious	0.08	Dhakal *et al.*, (2015)	TM
Trimming status	0.06	van der Spek *et al.*, (2015)	LM
Front lesion	0.015	Chapinal *et al.*, (2013b)	LM
Rear lesion	0.079	Chapinal *et al.*, (2013b)	LM
Locomotion	0.014	Linde *et al.*, (2010)	
Locomotion traits			
Lameness	0.15	Weber *et al.*, (2013)	
Claw shape	0.16 - 0.32	Jeyaruban *et al.*, (2012)	TM
Foot angle	0.17 - 0.32	Jeyaruban *et al.*, (2012)	TM
Mobility	0.21	Wright *et al.*, (2013)	
Feet and legs	1.18	Onyiro *et al.*, (2008)	

[1]LM = Linear Model, TM = Threshold model

Heritability estimated using the threshold models were higher compared to linear models (Table 2.3). The effects of models have been highlighted by several authors stating that threshold models consider multiple disease incidences or make use of longitudinal threshold models (Heringstad *et al.*, 2003; Chang *et al.*, 2006), while in linear models such cases are not considered. The grouped infectious lesions (0.11) revealed a higher heritability than the non-infectious (0.08) (Table 2.3). This could be explained by data availability recorded in each grouping. Authors have shown that non-infectious lesions are the most prevalent lesions in dairy herds (Ariza *et al.*, 2019), this could be suggesting that the lesions are more likely to be recorded than the non-infectious ones.

A heritability of 0.06 was reported on trimming status. On the other hand, a higher heritability for claw disorders on rear legs (Table 2.3) was reported compared to front legs (Chapinal *et al.*, 2013b), suggesting that this could be due to the higher frequency observed on rear legs (34.5 %) than on front legs (7.0) during the study.

Trimming status on whether the cow was trimmed or not showed a heritability of 0.06. This grouped trait is related to early detection of claw lesions (Heringstad *et al.*, 2018). Higher heritability ranging from 0.11 to 0.33 was reported on locomotion and locomotion traits (Table 2.3). Several studies have illustrated the importance of including lesions or lameness records and the genetic correlation with other traits (van der Waaij *et al.*, 2005; Onyiro *et al.*, 2008; Linde *et al.*, 2010). A negative genetic correlation between foot angle and lameness has been reported and as such selection for higher foot angle scores may lead to improved genetic resistance to lameness (van der Waaij *et al.*, 2005; Onyiro *et al.*, 2008). Milk yield has also been found to have a negative genetic association with body condition score, while on the other hand increased susceptibility to lameness has been genetically and phenotypically correlated to body condition score (Bicalho *et al.*, 2009; Kougioumtzis *et al.*, 2011; Loker *et al.*, 2012). Selection of higher producing cows that are also cable of maintaining their body conditioning could add value to the genetic improvement of cows' resistance to lameness.

A significant (0.75) genetic correlation between lameness and milk yield has been reported (Kougioumtzis *et al.*, 2011), suggesting that constant selection for increased milk production without considering lameness in the breeding goal can lead to a decline in claw health. Oikonomou *et al.*, (2013) recently reported that intermediate sire's predicted transmitting ability values for foot angle correlates with the lowest incidence of daughters' sole ulcers and white line disease. Koenig *et al.*, (2005) reported a negative genetic correlation between rear legs rear view and incidence of sole ulcers or lameness. Furthermore, a study by Buch *et al.*, (2011) also reported that including claw-trimming records in a selection index may reduce the genetic decrease in resistance to claw diseases. High producing cows are disposed to become lame (Bicalho *et al.*, 2008; Archer *et al.*, 2010) and are correlated with a higher prevalence of claw disorders with certain breeds at higher risk compared to others (Baird *et al.*, 2009). In a study comparing Norwegian (N) and Holstein Friesian (HF), N breeds have shown that the N breed had a higher body condition score as compared to the HF (Yan *et al.*, 2006). The observation deduced from the study suggested that the Norwegian genotype partitions less energy into milk, thereby preserving more energy for body reserves compared to the HF genotype. Increased lameness incidences have phenotypically and genotypically been associated with low body condition score (Bicalho *et al.*, 2009; Kougioumtzis *et al.*, 2011). Low body weight cows are related to notably higher chances of mild or severe frequent lameness events compared with heavier bodyweight cows (Randall *et al.*, 2015). Baird *et al.*, (2009) reported a lower prevalence of white-line lesion in Norwegian cows than in Holstein-Friesian.

2.4.5. **Conclusion**

The prevalence of lesions is increasing in dairy herds, resulting in severe cases of lameness and subsequent economic losses. Although, some lesions have been associated with genetic factors, management, and productions systems are the major risks factors for increased claw lesions and subsequent lameness. Therefore, proper implementation of preventative, control and treatment programs in dairy herds, require attention. Literature indicates that there is a need for improving animal recording, data storage systems and increased awareness around lameness.

Chapter 3: Materials and Method

3.1. Introduction

In this study, claw traits in dairy cows were evaluated based on available records from farmers in central regions of South Africa. This chapter provides a detailed description of the materials and methods used to achieve the objectives of this study. The study was carried out with ethical approval (EC: 180000123) of the University of Pretoria research and ethics committee for external data use and consent of the farmers that provided claw lesions recordings.

3.2. Materials and methods

Farms

The data was provided by 10 commercial dairy farms situated in the central regions of South Africa. This included farms that are situated in the Mpumalanga, Free State and Gauteng provinces of South Africa (. Temperature and rainfall range from a minimum to a maximum of 9.6 - 28.2 °C and 496 - 708 mm respectively (Table 3.1). The predominant soil types for these farms include undifferentiated structure-less soils, texture contrast soils often poorly drained, freely drained structure-less soils, undifferentiated clays, as well as undifferentiated shallow soils and land classes (Table 3.1). The soil types are classified according to their physical properties as well as their limitations.

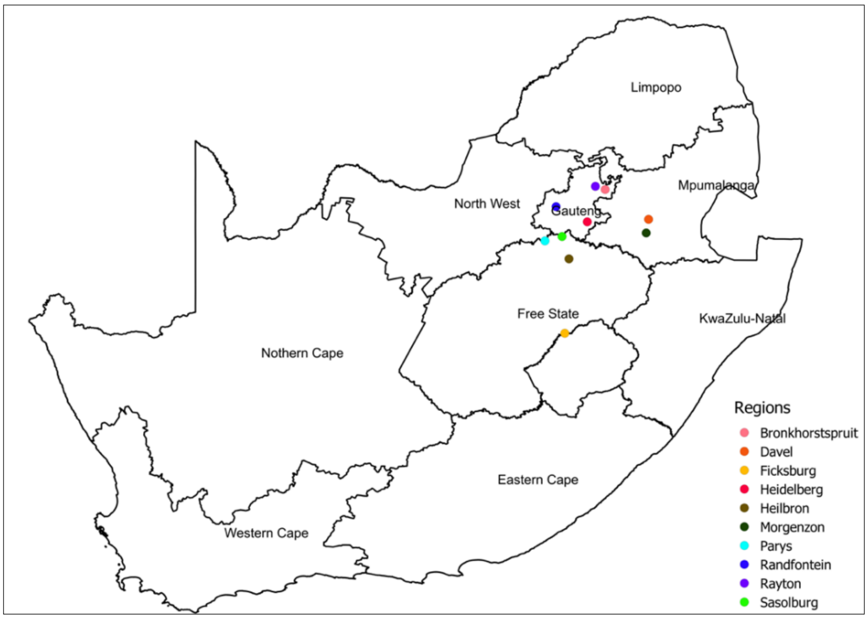

Figure 3.1. Locations for participants in the study.

The undifferentiated structure fewer soils (S17) are soils that have favorable physical properties but has one or more low base status such as restricted soil depth, excessive or imperfect drainage, and high erodibility (Soil classes, 2006). The S14 soils, which are also classified as a texture contrast soils often poorly drained with relative wetness, suitable in dry areas (Soil classes, 2006). The S25 soil class is structure less and shallow. It is known for its favourable physical properties such that soil components may receive water runoff from the associated rock (Soil classes, 2006). The limitations of this soil class include restricted soil depth, excessive drainage, high erodibility and low natural fertility (Soil classes, 2006). The undifferentiated clays, identified as S18 soils, are naturally fertile soils with high swell-shrinking potential, plastic, and sticky texture, restricted effective depth, and wetness (Soil classes, 2006. Moreover, the undifferentiated shallow also identified as S21 soils have favourable physical properties such that soil components may receive water runoff from the associated rock. However, it has restricted land use options (Soil classes, 2006).

Table 3.1. Soil types and climatic parameters of the dairy farms.

Farm names	Regions	Soil ID	Temperature (°C) ranges	Rainfall (mm) / annum
A	Randfontein	Undifferentiated structureless soils	16.3 – 26.3	571
B	Davel	Texture contrast soils often poorly drained	15.9 - 24.8	594
C	Bronkhorstpruit	Freely drained, structureless soils	17.8 - 26.7	570
D	Morgenzon	Undifferentiated clays	16.1 - 25.2	560
E	Ficksburg	Undifferentiated shallow soils and land classes	15.6 - 27.6	621
F	Heilbron	Undifferentiated structureless soils	16.2 - 27.1	530
G	Heidelberg	Undifferentiated clays	16.6 - 26.3	588
H	Rayton	Freely drained, structureless soils	9.6 - 20.8	708
I	Parys	Freely drained, structureless soils	17.2 - 28.2	496
J	Sasolburg	Freely drained, structureless soils	17 - 27.9	550

3.3. Materials

3.3.1. Data sets and lesion identification manuals

The claw lesion data for the selected 10 dairy farms were obtained from DairySmid Trimming Association for analysis. DairySmid is an independent, internationally recognized trimming association responsible for recording, identification, control and prevention of claw traits, with a purpose of improving the health and longevity of the cows (DairySmid, 2016. Trimming Association. Https://dairysmid.wixsite.com/dairysmid). Their standard is used by the majority of dairy producers in the central region of SA. The association thus served as a source of data for all the participants in this study. The data provided included eight years of data records arranged according to farm names. Information on the cow numbers, lesion type, date of recording, the number of lesions recorded as well as the number of cows trimmed was also included on the datasheets. Additional data on the herd sizes for the year 2018 for all the 10 farms was provided by the South African Stud Book Association (SA Studbook). No data on overall herd sizes for the remaining years were available.

In addition, the claw identification manual, which includes different claw lesions was also provided by DairySmid association. This manual was compiled and produced by the Zinpro Corporation International Bovine Lameness Committee (Https://www.zinpro.com/lameness/dairy/lesion-identification). The ICAR claw health ATLAS was downloaded from the ICAR website (Https://www.icar.org/documents/ICAR_Claw_Health_Atlas.pdf) published by ICAR in June 2015. The ICAR recording system was compared with that of the Zinpro lesion identification procedure, to investigate its applicability thereof in South African dairy cattle. This was done during hoof trimming with claw trimmers, for the two visited farms.

3.4. Methods

3.4.1. Herd selection

The study was carried out using dairy cows on commercial dairy farms that are participants in the SA lesion recording system with DairySmid. A selected sample of 10 commercial dairy farmers (Table 3.1) was identified in the central regions of South Africa. To avoid bias, any client who participated in the SA lesion recording carried out by the lesion recording organization was suitable to participate. For eligibility to participate in this study, producers were required to have had at least a minimum of 5 years' lesion data records. All the selected farmers were Total Mixed Ration (TMR) producers since the predominant production system in the central region of SA is a TMR system. The producers were either using one or both of the two types of TMR systems for production, which includes free stall and dirt (dry) lot housing system.

3.4.2. Data collection

Claw lesion data

The present study used claw health data collected during trimming, performed by claw trimmers (DairySmid) in the period from January 2011 to May 2018. Trimmed cows and observed claw disorders were recorded on the lesion recording sheets (Addendum A). The dataset comprised of 24 887 claw disorders from 48 993 cows in 10 dairy herds (Table 3.2.). These values were calculated from the total number of cows trimmed and lesions recorded across all farms. The scored claw disorders included heel erosion (**E**), digital dermatitis Foot rot (**F**), hairy attack (**HA**), axial fissure (**AX**), sole ulcer (**SU**), toe ulcer (**TU**), white line (**WL**), sole fracture (**SF**) and corkscrew (**C**).

Table 3.2. Summary of the recorded data per producer.

Producer	Housing system	No. of lesions recorded	No. of cows trimmed	No. of years collected	Milk yield Yes/No
A	Free stall	2735	3454	4	No
B	Free stall	1758	3014	7	Yes
C	Dirt lot & free stall	1374	4742	7	No
D	Free stall	5146	11237	7	No
E	Dirt lot	3157	6164	7	No
F	Dirt lot	3587	7103	7	No
G	Free stall	2183	2752	6	No
H	Dirt lot	1224	1741	7	Yes
I	Free stall	1310	3113	6	No
J	Free stall	2413	5673	6	No

Additional information was provided from the lesion record sheets (Addendum A) which included the position of the lesions (POL) as it was identified using the claw zones diagram (Figure 3.2), the severity of the lesions and whether the lesion occurred on the front or rear legs. Chapinal *et al.*, (2013b) indicates that a majority of the lesions occur on the rear legs with both rights and left rear claw disorders occurring. However, this additional information was out of the scope required for this study, hence it was not included in the lesion dataset.

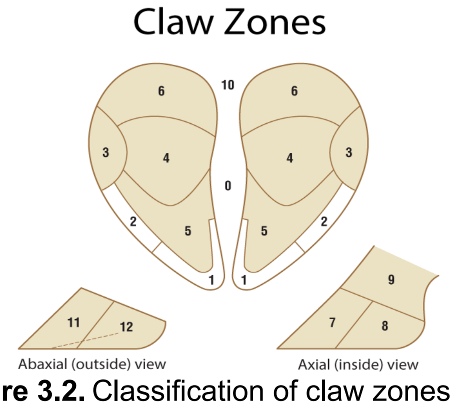

Figure 3.2. Classification of claw zones (Larson *et al.*, 2014).

3.4.3. Comparison with ICAR claws health ATLAS.

Hoof health or lameness observations

Due to limited research funds, only two dairy farms (Farm B and H) were visited in Mpumalanga and Rayton. Each farm was visited once during the summer season following the trimming dates provided by the claw trimmer for the different farms. The observations were done on two different occasions at different farms. Farm H was visited in November 2018 and farm A in February 2019. During hoof trimming with claw trimmers, claws for the two selected herds were evaluated and compared with the ICAR claw health ATLAS to investigate its applicability thereof in South African dairy cattle. The hoof scoring and trimming was carried out by the same person throughout the observation period, following the DairySmid recording procedures (Appendix A.1). During trimming the cows were restrained in a metal handling machine; their hind and front legs were lifted subsequently (Figure 3.3), and the claws were individually examined and trimmed. The horn was trimmed using the electrical trimming machine (grinder) from the whole area of the weight-bearing surface to expose the fresh horn.

Figure 3.3. Three trimming stages, A = Restrained right leg, B = Claw measuring and C = Trimmed claw.

Claws with uneven length were trimmed and shaped to the correct desired size. The size and shape of the claws were then confirmed manually using the Pacman claw measuring hand equipment. All trimmed claws with or without lesions were recorded on the recording lesion sheet (Appendix B). Scored claw disorders recorded during the visit included heel erosion (**E**), digital dermatitis (**DD**), foot rot (**F**), hairy attack (**HA**), axial fissure (**AX**), sole ulcer (**SU**), toe ulcer (**TU**), white line (**WL**), sole fracture (**SF**) and corkscrew (**C**) (Figure 3.4). The sole lesions were scored for extent and severity of the claw affected, the position of the lesion on the claw zones, whether it developed on the left or right legs (lateral or medial) for both hind and front legs.

Figure 3.4. Ten recorded claw lesion types A = Corkscrew, B = Axial fissure, C = While line, D = Foot rot, E = Toe ulcer, F = Digital dermatitis, G = Sole fracture, H = Hairy attack, I = Heel erosion and J = Sole ulcer.

The claws of the cows observed with lesions were trimmed and treated appropriately, immediately during the trimming and claw health observation (Figure 3.5). In the process of claw trimming and lesion recording with the claw trimmer, a comparison between the ICAR claw health ATLAS and Zinpro lesion identification manuals was carried out. The appearance of the lesions from the affected cow was classified according to the Zinpro identification and subsequently compared to the picture of the same lesion from the ICAR claw health ATLAS to record the similarities and differences between the two methods. The comparisons were made from clear definitions of 23 and

14 claw lesions from both the ICAR and Zinpro methods, respectively. All the lesions that did not appear on any of the cows during trimming were then compared separately using manuals for the two claw identification systems. The comparisons were made by both the trimmer and the researcher after the trimming of all cows for each section. Classifications and definitions of the lesions according to aetiology, which included non-infectious and infectious lesions, were compared between the two recording manuals. During the process, information on common lesions, lesions with different names and lesions that were present on one but not included in the other system were also noted down.

Figure 3.5. Lesion identification and treatment process, A = claw evaluation, B and C = identified lesions, D and E = claw lesion treatment (Copper sulphate) and F = treated claw lesion with a block.

Furthermore, the two systems were also compared for additional important similarities and differences. This included information on the claw zones affected by a particular lesion which was also recorded. All the lesion data recorded during the comparisons were not included in the analysis. However, it was provided as supportive information in Addendum B to be used as a reference for the type of lesions recorded during this process.

3.5. Statistical analysis

Statistical analyses using SPSS software (IBM SPSS Inc., 2019) were performed on available data. The data was first edited where all farms went through data quality check and the number of complete records from each year for each farm was considered. Ninety-five percent of the complete records were from January 2014 to March 2018. Years with fewer records were therefore excluded for accuracy. Farm A had recorded less than the required years, hence it was excluded from the entire dataset for statistical analysis. As a result, the number of claw disorders and trimmed cows decreased to 34 526 and 12 309 claw disorders (Table 3.3).

Table 3.3. Summary of the edited data per producer.

Producer	Housing system	No. of lesions recorded	No. of cows trimmed	No. of years collected
B	Free stall	865	1995	5
C	Dirt lot & free stall	645	3621	5
D	Free stall	2731	8790	5
E	Dirt lot	1732	4508	5
F	Dirt lot	1398	4233	5
G	Free stall	1568	2426	5
H	Dirt lot	974	1600	5
I	Free stall	951	2504	5
J	Free stall	1445	4849	5

In preparation for statistical analyses, the remaining dataset was then categorized as indicated in Table 3.4, and analyses were performed on the categorized data. The data used in this study consisted of records compiled by two different trimmers trained by the same trimming association namely the DairySmid. Trimmer A was responsible for records from 9 different farms, while only records from 1 farm were recorded by trimmer B. The category for trimmer was created where trimmer A was classified as 1 and trimmer B as 2 for statistical analysis, although the ratio for farms per trimmer was not ideal to perform statistical analysis. The one farm had complete claw lesions data records; therefore, it could not be excluded. Frequencies for the 10 farms before data editing were calculated using excel and frequency graphs were computed to study the patterns of each lesion. All the data were analysed using Chi-square analysis using SPSS v 25 (IBM SPSS Inc, 2019) software at $P < 0.05$ to identify significant differences among lesion types. Contingency tables (Crosstabs) and the omnibus Chi-squares were generated to see if there were significant differences between the lesion frequencies. Further analyses were performed to specify which variables contributed to the significant difference using SPSS v 25 (IBM SPSS Inc, 2019) software.

Table 3.4. Variable (s) categories for SPSS analyses

Lesion type	Infectious Lesion	Non-infectious lesions	Farm name	Season*house type	Year	Season	Housing type
E =1	E = 1	HA = 1	A = 1	Free stall* Summer = 1	2014 = 1	Summer = 1	Free stall = 1
DD = 2	DD = 2	AX = 2	B = 2	Free stall* Autumn = 2	2015 = 2	Autumn = 2	Dirt lot = 2
F = 3	F = 3	U = 3	C = 3	Free stall* Winter = 3	2016 = 3	Winter = 3	Both F&D = 3
HA = 4		TU = 4	D = 4	Free stall* Spring = 4	2017 = 4	Spring = 4	
AX = 5		WL = 5	E = 5	Dirt lot* Summer = 5	2018 = 5		
U = 6		SF = 6	F = 6	Dirt lot* Autumn = 6			
TU = 7		C = 7	G = 7	Dirt lot* Winter = 7			
WL = 8			H = 8				
SF = 9			I = 9				
C = 10							

Therefore, a significant difference (Post-hoc tests) after Chi-square were performed as described by Beasley *et al.*, (2019). To avoid type one error, p-value adjustments (Bonferroni adjustments) were also performed, where the p-value of 0.05 was divided by the number of tests performed to obtain the correct p-value for individual variables. Descriptive statistics were also estimated for variables such as year, trimmer, season, housing type as well as housing and season interactions.

Chapter 4: Results

In this study, statistical analyses were performed using Chi-square of SPSS v 25 (IBM SPSS Inc, 2019) at $P < 0.05$ to identify significant differences among claw lesion types. The frequency of claw lesions over the years across all farms varied considerably. The occurrence of infectious lesions was significantly high when compared to the non-infectious lesions. Housing (Free stall and dirt lot) and seasons were observed to be risk factors for certain lesion while other lesions were not influenced by these factors. Management, trimming program and intervention contributed significantly to lesion occurrences.

4.1. **Claw lesion overview in the central regions of SA (2011- 2018)**.

To better understand the rate of lameness in dairy herds in the central regions of South Africa, lesion incidence was studied on the initial dataset before editing. The overall herd lesion prevalence was determined on the 2018 dataset. The occurrences of claw lesions were evaluated in the study and results are presented in Figure 4.1. Overall lesions assessed were found to occur on all the farms although some were more prevalent than others. High incidences were recorded for digital dermatitis on farms A, D, G, H and I, with farm E being the highest. High incidence for heel erosion was also recorded on farm D, G, and B, with relatively high values recorded on farm A, F, H, I and J. Although corkscrew lesion was relatively high on farms B, C, D, F, G, and H, its highest incidence was recorded on-farm E and J. Lower to moderate white line and sole ulcer incidences were observed on all the farms. However, the highest incidence for the white line was recorded on farm E, while sole ulcer was more prevalent in farms B and J. The incidences of the other lesions such as foot rot, hairy attack, axial fissure, toe ulcer, and sole fracture were relatively low. However, a high incidence of foot rot and toe ulcer was observed in farm F.

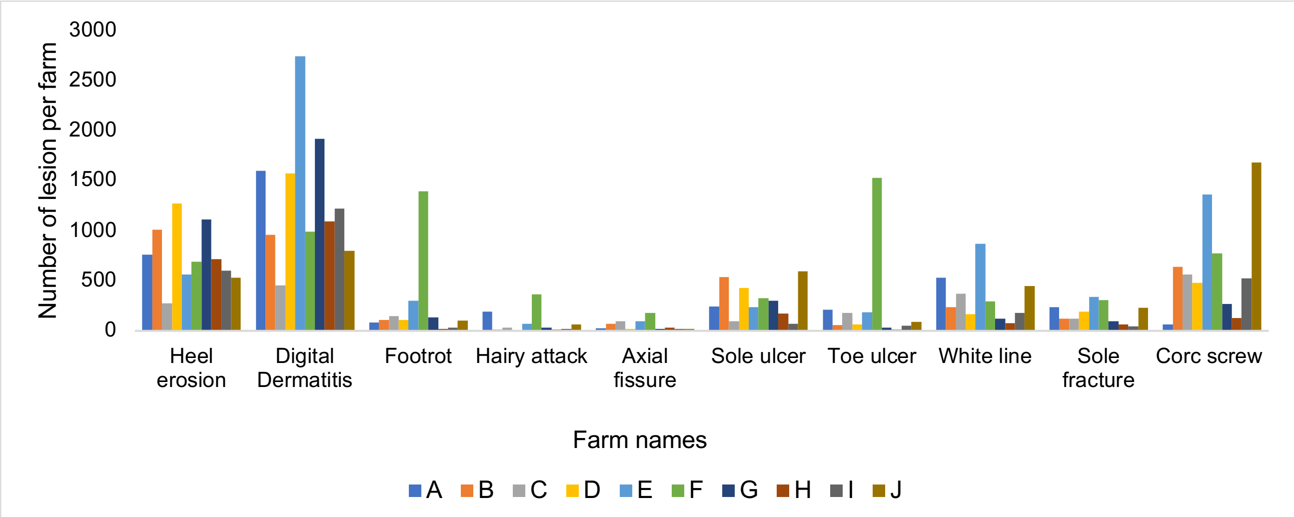

Figure 4.1. Number of lesion prevalence across all farms over years (2011 – March 2018).

The frequency of lesions over the years for the whole dataset was tested using SPSS (IBM SPSS Inc., 2019) software at P - value < 0.001. The results are shown in Figure 4.2 and summarized in addendum C. The overall prevalence rate for all the lesions was greatest in 2017 (30%) and 2016 (28%), compared to 2014 (17%), 2015 (18%) and 2018 (7%). Digital dermatitis was the most prevalent lesion in all the years followed by heel erosion. Although these two lesions were the most prevalent, no significant differences (P > 0.05) were observed for digital dermatitis across the years, while significant differences (P < 0.001) were present for heel erosion in 2016 (5%) and 2017 (10%).

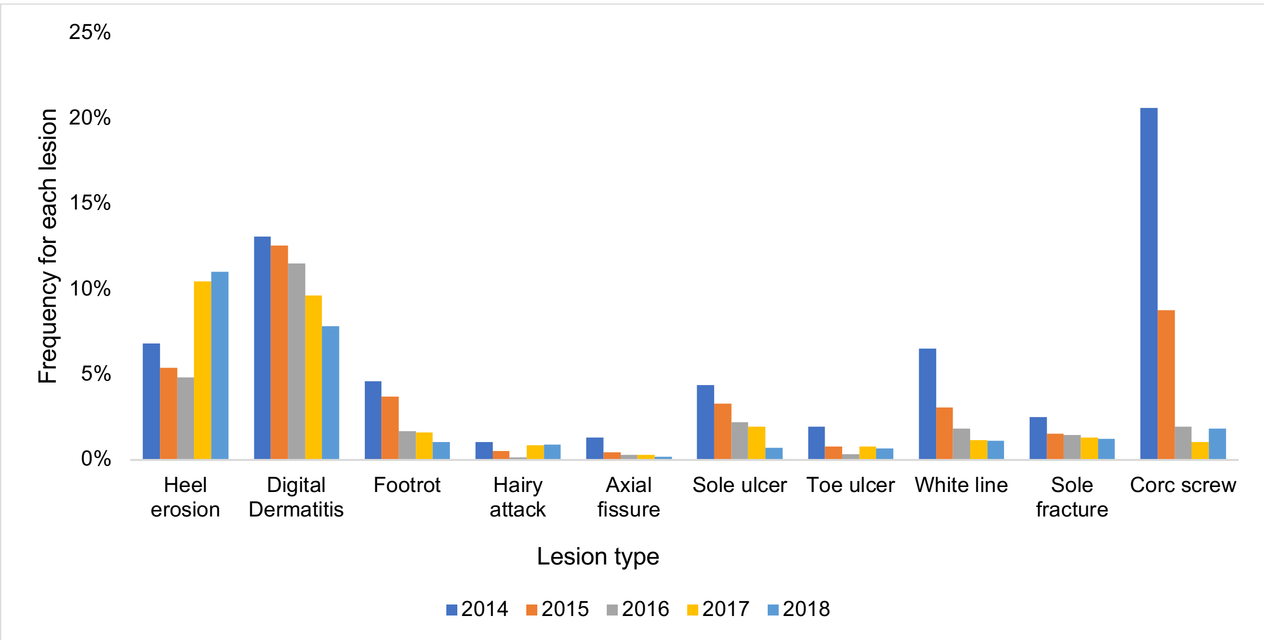

Figure 4.2. Frequencies of all lesions across all farms of the complete edited dataset (2014 - 2018) at P < 0.001.

Significant differences (*P* < 0.001) were observed for corkscrew across the years, with the highest frequencies observed in 2014 (21%) and 2015 (9%). Significant differences were observed in 2014 for foot rot, sole ulcer, axial fissure, toe ulcer and white line lesions on all the farms. A distinct difference (*P* < 0.001) was also observed in 2014 and 2017 for white line disease.

4.2. Infectious vs non-infectious lesions

The results of the occurrence of lesions categorized as infectious and non-infectious lesions were tested, and the most prevalent lesions are shown in Figure 4.3. The results of the remaining claw lesions are shown in addendum D. The tests were performed on the data recorded from 9 dairies for the year 2014 - March 2018. The occurrence of infectious (59%) lesions was higher compared to the non-infectious (41%) across years in all farms. However, digital dermatitis, heel erosion, and corkscrew were the most problematic, with the highest frequencies of 64%, 53% and 54% observed in 2016, 2018 and 2014 respectively.

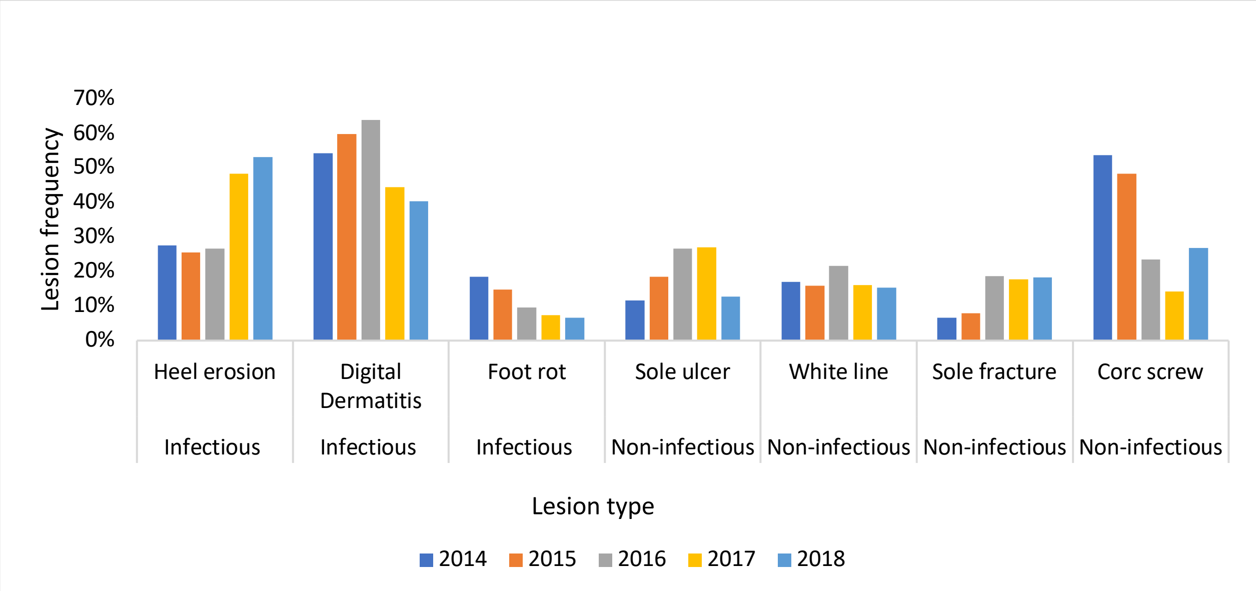

Figure 4.3. The occurrences of infectious and non-infectious lesions (*P* < 0.001) over years of the complete edited dataset (2014 - 2018).

The frequency of heel erosion and digital dermatitis increased with years while that of foot rot decreased. A decrease in frequency was also observed for digital dermatitis in the year 2017 (44%) and 2018 (40%). The frequencies of the corkscrew, sole ulcer, and white line, all of which are non-infectious lesions were higher as compared to sole fracture (11%) in the same category. The highest frequencies were also notable for a corkscrew in the year 2014 (54%) and 2015 (48%), while that of the sole ulcer was marked in 2016 (27%) and 2017 (22%).

4.3. **Effects of season on claw lesions**

The result of the effect of season on lesion occurrence across years (2014 - 2017) on 5 dairy farms is presented in Table 4.1. The season had a significant influence (*P* < 0.001) on the development of different claw lesions on all farms. Heel erosion was significantly influenced (*P* < 0.001) by Autumn and Spring (Table 4.1), with profound effects observed in Spring (8.4%). A significantly higher effect on digital dermatitis (10.7%) was present for Summer. Foot rot was significantly influenced by Autumn (*P* = 0.000) and Spring (*P* = 0.000), with a significantly (*P* = 0.000) high frequency observed in autumn (5.2%) compared to spring (1.0%).

Table 4.1. Frequencies (%) of all lesions for 5 farms with complete data over seasons for the year 2014 - 2017.

Season	**Lesion type**									
	Heel erosion	Digital dermatitis	Foot rot	Hairy attack	Axial fissure	Sole ulcer	Toe ulcer	White line	Sole fissure	Corkscrew
Summer	5.7	**10.7**^{a}	4.2	0.9	0.9	1.0	2.7	4.2	1.9	7.5
Autumn	**3.5**^{b}	6.2	**5.2**^{a}	1.4	0.9	**1.8**^{a}	**3.3**^{a}	3.6	2.6	4.8
Winter	6.7	9.8	1.8	0.2	0.5	0.6	1.4	1.8	1.3	7.6
Spring	**8.4**^{a}	5.7	**1.0**^{c}	0.1	0.2	0.3	1.3	**1.2**^{d}	1.0	5.2

$^{a, b, c}$ Frequencies within the same column with different superscripts differ significantly (*P* < 0.001).

Similarly, a prominent effect (*P* < 0.001) on the sole ulcer and toe ulcer was observed in Autumn, with no significant effects (*P* > 0.001) in the other seasons.

4.4. **Effects of free-stall vs dirt lot system on claw lesions**

The prevalence of claw lesions varied considerably (*P* < 0.05) among housing systems as presented in Figure 4.4 and Addendum E. The occurrence of heel erosion was significantly high (*P* < 0.002) in the free-stall housing system (10%) compared to the dirt lot housing system. A significantly higher incidence of sole ulcer (*P* < 0.002) was observed in the dirt lot system of 1.2 %.

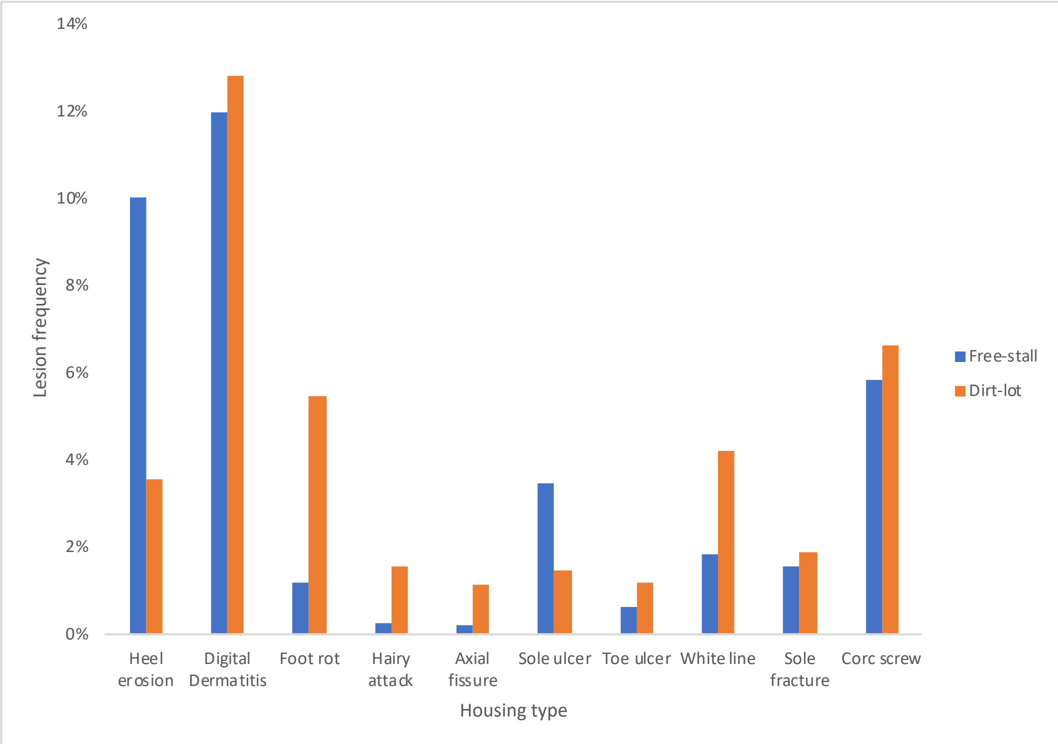

Figure 4.4. Frequencies of all lesions for 8 farms with complete data (2014 - 2018) based on the type of housings (F = free stall, D=dirt-lot) at P < 0.002).

White line, axial fissure, hairy attack, and foot rot were significantly affected by the dirt lot housing system, with the highest frequencies observed for foot rot (5.4%) and white line (4.2%) compared to the other lesion types. Conversely, no significant differences (*P* > 0.002) were present for sole fracture and corkscrew in all the 2 housing systems.

4.5. Effect of season and housing interactions on claw lesions

The interaction of the results of the most frequent lesion is presented in Table 4.2. The detailed results of all the claw lesions are presented in addendum F. The analysis was performed on 4 dairies that recorded both cows that were lame, and those that were trimmed, with no lesion present or recorded. Results of the free-stall housing system and season analyses indicated significant interactions between free stall and summer (*P* value = 0.000) as well as free stall and spring (*P* = 0.000) for heel erosion. There was no significant season by housing interactions for digital dermatitis, foot rot, sole ulcer and white line lesions (*P* > 0.001). Similarly, digital dermatitis, foot rot, sole ulcer, and corkscrew were not significantly influenced (*P* > 0.001) by season and dirt lot housing interactions. A significant summer by free-stall housing interactions (*P* = 0.000) was observed for toe ulcer. Conversely, no significant season by dirt lot housing was present for toe ulcer.

Table 4.2. The interaction (%) between housing type and season for 4 farms with complete data for the year 2014 -2017).

Housing*season	Lesion type						
	Heel erosion	Digital dermatitis	Foot rot	Sole ulcer	Toe ulcer	White line	Corkscrew
Free stall*Summer	7.4	11.1	1.3	0.4	**3.9**[b]	1.4	3.9
Free stall*Autumn	7.3	7.9	1.7	1.4	6.3	1.8	5.4
Free stall*Winter	**16.7**[b]	7.8	0.6	0.6	2.5	1.1	8.8
Free stall*Spring	**17.5**[a]	5.6	0.9	0.1	2.0	1.4	5.4
Dirt lot* Summer	1.4	8.4	**8.4**[b]	1.9	1.2	**7.2**[a]	11.1
Dirt lot* Autumn	**0.8**[b]	7.2	**11.4**[a]	1.8	1.2	**6.6**[b]	6.2
Dirt lot* Winter	1.0	13.2	3.0	0.8	0.8	2.8	6.5
Dirt lot* Spring	1.3	9.2	1.8	0.5	0.6	1.4	7.1

[a, b] Season by housing interactions frequencies with different superscripts within the same column, show a significant ($P < 0.001$) relationship between the two factors on specific lesion occurrence.

There was also a significant effect due to dirt lot housing and autumn on the occurrence of heel erosion. Foot rot was also influenced by summer, autumn and dirt lot housing interactions, with a higher frequency, observed for foot rot (11.4%) in dirt lot by autumn interactions. A significant dirt lot housing by summer interactions (7.2%) and dirt lot by autumn was notable for white line lesion, with highest interactions frequency recorded between dirt lot and summer (7.2%).

4.6. Management and claw lesion recording

In Table 4.3 the frequency of the incidence of claw lesions was assessed and tested in two farms using ICAR (dirt lot and free stall). The frequency of cows that were trimmed was significantly higher ($P < 0.002$) in farm B free stall (56.6%) compared to that of farm H dirt lot (39.1%). The dirt lot farm had higher ($P < 0.002$) heel erosion (17.0%) and digital dermatitis (31.2%) compared to the free stall farm.

Table 4.3. Frequency (%) of lesions between two farms compared with ICAR.

Farm	Lesion type									
	Heel erosion	Digital dermatitis	Foot rot	Hairy attack	Axial fissure	Sole ulcer	Toe ulcer	White line	sole fissure	Cork-screw
B (FS)	**10.6^{b}**	**10.7^{b}**	1.7	0.2	0.9	5.1	0.7	2.6	1.8	**9.3^{a}**
H (DL)	**17.0^{a}**	**31.2^{a}**	0.5	0.4	0.8	4.3	0.5	2.0	1.4	**2.8^{b}**

$^{a, b}$ frequencies within the same column with different superscripts represent a significantly different (*P* < 0.002) on lesion occurrence between farm H and B. FS= free stall and DL= dirt lot.

A prominent recording variance (*P* < 0.002) was observed between trimmer A and B for digital dermatitis and heel erosion (Table 4.4). The highest frequencies were observed for digital dermatitis (8.3%) with trimmer A, while heel erosion (14.5%) was the highest with trimmer B. A significant recording difference (*P* < 0.002) was recorded for sole ulcer with trimmer A, while that of trimmer B was present for toe ulcer, white line, sole fissure, and corkscrew.

Table 4.4. Trimmer recording differences on lesion frequencies (%) of the complete edited data (2011 - 2018).

Trimmer	Lesion type									
	Heel erosion	Digital dermatitis	Foot rot	Hairy attack	Axial fissure	Sole ulcer	Toe ulcer	White line	sole fissure	Corkscrew
A	**10.6^{b}**	**8.3^{a}**	2.5	0.7	0.5	**2.8^{a}**	**0.8^{b}**	**2.1^{b}**	**1.4^{b}**	**5.5^{b}**
B	**14.4^{a}**	**1.8^{b}**	2.0	0.3	0.4	**1.3^{b}**	**1.3^{a}**	**5.4^{a}**	**2.6^{a}**	**9.1^{a}**

$^{a, b}$ frequencies with different superscripts within the same column, show significant (P < 0.02) recording differences between the two trimmers.

4.7. ICAR claw health ATLAS comparisons with Zinpro

Results of the 23 and 14 claw lesions from both the ICAR and Zinpro identification manuals are presented in Tables 4.5 and 4.6. Sixteen common claw lesions were observed from both the manuals, with some lesions classified with different abbreviations. The claw lesions observed with different abbreviation included; corkscrew, heel erosion, axial fissure, vertical fissure, sole hemorrhage, sole ulcer, and white line. All the observed claw lesions on the Zinpro manual were classified with claw zones, while no claw zones were observed on ICAR.

Table 4.5. Common included in Zinpro claw lesions with different abbreviations and names

ICAR	ZINPRO	CLAW ZONE(S) (ZINPRO)
Asymmetric claws (AC)	Not included	
Concave dorsal wall (CD)	Not included	
Corkscrew claw (CC)	Corkscrew claw (C)	7
Digital dermatitis (DD)	Digital dermatitis (DD)	9 and 10
Interdigital dermatitis (ID)	Not included	
Double sole (DS)	Not included	
Heel Horn erosion (HHE)	Heel erosion (E)	6
Axial horn fissure (HFA)	Axial fissure (AF)	11 and 12
Horizontal horn fissure (HFH)	Horizontal fissure (G)	7 and 8
Vertical horn fissure (HFV)	Vertical fissure (V)	7 and 8
Interdigital hyperplasia (IH)	Interdigital hyperplasia (K)	0
Interdigital phlegmon (IP)	Foot rot (F)	9
Scissor claws (SC)	Not included	
Sole hemorrhage diffused (SHD)	Sole hemorrhage (H)	4, 5 and 6
Sole hemorrhage circumscribed (SHC)	Sole hemorrhage (H)	4, 5 and 6
Swelling of coronet or bulb (SW)	Not included	
Sole ulcer (SU)	Sole ulcer (U)	4
Bulb ulcer (BU)	Not included	9
Toe ulcer (TU)	Toe ulcer (TU)	1
Toe necrosis (TN)	Toe ulcer (TU)	1
Thin sole (TS)	Toe ulcer (TU)	1
White line fissure (WLF)	White line separation (WS)	4
White line abscess (WLA)	White line (WL)	4

Other lesions such as heel erosion, sole hemorrhage, horizontal fissure, foot rot as well as corkscrew were recorded in both manuals but with different abbreviations. However, foot rot was reported with a different name (Table 4.5), while sole hemorrhage was classified in to two different lesions namely; Sole hemorrhage diffused and circumscribed lesions in the ICAR claw health Atlas. A total number of 7 claw lesions namely asymmetric, concave dorsal wall, interdigital dermatitis, double sole, scissor claws, swelling of the coronet or bulb and bulb ulcer on the ICAR were not present on the Zinpro claw identification manual (Table 4.6). However, 4 claw lesions were observed with different names on the Zimpro manual. This included claw lesions such as the unbalanced claws, buckle, corkscrew and sole fracture (Table 4.6).

Table 4.6. Claw lesions that are not included in the Zinpro lesion identification manual.

ICAR	ZINPRO	DIFFERENT NAME (ZINPRO)
Asymmetric claws (AC)	Not included	Unbalanced claws
Concave dorsal wall (CD)	Not included	Buckle
Interdigital dermatitis (ID)	Not included	
Double sole (DS)	Not included	
Scissor claws (SC)	Not included	Corcscrew (C)
Swelling of coronet or bulb (SW)	Not included	
Bulb ulcer (BU)	Not included	Sole fracture (SF)

In addition, interdigital dermatitis observed on ICAR was classified as M-stage digital dermatitis on Zinpro, although it was not included in the main manual.

Chapter 5: Discussion

Lameness has detrimental effects on the welfare and longevity of dairy cattle. Therefore, an understanding of the factors that contribute to the prevalence of claw disorders, which in turn results in lameness, is important to better help develop preventative measures for the condition. This study evaluated the effects of housing type and season on the development of claw diseases. Given the changes that the South African dairy industry has undergone in the past decade, it is particularly critical to look at the prevalence of lesions over years, the effects of housing type, season as well as to identify important management factors which might reduce the risk of the condition.

5.1. **Overview of claw lesions in the central regions of SA (2011 – 2018).**

To better understand the rate of lameness in dairy herds in the central regions of South Africa, lesion incidence was studied on the initial dataset before editing. The overall herd lesion prevalence was determined on the 2018 dataset. The results revealed that farms who trimmed fewer cows (< 20%) in their herds had more lesion incidences, while those who trimmed a higher (> 20%) percentages of the herd were observed with lower lesion incidences based on the cords. The variation indicates that producers follow different trimming programs on their farms. The practice of different programs by producers was reported by DairySmid in the central regions of South Africa, suggesting that some producers perform preventative trimming, while others perform trimming to treat the already lame cows (Personal communication; van Zyl, 2018. Hoof trimmer and consultant. riaan@dairysmid.com).

Digital dermatitis and heel erosion lesions are reported to be the most problematic lesions in dairy herds worldwide (Chapinal *et al.*, 2010a; Holzhauer *et al.*, 2012). A similar trend in dairy farms in the central region of South Africa was observed whereby about 70 to 80% of the 10 herds were affected by digital dermatitis and heel erosion. The corkscrew lesion which is non-infectious was also observed to be the highest in about 70% of the herds. Digital dermatitis and heel erosion lesions are mostly associated with management (Chapinal *et al.*, 2010a; Evans *et al.*, 2016; van Metre, 2017), indicating that control and management of these lesions in the central regions may be a concern. These lesions are difficult to manage, making control of outbreaks in the dairy herds even more difficult. Although, a corkscrew is a genetic lesion, management play a role in the reduction of its occurrence (van Amstel, 2017) which includes trimming frequency, exposure of cows to softer walking floors and exclusion of the affected cows to genetic programs.

This study showed that trimming is not a standard procedure in the dairy farms in the central regions of South Africa. The trimming practices could, therefore, be another reason contributing to the higher incidence of the corkscrew lesion. Cows with this lesion are not identified and are included in breeding programs. The occurrence of foot rot, hairy attack, axial fissure, toe ulcer, and sole fracture are dependent on individual farms (Personal communication; van Zyl, 2018. Hoof trimmer and consultant. riaan@dairysmid.com). The majority of the farms were observed with relatively low incidences while 30% of the herds had higher rates of the white line, sole ulcer, and foot rot lesions. These farms have risk factors that include the type of housing, hard walking surfaces, hygiene management and season.

The overall incidence of claw disorders observed in this study varied considerably with years across all farms. The highest lesion prevalence was observed between the first two years (2014 – 2015), with a decrease seen in the last three years (2016 - 2018). The increase in the prevalence of lesions was shown by the lower number of the total cows that were trimmed with no lesions in 2014 to 2015 compared to 2016 to 2018 where the number of cows with no lesion was higher (Appendix C). Steady improvements have been made from 2016 to 2018, which could indicate that there is more awareness around lameness, and producers are taking action in controlling lameness incidences. Digital dermatitis was the most prevalent lesion, followed by heel erosion and corkscrew on all farms and years. Defrain *et al.*, (2013) also reported digital dermatitis as one of the five common lesions recorded more frequently in the United States. The study found this lesion to be among the lesions that accounted for 93.2% of the recorded claw lesion from 17 free stall and dirt lot dairy farms. The rate of digital dermatitis in the study seemed to be similar in all the dairy farms which were indicated by the absence of statistical significance variations in all the farms and years. However, significant variation for heel erosion between the year 2016 (5%) and 2017 (10%) was present.

Both the aetiology of digital dermatitis and heel erosion includes hygiene management related to biosecurity, foot bathing frequency, and efficacy (Chapinal *et al.*, 2010a, 2013a; Hulek *et al.*, 2010; Evans *et al.*, 2016; Jacobs *et al.*, 2017; van Metre, 2017). There is clearly a need for producers to understand the complexity of the lesions and develop preventative strategies. Infectious lesions are often associated with inadequate hygiene practices (Chapinal *et al.*, 2010a, 2013a; Evans *et al.*, 2016; van Metre, 2017). Similarly, Somers *et al.*, (2005) suggested that exposure of the cow's feet on floors contaminated by manure slurry resulted in almost the doubled number of cows being affected by heel erosion and interdigital dermatitis.

Corkscrew was amongst the most prevalent lesions in central South Africa, observed with the highest frequencies (21%) in 2017. However, its occurrence must be carefully interpreted, as the recording was occasionally dependent on the value attached to it by the specific producer (Personal communication; van Zyl, 2018. Hoof trimmer and consultant. riaan@dairysmid.com). Even though it was under-recorded, it was suggested to be among the problematic lesions in the dairy herds and required attention through selection against this lesion (Manske, 2002a; van Amstel, 2017). Furthermore, cows suffering from this lesion stand a 90% chance of suffering from other lesions such as toe ulcer, suggesting that corkscrew lesion can be fundamental in the development of other claw lesions (van Amstel, 2017). However, a reduction of this lesion was also observed over the years, which could be due to awareness in selection programs. White line lesion was relatively low and was observed to decrease over the years. For most lesions, a significant decrease was observed (foot rot, sole ulcer, axial fissure, and toe ulcer) on all farms from the year 2015 to 2018.

5.2. **Infectious vs non-infectious lesions.**

Infectious lesions are one of the most problematic lesions reported to be affecting dairy cows worldwide (Knappe-Poindecker *et al.*, 2013). Their occurrence was also high (59%) in the central regions of South Africa when compared to the non-infectious lesions (41%). The aetiology of the infectious lesions involves hygiene management related to biosecurity, frequency of scraping the floors, foot bathing frequency and efficacy (Nuss, 2006; Bell *et al.*, 2009; Cramer *et al.*, 2009; DeFrain *et al.*, 2013). An American study conducted on 184 dairies found that foot control and preventative measures were not frequently implemented in dairy farms (Adams *et al.*, 2017). This was also supported in a study by Gunn *et al.*, (2008) where farmers classified internal biosecurity as time-consuming. Low interest in implementing proper preventative and biosecurity control measures by producers could also be related to the observations in this study. In most case producers do not want to implement control measures such as the use of footbaths, leading to the high spread of the diseases within their herds. This was illustrated by the significantly higher overall prevalence of infectious lesions (59%) compared to non-infectious (41%) lesions.

Regardless of the observed high occurrences of infectious lesions, it appears that in the central regions of South Africa, awareness around hygiene management has increased and that farmers differ in management of biosecurity. Thus, the decline in frequencies for digital dermatitis in 2017 and 2018 in this study. The decline was also observed in other infectious lesions such as foot rot, indicating that cows are being identified and treated in time. Leach *et al.*, (2012) suggested that early identification and treatment may reduce lameness recovery rates. Early identification assists in the prevention and improved recovery (Bell *et al.*, 2009; Barker *et al.*, 2010). Other non-infectious lesions observed with high frequencies included corkscrew (41%), white line (17%) and sole ulcers (18%). Sole fracture (11%) was the lowest when compared to the other lesions. Similarly, Defrain *et al.*, (2013) reported sole ulcer and white line as the most frequent non-infectious lesion, which accounted for 93.2% of the recorded claw lesions from 17 free stall and dirt lot dairy farms. The study suggested that lactation stages and heat stress play an important role in the development of these lesions.

5.3. Effect of season on claw lesions.

Heel erosion, digital dermatitis as well as foot rot are more common in the winter months, as the bacteria are more likely to be concentrated in wet areas. Cattle are associated with defecating and congregating in wet areas (van Metre, 2017). These winter lesions will carry on into spring which is illustrated by the results, whereby heel erosion and foot rot lesions were influenced by autumn and spring. This was also illustrated in a study by Defrain *et al.*, (2013) where the infectious lesions were more prevalent during the cooler season. In contrast, digital dermatitis was significantly higher during the summer season in the current study, where these lesions are usually associated with very wet and humid conditions (Sanders *et al.*, 2009). A study by Defrain *et al.*, (2013) and van Metre, (2017) indicated an association between higher incidences of infectious lesions during the wet and warm season.

Toe ulcer, sole ulcer, and white line lesions are usually higher towards the end of summer all through autumn due to weaker claw development during heat stress (Shearer & van Amstel, 2017). This is supported by the findings in this study as white line lesions were observed to have a lower incidence in spring, while the toe and sole ulcers were significantly higher in autumn. In line with these results, Shearer *et al.*, (2006) and Sanders *et al.*, (2009) in the United States found a higher white line, toe ulcer as well as sole ulcer incidences towards the end of Summer (August) and early Autumn (September). Other authors Defrain *et al.*, (2013) also found high incidences of the white line, toe ulcer and sole ulcer following heat stress after the summer season. In this study, data was limited for to the number of farmers representing different environments and seasonal variation. All these provinces experience change in seasons at different times, which could have contributed to our results and further study is required on the effects of seasons on different claw lesions.

5.4. Effects of free-stall vs dirt lot system on claw lesions.

The occurrence of claw lesions varied considerably with housing systems. Heel erosion was more prevalent in free-stall housing compared to a dry lot. The findings in this study were similar to that of Sogstad *et al.*, (2005), where higher (38%) incidences of heel erosion were recorded in free stalls although the comparisons were done between free stalls and tie stalls which suggest that cows housed in free stalls are at high risk since their feet are more likely to be exposed to manure slurry in the alleys. These reports were also in agreement with that of Capion *et al.*, (2009) where almost all the cows had heel erosion in free-stall housing, and showed a correlation with digital dermatitis. The relationship between digital dermatitis and heel erosion was also reported in other studies suggesting that both are infectious lesions and related to common environmental risks factors (Manske, 2002a; Frankena *et al.*, 2009; Knappe-Poindecker *et al.*, 2013). In agreement to this, an association between the two lesions was also observed by the DairySmid trimmer (Personal communication; van Zyl, 2018. Hoof Trimmer and consultant. riaan@dairysmid.com), suggesting that cows suffering from heel erosion stand a chance to suffer from digital dermatitis. Furthermore, severe heel erosion results in altered and compromised weight-bearing in the heel as well as shock absorbance (Chapinal *et al.*, 2010a), resulting in changes in the internal claw horn structure. Consequently, other claw lesions other than digital dermatitis may occur.

A study by Chapinal *et al.*, (2010a) reported heel erosion as one of the most prevalent lesions in free stalls. The study suggested that parity and lactation stages are major risk factors for cows housed in free stalls in dairy herds for severe heel erosion. Unexpectedly, no significant differences were found in this study for digital dermatitis between free stall and dirt lot housing systems. Solano *et al.*, (2016) reported a higher prevalence of digital dermatitis among all the housing types, however, the comparisons were made between free stalls and deep-bedded packs. These results can be attributed to the fact that both housing systems expose the cow's feet to common environmental risk factors. Cows housed in a dirt lot and free stall, are more likely to be exposed to wet conditions due to rain or leaking drinking water trumps and manure slurry (DeFrain *et al.*, 2013; Chen *et al.*, 2017; van Metre, 2017). However, dirt lot housing systems are commonly associated with wet and muddy conditions, while free stalls are related to wet floors in the walking alleys. Highly moisturized conditions appear to be fundamentals for infectious diseases (Berry, 2006). The skin of the hoof and horn exposed to these kinds of environmental conditions are more likely to develop infections of the digits. Furthermore, when the claws are exposed to water, the horn tissue becomes softer which in-turn compromises the quality and hardness of the claw (Borderas *et al.*, 2004; Popescu *et al.*, 2010). The hardness of the claw influences the susceptibility of the claw to environmental effects and the rate of horn wear and erosion (Borderas *et al.*, 2004; Popescu *et al.*, 2010).

In the current study, dirt lot showed significantly more cows with a sole ulcer, axial fissure, hairy attack, white line, and foot rot compared to free-stall housing. Cows kept in dirt lots are inadequately sheltered than cows housed in free stalls (Chen *et al.*, 2017), exposing them to hot and wet weather, cows exposed to these conditions spend more time standing than lying down. The hooves are more prone to sole and white line damage when exposed to such unfavourable environmental conditions. According to a study by Borderas *et al.*, (2004) where the relationship among hardness of claws and water was assessed, it was documented that exposure of claws to a moist surface result in claws that absorb water, and as a consequence, loss of hardness. Similarly, the claw of cows with claw problems was found in a study by Higuchi & Nagahata, (2001) to have greater water content as compared to healthy cows. Conversely, other authors (MacCallum *et al.*, 2002) suggested that this could also be due to seasonal changes in proliferation and keratinization of claw cells. Moreover, the relationship between hardness and claw lesions showed that cows with softer claws are at higher risk for lameness (Solano *et al.*, 2016). It was further suggested that weaker claws are more likely to separate creating a conducive environment for foreign particles to be lodged in the white line causing colonization of bacteria and fungus to the corium, thus the development of white line lesion (Cook & Nordlund, 2009; Shearer & van Amstel, 2017).

In the central regions of South Africa, sand is the predominant walking surface in dirt lots known to be providing the cows with softer walking surfaces. The types of walking conditions in dirt lot are uneven slopes, coarse sands, poor walking tracks, which may result in mechanical trauma or injury (puncture) (Manske, 2002a). Mechanical trauma or injury (puncture) is a common causative factor for lesions such as axial fissures in dairies in the central regions of South Africa. No relationship was found between housing and corkscrew and sole fracture in this study. The findings are not in line with other studies, where housing was reported to be one of the important factors contributing to the phenotypic changes resulting in corkscrew lesion development (Liinamo *et al.*, 2009; Johansson *et al.*, 2011; van Amstel, 2017). In this case, data availability on the corkscrew and sole fracture lesions in this study may have influenced the differences in results. Other authors have associated a sole fracture with heat stress (which is more common in dirt lot) and poorly designed houses more especially free stalls (Larson *et al.*, 2014). Both factors result in increased standing periods associated (Allen *et al.*, 2015) with the higher development of a sole fracture. Solano *et al.*, (2016) found a higher incidence of toe ulcers when cows were housed in a free-stall with no access to exercise areas. Similarly, a higher incidence of toe ulcers was observed in free stalls in the current study. Sanders *et al.*, (2009) associated misidentification of thin sole toe ulcers as being usually misidentified as toe ulcers in farms with longer walking distance, especially on larger farms.

5.5. **Effect of season and housing interactions on claw lesions.**

The results on the higher heel erosion observed between summer and free stall interactions were expected. Heel erosion occurs as a result of chemical and mechanical erosion of the hoof, which is more likely to rapidly arise on softer claws (Knappe-Poindecker *et al.*, 2013). In free stalls, floors are usually wet and covered with manure slurry resulting in cows with softer claw horn (Chapinal *et al.*, 2013a; Metre, 2017) and increased wear and subsequently heel erosion (Defrain *et al.*, 2013; Metre, 2017). Capion *et al.*, (2009) and Chapinal *et al.*, (2010a) found higher incidences of heel erosion on cows housed in free stalls, thus associating heel erosion with exposure of the claw hoof to concrete floors and manure slurry. Furthermore, concrete walking surface in free stalls has been correlated with higher claw horn wear (Solano *et al.*, 2016; Endres, 2017), resulting in an increased rate of heel erosion (Vanegas *et al.*, 2006). Summer season is associated with high precipitation and humidity especially in South Africa, contributing to keeping the floors wet in confined herds, thus aids in the development of heel erosion (Sanders *et al.*, 2009). Therefore, these results suggest that summer and free stalls interaction are risk factors for heel erosion in dairy herds.

Summer and free stalls interactions also appeared to be risk factors for toe ulcers; these results can be expected since summer is associated with heat stress and increased standing hours (Allen *et al.*, 2015). Increased standing in free stalls is related to claw horn disruptions (CHD), which are correlated to toe ulcer (Allen *et al.*, 2015). Conversely, Haufe *et al.*, (2012) associated higher summer temperatures with dry floors and low heel erosion, suggesting that higher summer temperatures may facilitate rapid floor drying in confined dairies, thereby minimizing urine and manure slurry as well as heel erosion incidences. This can be expected to happen in dirt lots, because of the housing design, soils will be more likely to dry quicker during summer. In the current study, summer and dirt lot interactions significantly influenced heel erosion and foot rot. Furthermore, foot rot was also influenced by autumn and dirt lot interaction, which could be the result of the summer season. This finding thus shows that muddy conditions are a problem due to rain regardless of the higher summer temperatures.

The association between spring and free stall on heel erosion was expected. As the effect of these two factors on heel erosion was demonstrated when they were studied as individual factors. It was revealed that this lesion is more likely to occur when the skin is frequently exposed to moist conditions in free stalls (Metre, 2017) and carry on into spring following winter, which is also demonstrated by the current results. There was an association observed between white line and summer and dirt lot interactions. Several authors associated heat stress and muddy conditions to be risk factors for a white line (Chen *et al.*, 2012; Larson *et al.*, 2014; Allen *et al.*, 2015; Metre, 2017). Furthermore, sole ulcers were also related to similar risk factors (Chen *et al.*, 2012; Larson *et al.*, 2014; Allen *et al.*, 2015; Metre, 2017). In contrast, no significant season by housing interactions was found for ulcer and white line lesions in the current study.

5.6. **Management and claw lesion recording**

Management and production systems in dairy herds play a major role in the occurrence of claw lesions. Controlling and prevention strategies to reduce the occurrence of claw disorders in dairy herds are currently available (Solano *et al.*, 2017a). This includes the use of footbaths, trimming frequency and treatment of lesions. However, Adams *et al.*, (2017) revealed that recommended preventative and control measures are not consistently implemented in US dairies. This is confirmed in the current study, where highest claw lesion prevalence was observed in farm H (56.6%) where preventative programs were not routinely implemented than they were in farm B (39.1%), whereby in farm H only trimmed cows that were showing lameness signs, while farm B performed preventative trimming on dry cows. Therapeutic trimming facilitates early identification of lesions and early treatment (Egger-Danner *et al.*, 2014). Studies have associated routine claw lesion management with early identification and treatment of claw lesions (Cramer *et al.*, 2008; Chapinal *et al.*, 2009b). Considering that cows were housed in a dirt lot on farm H and free stall on farm B, could have also contributed to the results. Higher heel erosion and digital dermatitis were significantly higher on farm H compared to farm B. This results could be due to less focus on management observed on farm H, where foot bath was only used once in two weeks. On the other hand, farm B implemented foot bath once a week, which could support the low heel erosion and digital dermatitis incidences. Several studies have found lower incidences of digital dermatitis as well as heel erosion when a footbath was used (Cook *et al.*, 2012; Logue *et al.*, 2012; Speijers *et al.*, 2012; Jacobs *et al.*, 2017). The authors suggested that proper footbath implementation may reduce the rate of digital dermatitis and heel erosion.

As mentioned earlier on corkscrew is a genetic lesion with a lower heritability (Manske *et al.*, 2002b; Johansson *et al.*, 2011). This could mean that environmental factors play an important role in the development of this lesion. This is supported in the current study, where higher corkscrew incidences were recorded on farm B where cows were housed in a free-stall with the hard walking surface than on farm H where cows were housed in a dirt lot. There were no significant differences between the two farms for the other lesions both infectious and non-infections. The results could be explaining the important role played by the trimmers in controlling these lesions on both farms. The impact of trimming and data provided by hoof trimmer on the reduction of lameness has been highlighted in several studies (Alsaaod *et al.*, 2015; Evans *et al.*, 2016; Solano *et al.*, 2016).

The findings reported in a study by Sogstad *et al.*, (2005) showed that experienced and well-trained trimmers were well qualified for identifying and recording claw lesions. It is noteworthy to say that, analyses in this study revealed significant recording variation for some variables between the two trimmers. However, having had one trimmer responsible for 9 farms, this would contribute to this one trimmer having a greater influence on the results. Highly significant differences between the two trimmers would be for both infectious (digital dermatitis and heel erosion) and non-infectious (toe ulcer and sole ulcer) lesions, whereby one trimmer observed the highest frequencies of either for the two-class of lesions. This could be due to significant differences in understanding specific lesions and treatment amongst the two trimmers. Although, herd differences in terms of management, housing systems, nutrition, genetics as well as trimming frequency could have been an important influence on claw lesion prevalence.

5.7. **ICAR claw health ATLAS comparisons with Zinpro.**

The ICAR claw health Atlas manual consisted of 23 described claw lesions and was compared to the 14 claw lesions from the Zinpro claw lesion identification manual. Of the 23 listed lesions on the ICAR claw health Atlas, only seven claw lesions were not included in the Zinpro claw lesion identification book. However, from the seven claw lesions, four claw lesions were identified with a different name on the Zinpro manual. This shows that only three different lesions from ICAR manual were not included in the Zinpro manual. Although, the trimmer associated one lesion (Interdigital dermatitis) from the three lesions as M-stage digital dermatitis, suggests that Zinpro classify all stages of digital dermatitis using one name. Moreover, the ICAR manual did not associate the claw lesions with claw zone (Figure 3.2), while it was included on the Zinpro manual. Claw zones minimize confusion during the process of claw lesion identification, as claw lesions can be easily identified following the claw zones they are associated with. Regardless of the claw zones that were not included, which can be classified as a limitation of the ICAR claw Health Atlas. The results suggest that ICAR claw health Atlas can be applicable thereof in South African dairy cattle.

The differences between the two identification systems should, however, be clearly noted by trimmers if the recording data will be used for genetic evaluation. It must be made clear that the lesion recorded is comparable across herds and countries.

5.8. **Conclusion**

The study confirmed that different lesions have significantly different risk factors and it indicates that housing and season have a negative influence on the occurrence of claw lesions. The distribution differences between infectious and non-infectious claw lesions showed that different management approaches have a significant influence on their occurrence. Therefore, improved housing and management systems may result in a significant decrease in the incidences of lameness in dairy cows.

Chapter 6: Conclusion

The aim of this study was to evaluate the claw health of dairy cattle housed in dirt lot vs free stall in TMR systems in the central regions of South Africa. The results indicate that claw lesions are a problem in some farms. This was indicated by the higher overall incidence of claw lesions on certain farms, while other farms were observed with lower prevalence. Infectious lesions are the most problematic lesions in the central regions of South Africa compared to non-infectious lesions. Heel erosion and digital dermatitis were the most prevalent infectious lesions reported in 70 to 80% of the total herds involved in the current study. Other non-infectious lesions especially corkscrew were most prevalent in about 30% of the total herds. Although corkscrew was the most prevalent, it was not routinely recorded. This study confirmed that this lesion forms part of the top three lesions affecting dairy herds in the central region of South Africa, suggesting routine recording for this lesion in dairy farms by farmers together with the trimmers.

The study also confirmed that housing, season and management have an influence on the occurrence of claw lesions. Heel erosion was significantly higher in free stalls compared to a dirt lot system. No significant difference was present for a corkscrew and digital dermatitis by housing. There is a need for the improved recording of the corkscrew on all dairy cows. Season significantly influenced digital dermatitis and heel erosion. Heel erosion was also significantly influenced by spring, autumn, and free stall interactions. Taken together, all these findings indicate that management plays an important role in the occurrence of claw lesions especially on the most prevalent lesions in the central regions of South Africa. Therefore, it is also important to identify important management factors which might reduce the risk of the conditions.

6.1. Recommendations

Claw trimming and recording are limited to farms that make use of a professional hoof trimmer. The claw lesion records used for the current study were available on hard copies, as a result, 48 993 records were typed in excel to create a database. Therefore, consistent trimming and recording may be recommended for South African dairy producers. A national electronic database system for claw and other important feet and legs traits can be developed. This system will assist in mitigating and managing claw lesion incidences in dairy herds. In addition, the distribution differences between infectious and non-infectious lesions claw lesions showed that different hygiene management approaches have a significant influence on their occurrence. Therefore, improved biosecurity and preventative measures are recommended.

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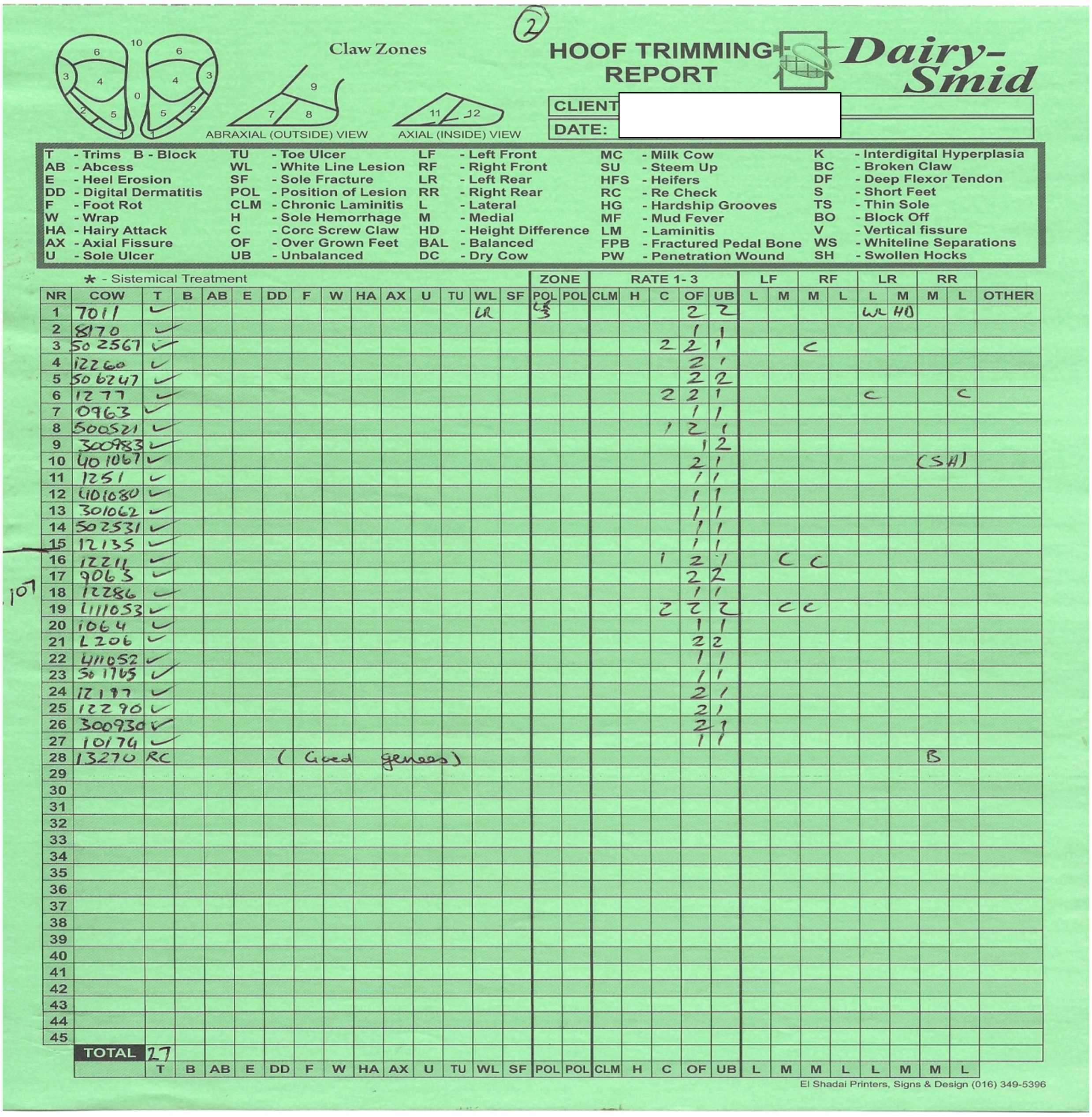
Addendum A

Figure A 1. Example of a claw lesions recording sheet **– Chapter 3**



②

HOOF TRIMMING REPORT

Dairy-Smid

Claw Zones

ABRAXIAL (OUTSIDE) VIEW

AXIAL (INSIDE) VIEW

CLIENT:

DATE:

T - Trims B - Block	TU - Toe Ulcer	LF - Left Front	MC - Milk Cow	K - Interdigital Hyperplasia
AB - Abcess	WL - White Line Lesion	RF - Right Front	SU - Steem Up	BC - Broken Claw
E - Heel Erosion	SF - Sole Fracture	LR - Left Rear	HFS - Heifers	DF - Deep Flexor Tendon
DD - Digital Dermatitis	POL - Position of Lesion	RR - Right Rear	RC - Re Check	S - Short Feet
F - Foot Rot	CLM - Chronic Laminitis	L - Lateral	HG - Hardship Grooves	TS - Thin Sole
W - Wrap	H - Sole Hemorrhage	M - Medial	MF - Mud Fever	BO - Block Off
HA - Hairy Attack	C - Corc Screw Claw	HD - Height Difference	LM - Laminitis	V - Vertical fissure
AX - Axial Fissure	OF - Over Grown Feet	BAL - Balanced	FPB - Fractured Pedal Bone	WS - Whiteline Separations
U - Sole Ulcer	UB - Unbalanced	DC - Dry Cow	PW - Penetration Wound	SH - Swollen Hocks

* - Sistemical Treatment

NR	COW	T	B	AB	E	DD	F	W	HA	AX	U	TU	WL	SF	ZONE POL	POL	RATE 1-3 CLM	H	C	OF	UB	LF L	LF M	RF M	RF L	LR L	LR M	RR M	RR L	OTHER
1	7011	✓											LR		LR 3					2	2					WL	HD			
2	8170	✓																		1	1									
3	502567	✓																	2	2	1			C						
4	12260	✓																		2	1									
5	506247	✓																		2	2									
6	1277	✓																	2	2	1					C			C	
7	0963	✓																		1	1									
8	500521	✓																	1	2	1									
9	300983	✓																		1	2									
10	401067	✓																		2	1							(SA)		
11	1251	✓																		1	1									
12	401080	✓																		1	1									
13	301062	✓																		1	1									
14	502531	✓																		1	1									
15	12135	✓																		1	1									
16	12211	✓																	1	2	1		C	C						
17	9063	✓																		2	2									
18	12286	✓																		1	1									
19	411053	✓																	2	2	2		C	C						
20	1064	✓																		1	1									
21	L206	✓																		2	2									
22	411052	✓																		1	1									
23	501765	✓																		1	1									
24	12197	✓																		2	1									
25	12290	✓																		2	1									
26	300930	✓																		2	1									
27	10174	✓																		1	1									
28	13270	RC				(Goed genees)																						B		
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45																														
TOTAL		27																												
		T	B	AB	E	DD	F	W	HA	AX	U	TU	WL	SF	POL	POL	CLM	H	C	OF	UB	L	M	M	L	L	M	M	L	

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Addendum B

Table B.1. Additional lesion data collected during farm visits **- Chapter 4**

Cow number	Lesions		
1. 15117	E	DD	SF
2. 16623	E		
3. 16121	DD		
4. 16207	DD		
5. 16175	DD		
6. 16184	DD		
7. 16188	DD		
8. 1606	DD		
9. 1555	DD		
10. 12211	DD		
11. 1330	DD		
12. 16193	E		
13. 1604	DD	C	
14. 1258	DD		
15. 14227	E		
16. 15422	DD		
17. 15318	DD		
18. 575188	DD		
19. 14194	DD		
20. 8076	H		
21. 12244	HA		
22. 515055	DD		
23. 515023	E		
24. 515170	DD		
25. 15317	DD		
26. 15306	E		
27. 12186	E		
28. 51517	E		
29. 1625	DD		
30. 13384	E	H	
31. 11125	H		
32. 13138	E		
33. 13399	E		
34. 12224	H		
35. 15050	DD		
36. 15171	E		
37. 152228	SU		
38. 16008	E		
39. 16018	DD		
40. 12115	HA		
42. 16061	E		
43. 15045	E		
44. 14091	XA	WL	
45. 14149	DD		
46. 14152	E		
47. 14156	E		
49. 13030	E		
50. 14144	E		

Addendum C

Table C.1. The prevalence of claw lesions over years (2014 - 2018) **- Chapter 4**

	Lesion type										
Years	No lesion	Heel erosion	Digital dermatitis	Foot rot	Hairy attach	Axial fissure	Sole ulcer	Toe ulcer	White line	Sole fracture	Corkscrew
2014	**37.1**[c]	6.8	13.1	**4.6**[a]	1.0	**1.3**[a]	**4.4**[a]	**2.0**[a]	**6.5**[a]	2.5	**20.6**[a]
2015	**59.9**[b]	5.4	12.6	3.7	0.5	0.4	3.3	0.8	3.1	1.5	**8.8**[b]
2016	73.7	**4.8**[d]	11.5	1.7	0.2	0.3	2.2	0.3	1.8	1.5	**1.9**[c]
2017	70.9	**10.4**[b]	9.6	1.6	0.9	0.3	2.0	0.8	**1.2**[c]	1.3	**1.1**[e]
2018	73.4	**11.0**[a]	7.8	1.0	0.9	0.2	0.7	0.7	**1.1**[d]	**1.2**	**1.8**[d]

[a, b, c, d, e] Frequencies (%) with different superscripts within the same column, show a significant difference of lesions over year.

Addendum D

Table D.1. The occurrence of lesions categorized as infectious and non-infectious lesions **- Chapter 4**

	Infectious lesions				Non-infectious lesions					
Years	Heel erosion	Digital dermatitis	Foot rot	Hairy attach	Axial fissure	Sole ulcer	Toe ulcer	White line	Sole fracture	Corkscrew
2014	27.5	54.1	18.4	2.7	3.4	11.6	**5.0**[a]	17.1	6.6	53.7
2015	25.5	59.7	14.8	2.6	2.5	18.4	4.3	15.9	8.0	48.3
2016	**26.6**[b]	63.8	9.6	1.6	3.8	26.7	4.1	21.7	18.7	23.4
2017	**48.2**[a]	44.4	7.4	11.1	4.0	26.9	10.1	16.0	17.6	14.2
2018	53.1	40.4	**6.5**[a]	**14.0**[a]	3.0	12.8	9.8	15.2	**18.3**[a]	26.8

[a, b] Infectious and non-infectious lesion frequencies (%) with different superscripts within the same column, show a significant difference (*P* < 0.001) between lesion in the two categories.

Addendum E

Table E.1. The effect of housing on the occurrence of lesions **- Chapter 4**

Housing	Lesion type										
	No lesion	Heel erosion	Digital dermatitis	Foot rot	Hairy attach	Axial fissure	Sole ulcer	Toe ulcer	White line	Sole fracture	Corkscrew
Free stall	63.2	10.0	11.9	1.2	0.2	0.2	0.6	**3.5**[a]	1.8	1.5	5.8
Dirt lot	60.3	**5.5**[a]	12.8	**5.4**[a]	1.6	**1.1**[a]	**1.2**[a]	1.4	**4.2**[a]	1.9	6.6

[a,] Frequencies (%) with different superscripts within the same column, show a significant difference between two housing system.

Addendum F

Table F.1. Interaction (%) between housing type and season on the occurrence of all the lesions across all farms and years - **Chapter 4**

	Lesion type										
Housing*season	No lesion	Heel erosion	Digital dermatitis	Foot rot	Hairy attach	Axial fissure	Sole ulcer	Toe ulcer	White line	Sole fracture	Corkscrew
Free stall*Summer	68.3	7.4	11.1	1.3	0.1	0.4	0.4	**3.9**[b]	1.4	1.9	3.9
Free stall*Autumn	65.5	7.3	7.9	1.7	0.2	0.3	1.4	6.3	1.8	2.1	5.4
Free stall*Winter	60.0	**16.7**[b]	7.8	0.6	0.1	0.1	0.6	2.5	1.1	1.5	8.8
Free stall*Spring	65.5	**17.5**[a]	5.6	0.9	0.1	1.4	0.1	2.0	1.4	1.5	5.4
Dirt lot* Summer	54.1	1.4	8.4	**8.4**[b]	**2.0**[b]	1.9	1.9	1.2	**7.2**[a]	2.8	11.1
Dirt lot* Autumn	56.8	**0.8**[b]	7.2	**11.4**[a]	3.5	0.8	1.8	1.2	**6.6**[b]	2.7	6.2
Dirt lot* Winter	68.9	1.0	13.2	3.0	0.3	0.5	0.8	0.8	2.8	1.5	6.5
Dirt lot* Spring	76.9	1.3	9.2	1.8	0.1	0.5	0.5	0.6	1.4	0.7	7.1

[a, b] Season by housing interactions frequencies with different superscripts within the same column, show a significant relationship between the two factors on specific lesion occurrence.