Morphological and physiological characteristics for the evaluation of claw quality in Bonsmara cattle

by

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DECLARATION

I, Susanna Johanna Myburgh, declare that the dissertation, which I hereby submit for the degree MSc (Agric) Animal Science: Production Physiology at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ……..

DATE: ……..

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LIST OF ABBREVIATIONS

˚C	degrees Celsius
Ca	calcium
cm	centimetre
Co	cobalt
Cu	copper
Cu/Zn SOD	copper/zinc superoxide dismutase
Cys	cysteine
F	front claws/limb
g	gram
GEBV	genomic breeding value
Gm	Mesic Highveld Grassland Bioregion
H	hind claws/limb
HDM	herd designation mark
ICS	intercellular cementing substance
L	front legs inspection category
LL	lateral toe length
M	hind legs inspection category
mA	milliampere
Met	methionine
mL	millilitre
ML	medial toe length
mm	millimetre
mm/min	millimetre per minute
Mn	manganese
Mn SOD	manganese superoxide dismutase

MPa	megapascal
N	newton (force)
N	pastern inspection category
nm	nanometre
P	phosphorus
P	claw inspection category
PCA	Principal Component Analysis
Prin1	Principal component 1 (morphological measurements: LL, ML, circumference)
Se	selenium
S	sulphur
SVcb	Central Bushveld Bioregion
SVk	Eastern Kalahari Bioregion
TG	epidermal transglutaminase
TS(s)	tensile strength(s)
Zn	zinc

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ABSTRACT

The functional efficiency of beef cattle including sound claws are essential given that it has a marked influence on functional longevity and subsequent performance. The aim of this study was firstly to analyse Bonsmara inspection data to determine the extent of claw problems in the breed. Secondly, the evaluation of morphological and physiological claw characteristics with specific reference to major bioregions. Inspection data analyses indicated that 2.84% of Bonsmara cattle exhibited claw problems at inspection over a period of 11 years. Logistic regression models on a subset of inspection data revealed a significant influence (P <0.05) of sex and bioregion on claw problems with the sire effect insignificant. Breeder had the most significant effect on claw problems implying stricter selection policies of certain breeders with regard to claws as well as possible differences in management practices. Normal claws of 89 Bonsmara stud animals were collected from the three main bioregions where Bonsmara cattle are farmed (Mesic Highveld Grassland (Gm), Eastern Kalahari Bushveld (SVk) and Central Bushveld (SVcb) bioregions). The majority of the claws obtained were from Bonsmara bulls slaughtered after phase D testing with a few claws from older cows. Lateral toe length (LL), medial toe length (ML), claw circumference, colour coding and tensile strength (TS) were determined on fore and hind claws and mineral composition only on fore claws. Multiway ANOVA models indicated that bioregion, moisture content, calcium (Ca), selenium (Se) and claw position (fore versus hind) had a significant effect (P <0.05) on tensile strength. Bioregion, AgeSex and ForeHind effects were significant (P <0.05) with regards to the respective morphological measurements (LL, ML and claw circumference). The research serves as a benchmark for claw traits in the Bonsmara breed and will assist in future studies.

EXECUTIVE SUMMARY

The evaluation of Bonsmara claws was divided into two parts: firstly the analysis of Bonsmara inspection data to determine the extent of claw problems in the breed and, secondly, the morphological and physiological description of Bonsmara claws collected from the major bioregions in South Africa. The two parts of the project were dealt with in two separate chapters and each chapter is presented in article format rendering it more comprehensive and suitable for publication. In chapter 1, the motivation for the research project is provided followed by an overview of the relevant claw research and literature available. The first part of the project (discussed in chapter 2) focused on the application of Bonsmara inspection data ranging over a decade to determine the extent of claw problems in inspected Bonsmara stud cattle. The scores at inspection for feet and leg traits (relevant to claws) were of interest. The effect of sex, sire, bioregion and HDM (Herd Designation Mark) on the observed claw problems was determined on a subset of inspection data by means of different logistic regression models. The evaluation of the inspection data will also give insight to the use of inspection data in the breed and possible improvements for more accurate assessment of various claw traits in the breed. The focus of chapter 3 was morphological claw measurements (lateral toe length (LL), medial toe length (ML), claw circumference, colour and tensile strength (TS)) and physiological parameters (claw mineral composition) associated with claw quality. These claws evaluated represented the three main bioregions in South Africa where Bonsmara cattle are farmed. This part was conducted to determine the effect of various factors (sex, age, colour, bioregion, minerals, and claw limb position) on different dependent variables (TS, LL, ML and claw circumference respectively) by means of multiway ANOVA models. This study serves as a benchmark for Bonsmara claw characteristics associated with different environments. In conclusion, the results of the research are discussed in chapter 4 and recommendations made for future research on claw quality in Bonsmara cattle.

CHAPTER 1

1.1 INTRODUCTION

The Bonsmara (Bos taurus africanus) is a locally bred composite breed that has been developed by means of a well-documented scientific program under the late Prof Jan Bonsma and colleagues at the Mara Research station in the Limpopo province, Northern part of South Africa (Bonsma, 1980). Intensive crossbreeding trials between 1937 and 1963 resulted in an animal composed of 5/8 Afrikaner and 3/8 Exotic Hereford/Shorthorn, a combination found to be best suited for the warm subtropical South African environment (Bonsmara SA, 2012). It is the dominant cattle breed in South Africa with more than 120 000 registered animals and can be found in all the agro-ecological regions of Southern Africa due to its adaptability and excellent dam lines. The breed is also popular in other African countries like Namibia, Uganda and Zambia and has been exported to Argentina, Brazil, Paraguay, Colombia, USA and Uruguay since 1995 (The Bonsmara System, Bonsmara Breeder Society of SA, Henry Straat 118, Westdene, Bloemfontein, 9301).

In the development of the Bonsmara breed, the traits associated with functional efficiency played a major role and remain part of the selection programs of the breeders. Sound claws are essential in determining functional efficiency and stayability of both males and females in the herd. The main function of the claws is to effectively bear the weight of the animal as well as to protect the underlying soft tissue (Toussaint-Raven 1989; Hepburn *et al.*, 2007). Good quality claws can be defined as claws of good structure, colour and being free of disease and other lesions (Politiek *et al.*, 1986). Sound claws are a prerequisite for proper movement and serving ability and are associated with increased lifetime performance and longevity in dairy cattle (Politiek *et al.*, 1986; Distl *et al.*, 1990; Vermunt & Greenough, 1995; Enting *et al.*, 1997).

A thorough understanding of the basic micro and macro structure of the bovine claw and the functions of the different components are essential in order to obtain a better understanding of what constitute good claw quality. The claw horn capsule is composed of tubular, inter-tubular and laminar horn cells that will determine the structural strength, biomechanical behaviour and resistance of claws to external stressors (Franck *et al.*, 2006). Bovine claw horn could also be characterised by various colour variations ranging from light to dark or a combination of colour bands and is the result of melanin being present (Montagna & Carlisle, 1991). The perception exists that pigmented bovine claws or equine hooves are less prone to problems and of better quality than lighter or non-pigmented counterparts (Hepburn *et al.*, 2007) but results published in the literature are not consistent (Vermunt & Greenough, 1995). Some studies in horses could not confirm a relationship between pigmentation and horn quality whereas other studies in dairy cattle found the opposite with an improvement in quality and decrease in claw disease observed (Dietz & Prietz, 1981 Petersen *et al.*, 1982; Chesterton *et al.*, 1989). A more recent study in dairy cattle however failed to establish

a relationship between colour and disease incidence in dairy cattle (Boelling *et al.*, 2001b). The pigmentation of claw and hoof horn of the bovine and equine species remains a controversial subject and their association is not always well understood. There seems to be a preference for darker claws in beef cattle, also among Bonsmara breeders, but possible advantages over lighter claws requires further investigation

Claw quality is a complex trait influenced by a combination of factors (genetic and non-genetic) and consequently renders it difficult to attribute only a single factor to the observed claw characteristics (Vermunt & Greenough, 1995; Cook *et al.*, 2003; Fjeldaas *et al.*, 2007; Muelling, 2009). Claw traits are low to moderately heritable but sufficient genetic variation exists rendering genetic improvement in these traits possible. A few limitations with regard to the genetic analysis of claw traits exist which in turn influences the availability of genetic parameters (Choi & McDaniel, 1993; Perez-Cabal *et al.*, 2006) compared to other traits measured in beef cattle. Some of these limitations include the subjective judging or scoring of claws, challenges associated with claw measurements, the availability of large accurate datasets and claw terminology discrepancies between countries (Huang & Shanks, 1995). At present, these limitations are relevant to beef cattle in South Africa where claw datasets and recordings are limited. Non-genetic factors influencing claw quality include nutrition, management and the physical environment (Politiek *et al.*, 1986; Vermunt & Greenough, 1995). Various nutrients have been shown as essential for the maintenance of claw integrity, including amino acids, fatty acids, trace elements, and vitamins (Mülling *et al.*, 1999; Nocek *et al.*, 2000; Tomlinson *et al.*, 2004).

Limited research with regards to claw quality (physiological and morphological characteristics) exists in beef cattle and none on Bonsmara cattle farmed under South African conditions. Research has focused predominantly on dairy cattle farmed intensively and horses where laminitis occurs frequently (Choi & McDaniel, 1993; Perez-Cabal *et al.*, 2006). Furthermore, emphasis is placed on female animals (dairy cows in lactation) with limited attention to male animals (specifically beef bulls). Distl *et al.* (1984), Boelling *et al.* (2001a & 2001b) and Becvar (2006) were some of the few researchers that investigated some claw aspects in bulls (predominantly dairy bulls with the exception of Becvar (2006) who studied claw traits in beef bulls). Breed differences also exist with regards to certain morphological claw properties (claw shape, size, conformation and horn composition) and may explain why some breeds are more susceptible to claw disorders compared to others (Townsend *et al.*, 1989; Huang & Shanks, 1995; Fatehi *et al.*, 2003; Nüske *et al.*, 2003).

Bonsmara cattle experience claw problems in certain regions of South Africa and it appears that the physical environment or surface texture of certain grazing regions has a large influence in this regard. Claw problems were also reported for bulls and steers under intensive feeding systems that could be attributed to physiological mechanisms. Partial concrete floors used in intensive feedlot systems may also be to blame. It is important to distinguish between claw problems experienced under extensive versus intensive production

systems for a fair and accurate evaluation of the problem. It is also important to consider the genetic basis of claw quality and potential inheritance of defects. The current system or regulations of the Bonsmara Society makes provision for superior stud bulls to be culled if they have any claw defect despite having superior estimated breeding values for performance. Solutions to the problem will ensure that more Bonsmara bulls will be available in the commercial market in the long term. Bonsmara females are used extensively as dam lines and claw problems should thus be eliminated completely. Although it has been recognised for many years that claws are an important component of functional efficiency, there is still room to gain more information and understanding around the genetic and physiological aspects associated with claws and the related disorders in beef cattle. The Bonsmara Society supports continuous research of their breed and, due to claw problems experienced in certain areas of South Africa, it was requested that the Department of Animal and Wildlife Sciences conduct research on claw quality.

Aim of the study

The aim of this study was to evaluate morphological and physiological factors that influence claw quality in the South African Bonsmara cattle breed, with specific reference to the major bioregions where Bosmara cattle are farmed.

To achieve this aim the following objectives were set:

1. Analyse the Bonsmara inspection data to establish the extent of the claw problem with reference to the major bioregions
2. Investigate the potential genetic basis associated with claw problems using available Bonsmara inspection data
2. Describe the morphology of Bonsmara claws collected from the major bioregions (claw shape, circumference, lateral toe length (LL), medial toe length (ML), tensile strength (TS) and colour)
3. Analyse the physiological parameters associated with claws obtained from Bonsmara cattle (claw mineral composition)

1.2 LITERATURE REVIEW

1.2.1 Introduction

Functional efficiency in both beef and dairy cattle is of key importance to ensure optimum reproduction and production (growth), which in turn will have a major impact on the profit and success of a farming enterprise (Vermunt & Greenough, 1995; Enting *et al.*, 1997). Functional efficiency refers to those structural traits related to various performance aspects of an animal required for optimal production (Bonsma, 1980). Structural soundness, including sound legs and especially sound claws, are functional traits

that influence the mating ability, longevity and welfare of animals (Vermunt & Greenough., 1995, Enting *et al.*, 1997; Barth & Waldener, 2002; Fjeldaas *et al.*, 2007).

Claw quality is dependent on the inherent genetic and physiological mechanisms of the individual. It is also influenced by a number of environmental factors, management - and nutritional practices emphasizing the complexity of claw problems (Vermunt & Greenough, 1995; Cook *et al.*, 2003; Fjeldaas *et al.*, 2007; Hepburn *et al.*, 2007). Although it has been recognised for many years that claws are an important component of functional efficiency in beef cattle, there is room to obtain a better understanding of the genetic, histological and physiological mechanisms associated with claw quality as well as the related claw disorders in beef cattle. The aim of this literature review is to describe claw structure with reference to morphological, histological and physiological properties and a review of various genetic and non-genetic factors that significantly contribute to claw quality.

1.2.2 Claw morphology

A description of the basic macro- and micro-structure (anatomy and histology) of the bovine claw and the functions of the different components are required to gain an understanding of what constitute good claw quality as well as the various claw disorders that can occur (Blowey, 2008). Detail on the anatomical and histological structure and functions of different components are described in a number of animal anatomy, histology and laminitis textbooks and here a brief discussion follows on the structure and associated disorders (Toussaint Raven, 1989; Van Amstel & Shearer, 2006; Blowey 2008).

Macro-structure, Micro-structure, Keratinization and Biomechanics of the bovine claw

Cattle are cloven-footed animals with the bovine foot consisting of two digits, the outer (lateral) and inner (medial) claw (Figure 1.1). The two digits are separated by a space termed the interdigital cleft and the surface areas of the claw are referred to as the outer, abaxial surface and the inner, axial surface (Toussaint-Raven, 1989; Van Amstel & Shearer, 2006; Greenough, 2007; Blowey, 2008).

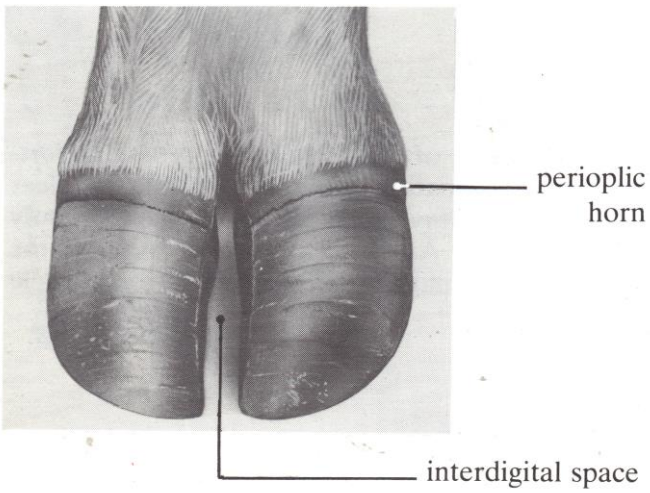


Figure 1.1 The bovine cloven-foot (lateral and medial claws) (Toussaint-Raven, 1989)

The main components that constitute the claw are the periople, coronary band, the horny wall, the sole, the white line and the heel or bulb (Blowey, 2008) (Figure 1.2 & 1.3). Each of these components has a specific function in the bovine claw to ensure normal claw function and claw structure. These regions also differ with regards to their microstructure and will be referred to at a later stage.

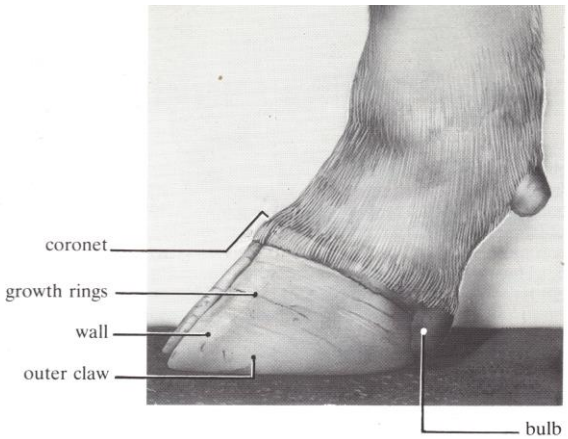


Figure 1.2 Side view of the bovine foot (Toussaint-Raven, 1989)

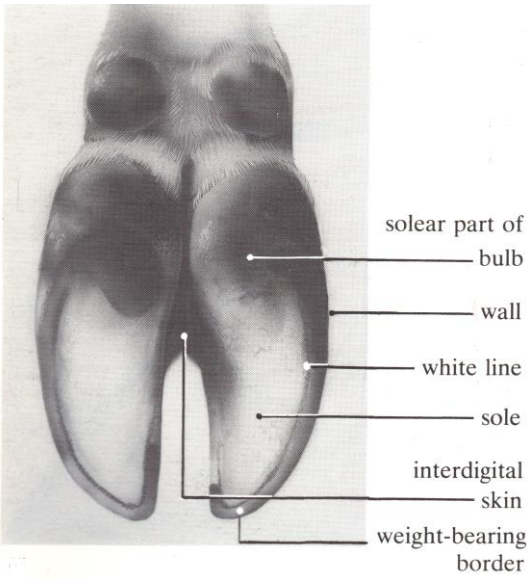


Figure 1.3 The bovine claws as seen from underneath (Toussaint-Raven, 1989)

The bovine claw consists of functionally important tissue layers namely the epidermis (horny wall), the dermo-epidermal junction (basement membrane), the corium or dermis and the subcutis (digital cushions) (Figure 1.4) with the epidermis and dermis that can be further divided in different layers (Van Amstel & Shearer, 2006; Greenough, 2007). The epidermis consist of the outer hard epidermal protective covering of the foot (horny wall) that does not contain nerves or blood vessels and the inner living epidermis located at the germinal layer. The basement membrane or the dermo-epidermal junction is situated between

the epidermis and corium and has a regulatory function (Van Amstel & Shearer, 2006; Greenough, 2007). The corium (dermis) is located beneath the epidermis and contains blood vessels and nerves that supply the epidermis with nutrients, minerals, vitamins and trace elements for the process of keratinisation (Mülling *et al.*, 1999). The corium, which consists of collagen, elastin and proteoglycans (Van Amstel & Shearer, 2006) functions additionally as a suspensory apparatus that provides the necessary support and suspension to the major bone located in the claw, the pedal bone or third phalanx (P3) (Blowey, 2008). The subcutis or digital cushion is located beneath the pedal bone and consists predominantly of fat pads that absorb the shock associated with walking and subsequent shifts in weight distribution on the digits (Raber *et al.*, 2004). The pedal bone and the navicular bone that are located inside the claw capsule function as support structures for weight bearing (Van Amstel & Shearer, 2006).

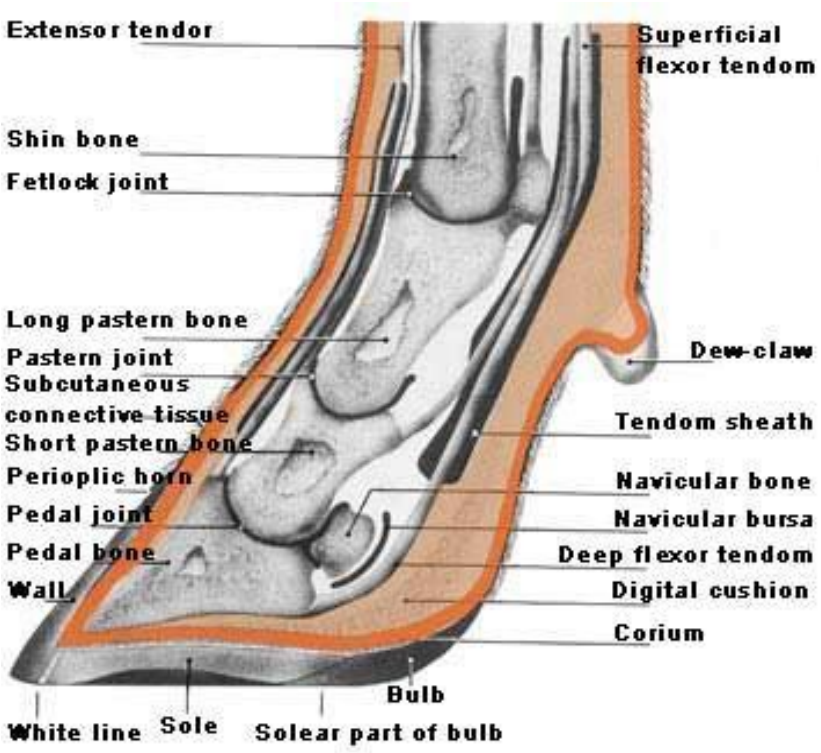


Figure 1.4 Inner anatomy of the bovine foot (Toussaint Raven, 1989)

The growth of claw horn (keratinization) is a continuous process and grows about 0.5 cm per month. Under normal conditions, horn growth and horn wall wear occurs at the same rate (Vermunt & Greenough, 1995). The process of keratinisation (horn formation) occurs in different areas of the claw (coronary, laminar, sole and heel regions) and differs in composition and physical characteristics. The dorsal claw wall is formed at the coronary band (periople) located between the skin and horny wall of the claw and occurs in a downward fashion towards the toe area (Van Amstel & Shearer, 2006). The horn-forming cells are located in the inner part of the epidermis that is adjacent to the basement membrane namely the germinal layer. At this location proliferation of the living keratinocytes occur as well as further differentiation throughout the various epidermal layers and ultimately cornification (programmed cell death) that transforms the living

epidermal cells into dead horn cells linked together with cross-linked disulphide bonds and intercellular cementing substance (ICS) (Tomlinson *et al.*, 2004). The whole process is regulated through various bioactive molecules and hormones (epidermal growth factor, prolactin and glucocorticoids) (Cowie *et al.*, 1980; Goff & Horst; 1997; Hendry *et al.*, 1999) and depends on an ample supply of nutrients (Vermunt & Greenough, 1995; Mülling *et al.*, 1999; Tomlinson *et al.*, 2004). The horn must provide adequate resistance to external stressors and would only be achieved through meticulous keratinization characterized by epidermal cells with good functional structure adequately link to each other by intercellular adhesions (Hepburn *et al.*, 2007). Hendry *et al.* (2001) found that changes in the keratin synthesis rate of animals with sole ulcers were associated with cell repair. However, a change in the distribution of keratinocytes was observed in ulcerated tissue and this imbalance of keratinocytes is a probable cause for the deteriorating claw horn structure.

The biomechanics of the claws refer to the weight bearing dynamics within and between claws and is associated with the micro – and macrostructures of the claw. The distribution of weight between and within claws is determined by several factors including the age, weight and location (front or hind legs) of the claws (Toussaint-Raven, 1989) as well as the shape of the claws (Van der Tol *et al.*, 2002). The lateral, hind claw is more stressed since it carries considerably more weight than the medial hind claw (Van der Tol *et al.*, 2004) and it has been reported that 85% of the lameness observed in dairy cattle involves this claw (Murray *et al.*, 1996; Van Amstel & Shearer, 2006). The weight distribution between the fore claws is more even, but the inner claw carries a slightly heavier weight than the lateral claw (Toussaint Raven, 1989). Correspondingly, Van der Tol *et al.* (2002) observed that the medial fore and lateral hind claw were exposed to the greatest pressures when standing on a flat surface area. These weight distributions on the fore and hind claws results in a lateral hind claw that is slightly larger than the medial hind claw and this is reversed in the front feet, where the medial front claw is slightly larger than the lateral front claw. Overall, the front legs and claws have to bear in total a slightly higher weight load (ca 60% of the weight) than the hind legs and claws (Toussaint-Raven, 1989; Van Amstel & Shearer, 2006; Greenough, 2007; Blowey, 2008). The abaxial claw wall carries the maximum weight (Van Amstel & Shearer, 2006). Conversely Van der Tol *et al.* (2002) found that the highest pressure was exerted on the posterior part of the sole in the front limbs and anterior part of the hind limbs (not the claw wall) in dairy cattle when standing on a level surface and might therefore explain the higher occurrence of problems in the solar areas. Surfaces that do not promote comfort will lead to a shift in the weight bearing dynamics (Neveux *et al.*, 2006) and subsequent interference with normal claw horn production (Vermunt, 1996).

The structural strength and biomechanical behaviour of claw material in response to forces or stress associated with weight bearing and different surfaces will therefore determine if the claw constituents will succeed in their main function (Hinterhofer *et al.*, 2004). The structure, position, density and arrangement of tubular, inter-tubular and laminar horn cells that constitute the claw wall and heel will determine the

biomechanical characteristics of the claw especially the hardness or structural strength thereof (Kasapi & Gosline, 1998; Reilly *et al.*, 1998; Franck *et al.*, 2006; Hinterhofer *et al.*, 2007). The claw wall is harder than the sole and heel area due to differences in the quantity and size of the horn tubules present (Dietz & Prietz, 1981; Borderas *et al.*, 2004). The hardness of horn will influence the rate of wear of the claw and therefore an important determinant of claw quality. An increase in the hydration level due to the continuous exposure to wet environments is associated with more elastic or softer claw horn that is less resistant to the higher abrasion properties of rough and hard walking surfaces (Baillie *et al.*, 2000; Bonser *et al.*, 2003; Winkler *et al.*, 2004). Claw horn that is too hard is also detrimental since it will be more resistant to wear and can lead to overgrown claws and associated problems. Physical claw hardness is therefore a threshold trait.

1.2.3 Claw colour and pigmentation

Bovine claws are generally dark in colour, with varying shades from dark grey to black and can be of solid colour or banded. Some individuals or specific breeds also have lighter brown claws (opaque); these are often referred to as white claws. Pigmentation observed in skin and hair as well as claw horn are due to the presence of melanin that are produced by melanocytes (Fitzpatrick & Breathnach, 1963; Bonsma, 1980). Melanocytes transfer melanosomes, which contains the pigment melanin to the keratinocytes and will determine colour either by its presence or absence (Montagna & Carlisle, 1991). Different types of melanin pigments exist with the principal ones being eumelanin (black-brown) and pheomelanin (red-yellow) (Thody *et al.*, 1991).

Perceptions exist that pigmented claw horn are of higher quality and characterised by increased strength and hardness to provide more resistance against abrasion and external stressors as well as claw disease (Pflug *et al.*, 1980; Hieronymus *et al.*, 2006; Hepburn *et al.*, 2007). Melanin acts as a protective agent of tissues against ultraviolet radiation and subsequent photodamage (Hieronymous *et al.*, 2006; Brenner & Hearing, 2008). The integrity of keratins is adversely affected by prolonged exposure to ultraviolet radiation and the presence of melanin pigment can therefore play a possible role in horn quality (Jimbow *et al.*, 1986; Marshall, 1986). Another possible explanation for a possible relationship between melanin and claw quality is the calcification that usually accompanies melanisation that has an effect on the hardness of the claw wall (Bonser & Witter, 1993).

Results published in the literature with regards to claw pigmentation and its influence on claw quality are inconsistent or not well described (Vermunt & Greenough, 1995) and the effect of pigmentation on the physical properties of the bovine claw is not always clear (Hepburn *et al.*, 2007). Several studies in horses show no link between colour and claw quality or mechanical strength (Landeau *et al.*, 1983; Douglas *et al.*, 1996). The peak extraction force and energy required to remove nails that are used to fit horses' hooves with shoes were found to be more variable or inconsistent in darker hooves than lighter hooves (Runciman *et al.*,

2004). Overall the effect of colour did not have a convincing effect on the hoof strength in this study conducted by Runciman *et al.* (2004) on horses. Hepburn *et al.* (2007) noted an initial decrease in hardness development of pigmented horn in cattle when measured from the coronary region downwards towards the toe on the dorsal border in 5mm intervals. The initial hardness differences between pigmented and non-pigmented horn in the dorsal border were only observed from the lower perioplic horn to the 40 mm site where after no differences were observed (Hepburn *et al.*, 2007). Some studies found a relationship between claw colour and disease incidence in dairy cattle (Chesterton *et al.*, 1989) whereas Boelling *et al.* (2001b) failed to establish or confirm such a relationship. However, in practice darker claws in beef cattle do seem to have a better advantage compared to lighter claws (Bosman & Scholtz, 2010), but requires further investigation.

1.2.4 Claw size and shape

Claw conformation (size and shape) is described by means of toe angle, dorsal border length, heel height, heel angle and ground circumference (Politiek *et al.*, 1986; Distl *et al.*, 1990). Claw size measurements are important since it can be a useful indicator of cattle more prone to the development of claw defects (Distl *et al.*, 1990). The size and shape of the bovine claw is functionally important especially as a shock absorber since larger claws promote better weight bearing and pressure distribution (Phillips *et al.*, 1996) which explains the occurrence of larger claws in heavier animals (Morris & Baker, 1988). Abnormal pressure distribution will possibly lead to the interference of normal horn production and changes in claw wearing properties that may result in claws of abnormal shape (Bergsten & Stranberg, 1990; Phillips *et al.*, 1996; Vermunt, 1996). The type of walking surface that cattle are exposed to and the abrasiveness thereof also plays an important role in determining claw conformation and subsequent occurrence or absence of claw problems (Telezhenko *et al.*, 2008). Malformed or overgrown claws will deem animal more vulnerable to infections, haemorrhages and lesions and eventually impaired locomotion (Greenough, 2001; Blowey *et al.*, 2000; Hinterhofer *et al.*, 2006). On the other hand, increased claw size (increased claw volume as well as longer dorsal wall length) is associated with a higher prevalence for vertical fissures (sand cracks) in the dorsal claw wall (Clark *et al.*, 2004). Therefore an intermediate optimum should be the goal. Boelling *et al.* (2001b) observed that selecting bulls with smaller claws results in daughters with better feet and legs.

The frictional interaction between the claws and the ground surface are also determined by claw shape and size (Bonser *et al.*, 2003; Shakespeare, 2009). Claws that are shorter with steeper angles are preferred in cattle and tend to show fewer problems than longer less steep claws (Choi & McDaniel, 1993; Vermunt & Greenough, 1995). Inadequate depth of heel will result in more pressure on the heel or bulbar part of the claws and overgrown claws can be of consequence since changes in the weight distribution and abrasion properties have occurred (Bosman & Scholtz, 2010). The same phenomenon is observed in cattle with weak pasterns (Bosman & Scholtz, 2010) and emphasizes the importance of structurally sound legs. Conversely,

Vermunt & Greenough (1994) pointed out that the conformation of the animal (body, legs and claws) should not be taken as a definite indicator of possible laminitis development and that conformation traits should only be considered after two years of age since changes in claw shape, claw size and leg conformation are associated with age in combination with management. They also stated that confusion between cause and effect should be avoided. Boelling *et al.* (2001b) found that genetic correlations between claw disorders and claw shape were low and inconsistent in dairy bulls.

1.2.5 Claw disorders

Various claw disorders occur in cattle with the majority being more prevalent under intensive production systems like dairy - and feedlot enterprises. Blowey (2008) described lesions that may lead to lameness by focusing on conditions associated with the claw horn capsule, the bones inside the claw capsule as well as skin conditions (Table 1.1). The nature or underlying cause of claw lesions or defects could also be categorized as either infectious, non-infectious, metabolic or traumatic (physical) (Greenough *et al.*, 1981).

Table 1.1 Claw lesion classification system as described by Blowey (2008)

Category	Description of claw disorders (lesions)	Aetiology
Claw horn capsule	Sole Haemorrhage	Non-infectious
	White Line Disease	Non-infectious
	Sole Ulcer	Non-infectious
	Heel Ulcer	Non-infectious
	Toe Ulcer	Non-infectious
	Vertical Fissure (Sand Cracks)	Non-infectious
	Horizontal Fissure	Non-infectious
	Axial wall fissures	Non-infectious
	Thin Sole Syndrome	Non-infectious
	Deeper Pedal Bone Infections	Non-infectious
	Penetration of the Sole	Traumatic
Bone	Apical Necrosis of the Pedal Bone	Traumatic
	Pedal Bone Fracture	Traumatic
Digital Skin	Interdigital Hyperplasia (growths)	Other
	Digital Dermatitis	Infectious
	Interdigital Phlegmon (Foot Rot)	Infectious
	Mud Fever	Infectious
	Heel Horn Erosion	Infectious

Muddy or unhygienic conditions (Bergsten, 1997), the type of feeding regime and improper handling facilities promoting slipping or sharp protruding objects are some of the factors associated with the above mentioned categories and render cattle vulnerable for claw problems in feedlots (Stokka *et al.*, 2001). Behavioural aspects like buller steer syndrome, where bulls get ridden by others, can also result in physical injuries to claws in feedlot environments (Stokka *et al.*, 2001). All of the mentioned claw disorders categories predispose cattle to laminitis (Murray *et al.*, 1996), where laminitis related lesions and injuries (bruises, lacerations and broken bones) are the major constituents of the non-infectious diseases observed in feedlot cattle (Stokka *et al.*, 2001). Claw lesions are usually the result of abnormal keratinisation and horn deterioration that will render animals more susceptible to the development of laminitis and lameness due to impaired claw integrity (Greenough, 1991; Hendry *et al.*, 2001; Hinterhofer *et al.*, 2007). Laminitis is defined as the histamine-induced inflammation of the claw lamellae (Vermunt & Greenough, 1994). 'Subclinical laminitis' or 'claw horn disruption' is the focus of a lot of research in the dairy industry (Hoblet & Weiss, 2001) due to welfare and economic implications because affected animals are more prone to develop secondary lesions and eventually lameness (Capion *et al.*, 2008).

Vertical fissures (sandcracks) are claw defects that predominantly occur in beef cattle especially the front lateral claws (Clark *et al.*, 2004). It is characterized by a vertical crack along the superficial dorsal wall of the bovine claw (Murray *et al.*, 1996; Clark & Petrie, 2007) that may reach or spread to the underlying sensitive tissue rendering the claw more susceptible to infection and eventually lameness (Clark *et al.*, 2004). Moisture content of claws influences the mechanical properties of claw horn (Borderas *et al.*, 2004). Research indicates that the dorsal claw wall has a lower moisture content than other parts and therefore may rationalise the higher occurrence of sand cracks in the dorsal wall (Borderas *et al.*, 2004; Hinterhofer *et al.*, 2005). Similarly in seasonal periods when the relative humidity is low claws may become more brittle and crack (Hinterhofer *et al.*, 2005). Vertical cracks have also been associated with older, heavier cattle (Goonewardene & Hand, 1995) as well as a larger claw size (Clark *et al.*, 2004). Biotin supplementation has been proposed as a possible solution to decrease the occurrence of vertical fissures (Campbell *et al.*, 2000).

The conformation of the fore and hind legs may be associated with functional efficiency of the claw and summarized in Table 1.2 as described by Ritchie & Anderson (unpublished). Breeding programs should take these conformational aspects into consideration when selecting bulls for breeding purposes (Blowey, 2005). On the contrary no correlation between claw disorders and leg conformation were observed by Boeling *et al.* (2001b) in young dairy bulls.

Table 1.2 Claw defects and associated leg conformation in beef cattle (Ritchie & Anderson, unpublished)

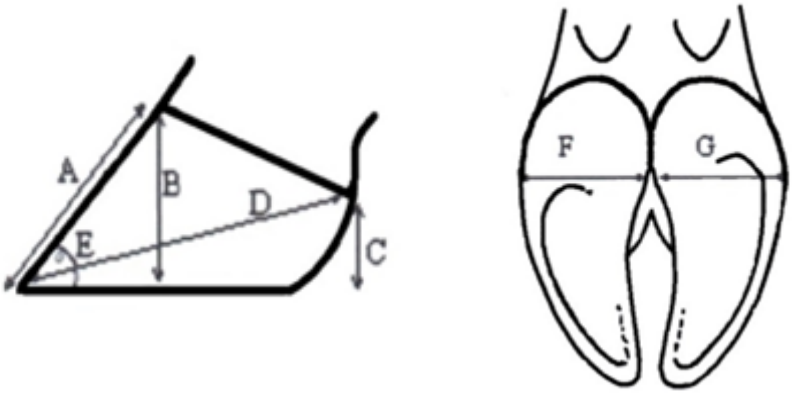
Claw defect	Description	Leg conformation
Beak claw	Turned up toes, too much wear on back part of foot and heal.	Sickled hind legs
Rolled (corkscrew claw)	Outside claw grows over the sole.	Bowed hind legs – more weight on outside of foot, claw roles under
Scissor (curled claw)	Claw grows outward, upward and curls.	Knock knees
Small feet	Must carry larger weight in relation to foot size - abrasion of the sole occur.	Usually larger breeds and straight hocks
Uneven claw size	Should be the same - not a huge concern.	Knock knees
Splayed toes	Due to weakness of tendons between toes - stress on soft tissue, cracks and corns form.	
Pigeon toed	Toes inward	
Steep pasterns & weak pasterns	Stress on skeleton - shock absorption of front limb is reduced	Narrow stance - uneven weight on outside claw
Cracked claws	Older cattle (can result in lameness).	

1.2.6 Claw quality measurements

The morphological, histological, chemical and physical properties of claws can be measured as possible indicators of claw quality as summarised in Table 1.3 (Politiek *et al.*, 1986) and claw conformation measurements shown in Figure 1.5. The impact of the environment, nutrition and management practices on the functional integrity of the claws can be assessed through these measurements (Hahn *et al.*, 1984). Differences between dairy and beef cattle exist with regards to certain morphological measurements (toe or dorsal wall angle, claw height, heel height, thickness of solear horn and heel soft tissue) as well as hardness (Browne *et al.*, 2007) possibly explaining the differences between dairy and beef cattle in how claws react to stressors.

Table 1.3 Morphological, histological, chemical and physical claw measurements (Politiek *et al.*, 1986)

Measurement	Description of characteristics
1. Morphological/ Claw conformation measurements	Diagonal length (tip of toe to proximal heel) Dorsal border length Heel length (height & depth) Dorsal wall angle Ground surface area Abaxial wall angle Spreading of claws
2. Histological properties	Number of horny tubules/mm^2 Tubule cortex & tubule medulla diameter & ratio
3. Chemical properties	Mineral content Protein content & composition
4. Physical properties	Water content Water absorption capacity Horn hardness Horn pressure elasticity Sole pressure distribution



Claw (toe) length (**A**), claw height (**B**), heel height (**C**), claw diagonal (**D**), toe angle (**E**) and claw width (**F & G**), F + G = digit width

Figure 1.5 Claw conformation measurements (Greenough & Weaver, 1997)

1.2.7 Genetic parameters

Feet and leg traits are not that frequently recorded in beef cattle and limited estimates for genetic parameters are available. The majority obtainable are limited to dairy cattle (Choi & McDaniel, 1993; Perez-Cabal *et al.*, 2006). Attempts have been made to estimate genetic parameters for some claw traits due its association with other traits of economic importance (Politiek *et al.*, 1986). It is clear that most claw traits are lowly heritable with the exception claw angle, length and hock quality that vary between low to moderate (Table 1.4). Claw disorders are also of low heritability and this was confirmed by Häggman *et al.* (2013) who investigated eight different claw defects. Evidence for sufficient genetic variation among animals does exist justifying the selection of specific animals to ensure the genetic improvement of certain claw traits or selection against claw disorders, but it would be a long-term approach since the environmental effect is larger than the additive genetic variance component (Choi & McDaniel, 1993; Huang & Shanks, 1995; Nocek *et al.*, 2000; Perez-Cabal *et al.*, 2006). Several factors exist that complicate genetic analyses of claw traits with the consequence that relatively few estimates are available compared to other performance traits measured in beef cattle. Records for measured claw traits may exist but the majority of data are usually sparse and not as accurate or complete in comparison to other production traits measured (Huang & Shanks, 1995) and depend on the country or breeder society and emphasis that they place on claw quality. Boelling *et al*. (2008) have indicated that the recording of claw trimming data that include various claw traits could increase the accuracy of genetic parameter estimates. Claw traits are difficult to measure and depending on the environment and management conditions, objective and accurate scores are hard to obtain (Huang & Shanks, 1995; Boelling *et al.*, 2001a).

A further complication is that lay terms for describing claw characteristics or disorders also differ between countries, which further confuses the use of available data (Huang *et al.*, 1995; Boelling *et al*., 2001a). The traits measured and scored need to be the same for comparison and to obtain genetic parameters that can be applied. It is also essential that for accuracy and consistency the same individual would perform the scoring, which is often not possible or feasible for a breeder interested in collecting claw data (it is labour intensive and time consuming) (Huang & Shanks, 1995). A study that investigated the effect of different inspectors in the scoring of claw traits and diseases revealed that only objective measurements and well defined claw diseases provide similar results from the two inspectors (Boelling *et al.*, 2001a). Uncommon traits and subjective scoring of certain traits proved to be a problem since dissimilar results were obtained from the different inspectors and should either be eliminated or consistently performed by the same individual (Boelling *et al.*, 2001a). Breeder societies usually rely on more than one individual to record and collect data and therefore it is essential that the human factor associated with the recording of certain traits should be taken into consideration. Although a positive genetic correlation between claw measurements and certain claw disorders exists (Politiek *et al.*, 1986; Distl *et al.*, 1990; Greenough, 1991; Boeling & Pollot, 1998), it can pose a problem due to the subjective judging of claws as previously discussed (Murray *et al.*,

1994; Huang & Shanks, 1995). Nonetheless, Boelling *et al.* (2001b) found that objective claw measurements (claw size and cannon bone circumference) of potential AI bulls should be considered in breeding programs to improve the functional claw efficiency in their daughters but that information on claw disorders were of lesser importance in this regard.

Associations between leg conformation and claw disorders also exit and play an important role in determining functional longevity (Boelling & Pollot, 1998; Boelling *et al.*, 2008) and should be taken into consideration when selecting bulls (Blowey, 2005). The relationships between various types of claw disorders and the conformation of claws and legs should however be investigated and clearly identified for selection programs (Häggman *et al.*, 2013). In dairy cattle reference is made to locomotion type traits that include scores for foot angle and rear leg set (Van Dorp *et al.*, 2004; Van Amstel & Shearer, 2006; Greenough, 2007; Blowey, 2008). The locomotive ability of cattle is genetically correlated with the feet and legs as well as the foot angle and rear leg set (side view) of the cow (Van Dorp *et al.*, 2004). This is in agreement with Choi & McDaniel (1993) who established that that the best claw trait to select for would be claw angle due to its favourable genetic association with longevity. Distl *et al.* (1984) found that sufficient genetic variation for dorsal border length, dorsal border angle and ground surface area exist within a breed and can be selected for to improve these traits. Selection criteria for claw traits should however be well thought out due to inconsistent interactions with production traits throughout lactations (Choi & McDaniel, 1993). Furthermore, a study conducted by Quintanilla *et al.* (2006) focusing on excessive hoof growth and subsequent hoof deformities in purebred pig populations confirmed a genetic component influencing the rate of hoof growth. Some individuals are therefore more prone to excessive hoof growth and possible selection for optimum hoof growth could be possible and requires further investigation in other species.

Table 1.4 Heritability estimates for claw measurements and associated disorders in dairy cattle

Claw trait	Heritability	Reference
Claw measurements:		
Claw angle**:** Lateral	*0.03-0.39	Choi & McDaniel (1993)
Medial	*0.06-0.39	Choi & McDaniel (1993)
Claw length: Lateral	*0.15-0.53	Choi & McDaniel (1993)
Medial	*0.08-0.28	Choi & McDaniel (1993)
Heel depth	*0.02-0.16	Choi & McDaniel (1993)
	0.06	Fatehi *et al.* (2003)
Claw uniformity	0.04	Fatehi *et al.* (2003)
Foot angle	0.12; 0.13	Perez-Cabal et al. (2006)
		Laursen *et al.* (2009)
Disorders:		
Laminitis	0.14	Huang & Shanks (1995)
Chronic Laminitis	0.01	Van der Waaij *et al.* (2005)
Corkscrew claw	0.05	Huang & Shanks (1995)
Sole ulcers	0.03	Huang & Shanks (1995)
Sole Haemorrhage	0.08	Van der Waaij *et al.* (2005)
Heel erosion	0.13	Huang & Shanks (1995)
Interdigital dermatitis	0.07	Huang & Shanks (1995)
White line separation	0.08	Huang & Shanks (1995
Other:	0.05-0.07	Van Dorp *et al.* (2004)
Locomotion	0.01	Laursen *et al.* (2009)
Claw health	0.01	Laursen *et al.* (2009)
Leg health	0.27	Laursen *et al.* (2009)
Bone Structure	0.22	Laursen *et al.* (2009)
Hock quality		

*Estimations for dairy cattle over four lactations

Genomic breeding values (GEBV) and genomic selection against claw disorders are a new field of interest in dairy cattle to improve claw health. Ødegård *et al.* (2013) investigated the reliability of GEBV for various claw disorders in Norwegian dairy cattle and found it to be moderate to high (0.39-0.65) and high compared to other traits. Genomic breeding values could be a powerful selection tool, but require ample claw health records (a large enough reference population and enough daughters per sire) to ensure reliability and would become more accurate with an increase in available records (Ødegård *et al.*, 2013).

Breed differences with regards to claw quality exist and this has been proven especially in the dairy industry where certain breeds are more prone to lameness than other breeds (Murphy & Hannan, 1986; Townsend *et al.*, 1989; Vermunt & Greenough, 1995; Boelling *et al.*, 2001b; Cook *et al.*, 2003; Rama, 2006). The variation observed in certain morphological claw properties (claw shape, size, conformation and

horn composition) as well as body conformation among different breeds may explain why some breeds are more susceptible to claw disorders compared to others (Townsend *et al.*, 1989; Vermunt & Greenough, 1994; Huang & Shanks, 1995; Fatehi *et al.*, 2003; Nüske *et al.*, 2003). Significant differences were observed by Pflug *et al.* (1980) in different beef cattle breeds with regard to the number of tubular cells in the claw wall as well as their diameters.

1.2.8 Nutritional influences on claw quality

Various nutrients are required to ensure the normal keratinisation and cornification of the living claw epidermal cells (i.e. normal horn wall growth) and therefore essential for the maintenance of claw integrity. Important nutrients include amino acids, fatty acids (Mülling *et al.*, 1999), macro – and trace elements, as well as vitamins (Mülling *et al.*, 1999; Tomlinson *et al.*, 2004). Nutrients for horn growth and development are supplied to the keratinocytes or epidermal cells by means of blood vessels that are present in the vascular, living corium (dermis) of the claw (Mülling *et al.*, 1999). The nutrients are transferred to the non-living, vascular epidermis (which lies above the corium) by means of diffusion (Mülling *et al.*, 1999). The rate at which the various nutrients will reach the target cells will depend on the nutrient concentration gradient as well as the distance of the cells from the blood vessels transporting the nutrients (Mülling *et al.*, 1999). Interference with the nutrient supply and circulation in the corium or overall malnutrition will decrease the amount of nutrients reaching the target epidermal cells and will have a marked effect on the cell structure and horn quality (Mülling *et al.*, 1999). Claws with inferior structural properties are rendered more susceptible to environmental damage either physical, mechanical, chemical or microbial that may lead to various claw disorders and eventually lameness (Mülling *et al.*, 1999; Nocek *et al.*, 2000; Tomlinson *et al.*, 2004). Recent review articles on the impact of nutrition on claw quality and claw health still confirms the vital role of specific nutrients in determining adequate claw structure and horn growth to prevent lameness and other claw problems (Lean *et al.*, 2013; Van Riet *et al.*, 2013).

Minerals

Numerous micro-nutrients (macro minerals and trace elements) are involved in various biochemical processes and physiological functions related to claw structure and health (Mülling *et al.*, 1999; Greenough, 2007; Gressley, 2009). Trace elements like zinc (Zn), copper (Cu), manganese (Mn), cobalt (Co) influence claw horn growth (keratinisation) and are imperative for proper immune function ensuring healthy connective, epithelial and keratinized tissues in dairy cattle (Nocek *et al.*, 2000; Ballantine *et al.*, 2002). Research on feedlot bulls established a relationship between claw growth and claw mineral composition where higher claw mineral levels were associated with bulls that had higher or better claw growth (Sugg *et al.*, 1996)

Trace mineral utilisation and their effectiveness in contributing to horn structure integrity depend on the bioavailabilty of these trace elements (Ballantine *et al.*, 2002; Gressley, 2009). Trace mineral supplements in the organic form (mineral bound to an amino acid or protein and referred to as a proteinate, complex or chelate) tend to show a higher availability than those in an inorganic form (fed as inorganic salts like zinc sulphate and magnesium sulphate). Inorganic salts are more unstable and tend to interact and bind to other feed components in the upper gastrointestinal tract rendering them less available than those bound to an organic compound (McDonald *et al.*, 2002b). Research findings in terms of the degree of mineral availability, however, differ since the measurements to determine availability proves to be complicated (Wedekind *et al.*, 1992; Spears, 1996; Ott & Johnson, 2001; Gressley, 2009). It is therefore important that the minerals should be provided in the right quantities and proportions to ensure adequate availability because interactions between individual minerals can have an effect on their availability and utilisation. In extensive grazing systems, nutrient composition and subsequent quality of plants are influenced by specie, plant maturity, season, weather and soil type (Whitehead, 2000) and should be taken into consideration so that nutrient requirements of the animal are met through strategic mineral supplementation where required.

Zinc (Zn)

Zinc, a trace mineral, is found in abundance throughout the body with its presence noted in all tissues (McDonald *et al.*, 2002b). It is involved in a vast amount of biochemical pathways and enzyme systems (McDonald *et al.*, 2002b; Greenough, 2007) including those associated with the keratinization process and consequently imperative for functionally efficient claws. The three primary functions of Zn during keratinisation is of catalytic, structural and regulatory nature (Vallee & Falchuk, 1993; Cousins, 1996).

Specific catalytic enzymes, referred to as Zn metalloenzymes, are involved in the process of keratinization (epidermal cell/keratinocyte differentiation) and are dependent on Zn for their activation (Tomlinson *et al.*, 2004). Zinc metalloenzymes include RNA nucleotide transferases, RNA polymerase (Cousins, 1996), alkaline phosphatase, carboxypeptidase, alcohol dehydrogenase and the carbonic anhydrases (Cousins, 1996; McDonald *et al.*, 2002b). In addition, lipid peroxidation of the ICS is counteracted by Zn through the activation of the cytosolic enzyme Cu/Zn superoxide dismutase (Cu/Zn SOD) (Tomlinson *et al.*, 2004). This will ensure ICS that is functionally efficient in binding keratinocytes together as well as moisture regulation to ensure structural strength of the claw (Mülling *et al.*, 1999).

Zinc is also required for the synthesis of keratin proteins or zinc-finger proteins that are necessary to lend appropriate structure and rigidness to claw horn (Cousins, 1996; Tomlinson *et al.*, 2004, Greenough, 2007) through disulphide cross-linkage (Bragulla *et al.*, 1994). Furthermore, the regulation of various factors like calmodulin, inositol phosphate synthesis, protein kinase C and thyroid hormone binding by means of Zn and the effectiveness thereof will determine the quality of horn growth (NRC, 2001). These

chemical substances are respectively, in the order that they are mentioned, responsible for the transport of calcium (Ca) into the cell thereby activating epidermal transglutaminase (important for differentiating keratin cells), mobilization of Ca from the endoplasmic reticulum, phosphorylation of proteins as additional source of energy for keratinization (Ca dependent) and regulation of calmodulin and protein kinase. All these actions are therefore imperative for keratinization process (Tomlinson *et al.*, 2004).

The immunological properties of Zn could also be an explanation for healthier feet in observed cattle receiving adequate quantities (McDonald *et al.*, 2002b; Greenough, 2007). Various studies have shown that Zn should be supplemented in the organic form due to its higher bioavailability than inorganic sources and therefore more beneficial for the improvement of claw quality (Wedekind *et al.*, 1992).

Calcium (Ca), Phosphorus (P) and Sulphur (S) (Macro-minerals)

Calcium is predominantly associated with the keratinization process, specifically keratinocyte cornification, through the activation of epidermal transglutaminase (TG). This enzyme is essential for the cross-linkage of the keratin filament bundles by means of glutamyl-lysine bonds as well as the regulation of epidermal cornification (Mülling *et al.*, 1999). A Zn and Ca interaction exists since Zn activates various chemical substances whose function in turn involve Ca for example calmodulin that transports Ca into the epidermal cells necessary for keratinisation (Tomlinson *et al.*, 2004). The occurrence of claw problems in dairy cows around calving could be explained by hypocalcemia, a condition common during the periparturient period (Tomlinson, *et al.*, 2004; Van Amstel & Shearer, 2006) causing a decrease in Ca availability and subsequent TG activity with inferior claw horn as end result (Nocek, 1997*).*

The role of P with regards to claws is more of an indirect nature. Phosphorus is closely linked to Ca and subsequent bone formation and necessary for functional legs of good structure (Greenough, 2007). Leg conformation is connected to claw quality in the sense that it will influence the weight distribution and pressure on the claws. A deficiency of both Ca or P or inadequate Ca:P ratio can result in rickets that is characterised by deformed bones, joint problems, lameness and stiffness (McDonald *et al.*, 2002b).

Amino acids like cysteine (Cys) and methionine (Met) contain S that is important for the disulphide cross-linkage of keratin proteins ensuring adequate claw structure or rigidity (Rakes & Clark, 1984). It will be discussed in more detail under amino acid influences on claw quality.

Copper (Cu)

Copper acts as a facilitator of various enzymes involved in different functions pertaining to keratinization. These enzymes include cytochrome oxidase, thiol oxidae, ceruloplasmin, and Cu/Zn SOD (McDonald *et al.*, 2002b). Cytochrome-c oxidase has its function in aerobic respiration and oxidative phosphorylation providing energy for claw horn growth (Linder, 1996; McDonald *et al.*, 2002b). Thiol

oxidase in turn is essential to ensure the proper binding of the keratin cells by means of disulphide bonds between the adjacent Cys molecules providing sufficient structure and adequate strength (O'Dell, 1990). Ceruloplasmin is involved in haemoglobin synthesis through the mobilisation and utilisation of iron and Cu/Zn SOD has anti-oxidative properties that protect the ICS from oxidative damage ensuring structurally functional ICS (McDonald *et al.*, 2002b).

Copper is also a component of pigment specifically in feathers, hair, fur and wool (McDonald *et al.*, 2002b) and could be a possible explanation for darker (pigmented) claws being stronger than light coloured claws, but this relationship requires further investigation.

Cobalt (Co), Selenium (Se), Manganese (Mn) and Iodine (I)

Cobalt (Co) is an important component of vitamin B12 and therefore it is required in sufficient amounts by the rumen microbes in order to synthesise adequate amounts of vitamin B12 (McDonald *et al.*, 2002b). Vitamin B12 in turn is important since it influences protein and energy metabolism that is essential for horn health and integrity (Smart & Cymbaluk, 1997).

Selenium (Se) is a component of the enzyme, glutathione peroxidase that prevents the oxidative damage of the ICS necessary for sound horn structure (Tomlinson *et al.*, 2004; Andrieu, 2008). This is achieved through the elimination of free radicals and hydrogen peroxide (H_2O_2) ensuring healthy cell membranes (McDonald *et al.*, 2002b). The over supplementation of Se or Se toxicity causes claw deformities through its interference with protein production and keratin cell binding during cornification, especially when selenoamino acids (SeCys or SeMet) are fed (Combs, 2000; Tomlinson *et al.*, 2004).

Manganese activates the enzymes pyruvate carboxylase as well as Mn superoxide dismutase (Mn SOD) (McDonald *et al.*, 2002b). Pyruvate carboxylase is a prerequisite for the process gluconeogenesis that produces energy essential for horn formation (Keen & Zidenberg-Cherr, 1996). Manganese SOD has anti-oxidative properties thereby removing the superoxide free radicals that could cause damage to the ICS and subsequent claw structure (Tomlinson *et al.*, 2004; Greenough, 2007). Manganese is necessary to prevent any skeletal abnormalities ensuring sound legs and subsequently sound feet (Greenough, 2007) as well as adequate Cu utilization (Greenough, 2007). Its role with regards to normal claws and their normal function is therefore more of an indirect nature (Tomlinson *et al.*, 2004).

Iodine (I) plays an important role in the regulation of metabolic rate and it is involved in the immune defence of the body (Greenough, 2007; McDonald *et al.*, 2002b). It is also required for thyroid hormone synthesis (tri-iodothyronine: T3 and thyroxine: T4) that has a regulatory function with regards to keratinization (calmodulin and protein kinase C regulation as stated previously) (Tomlinson *et al.*, 2004).

Research has shown that cattle have a lower incidence of foot rot when they are fed high levels of iodine in the form of ethylenediamine dihydroiodide (EDDI), but results are inconsistent (Greenough, 2007).

The synergistic effects of complexed organically bound trace minerals justify the feeding of it in combination with others (as opposed to only one complexed trace mineral). However, caution should be applied when formulating rations to ensure an ample supply and balance of minerals since interactions (antagonistic effects) between trace minerals can also occur (Tomlinson *et al.*, 2004). Research has indicated that combination of trace minerals will result in the decreased occurrence or severity of claw disorders like double soles, white line separation, digital dermatitis, sole haemorrhages and sole ulcerations in cattle (Nocek *et al.*, 2000).

Vitamins

Vitamins A, D, E and Biotin are important vitamins in the maintenance of claw quality (Mülling *et al.*, 1999; Tomlinson *et al.*, 2004; Greenough, 2007). Vitamin A regulates keratin cell differentiation and is also essential for growth and the maintenance of healthy epithelial tissue and mucous membranes in the body (McDonald *et al.*, 2002a). Inadequate supply of vitamin A will have claw horn of inferior quality as result.

Vitamin D and its involvement in keratinization are linked to its role as regulator of Ca metabolism. The mobilization and build-up of Ca in bones as well as the absorption thereof are controlled by vitamin D (Norman, 1996; McDonald *et al.*, 2002a). It also stimulates the uptake of Ca and P from the intestine (Greenough, 2007). Deficiencies in this vitamin are uncommon since it can be synthesized as well as stored in the body, but a lack of exposure to ultraviolet radiation without the supplementation of vitamin D can however result in minor deficiencies and have an impact on keratinisation (Tomlinson *et al.*, 2004).

Vitamin E contributes to claw horn integrity and structure through the counteractive effect on lipid peroxidation of cellular membranes and hence protection of the lipid rich ICS (Mülling *et al.*, 1999; McDonald *et al.*, 2002a). It works synergistically with Se as anti-oxidants in removing free radicals that may cause cellular damage (McDonald *et al.*, 2002a).

Vitamin C, a water soluble vitamin, is required for normal collagen metabolism (McDonald *et al.*, 2002a) and hence contributes to the collagen component in the claw for proper suspension of the pedal bone (Muelling, 2009).

Biotin and its effect on claw health and integrity has been the focus of a lot of research (Lean & Rabiee, 2011). It has been postulated that biotin is the most important vitamin determining or involved in claw quality because of its role in keratin protein synthesis and lipogenesis (Sarasin, 1994; Lean *et al.*, 2013). Three important enzymes that are biotin dependent are acetyl coenzyme A carboxylase, propionyl coenzyme A carboxylase and pyruvate carboxylase (McDonald *et al.*, 2002a). Acetyl coenzyme A carboxylase are

involved in lipid production (especially long chain fatty acids) and propionyl coenzyme A carboxylase and pyruvate carboxylase in glucose production that serve as an energy source for claw horn growth (McDonald *et al.*, 2002a). Lipogenesis (the process of complex lipid molecule production) is necessary to ensure an ICS of good quality to connect the structural keratin cells (Fitzgerald *et al.*, 1999; Mülling *et al.*, 1999; Higuchi *et al.*, 2004) and therefore biotin works well in conjunction with trace minerals like Zn that activate the production of the keratin cells (Mülling *et al.*, 1999; Tomlinson *et al.*, 2004).

Biotin is synthesised in varying quantities in the rumen and intestines of cattle by the microbes present (Bergsten *et al.*, 2003). It has been assumed that the rumen microflora can synthesize sufficient quantities of biotin and therefore dietary supplementation is not necessarily required (Campbell *et al.*, 2000; Lean *et al.*, 2013), but studies have shown that the rumen synthesis of biotin is not significant and that the demand for this vitamin is increased during stress periods (Frigg *et al.*, 1994; Smart & Cymbaluk, 1997). The amount of biotin produced will depend on the composition of the diet (forage:concentrate ratio). If the grain dry matter component exceeds 50% a decreased synthesis of biotin in vitro is observed (Da Costa Gomez *et al.*, 1998; Abel *et al.*, 2001) and an incomplete conversion of lactate to pyruvate in the rumen due to sub-optimal pyruvate carboxylase activity (Da Costa Gomez *et al.*, 1998). The end result of this is cellular lactic acidosis, which could eventually lead to lameness (Nocek, 1997). Research has shown that a decreased incidence of vertical fissures (sand cracks) as well as increased horn hardness resulted in beef cattle fed supplementary biotin (Campbell *et al.*, 2000).

Amino acids, Fatty Acids and Carbohydrates

Sulphur-containing amino acids (Met and Cys) play a role in the cross-linking of keratin proteins through disulphide bonds and, therefore, are essential in providing adequate structural strength to the claw (Rakes & Clark, 1984). Cysteine is specifically important in this function in the final stages of keratinization and cornification (Mülling *et al.*, 1999). In addition, a claw wall of good structure will also be more protective against various damaging proteolytic enzymes produced by bacteria ensuring claw health (Elias, 1981; Mülling *et al.*, 1999).

The ICS is a lipid rich binding substance that binds keratinocytes together for structural purposes to provide sufficient resistance against environmental stressors (Mülling *et al.*, 1999). It also is involved in the regulation of the moisture content of the claw wall and this will determine the biomechanical behaviour of the claw material (Mülling & Budras, 1998; Mülling *et al.*, 1999). Fatty acids (like linoleic - and arachidonic acid) are important in the synthesis of this binding substance and will determine if it succeeds in its structural function and protection (Mülling *et al.*, 1999).

Energy is required for all the biochemical pathways involved in the process of keratinisation and is imperative for claw horn production (Smart & Cymbaluk, 1997). High amounts of non-structural or highly

fermentable carbohydrates in the unadapt animal will however lead to a rapid decline in the rumen pH resulting in sub-acute rumen acidosis (SARA). A drop in the rumen pH results in the death of the gram-negative micro-organisms found in the rumen and subsequent release of endotoxins into the blood stream. Endotoxins have a damaging effect on the blood vessels present in the corium and this results in fluid leakage and tissue swelling. The blood is shunted away from the horn producing corium resulting in the death of the corium cells and poor quality horn (Nocek, 1997; Owens *et al.*, 1997; Kleen *et al.*, 2003; Oetzel, 2003). This can especially be a problem in beef cattle found in feedlot systems (as in bull growth performance testing systems) (Greenough & Gacék, 1987) and lactating dairy cows where rations are usually characterised by a high grain component, so extra care and attention should be given to these rations (Lean *et al.*, 2013).

1.2.9 Season

Seasonal trends with regards to the hardness of the claw wall, claw horn growth as well as the claw mineral content do exist (Ley *et al*., 1998; Vermunt & Greenough, 1995; MacCallum *et al.*, 2002). Maximum growth rate is observed during the warmer parts of the year (late spring, early summer) in cattle (Hahn *et al.*, 1986) and could be attributed to the changes in photoperiod, temperature, management or nutrition (Clark & Rakes, 1982; Hahn *et al.*, 1986).

Variation in the differentiation and keratiniztion of the keratinocytes of the claw is observed with the different seasons (MacCallum *et al.*, 2002). MaCallum *et al*. (2002) observed an increase in claw horn keratinisation and protein synthesis in the summer months compared to the winter months in dairy cattle and found claws to be harder in the summer than the winter months. A possible explanation for the horn growth variation observed in cattle during different months of the year may be due to a variation in the blood supply to the horn producing cells. Cold weather results in the constriction of the arterioles and a subsequent decrease in blood supply to claws occurs, which has an adverse effect on horn growth, since less oxygen and nutrients reach the claw that are necessary for horn growth (Vermunt, 1990). Seasonal variations in claw mineral composition was observed by Hidiroglou & Williams (1986). The levels of Ca, Mg, Zn and Cu were lower during the winter months and could be attributed to changes in diet associated with season or changes in management practices.

The incidence of lameness is also more prevalent during specific months of the year (Bokko & Chaudhari, 2001; MacCallum *et al.*, 2002). Impaired claw integrity has been observed to be more prevalent during months that are characterised by high or excessive rainfall (Bokko & Chaudhari., 2001). Claws that are continuously exposed to wet conditions become softer due to the water absorbed over time and create a risk for lesions (dermatitis and heel erosion) and eventually lameness (Mülling *et al.*, 2006) due to increased wear rate of the claw (Bonser *et al.*, 2003). Conversely, an increased prevalence of vertical fissures is

observed in beef cattle during the months when the relative humidity is low. This leads to claws with lower moisture content and therefore claws that are more brittle and easily cracked or fracture resulting in vertical fissures (Clark & Petrie, 2007).

Under intensive environments (most dairy farms and feedlots), special care should also be taken to prevent heat stress in animals during the warmer months. Heat stress predisposes animals to acidosis that eventually could lead to laminitis (Nocek, 1997; Owens *et al.*, 1997; Kleen *et al.*, 2003; Oetzel, 2003) as explained previously under nutritional influences on claw quality (high energy rations leading to acidosis in unadapted animals). Extreme heat has a negative influence on feed intake (especially roughage), which will result in decreased rumination and therefore a decrease in saliva production. Saliva functions as a buffer against the acids produced by the rumen microbes. In addition, animals experiencing heat stress pant and this results in extra loss of saliva, which in turn results in a decreased buffering capacity (Nocek, 1997; Owens *et al.*, 1997; Kleen *et al.*, 2003; Oetzel, 2003).

1.2.10 Age, weight and sex

The age, weight and sex of cattle are some other possible factors that may predispose cattle to poor claw integrity and eventually lameness (Hahn *et al.*, 1986; Vermunt & Greenough, 1995; Bokko & Chaudhari, 2001). An increase in the severity and a decrease in the frequency of lameness with advancing age have been observed in sheep (Bokko & Chaudhari, 2001) and dairy cattle (Manske *et al.*, 2002; Yaylak *et al*., 2010). Parity or lactation number is usually used as an indicator of age in studies investigating claw disorders and their association with age in dairy cattle (Yaylak *et al*., 2010). Other studies indicated that the risk of lameness increased up to eight years and then declined, but the decline is probably due to the fact that the cows that have shown problems with regards to claw integrity have been selected against (Manske *et al.*, 2002; Fjeldaas, 2007). More laminitis-related and infectious claw lesions associated with older animals have been noted by several authors (Wells *et al.*, 1993; Boelling & Pollot, 1998; Ward, 1999; Offer *et al.*, 2000; Manske *et al.*, 2002; Sogstad *et al.*, 2005; Mülling *et al.*, 2006; Fjeldaas *et al.*, 2007). Changes in claw measurements (claw angles and lengths) with increasing age detected by Hahn *et al.* (1984) might explain the increased occurrence of problems. Boelling *et al.* (2001a) noted differences in claw size measurements and claw disease incidence between the same dairy bulls a different ages (5 and 10 months respectively) and found an increase in claw size and disease incidence associated with an advancement in age. Another explanation for observed claw problems in older animals are the aggregate effects of various types of claw damage associated with various stressors claws are exposed to (Sogstad *et al.*, 2005).

There exists an unfavourable, negative phenotypic correlation between body weight and claw integrity and therefore a positive, unfavourable relationship between body weight and lameness (Townsend *et al.*, 1989; Stanek *et al.*, 2004; Van Dorp *et al.*, 2004). It has been proposed that the increased claw disorders

observed with increased age may be partly explained by the relationship between body weight and age given that they usually increase concurrently (Stanek *et al.*, 2004). Older and heavier beef cattle tend to be more susceptible to the development of vertical fissures (Goonewardene & Hand, 1995; Petrie *et al.*, 1998). Hence there exists a positive, unfavourable phenotypic correlation between the occurrence of vertical fissures and age as well as between vertical fissures and weight (body condition). Other studies also confirmed that foot and leg problems and subsequent culling of these animals were more common among heavier cows than smaller cows (Hansen *et al*., 1999; Dechow *et al*., 2003; Rama, 2006). Conversely, Pflug (1978) indicated that rainfall and soil type were of greater importance than body weight and age with regards to horn growth and their consequent wearing properties.

Bokko & Chaudhari (2001) found no evidence suggesting sex as a significant predisposing factor to claw problems and lameness in sheep but Nüske *et al.* (2003) however found significant differences in various claw measurements or parameters among male and female dairy calves that may have an effect on claw functionality. Male calves had significantly higher values for wall length, bulb depth, diagonal, sole length, axial wall length, claw width and dorsal angle with bulb length and bulb angle higher in female animals. The improvement of feet and leg traits should however take both sexes into account (Nüske *et al.*, 2003).

1.2.11 Intensive versus extensive production systems

The disorders associated with claws will also differ significantly between cattle kept in intensive versus extensive production systems and therefore it is important to distinguish between systems for a fair and accurate evaluation of the problem. Intensive production systems tend to present more problems with regard to claws due to more environmental stressors than extensive production systems (Rama, 2006; Fjeldaas *et al.*, 2007; Greenough, 2007). It is important that the animal type and breed are well adapted to the specific production system they are used in to ensure optimum production and claw health (Rama, 2006).

Beef cattle that are kept under intensive feedlot conditions are at risk for developing claw problems resulting in impaired locomotive ability (Bosman & Scholtz, 2010). As already mentioned, beef cattle can experience conditions like laminitis due to a specific feeding regime such as too high concentrate intake under intensive conditions (Lean *et al.*, 2013). This problem is however further aggravated if the animal is restricted to a feedlot system with partial or whole concrete flooring as in bull performance testing systems.

The type of floor system or physical walking surface that animals are exposed to have received attention from researchers (Vokey *et al.*, 2001), specifically in the dairy industry, and the majority has established that there is a significant interaction with claws (Telezhenko *et al*., 2008). Horn growth and horn wear occur at approximately the same pace under normal conditions and the bovine claw is therefore in an incessant state of turnover (Vermunt & Greenough, 1995). Hard concrete surfaces (especially new concrete)

instigate changes in claw conformation (Hahn *et al.*, 1986; Mülling *et al.*, 2006; Telezhenko *et al.*, 2008) and consequently results in unfavourable pressure distribution on the feet and overburdening of underlying corium (Bergsten & Stranberg, 1990; Vermunt, 1996). Normal horn production is disrupted and an increase in horn growth is observed (Murphy & Hannan, 1986; Bergsten & Stranberg, 1990; Vermunt, 1996) resulting in an increase in claw size (especially the lateral, hind claw) (Toussaint-Raven, 1989) deeming animals more susceptible to claw disorders and eventually lameness (Van der Tol *et al.*, 2004). Although the relationship between wear and growth has been found to be of positive nature (Vokey *et al.*, 2001; Telezhenko *et al.*, 2008) animals that are not adapted to a specific type of floor (high abrasiveness of concrete), acquire thin soles due to the increased wear before an increase in horn growth can occur (Shearer & Van Amstel, 2003; Mülling *et al.*, 2006). However, Somers *et al.* (2005) found no association between floor types (softer straw yards versus harder concrete) and claw shape (except claw angle), horn growth and wear and associated disorders in dairy cattle, meaning this is still a controversial subject. Becvar (2006) found marked differences in claw parameters of Angus steers from different types of finishing systems (feedlot versus pasture). Bonser *et al.* (2003) indicated that the floor surface must be rough enough to prevent slippage of animals and adequate claw wear but also not too abrasive because this in turn can lead to more claw wear than required to maintain the balance of hoof growth.

In addition, if beef cattle are continuously exposed to wet conditions for e.g. wet, muddy or slurry conditions (Higuchi *et al.*, 2008) in feedlots claws can become softer due to the water absorbed over time and create a risk for lesions and eventually lameness due to increased wear rate (Bonser *et al.*, 2003) and decreased resistance to external stressors or infections (Borderas *et al.*, 2004; Lawrence *et al.*, 2004; Mülling *et al.*, 2006; Higuchi *et al.*, 2008). In feedlots heel erosion and sole ulcers are some of the major claw disorders that were observed (Mülling, 2006). Research done by Olmos *et al.* (2009) indicated that dairy cattle on pasture have a decreased risk of developing lameness than housed animals due to the nature of the environment and differences in stressors influencing the claws.

Not much research has been done on veld grazing animals kept under extensive production systems and the effect of the physical terrain on their claws (probably due to a lesser degree of claw problems observed in these animals). Claw problems are observed in beef cattle kept under extensive conditions specifically in regions consisting predominantly of sandy soils or softer soil textures (as opposed to rockier, harder terrains) (Bokko & Chaudhari, 2001; Bosman & Scholtz, 2010). Insufficient wear of the claws occurs due to the softer terrain (Pflug *et al.*, 1980) which results in cattle with overgrown claws or corkscrew claws as observed in sandier grazing areas in South Africa. Bokko & Chaudhari (2001) has noted this trend also in sheep and found that the fore limbs were mostly affected by overgrowth. This abnormal claw conformation deems animals more susceptible to injuries and problems due to abnormal gait (Boko & Chaudhari, 2001) and therefore the lameness risk is increased (Manske *et al.*, 2002). Overgrown claws could lead to an additional factor namely trimming that could further complicate the selection criteria of animals.

Sandy surface areas in South Africa are not the only environmental factor that can result in elongated claws. The plant, *Crotolaria burkeana* or Rattle Bush that is found in certain parts of South Africa causes overgrown claws when grazed (Figure 1.6 & 1.7). This specific plant is usually dominant in areas that have been disturbed or sandy areas and spreads easily. The specific active ingredient or toxin causing this phenomenon is not known. Cattle are mostly affected but other animals like goats, sheep, donkeys, horses and wild antelope can also suffer from (Kellerman *et al.*, 2007). The end result is therefore impaired claw integrity as well as animals with abnormal gait that are more susceptible to lesions and eventually lameness (Russel *et al.*, 1982; Distl *et al.*, 1984; Bokko & Chaudhari, 2001; Manske *et al.*, 2002; Bonser *et al.*, 2003; Dembeli *et al.*, 2006).

Source: http://repository.up.ac.za/handle/2263/9083

Figure 1.6 *C. burkeana* (Rattle Bush) leaves

Source: http://repository.up.ac.za/handle/2263/9083

Figure 1.7 *C. burkeana* (Rattle Bush) flower

1.2.12 The human factor

Yaylak *et al.* (2010) noted a significant effect of the stockmen or owner on observed laminitis in dairy cattle. The incidence of laminitis in dairy cattle was higher where stockmen were the main animal keeper responsible for the animals compared to owners as the head manager of the dairy enterprise (30.2% versus 22.3%). This could be explained by more attention given to animals if the owner is involved in the management of the animals (Yaylak *et al.*, 2010). Other explanatory factors include the personality of the

manager (level of impatience), the level of knowledge about lameness and predisposing factors as well as the ability to identify and manage lameness problems effectively (Vermunt, 2004; Rama, 2006).

1.2.13 Conclusion

The longevity and lifetime performance of cattle is highly dependent on proper claw functionality. This in turn has a significant influence on the success of a farming enterprise. Claw quality and associated disorders are influenced by non-genetic factors like nutrition, the physical environment and the type of management applied. Heritablity estimates are low to moderate for claw characteristics, which provides scope for selection. Claw disorders are extremely complex because it is a multifactorial problem and therefore a thorough understanding of these factors is necessary to ensure the proper management of the environment as well as the selection of animals to ensure the optimum performance of the beef cattle herd.

1.2.14 References

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CHAPTER 2

ANALYSES OF BONSMARA INSPECTION DATA TO DETERMINE CLAW PROBLEMS

2.1 INTRODUCTION

The Bonsmara is the dominant beef cattle breed found in South Africa, with more than 120 000 registered animals on record, and is known for its adaptability and growth performance under adverse South African conditions (Bonsmara SA, 2012). Traits associated with functional efficiency have received much attention in the development of the Bonsmara breed under the supervision of the late Prof Jan Bonsma. Functional conformation traits, including claws, are indicative of the longevity of an animal as well as its performance related to economically important traits (Bonsma, 1983). To date, functional efficiency traits are still emphasized in Bonsmara stud cattle and therefore all Bonsmara stud cattle are subjected to a compulsory physical inspection as set out in the rules and regulations of the Bonsmara Breeder Society (Bonsmara Breeder Society of SA, Henry Straat 118, Westdene, Bloemfontein, 9301). Only after animals underwent thorough inspection and have been approved by qualified breed inspectors, can they be registered and used for breeding purposes (SA Stud Book, 2007).

Functional traits and the growth performance of animals in the relevant environment are the focus at inspections and any deviations from the required breed standards will result in the culling of the specific animal. The inspection is carried out at various ages depending on the individual breeder or the specific time of growth phase testing for bulls. Inspection ages usually range from 12 months to 36 months if animals are registered from birth, but some animals can be younger than 12 months. Animals, however, can be inspected at an older age (older than 36 months) if they are brought in as base animals (Bonsmara Breeder Society of SA, Henry Straat 118, Westdene, Bloemfontein, 9301). A large number of the bulls are customarily inspected after phase D testing (on farm growth tests) where the post-weaning growth rates of young bulls are evaluated under controlled conditions on the farm of a breeder or private organisation (SA Stud Book, 2007; Bergh, 2010).

The Bonsmara breeder society uses a system with 20 inspection categories based on functional efficiency and performance traits with a subset of rejection codes (culling reasons) per category. Animals can be allocated at most five reasons or rejection codes for possible problems. If the animal does not meet minimum requirements associated with these inspection categories at inspection they are culled irrespective of the performance in other traits. Inspections therefore serve as a multiple-trait selection method that utilises independent culling levels or reasons (Bourdon, 2000). Claw defects or problems are recorded as part of the culling reasons and seven different rejection codes or culling reasons for the claw defect category (P category) exist. Currently this is the only available information recorded for claw defects and only avenue for obtaining an association between defects and specific farms, herds, regions and or sire lines.

Bonsmara cattle are distributed throughout South Africa and exposed to various types of production environments (Visagie, 2012). Different production environments are characterised by differences in nutritional, physical, climatic, management, and economic factors that will influence the adaptability of animals (Hohenboken *et al*., 2005). These various aspects or factors associated with the various beef cattle production environments should be identified and properly defined to ensure genetic improvement with regards to the adaptability of beef cattle (Hohenboken *et al*., 2005). The adaptability of an animal to its environment is imperative to express its productive and reproductive ability. Bovine claws are influenced by the environment (nutrition, physical, climatic and management factors) it is exposed to and therefore an important factor determining the animal's adaptability to its environment and subsequent longevity (Vermunt & Greenough, 1995). The feet and more specifically the claws of beef cattle are the interface between the animal and its physical environment and a result of the type of abrasion surface they are exposed to (Telezhenko *et al.,* 2008). Bonsmara breeders have indicated that there are certain beef cattle regions, specifically the ground surface or terrain associated with these regions (sandier areas versus rockier terrains), that are more prone to bring about claw problems. It was therefore investigated by means of the inspection data recorded by the breeder society.

The aim of this chapter was to report on the analyses of the available inspection data recorded on claws for the Bonsmara breed within predefined bioregions of South Africa.

2.2 MATERIALS AND METHODS

A protocol was prepared for the proposed study and ethical approval was obtained from the Ethics Committee of the University of Pretoria (EC110620-044). The dataset containing Bonsmara cattle inspected between January 2000 and April 2012 were provided by SA Stud Book with the permission of the Bonsmara Breeder Society. The inspections of animals were done by inspectors of the Bonsmara Breeder Society and data captured by personnel of SA Stud Book (118 Henry Street, Westdene, Bloemfontein, 9301). The dataset contained 171 487 animals (95 403 female, 76 077 male and 7 of unknown sex) and included each animal's identification number, birth date, sire identification number, dam identification number, sire and dam birth dates, inspection date, rejection codes (or culling reasons) and breeding values for mature weight. An example of the data structure of one individual is given in Table 2.1.

Table 2.1 Structure of the Bonsmara inspection data received from SA Stud Book

Data Heading	Example	Description
ANI_ID	43767292	Computer generated
ANIMAL_NID	BONMCJS 000221	Bon = Bonsmara, M= Male CJS = Herd Designation Mark 00 = year 0221 = unique nr
ANIMAL_BIRTH_DTM	2000/10/05	Year/Month/Day
ANI_ID_SIRE	28727998	Computer generated
SIRE_NID,	BONMAMF 930330	Bon = Bonsmara, M= Male AMF = Herd Designation Mark 93 = year 0330 = nr
SIRE_BIRTH_DTM	1993/08/24	Year/Month/Day
ANI_ID_DAM	37152659,	Computer generated
DAM_NID	BONFCJS 960143	Bon = Bonsmara, F= Female CJS = Herd Designation Mark 96 = year 0143 = nr
DAM_BIRTH_DTM	1996/09/09	Year/Month/Day
INSPECTION_DTM	22-Oct-01	Day-Month-Year
PASSED_OR_CULLED	None	None
REASON 1-5	B2 ,Q2	Rejection codes/Culling reasons
BREEDER_AT_INSPECTION	0409021BON	Inspector code
MATURE_WEIGHT_EBV_VG	42	Breeding value (Mature Weight)

The Bonsmara society has defined twenty inspection categories based on functional efficiency and performance traits with a subset of rejection codes per category (Addendum A). The focus in this study was mainly on four inspection categories (L, M, N and P) and the respective rejection codes (culling reasons) associated with these categories (Table 2.2). These four categories represented fore legs (L), hind legs (M), pasterns (N) and claw (P) defects respectively. The fore and hind legs and pasterns were of interest to investigate possible associations between them and claws.

Table 2.2 L, M, N and P inspection categories and the respective rejection codes (culling reasons) analysed in the study with the main focus on the P category (highlighted in grey)

Category	Description	Rejection Code	Description
L	Front legs	L1	X-legged
		L2	Pigeon toed
		L3	Bandylegged
		L4	Stag knees
		L5	Knees bent backwards
		L6	Duck feet (Stands on inner hooves)
M	Hind legs	M1	Straight hocks
		M2	Excessively sickle hocked
		M3	Excessively cow hocked
		M4	Short gait
		M5	Bandy legged
N	Pasterns	N1	Weak pasterns
		N2	Upright pasterns
		N3	Twisted pasterns
		N4	Missing dew claws
P	Claws	P1	Outgrowing hooves
		P2	Hooves curling inwards
		P3	Hooves too open (pole shoe)
		P4	Lack in depth of heel
		P5	Hooves differ in size
		P6	Corkscrew hooves
		P7	Standing on outside part of hind hooves

Data were edited for general data errors such as removing animals with invalid rejection codes and animals with duplicate records. A schematic presentation of the data utilisation and editing process is given in Figure 2.1. This resulted in a dataset containing 161828 animals in total. Animals were inspected by a number of inspectors but the inspector codes were incomplete, so variation among inspectors could not be accounted for. The dataset contained a field for passing or culling during inspection. This information was incomplete for the majority of the animals. If an animal was allocated a rejection code, it did not necessarily imply that the animal was culled due to that problem. Data was therefore described for the purpose of this analysis as problem animals versus non-problem animals and not passed versus culled. After editing for general data errors, the inspected animals were linked with a specific region (town and province) by linking

the herd designation mark (HDM) in the animal identification number with the corresponding breeder and address as it appears on the breeder list received from the Bonsmara Society. The HDM are a combination of one to four uppercase alphabetical and numerical characters that are used within a specific breed to indicate an animal's herd of origin (in effect also the breeder) and form part of the animal's unique identification number (SA Stud Book, 2007). Some breeders had more than one farm at different locations that needed to be accounted for. Farming region (town and province) was allocated to breeder as best as possible with the assistance of the Bonsmara Breeder Society.

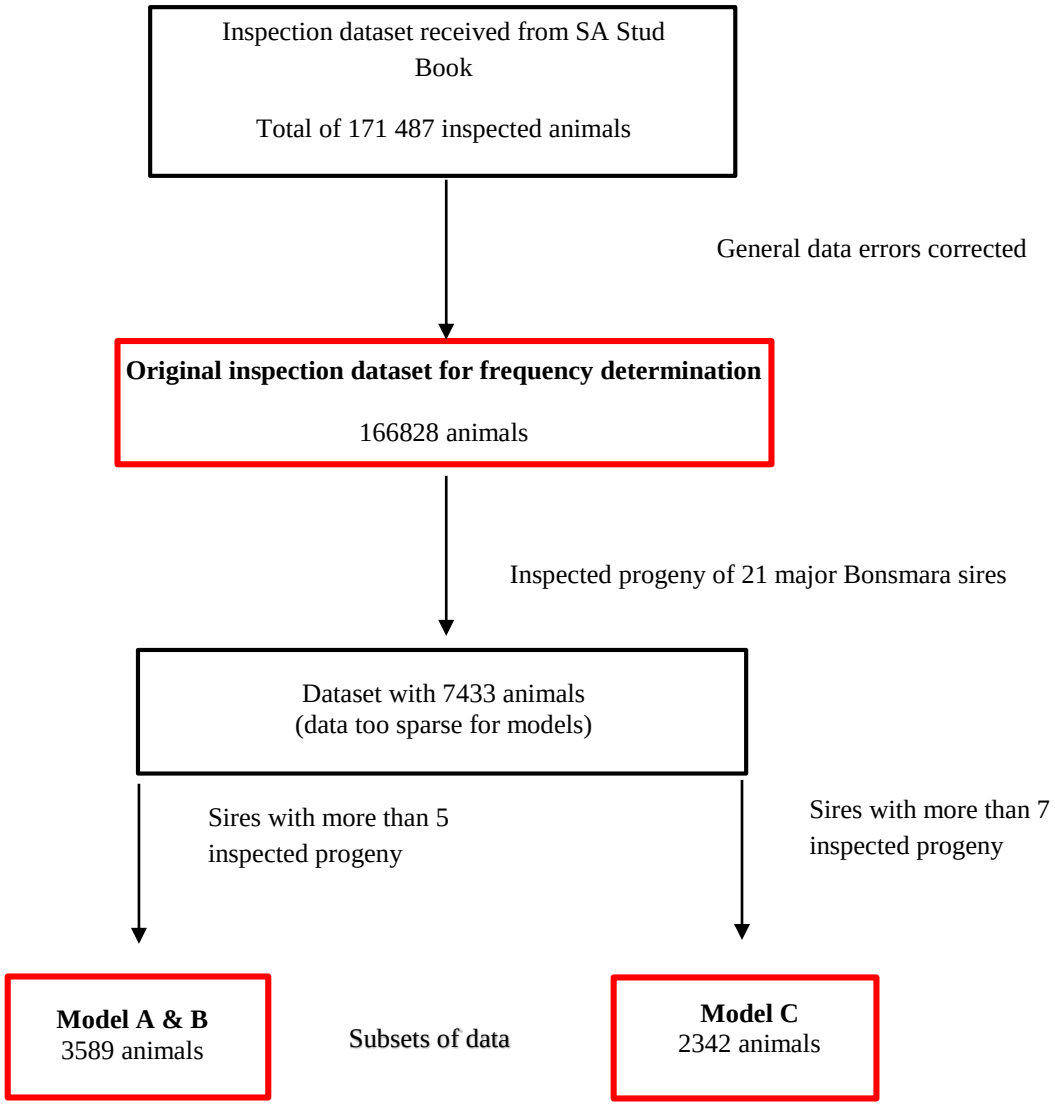


Figure 2.1 Schematic presentation of the editing process to analyse Bonsmara inspection data received from SA Stud Book with the red blocks indicating the specific datasets used for the various analyses

The province and town however posed a problem with the modelling of the data. Claw problems per province were too broad to use as a region category since variation within a province with regard to soil- and vegetation types exist and claw problems per town gave too many groups. A map of the Bioregions of South Africa (Figure 2.2 & Figure 2.3) was used to make broader groups by linking the towns associated with the inspected animals to the corresponding bioregion groups. A bioregion is defined as a unit of area with similar vegetation and physical characteristics exposed to similar conditions (Mucina *et al.*, 2006). There are distinct climatic differences between bioregions and Mucina *et al.* (2006) described 35 bioregions in South Africa. Summaries were generated with regard to the percentage or frequency of each rejection code, the amount of claw problems per town, province, bioregion, year, sex as well as the association of claw problems with leg, pastern and or other claw problems. The individual P rejection codes (P1-P7) was clustered together and the claw group as a whole was used to determine its association with other traits.

In order to determine the effect of different variables on claw problems using logistic regression models, a subset of data was obtained from the original dataset by focusing on the top twenty Bonsmara bulls used throughout South Africa and their inspected progeny. The effect of sire, sex and region on claw problems was of interest.

2.2.1 Statistical methodology

The different datasets were analysed using SAS Version 9.3 (SAS Institute, Cary, North Carolina, USA). The major Bonsmara sires used throughout South Africa were identified by SA Stud Book and used to isolate their inspected progeny from the inspection data for modelling purposes. The resultant subset of data consisted of 7433 inspected animals but modelling was difficult due to sparse data. To overcome this problem, the data was further reduced by focusing only on the inspected progeny of sires used more than five and seven times resulting in datasets containing 3589 and 2342 animals respectively

Three logistic regression models (A, B and C) were fitted to two datasets containing 3589 and 2342 inspected animals respectively. Models A and B both focused on the progeny of sires used at least six times by a breeder or different breeders (i.e. it resulted in six or more inspected progeny from a specific sire). The effects of sex and bioregion were included in both models with the effect of sire additional to model A (Table 2.3). Model C included only the effect of HDM or breeder and focused on inspected progeny of sires used at least eight times by different breeders (i.e. it resulted in eight or more inspected progeny from a specific sire). The HDM or breeder was included separately in a model and not in model B due to the nested effect since the HDM was used to determine bioregion. Frequencies and percentages of claw problems were generated from the dataset with regards to sire, sex and bioregion.

Table 2.3 Logistic regression models testing the effects of sire, sex, bioregion and HDM (breeder) on the observed claw problems in inspected progeny of sires used more than five or seven times respectively by breeders

Model	Sire utilisation by breeders	Number of inspected progeny	Effect
Model A	>5	3589	Sire
			Sex
			Bioregion
Model B	>5	3589	Sex
			Bioregion
Model C	>7	2342	HDM[1]

[1]HDM: herd designation mark

Similar frequencies that were determined on the original inspection dataset (consisting of 161828 animals) were also determined on the smaller datasets of model B and C to get an indication of how the inspected progeny of the major sires compare to the larger population with regards to claw problems.

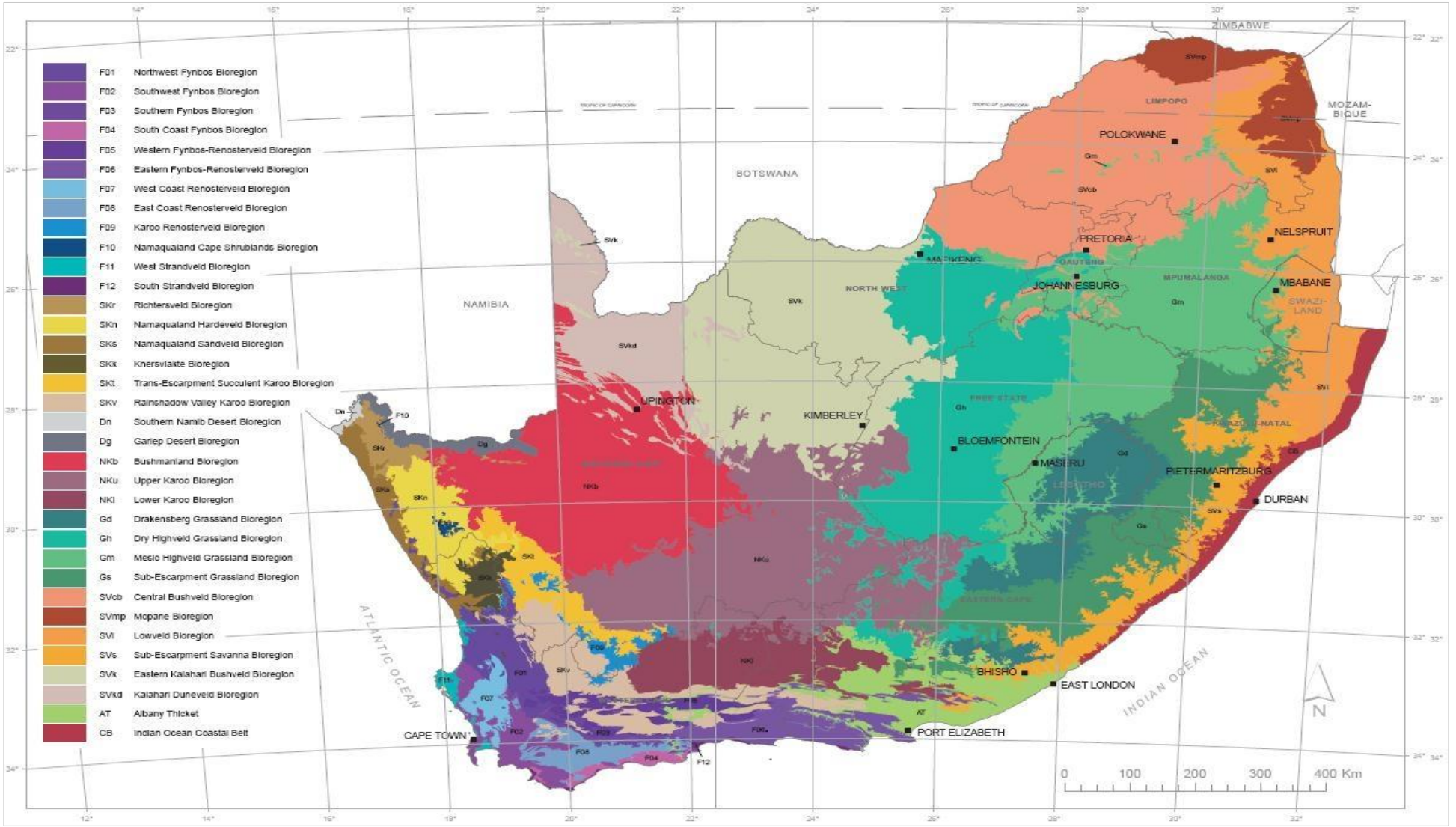


Figure 2.2 Bioregions of South Africa (Mucina *et al.*, 2006)

Figure 2.3 Bioregions of South Africa (enlargement of the map legend)

2.3 RESULTS AND DISCUSSION

2.3.1 Descriptive statistics determined on Bonsmara claw inspection data

Descriptive statistics were calculated based on the edited dataset containing 166828 records. 546 different Bonsmara breeders presented animals for inspections either at a certain stage or for the whole period from 2000 to April 2012. The allocation of town and province to the inspected animals indicated that the majority of breeders were located in the Free State and North West provinces with 146 and 114 breeders, respectively, which is expected since these areas are favourable for beef cattle farming (Bonsma & Joubert, 1957). Western Cape had the lowest number of breeders (Figure 2.4).

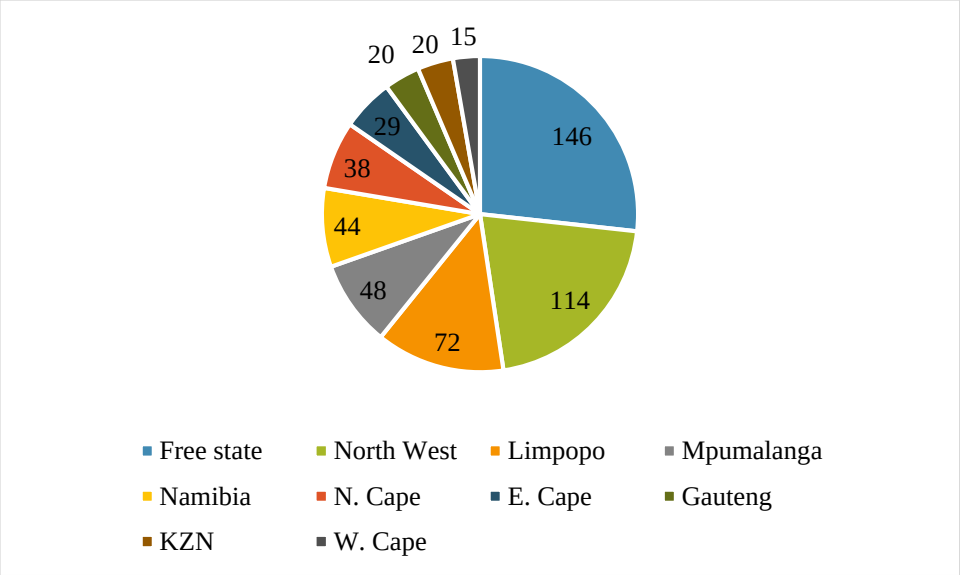


Figure 2.4 The total number of breeders involved in inspections over the period of 2000 to beginning 2012

Only 4731 (2.84%) of the 166828 inspected animals had claw problems at inspections over the specific time period. The occurrence is relatively low compared to other traits inspected in the Bonsmara breed (not shown, but was also determined). Tranter & Morris, (1991) investigated lameness incidence in dairy herds in New Zealand under grazing conditions and found it to be 2% - 38% depending on the herd. Beef cattle are not exposed to similar management practices, environmental conditions and physiological demands as dairy cattle and therefore a lower incidence of claw problems is expected (Rama, 2006). The majority of similar research focuses on dairy cattle and the incidence of lameness or lesions associated with intensive production systems, whereas it would be unlikely for Bonsmara stud animals to be lame at inspection. The focus at the Bonsmara inspections are therefore more on claw traits and possible deviations and not lameness per se. Unfavourable claw characteristics or defects could however eventually lead to lameness (Manske *et al*., 2002) and, therefore it is imperative to eliminate these animals as breeding stock

due to a genetic component involved (Perez-Cabal *et al.,* 2006). Another explanation for the low claw problem incidence in Bonsmara cattle could be that animals do not suffer from claw problems at the specific age when inspections are performed and only display problems at an older age after inspections. Vermunt & Greenough (1994) indicated that claw traits should only be considered after two years of age. Various studies have established a relationship between claw problems or claw disease incidence and age, with an increased claw problem occurrence associated with an advancement in age in dairy cattle (Boelling *et al.,* 2001; Manske *et al.*, 2002; Sogstad *et al.,* 2005; Yaylak *et al*., 2010). This relationship could be attributed to an age associated increase in the weight of the animal (Van Dorp *et al.,* 2004), claw conformation changes (Hahn *et al.,* 1984) and the aggregate effect of various environmental stressors on claw quality (Sogstad *et al.,* 2005). It should also be taken into account that if breeders observe any problems, they already cull animals before inspections and save costs.

The frequency of animals with claw problems (P1 to P7 clustered together) per province in South Africa as well as Namibia are given in Table 2.4. The claw problem percentage is given as the fragment of the total number of animals presented for inspection between 2000 and early 2012. A total of 166828 animals were inspected over the specific time period with 4731 (2.84%) of the inspected population exhibiting claw problems over this time period. The occurrence of claw problems per province ranged between 0.97% and 4.29% with the Northern Cape having the highest percentage and Kwazulu-Natal the lowest. The occurrence of claw problems in the Free State was also relatively high with 4.04% of the inspected animals from this province presenting problems. Namibia, a neighbouring country of South Africa where the Bonsmara breed is popular, had a 1.05% occurrence of claw problems over the specific time period.

Claw quality is influenced by multiple factors (Vermunt & Greenough, 1995) and, therefore, it is challenging to specifically indicate the underlying cause for the observed claw problems and it also depends on the type of claw problem. The high value for the Northern Cape could be due to the type of walking surface or ground surface that the animals are exposed to. The soil distribution map of South Africa indicates that the greater part of the Northern Cape Province is characterised by sandy soils as indicated by soil distribution maps of South Africa (Soil Types of South Africa Map, ARC-ISCW, 600 Belvedere Street, Arcadia, 0083). Cattle exposed to this type of surface area tend to develop overgrown claws due to the insufficient wear (Bosman & Scholtz, 2010) and may lead to abnormal gait and eventually lameness. As mentioned, the percentage claw problems exhibited by Bonsmara animals from the Free State was the second highest after the Northern Cape. The Free State is characterised by a different soil type than the Northern Cape (Soil Types of South Africa Map, ARC-ISCW, 600 Belvedere Street, Arcadia, 0083) as well as differences in vegetation, climate and rainfall properties (Smith, 2006). The quality of plants and their consequent nutrient composition are influenced by species, plant maturity, season, climate and soil type (Whitehead, 2000; McDonald *et al*., 2002). The higher incidence of claw problems in the Free State may be

more due to the quality of grazing and associated management aspects (as opposed to the texture of the ground surface claws are exposed to as in the Northern Cape) but requires further investigation. Chesterton *et al*. (1988) observed distinct differences between thirty two dairy farms and the incidence of lameness and claw problems. These authors indicated that it was difficult to identify the main causes of the observed problems due to multiple factors that can be involved and that it would differ from farm to farm. This should also be taken into consideration in the present study.

In general, different management practices (selection intensity and feeding supplement decisions) may play a role in the observance of claw problems or nutritional influences associated with the natural region (quality of available grazing material and raw materials) (Rama, 2006). The inspected animals with claw problems could also purely be due to inherent individual variation in the susceptibility to claw defects. Even though the Northern Cape had the highest incidence of claw problems (4.29%) it is still relative low compared to other traits inspected (not shown but were also determined) and the same applies for the overall claw problem over the specific time period.

Table 2.4 The percentage of Bonsmara animals inspected between 2000 and early 2012 that displayed claw problems (P1 to P7 clustered together)

Province	Number of animals with claw problems	Total inspected animals	% Claw problems of total inspected animals per province
Northern Cape	496	11575	4.29
Free State	2325	57507	4.04
North West	921	36221	2.54
Mpumalanga	290	13018	2.23
Eastern Cape	181	9758	1.85
Western Cape	21	1159	1.81
Other	33	1856	1.78
Gauteng	47	2654	1.77
Limpopo	213	13133	1.62
Namibia	133	12625	1.05
Kwazulu-Natal	71	7322	0.97
	4731	**166828**	**2.84**

The animals inspected over the time period originated from only thirteen of the thirty five existing bioregions. The occurrence of problems per bioregion ranged from 0.52% to 11.08 % with the majority of the animals inspected with claw problems arising from bioregion NKb (Bushmanland bioregion) and the lowest from Gd bioregion (Drakensberg Grassland bioregion) (Figure 2.5 & Figure 2.6). More detail with

regards to the frequency and percentage of animals inspected with claw problems per bioregion are given in Addendum B (Table B1). Although a total of 11399 animals were inspected from Namibia, only 0.84% had claw problems. The claw problem incidence per bioregion is similar to claw problem per province with regards to the location of the inspected animals but there is a difference in the magnitude since the borders or area perimeter of the bioregions differ from the provinces.

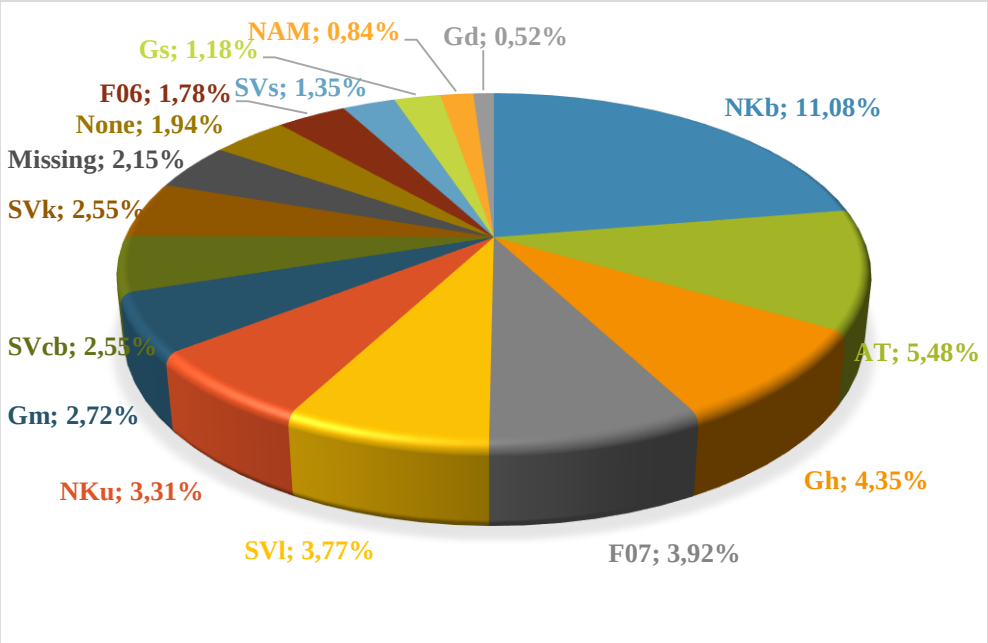
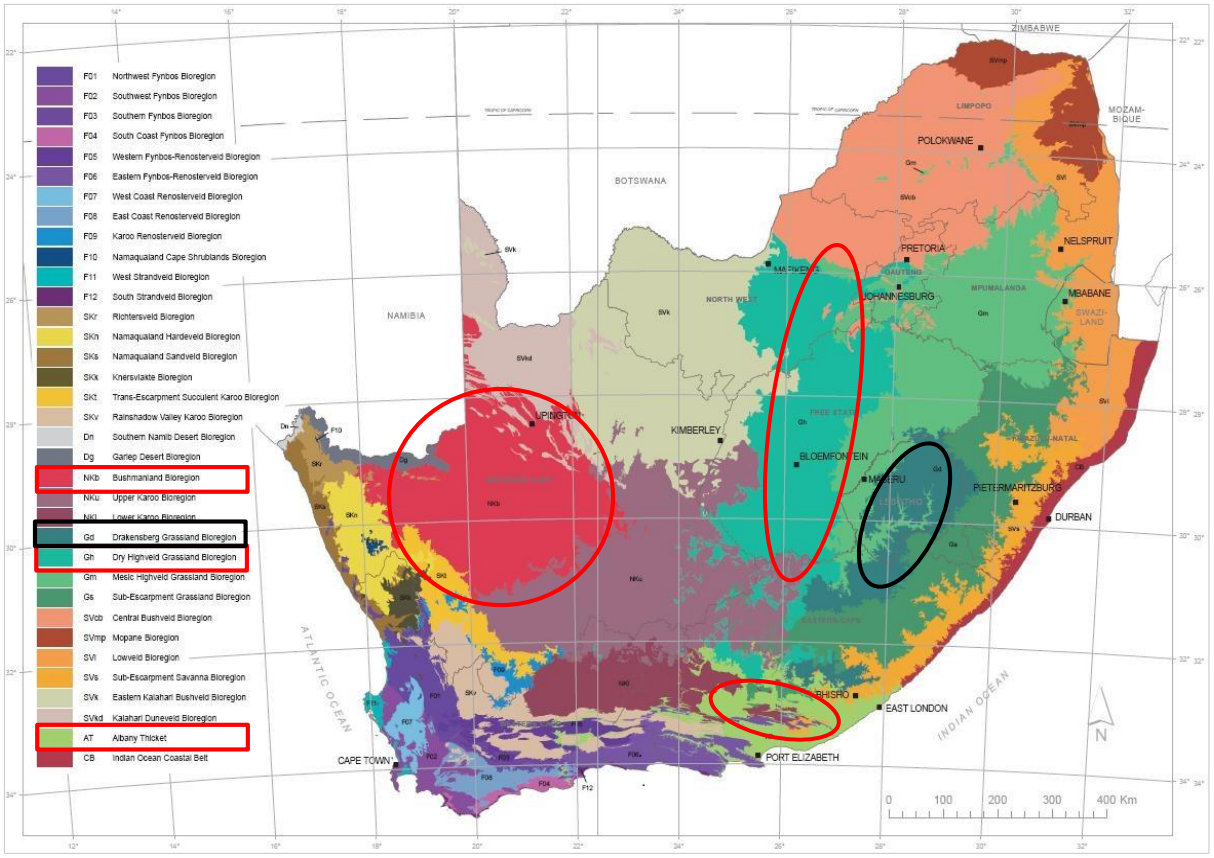


Figure 2.5 The occurrence of claw problems (%) in the different bioregions from where inspected animals originated



NKb: Bushmanland
AT: Albany Thicket
Gh: Dry Highveld Grassland
F07: West Coast Renosterveld
SVl: Lowveld
NKu: Upper Karoo
Gm: Mesic Highveld Grassland
SVcb: Central Bushveld
SVk: Eastern Kalahari Bushveld
Missing: Missing Bioregion
None: No Bioregion
F06: Eastern Fynbos Renosterveld
SVs: Sub-Escarpment Savanna
Gs: Sub-Escarpment Grassland
NAM: Namibia
Gd: Drakensberg Grassland

Figure 2.6 Location of the Bushmanland (Nkb), Albany Thicket (AT) and Dry Highveld Grassland (Gh) bioregions that had the highest claw problem percentages and the Drakensberg Grassland (Gd) with the lowest claw problem occurrence

The percentage of claw problems (P1 to P7 clustered together) by year remained relatively constant from 2001 to 2011 with an average incidence of 2.93% (Figure 2.7). The year 2000 and 2012 did not conform to this trend. The occurrence of rejection codes or culling reasons for Bonsmara animals born before 2000 in the inspection data are very sporadic but recording of it showed an increase after the year 2000 (Hunlun & Bezuidenhout, 2009). The more thorough recording of culling reasons in inspection data from 2000 probably explains the high occurrence of claw problems, where after possible improvement was made with regards to claws. This could be explained by an upsurge in the selection intensity by breeders, specifically with a focus on conformational functionality due to increased focus on recording. This

emphasizes again the importance of record keeping and the concept of 'Man must Measure' ensuring better management and selection decisions (Bonsma, 1983) Selection intensity is one of the components that is required for the genetic improvement of a trait as described by Bourdon (2000). The low occurrence in 2012 reflected only what happened the first few months of the year (January to April) and not the whole of 2012,since inspection data was only available up to this point at the time when it was requested and therefore incomplete for 2012. More detail is given with regards to the total animals inspected per year as well as the number that exhibited claw problems in Addendum B (Table B2).

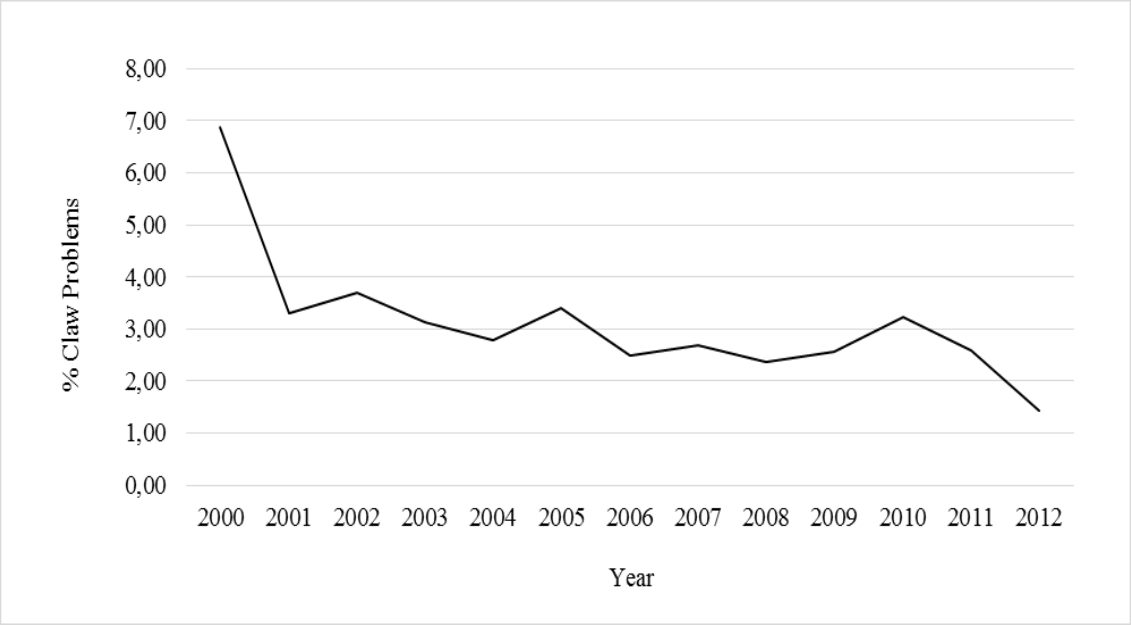


Figure 2.7 Trend for incidence of claw problems (P1-P7 clustered together) from 2000 to early 2012 given in percentage (%)

The original inspection dataset consisted of 74325 male animals (44.55%) and 92496 female animals (55.44%) that were inspected over the time period (Table 2.5). Claw problems per sex indicated that 4.76% of the inspected male animals exhibited claw defects (P1-P7 clustered together) and only 1.29% of the females had problems over the specific time period. This is probably due to stricter inspection of bulls pertaining to functional efficiency since the sire has an important long term genetic influence in a herd (Vermaak *et al.*, 2010). Gender differences could also be ascribed to claw conformational differences that exist between bulls and cows, hence differences in weight distribution on claws (Nüske *et al*., 2003). The gender of 7 animals was missing and 1 of these animals exhibited a claw problem. The frequency and percentage of progeny with claw problems per specific sire were also determined and the complete tables are given in Addendum B (Table B3 & Table B4).

Table 2.5 The frequency and percentage of claw problems (P1-P7 clustered together) associated with male and female animals related to the specific inspection period

Sex	Claw Problems	Total Animals Inspected	% Claw Problems
Male	3536	74325	4.76
Female	1194	92496	1.29
Missing	1	7	14.29
Total	**4731**	**166828**	**2.84**

The frequency and percentage of animals per individual claw rejection code (P1-P7 separately) out of the total inspected animals indicated that P1 (outgrown hooves) and P4 (lack of heel depth) were observed most during inspections with 2860 (1.71%) and 1095 (0.66%) animals displaying these problems over the specific time period (Table 2.6). Although these problems were observed the most, the occurrence was still low. Lack of heel depth and outgrown hooves can be phenotypically correlated since animals with shallow heels would place more weight on the bulbar part of the claw resulting in more opportunity for outgrown hooves and less wear of lateral and medial toes (Bosman & Scholtz, 2010). Structural characteristics like heel depth and pastern strength are not the only factors that can result in outgrown claws. Nutrition and the wear properties of the walking surface (physical environment) can also play a role and can explain the high occurrence of P1 problems (Bokko & Chaudhari, 2001; Bosman & Scholtz, 2010). The lowest frequency for claw problems was P6 (corkscrew claws) with only 110 (0.07%) animals displaying this defect at inspection over the specific time period. Bonsmara animals are inspected once in their lifetime at an early age. If claw problems occur later in life they are not recorded. Inspector bias or differences in how strict selections are performed with regards to claws should also be taken into consideration (but it was not possible with current inspection data since inspector codes were not recorded).

Table 2.6 Frequency and percentage of animals per individual claw reason (P rejection code) as inspected from 2000 to beginning 2012

Claw Rejection Code	Number of animals	% of total inspected animals
P1[1]	2860	1.71
P2[2]	502	0.30
P3[3]	233	0.14
P4[4]	1095	0.66
P5[5]	168	0.10
P6[6]	110	0.07
P7[7]	654	0.39

[1]P1: Outgrowing hooves
[2]P2: Hooves curling inwards
[3]P3: Hooves too open (pole shoe)
[4]P4: Lack in depth of heel
[5]P5: Hooves differ in size
[6]P6: Corkscrew hooves
[7]P7: Standing on outside part of hind hooves

The combination of claw abnormalities (individual P rejection codes) observed in the inspection dataset are shown in Table 2.7. The P rejection code combinations that had a frequency of zero, i.e. no combination, are not included in the table. The highest frequency combination was P1 (outgrown claws) with P4 (lack of heel depth), with 410 (0.25%) of the total animals inspected over the time period exhibiting both these problems. This again confirms that an association between these two claw defects exist (Bosman & Scholtz, 2010) as mentioned previously. The other P rejection code combinations in the table were very low with an average of 0.015% occurrence and, therefore, there are no strong indications of possible associations with each other.

Table 2.7 Combination of the individual claw problems (P rejection codes)

P1[1]	P2[2]	P3[3]	P4[4]	P5[5]	P6[6]	P7[7]	Number of animals	% of total inspected animals
							162097	97.16
						P7	475	0.28
					P6		79	0.05
					P6	P7	9	0.01
				P5			83	0.05
			P4				556	0.33
			P4			P7	43	0.03
			P4	P5			9	0.01
		P3					140	0.08
		P3				P7	16	0.01
		P3	P4				20	0.01
	P2						345	0.21
	P2					P7	31	0.02
	P2			P5			19	0.01
	P2		P4				12	0.01
	P2	P3					9	0.01
P1							2226	1.33
P1						P7	51	0.03
P1				P5			28	0.02
P1			P4				410	**0.25**
P1			P4	P5			12	0.01
P1		P3					28	0.02
P1		P3	P4				9	0.01
P1	P2						58	0.03
P1	P2		P4				11	0.01

Grey block indicates the highest P rejection code combination (%)
[1]P1: Outgrowing hooves
[2]P2: Hooves curling inwards
[3]P3: Hooves too open (pole shoe)
[4]P4: Lack in depth of heel
[5]P5: Hooves differ in size
[6]P6: Corkscrew hooves
[7]P7: Standing on outside part of hind hooves

The percentage of inspected animals that had front leg (L), hind leg (M) and pastern (N) problems over the specific time period were 0.47%, 3.05% and 0.63% respectively with hind legs the greatest (Table 2.8). The overall incidence of leg (fore and hind) and pastern problems over the inspection period were low. For the individual L, M, and N categories, L1 (X-legged), M3 (excessively cow hocked) and N1 (weak pasterns) were observed the most with 396 (0.23%), 3294 (1.92%) and 849 (0.50%) of inspected animals

respectively. Rejection codes, L5 (knees bent backwards), M4 (short gait) and N4 (missing dew claws), were the individual problems less frequently observed with only 9 (0.01%), 38 (0.02%) and 4 (0.002%) inspected animals displaying these defects (Table 2.8). Poor conformation of legs and pasterns also result in claw problems (Bosman & Scholtz, 2010). The low incidence of leg and pastern problems observed in Bonsmara animals inspected over the specific time period may indicate the emphasis of breeders on structural soundness as part of their breeding objectives. Blowey (2005) also emphasized the importance of these conformational aspects (sound legs) in breeding programs, especially when selecting bulls for breeding purposes (Blowey, 2005).

Table 2.8 Frequency and percentage of animals per individual front, hind and pastern reason (L, M and N rejection codes respectively) as inspected over the specific time period

Rejection Code	Rejection code description	Number of animals	% of total inspected animals
L1	X-legged	412	0.25
L2	Pigeon toed	190	0.11
L3	Bandylegged	33	0.02
L4	Stag knees	13	0.01
L5	Knees bent backwards	9	0.01
L6	Duck feet (Stands on inner hooves)	169	0.10
M1	Straight hocks	275	0.16
M2	Excessively sickle hocked	1547	0.93
M3	Excessively cow hocked	3278	1.96
M4	Short gait	38	0.02
M5	Bandy legged	45	0.03
N1	Weak pasterns	843	0.51
N2	Upright pasterns	121	0.07
N3	Twisted pasterns	115	0.07
N4	Missing dew claws	4	0.002

The percentage of inspected animals that had claw problems as well as front leg, hind leg or pastern problems over the specific time period are given Figure 2.8. The claw rejection codes as a group (P1-P7 clustered together) combined with either the front leg (L), hind leg (M) or pastern (N) groups were 149 (0.09%), 320 (0.18%) and 158 (0.10%) respectively over the time period (Figure 2.8). The combination of

the claw problem group with leg or pastern problem groups were highest for the hind legs and lowest for the front leg, but in general all three combinations were low and, therefore, not a strong indicator of a possible associations between these groups or structural traits.

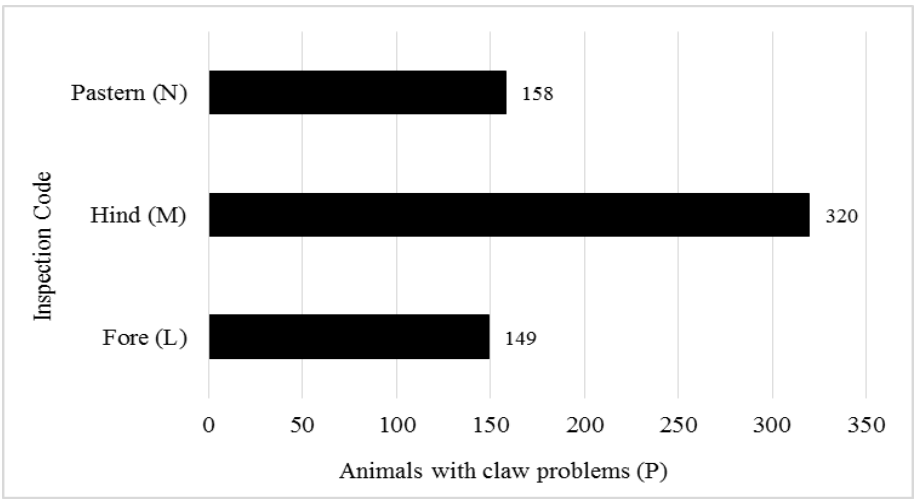


Figure 2.8 Frequency and percentage of animals out of total inspected animals that had claw problems (P) combined with either fore leg (L), hind leg (M) and pastern (N) problems

Some of the frequencies that were determined on the original inspection dataset (consisting of 161828 animals) were also determined on the subset of datasets of model B and C to get an indication of how the inspected progeny of the major sires compare to the larger population with regards to claw problems. Claw problem incidence remained relatively similar between animals of the original inspection dataset, Model B dataset and Model C dataset with 2.84%, 2.95% and 3.12% of the inspected animals displaying claw problems respectively. The results with more detail are given in Addendum C (Table C1 to Table C3).

2.3.2 The effect of sire, sex, bioregion and HDM on the observed claw defects of inspected animals as determined on a subset of inspection data

The results of the three different models (A, B and C) ran on a subset of inspection data and the respective effects tested with regards to claw problems are shown in Table 2.9. Sex (P <0.0001) and bioregion (P <0.0184) were significant in model A but sire was non-significant (P >0.19290) and, therefore, excluded from model B. Bioregion (P <0.0001) and sex (P <0.0431) remained significant in model B with the exclusion of the sire effect. Model C indicated that HDM (breeder) had a significant effect on claw problems (P <0.0001). The percent discordant (gamma) for the three models were 0.627, 0.624 and 0.543, respectively, indicating a strong predictive power of the models.

Table 2.9 Logistic regression models (A to C) on subsets of inspection data and the respective significance (P <0.05)

Model	Sires used[1]	Number of progeny	Claw Problem	Effect	df[2]	Wald Chi-Square	Pr > ChiSq[3]
Model A	>5	3589	106	Sire	19	24.0865	0.1929
				Sex	1	48.1146	<0.0001
				Bioregion	7	16.8518	0.0184
						Gamma	0.624
Model B	>5	3589	106	Sex	1	45.7902	<0.0001
				Bioregion	7	14.4935	0.0431
						Gamma	0.627
Model C	>7	2342	73	HDM[4]	10	53.673	<0.0001
						Gamma	0.543

[1]Sires that had been used more than 5 or 7 times by Bonsmara breeders
[2]df: degrees of freedom
[3] Pr > ChiSq: Probability of Chi-Square statistic
[4]HDM: herd designation mark

Although sire was insignificant with regards to claw problems in model A, three bulls (C, N and S) were signalled for having a possible effect (Table 2.10). The percentages of claw problems observed at inspection in the progeny from the major sires ranged between 0.85% and 5.29%. This, however, still illustrates that a variation between the inspected progeny of different sires with regards to claw problems exists even though sire was an insignificant explanatory variable. Claw disorders and claw characteristics have a genetic component but are only of low to moderate heritability due to the large influence of the environment (Perez-Cabal *et al.,* 2006; Häggman *et al*., 2013). Genetic improvement in claw traits are therefore possible through selection but the rate of genetic gain will be slow (Bourdon, 2000) but still worth exploiting.

Table 2.10 Frequencies and percentages of inspected progeny with claw problems that originated from the major sires

Sire	Claw Problems	Total Animals Inspected	% Claw Problems
A	2	209	0.96
B	2	103	1.94
C	3	71	**4.23**
D	5	127	3.94
E	3	145	2.07
F	1	68	1.47
G	3	133	2.26
H	4	229	1.75
I	2	96	2.08
J	1	62	1.61
K	2	98	2.04
L	9	250	3.60
M	7	246	2.85
N	29	674	**4.30**
O	2	76	2.63
P	1	118	0.85
Q	6	122	4.92
R	6	317	1.89
S	9	170	**5.29**
T	9	275	3.27
	106	**3589**	**2.95**

Grey blocks indicate sires that were identified as having a possible effect on claw problems observed in the inspected progeny (even though sire effect was insignificant)

Sex had a significant effect on the observed claw problems of inspected animals that were included in Model B. The occurrence of claw problems were significantly higher in male animals compared to female animals. Claw problem by sex showed that 5.41% of 1775 inspected male animals and 0.55% of 1814 inspected female animals had claw problems (Table 2.11). These results are similar to those obtained from the initial frequencies on the original dataset and can be explained by a stricter inspection policy applied to bulls by Bonsmara inspectors due to their long term genetic influence on the herd (Vermaak *et al*., 2010) and not necessarily that they are more prone to claw problems. The level of subjectivity related to the inspection of various functional traits in Bonsmara animals by different inspectors should therefore be taken into consideration. A study that investigated the effect of different inspectors on the scoring of claw traits and claw diseases revealed that only objective measurements and well defined diseases provided similar results

from the two inspectors (Boelling *et al*., 2001). Uncommon traits and subjective scoring of certain traits proved to be a problem since dissimilar results were obtained from the different inspectors and should either be eliminated or consistently performed by the same individual (Boelling *et al*., 2001). Breeder societies usually rely on more than one inspector to record and collect data and therefore it is essential that the human factor associated with the recording of certain traits should be taken into consideration.

Table 2.11 The sex distribution of inspected animals with claw problems (P1 – P7 clustered together)

Sex	Claw Problem	Total Animals Inspected	% Claw Problems
Female	10	1814	0.55
Male	96	1775	**5.41**
	106	**3589**	**2.95**

The grey block indicates the gender that were significant with regard to claw problems as per Model B

Conformational disparities between bulls and cows, however, can have an effect on the weight distribution between claws and may bring about differences in claw quality and structure. Differences in claw characteristics were observed between male and female calves by Nüske *et al*. (2003) and emphasizes the importance of claw traits in both sexes and should be taken into consideration. Bokko & Chaudhari (2001) however failed to establish a relationship between claw problems and sex in sheep. Heavier animals experience more foot and leg problems than smaller sized animals (Dechow *et al*., 2003) and this could explain why bulls, which are usually heavier than cows, could be more prone to problems if the weight distribution on their claws is abnormal.

Work done by Visagie (2012) indicated that bioregions are the best environmental classification system to predict the performance of beef cattle, specifically Bonsmara cattle. Model B identified eight bioregions possibly associated with claw problems but only the Sub-Escarpment Grassland (Gs) and Mesic Highveld Grassland (Gm) bioregions were significant (Table 2.12). These two bioregions (indicated on the bioregions map in Figure 2.9) had the highest percentage of inspected animals with claw problems with 5.56% and 4.05% problems respectively. These bioregions differ from the ones highlighted by the initial frequencies and could be due to the smaller sample size used in the models as well as the high percentage of Bonsmara animals farmed in specifically the Gm bioregion. However, the Eastern Kalahari Bioregion (SVk) and Drakensberg Grassland Bioregion (Gd) had the lowest percentage of claw problems with 0.71% and 0.90% inspected animals respectively. The SVk bioregion is also one of the major bioregions where Bonsmara cattle are farmed but had the lowest incidence of claw problems. Different production environments will differ with regards to climatic factors (rainfall, temperature), vegetation, quality thereof, and management practices (Bergh *et al*., 2010) that could all influence claw quality

Table 2.12 The distribution of inspected animals with claw problems (P1 – P7 clustered together) per specific bioregion

Bioregion Code	Bioregion description	Claw Problems	Total Animals Inspected	% Claw Problems
F06	Eastern Fynbos-Renosterveld	3	98	3.06
Gd	Drakensberg Grassland	2	222	0.90
Gh	Dry Highveld Grassland	15	474	3.16
Gm	Mesic Highveld Grassland	62	1530	**4.05**
Gs	Sub-Escarpment Grassland	7	126	**5.56**
Nku	Upper Karoo	3	208	1.44
SVcb	Central Bushveld	12	650	1.85
SVk	Eastern Kalahari	2	281	0.71
		106	**3589**	**2.95**

The grey blocks indicate the bioregions that were significant with regard to claw problems as per Model B

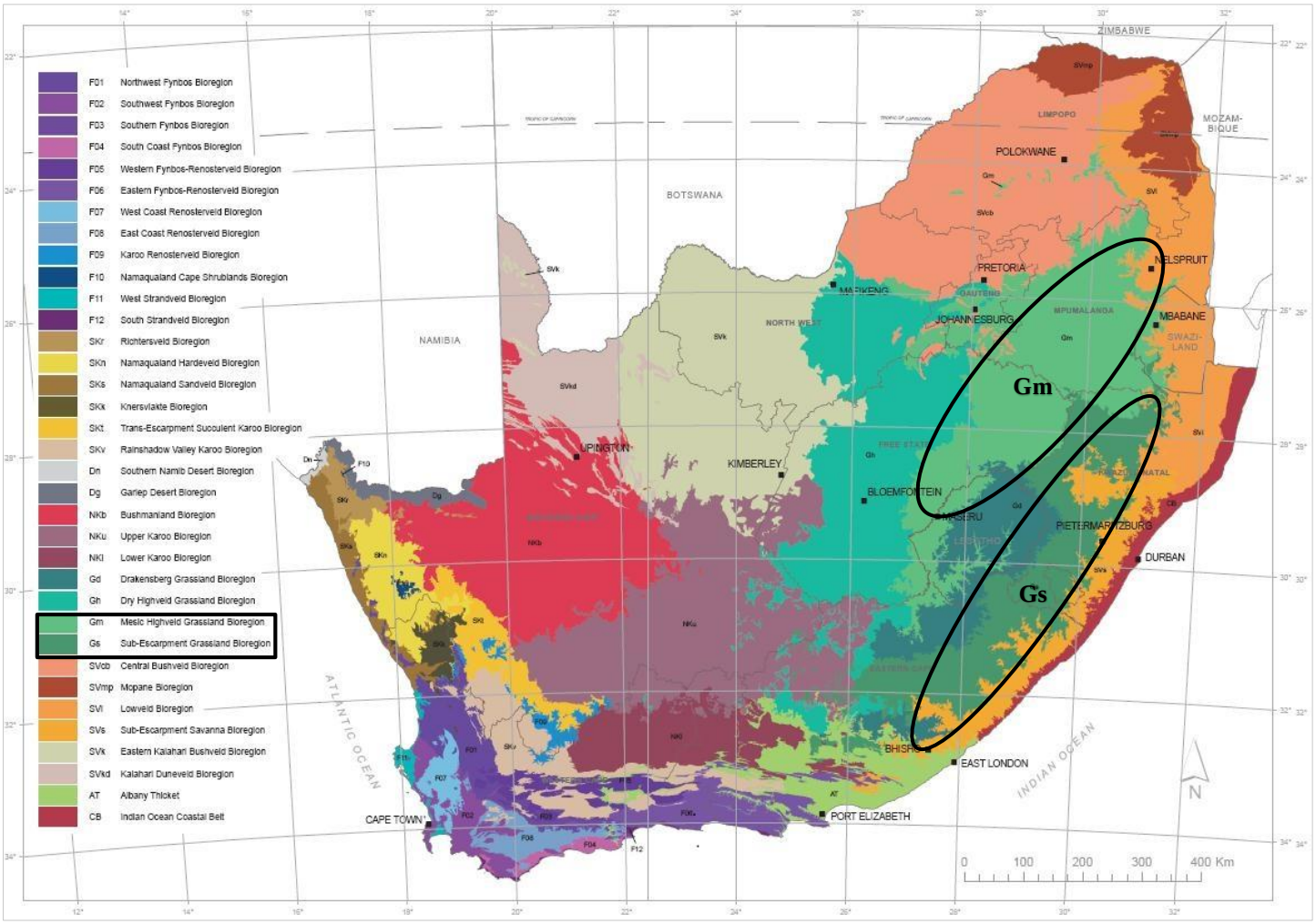


Figure 2.9 The location of the bioregions (Mesic Highveld (Gm) bioregion and Sub-Escarpment Grassland (Gs) bioregion) that had a significant association with claw problem occurrence

Model C investigated only the effect of HDM (breeder) on the observed claw problems and indicated a significant breeder influence on claw problems. It identified three HDMs or breeders of significance (A, H and J). The frequencies and percentages of claw problems per HDM or breeder are given in Table 2.13 (the larger subset of data containing 3589 animals used in Model B are shown due to identical results as the dataset containing 2342 animals for Model C, but the Model B dataset included more HDMs). The percentage of animals inspected exhibiting claw problems ranged from 0.74% to 10.66%. Breeders H and J had the highest percentages of 10.66% and 10.53% respectively. Breeder A fell in the lower range of problems but was also significant.

Table 2.13 The percentage of claw problems (P1 to P7 clustered together) per HDM or breeder with the highlighted breeders as significant (P <0.05)

HDM[1] (Breeder)	Claw Problems	Total Animals Inspected	% Claw Problems
A	7	614	**1.14**
B	3	155	1.94
C	3	75	4
D	1	86	1.16
E	4	247	1.62
F	2	233	0.86
G	1	132	0.76
H	21	197	**10.66**
I	13	318	4.09
J	8	76	**10.53**
K	10	206	4.85
L	1	87	1.15
M	0	95	0
N	2	129	1.55
O	1	21	4.76
P	0	31	0
Q	14	84	16.67
R	3	208	1.44
S	7	126	5.56
T	0	123	0
U	3	98	3.06
V	0	93	0
W	2	21	9.52
X	0	134	0
Total	**106**	**3589**	**2.95**

Grey blocks indicate the significant HDM associated with the observed claw problems as per model C
[1]HDM: herd designation mark

Model A and B indicated a significant sex effect with males being more prone to claw problems. The distribution of claw problems between male and female animals per breeder was determined in order to establish if the three noteworthy breeders in model C did not give a false positive result due to a higher percentage of males inspected. The female and male distribution for breeder A was 46.42% and 53.58% , breeder H was 40.1% and 59.9% and breeder J was 44.74% and 55.26% respectively. The percentage male

and female animals inspected were in close range and equally distributed eliminating the possibility of sex influencing the significant effect of the breeder (Table 2.14).

Table 2.14 Distribution of male and female animals inspected per HDM with the percentage (%) out of the total inspected animals indicated in the parentheses (Model C)

HDM[1]	Female	Male	Total animals inspected
A	285 (46.4%)	329 (53.6%)	614
B	48 (32.0%)	107 (69.0%)	155
C	41(54.7%)	34 (45.3%)	75
D	70 (81.4%)	16 (18.6%)	86
E	142 (57.5%)	105 (42.5%)	247
F	109 (46.8%)	124 (53.2%)	233
G	70 (51.9%)	65 (48.2%)	135
H	79 (40.1%)	118 (59.9%)	197
I	160 (50.3%)	158 (49.7%)	318
J	34 (44.7%)	42 (55.3%)	76
K	92 (44.7%)	114 (55.3%)	206
Total	**1130 (48,3%)**	**1212 (51,8%)**	**2342**

Grey blocks indicate the significant HDM associated with the observed claw problems
[1]HDM: herd designation mark

Bioregion effect was dealt with in the same manner as with sex effect in model C. It was necessary to eliminate bioregion as a possible cause of the breeder (A, H, J) significance since bioregion was significant in model A and B. The distribution of total animals inspected from a specific breeder or HDM in a specific bioregion and the percentage of animals displaying problems are indicated in Table 2.15. The highest and some of the lowest percentages of claw problems were observed in the Gm bioregion indicating a weak signal for bioregion as an explanatory variable. This implies that breeder or HDM has the largest influence on the observed claw problems. This agrees with the study done by Visagie (2012) who found that the management practices and breeding objectives of breeders had the greatest influence on the production traits of Bonsmara cattle and not bioregion, even though it was also significant. Significant differences in claw problems associated with different managers were observed by various researchers (Vermunt, 2004; Rama, 2006; Yaylak *et al.*, 2010). Bonsmara claw problems were more linked to the respective breeders than a genetic influence, since progeny of the same bull did not display claw problems in all the regions and the sire effect was overall insignificant.

Table 2.15 Percentage of inspected animals with a specific herd designation mark (HDM) exhibiting claw problems per bioregion over the specific time period of inspections

	Bioregion								
HDM[1]	**F06[2]**	**Gd[3]**	**Gh[4]**	**Gm[5]**	**Gs[6]**	**NKu[7]**	**SVcb[8]**	**SVk[9]**	**Total**
A				1.14%					614
B				1.94%					155
C				4%					75
D							1.16%		86
E			1.62%						247
F							0.86%		233
G							0.76%		132
H				10.66%					197
I				4.09%					318
J							10.53%		76
K			4.85%						206
L				1.15%					87
M								0%	95
N		1.55%							129
O			4.76%						21
P								0%	31
Q				16.67%					84
R						1.44%			208
S					5.56%				126
T							0%		123
U	3.06%								98
V		0%							93
W								9.52%	21
X								0%	134
									3589

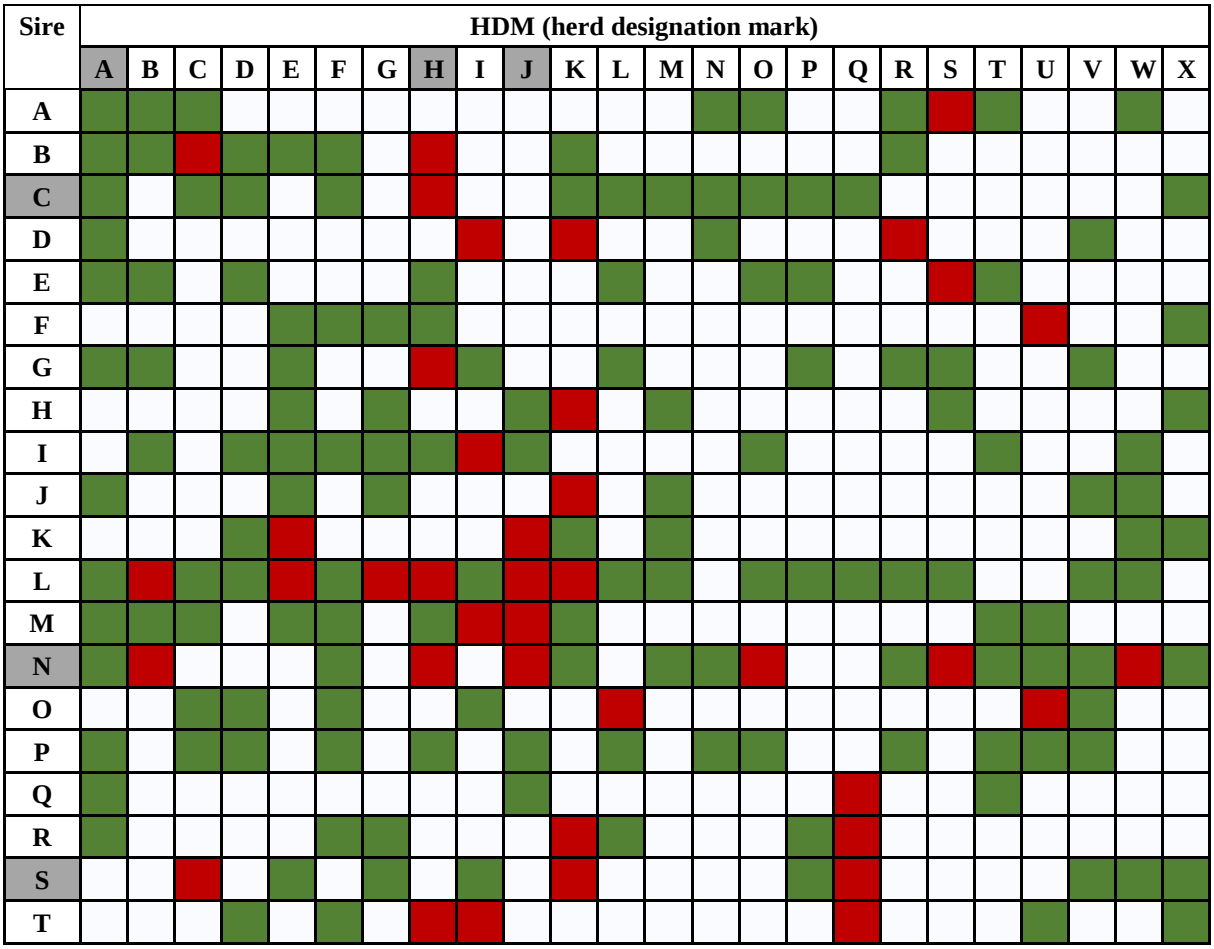
Grey blocks indicate the HDMs and bioregions that had a significant effect on the observed claw problems
Yellow blocks indicate a higher occurrence of claw problems and green blocks a lower occurrence or no occurrence of claw problems in inspected animals per specific HDM and bioregion
% in the table indicate the fraction of inspected animals with claw problems out of the total inspected animals
[1]HDM: herd designation mark
[2]F06: Eastern Fynbos Renosterveld Bioregion
[3]Gd: Drakensberg Grassland Bioregion
[4]Gh: Dry Highveld Grassland Bioregion
[5]Gm: Mesic Hihgveld Grassland Bioregion
[6]Gs: Sub-Escarpment Bioregion
[7]NKu: Upper Karoo Bioregion
[8]SVcb: Central Bushveld Bioregion
[9]SVk: Eastern Kalahari Bushveld Bioregion

Different inspectors are involved at inspections of stud animals therefore subjectivity and level of inspection strictness can also play a role with the observation of claw problems. Boelling *et al.* (2001) confirmed differences between inspectors in the judging of certain claw characteristic and defect evaluations. Inspector effect or bias should, consequently, be taken into consideration eliminating a distorted view of data and ensuring a fair and accurate evaluation of the problem. In addition, various researchers found large

differences in claw problems among herds (Tranter & Morris, 1991; Yaylak *et al*., 2010) and farms (Chesterton *et al*., 1988; Miteva *et al*., 2012) and it was difficult to ascribe or determine the major causative factors associated with these problems due to the complexity of claw problems (Chesterton *et al*., 1988). The cause of claw problems will also differ between farms and situations (Chesterton *et al*., 1988). During the different stages of development of the animal, nutrition and the environment may influence the structural development of claws, but the disorders may only become clinically visible in phenotype under certain management conditions.

The distribution of the inspected progeny with or without claw problems and the subsequent major sire and HDM or breeder associated with these inspected animals are indicated in Table 2.16. It illustrates that the major sires of the inspected progeny were used throughout South Africa by different breeders and that the progeny inspected were therefore exposed to a variety of environments. This was crucial in order to compare animals with regards to the occurrence of claw problems. The green blocks indicate that the progeny of a specific bull used by a specific breeder in a specific environment had no claw problems at inspection whereas the red blocks indicate claw abnormalities of inspected progeny. Grey blocks highlight the HDMs or breeders and sires that had a significant influence on claw problems. The complete table with percentages and frequencies can be found in Addendum D (Table D1). The distribution and occurrence of claw problems and absence of problems between the various breeders and major sires used illustrates the complexity of claw problems since it could be due to physical environment (walking surface, climate and quality of grazing), stricter selection policies applied by certain breeders, differences in management practices and possible genetic influences (the latter to a lesser extent in the present study since the sire effect was insignificant) (Rama, 2006; Yaylak *et al.*, 2010). Various researchers also found distinct differences between farms and the level of claw problems observed in dairy cattle (Chesterton *et al*., 1988; Tranter & Morris, 1991; Miteva *et al*., 2012).

Table 2.16 Sires used by different breeders (HDM) in different bioregions and the respective inspected progeny exhibiting claw problems (red blocks)



Grey blocks indicate the major sires that may have an effect on the claw problem occurrence in the inspected progeny (even though the sire effect was insignificant) as well as the HDMs that were significantly associated with claw problems

Green blocks indicate the progeny with a specific HDM from a specific sire that were inspected to be without claw problems and the red blocks the inspected progeny that had claw problems

2.4 CONCLUSION

The complexity of claw problems is yet again confirmed in this study. It is a multi-factorial problem and challenging to appoint only a single factor as the cause of the problem due to a combination of factors that are usually involved and would differ between environments. It is also difficult to accurately estimate to what degree each of the factors influence claws since this would also vary between different breeders and environments. Even though bioregion was significantly associated with the observed claw problems in inspected animals it seems that breeder has the primary influence in this regard. The identification of claw problems will greatly rely on the quality of the data recorded. It is important to realise that the inspection dataset had a variety of limitations but was dealt with in the best possible way. These limitations should be

addressed to acquire a more accurate picture of specific problems in the Bonsmara breed and to improve the practical value thereof. This is the first analysis of the Bonsmara inspection data on claws and provides valuable information with regards to claw problems experienced under South African conditions and can be useful as an indicator for further research, with careful interpretation.

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CHAPTER 3
EVALUATION OF CLAW QUALITY BASED ON MORPHOLOGICAL MEASUREMENTS AND PHYSIOLOGICAL PARAMETERS

3.1 INTRODUCTION

The Bonsmara breed was developed through a well-documented scientific breeding program that placed much emphasis on the functional efficiency of animals, including functional claws of good quality (Bonsma, 1980). Claws of good quality are defined by normal hoof growth ensuring adequate structural strength for effective weight bearing (Hepburn *et al.*, 2007) and resistance to external damage as well as the absence of any defects, lesions or infections (CRV, 2010). The claw characteristics of cattle are a reflection of the production environment, nutritional regime and management practices animals are exposed to and morphological, histological and physical properties of claws can therefore be measured as possible indicators of these influences and their effect on claw quality (Hahn *et al.*, 1984; Politiek *et al.*, 1986). The inner structural anatomy and physiology of the claw also contributes to functional integrity (Politiek *et al.*, 1986).

Claw morphology is described by means of toe angle, dorsal border length and heel height, heel angle and ground circumference (Politiek *et al.*, 1986; Distl *et al.*, 1990). The size and shape of claws are important in absorbing the shock associated with locomotion as well as ensuring adequate weight distribution (Phillips *et al.*, 1996; Van der Tol *et al.*, 2002). In addition, it determines the interaction of claws with the ground surface they are exposed to (Bonser *et al.*, 2003). Claws that are shorter with steeper angles are preferred in cattle and tend to show fewer problems than longer less steep claws (Vermunt & Greenough, 1995).

Another descriptive claw trait, namely claw colour, and its possible association with claw quality remains a controversial subject in the bovine and equine fields. The perception still exists among certain breeders that darker pigmented claws are of better quality and less prone to problems (Bosman & Scholtz, 2010) even though various scientific research studies in equines (Landeau *et al*, 1983, Douglas *et al.*, 1996) and dairy cattle (Boelling *et al.*, 2001b) oppose this view. Some research studies however did find a favourable colour and claw quality or claw disease incidence relationship (i.e. more pigment resulted in better claw quality and decreased disease incidence of claws) (Dietz & Prietz, 1981; Petersen *et al.*, 1982; Chesterton *et al.*, 1989) reinforcing the controversy around this topic. In practice it seems like darker claws have an advantage over lighter pigmented claws in beef cattle and therefore requires further investigation

Various review articles emphasize the importance of nutrients and their influence on the structural integrity of claws (Tomlinson *et al.*, 2004; Lean *et al.*, 2013; Van Riet *et al.*, 2013) and include certain minerals, vitamins, amino acids and fatty acids (Mülling *et al.*, 1999; Nocek *et al.*, 2000; Tomlinson *et al.*, 2004). The majority of these nutrients are usually in some way involved in the keratinisation process ensuring normal hoof growth or structural binding of keratin proteins (Lean *et al.*, 2013). Studies on the claw mineral composition

of beef cattle as an indicator of claw quality or possible nutritional exposure is sparse and the value thereof requires further investigation.

Limited research on claw morphology and physiological parameters exists in beef cattle and none on Bonsmara cattle farmed under South African conditions. The majority of research focuses on dairy cattle (specifically dairy heifers and lactating dairy cows) or horses due to the prevalence of laminitis and associated claw defects associated with these intensive production systems (Rama, 2006). These animals are usually also situated in countries of the Northern hemisphere other than Africa and are exposed to different environmental challenges as countries in the Southern Hemisphere. In addition, the availability of claw research on male animals, specifically beef bulls used as seedstock, is scarce. The Bonsmara breed is the dominant beef cattle breed in South Africa (Bergh *et al.*, 2010) and therefore it is essential that stud animals are structurally sound, ensuring offspring with adequate claw quality and claw structure suited to their environment. Breed differences exist with regard to various claw characteristics (claw shape, size, conformation and horn composition) as well as body conformation traits, which may be indicative of their susceptibility to claw problems (Townsend *et al.*, 1989; Vermunt & Greenough, 1994; Huang & Shanks, 1995; Fatehi *et al.*, 2003; Nüske *et al.*, 2003) and therefore worth investigating in the Bonsmara breed.

Beef cattle production in South Africa is performed under different conditions; both extensive (Van Zyl *et al.*, 1993) and intensive production systems (Ford, 2002) and claws of these animals are therefore exposed to a wide variety of environments and associated stressors. In the cow herd, claw quality will influence longevity, while in male offspring finished in feedlots claw quality will influence profitability. The elite Bonsmara breeders are spread throughout South Africa (Visagie, 2012) and these different locations and regions are characterised by differences in vegetation, climate and physical terrain (Mucina *et al.*, 2006). Differences between claw characteristics are therefore expected. Claw traits are low to moderately heritable, indicating that the environment animals are exposed to has a large influence on the observed claw quality, but improvement can be made through selection (Perez-Cabal *et al.*, 2006) and, therefore, it is imperative to eliminate any claw defects through sound breeding principles.

Due to claw problems experienced in Bonsmara cattle in certain areas of South Africa, various claw characteristics were investigated to obtain a better understanding of the influential factors associated with the observed claw properties. The aim of this study was to evaluate morphological measurements as well as physiological parameters to set a benchmark for claw quality in Bonsmara cattle originating from different bioregions in South Africa.

3.2 MATERIALS AND METHODS

A protocol was prepared for the study and ethical approval was obtained from the Ethics Committee of the University of Pretoria (EC110620-044). A total of 178 lateral claws and 178 medial claws from 89

Bonsmara stud animals were collected from abattoirs located in the Gauteng, Limpopo, North West and Free State provinces. The claws were collected from specific bioregions of South Africa, namely the Mesic Highveld Grassland (Gm) bioregion, Central Bushveld (SVcb) bioregion and Eastern Kalahari Bushveld (SVk) bioregion, as defined by Mucina *et al.* (2006) (Figure 3.1). Claws were collected from these bioregions since these are the main bioregions where Bonsmara breeders are located (Visagie, 2012). Samples included both normal and abnormal claws from bulls between the ages of 12 and 36 months. A few claws from older cows were also included (Table 3.1). Samples collected from the specific bioregions were subject to availability.

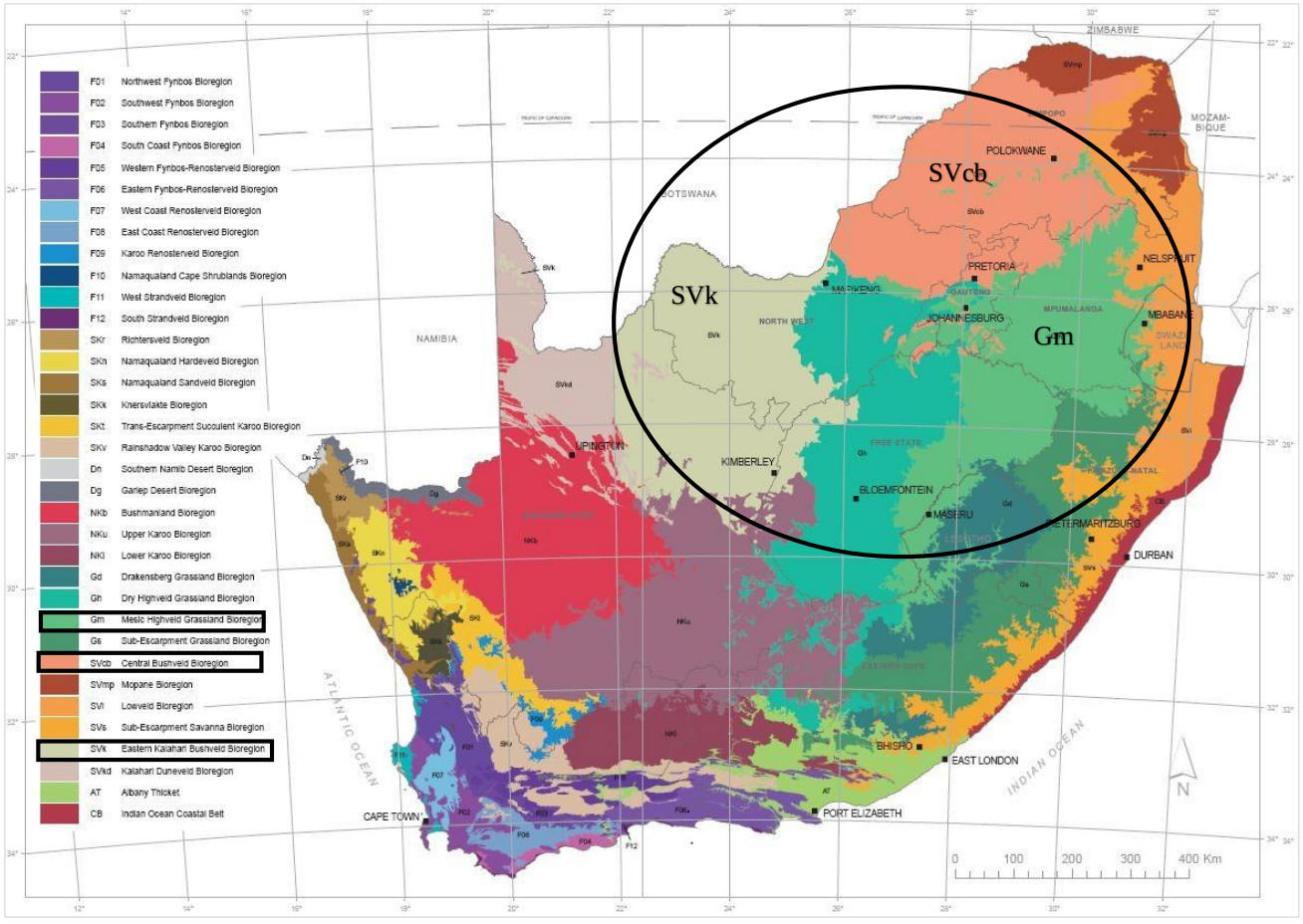


Figure 3.1 The bioregions of South Africa (Mucina *et al.*, 2006) with the three main Bonsmara claw collection areas (Mesic Higveld Grassland (Gm), Central Bushveld (SVcb) and Eastern Kalahari Bushveld (SVK) bioregions) indicated

Bonsmara stud bulls are subjected to intensive or extensive growth tests, where growth performance is tested and animals are inspected for any deviations from the required breed standards. If these bulls fail to meet breed standards they are culled at the end of the test period. The majority of claws collected for this study were from animals that failed Phase D growth test due to poor growth or not meeting the standards for functional traits. Only a few animals were culled due to claws that did not meet breed standards, so both claws acceptable by the breed standards (normal claws) and claws with defects could be collected. However, due to the limited

number of abnormal claws available, only claws that were normal (without defects) were included in the present study for analyses.

A front and hind foot (lateral and medial claws) per animal, either right or left, cut at the knee- and hock joint respectively were sampled. The lateral and medial claws were removed from the leg at the pastern joint after collection using an Okto Industrial Meat Band Saw (Crown National, South Africa). Claws were wiped clean, placed in a plastic bag and labelled with the identification number of the animal as well as front or hind claw. Claws were stored at -20˚C at the Hatfield Experimental farm of the University of Pretoria until further processing. It is important to take note that where reference is made to claws, it implies both lateral and medial claws as a unit (per hind or front limb) unless specified otherwise.

Table 3.1 The total number of Bonsmara claws (front and hind) collected from three main bioregions (Gm, SVcb and SVk)

Age (months)	**Mesic Hihgveld Grassland (Gm) bioregion**		**Central Bushveld (SVcb) bioregion**		**Eastern Kalahari Bushveld (SVk) bioregion**	
	Male	Female	Male	Female	Male	Female
12-36	50[1] (25)[2]	None	60 (30)	None	40 (20)	8 (4)
>36	2 (1)	6 (3)	None	None	None	12 (6)
Total claws (feet) per bioregion	**58**		**60**		**60**	

[1]The lateral and medial claw per front and hind limb are counted as one unit respectively
[2]The number in brackets indicate the number of animals involved

3.2.1 Morphological measurements

Morphological measurements included toe lengths, circumference, colour and hardness of the claw. Claws were defrosted and the lateral toe length (LL) and medial toe lengths (ML), from the coronary band along the dorsal border to toe of claw, were measured using a measuring tape (Politiek *et al.*, 1986) (Figure 3.2). The circumference of the lateral and medial claw as a whole was also recorded (Figure 3.3). Claws were photographed using a Canon IXY Digital 910IS camera (Canon Inc., Tokyo, Japan) in order to compile a colour chart according to the variation observed.

Figure 3.2 Claw toe length (measured from perioplе to tip of the toe)

Figure 3.3 Claw circumference measurement

3.2.2 Tensile strength (TS) testing

In order to measure TS of the claw, rectangular samples (4.5 cm x 1 cm) were obtained from the lateral claw wall by means of a Stryker 1100 oscillating saw (Stryker Corp., Michigan, USA) and a Dremel 3000 rotary multi-tool (Robert Bosch Tool Corp., Mount Prospect, Illinois, USA) (Figure 3.4 & 3.5). All samples were vacuum-sealed until analysis to prevent excessive moisture loss.

TS testing of claw samples occurred in the Civil Lab of the Department of Civil Engineering, University of Pretoria. The rectangular samples were tested with a LRX Plus Series Lloyd instrument (Ametek Inc., Lloyd Materials Testing Ltd, West Sussex, UK) fitted with a 5 kN (kilonewton) standard load cell (Figure 3.6 & Figure 3.7). NEXYGEN*Plus* 3 material testing and data analysis software (Lloyd Instruments Ltd., West Sussex, UK) was used for the TS analyses. The length and the width of each sample were measured with a digital 150 mm vernier calliper in order to determine the area size of predicted sample breakage. Samples were positioned between two clamps and pulled with a speed of 3 mm/min and a preload stress speed of 21 mm/min (Figure 3.7). The maximum load (N) of each sample was measured and used to determine the TS of each sample by the following formula: TS (MPa) = Force (N) / Area (mm^2).

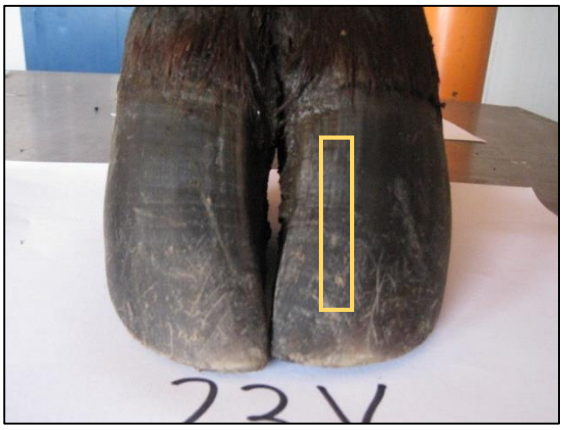


Figure 3.4 Position of rectangular claw sample on dorsal claw wall obtained for tensile strength (TS) testing

Figure 3.5 Sawn out sample for tensile strength (TS) testing

Figure 3.6 LRX Plus Series Lloyd instrument (Civil Laboratory, University of Pretoria)

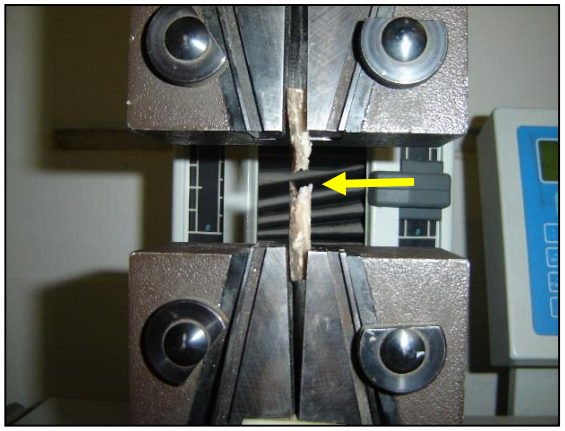


Figure 3.7 Sample breakage during tensile strength (TS) testing

Moisture determination was done on all the sample pieces just after it was tested since moisture plays an important role in the determination of claw hardness (Borderas *et al.*, 2004). Moisture levels (or dry matter content) of claw samples were determined at Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria, according to standard AOAC procedures. This entails samples being weighed, dried at 105˚C for 24 hours and weighed again to determine moisture loss (AOAC, 2000).

3.2.3 Mineral analyses

Additional claw material for mineral analyses were obtained from the 89 front claws collected. Claw samples were defrosted and two round discs (3.2 cm in diameter) were drilled from the lateral claw wall using a Ryobi D-550 electrical drill (Ryobi Ltd., Techtronic Industries Co. Ltd., Hong Kong, China) fitted with a holesaw drillbit (Figure 3.8). The round discs were cut smaller by means of a Stryker 1100 oscillating saw (Stryker Corp., Michigan, USA) rendering it suitable for the milling process (Figure 3.9).

Figure 3.8 Round claw disc

Figure 3.9 Claw disc cut into smaller pieces for milling

The determination of moisture content and mineral analyses of claw samples were done at Nutrilab, at the Department of Animal and Wildlife Sciences, University of Pretoria. Mineral analyses included zinc (Zn), calcium (Ca), copper (Cu), manganese (Mn), phosphorus (P) and selenium (Se) levels. The initial dry matter content analysis was done using the standard AOAC (2000) method. Ceramic crucibles were dried at 105˚C for at least an hour and then cooled down in a desiccator for 20 minutes after which each was weighed. 1 g or less of each claw sample was weighed into a crucible and placed in a drying oven at 105˚C to be dried for 24 hours. After drying, crucibles with sample were cooled down in the desiccator and weighed back to determine the initial dry matter content or moisture loss of each. The remaining claw samples were dried for 2 to 3 days at 55˚C in a drying oven followed by milling. Samples were however too hard to be milled with the equipment used to mill feed samples at Nutrilab. Samples had to be milled at the Department of Geology, University of Pretoria, with a swing mill capable of milling hard samples (Figure 3.10). This involved samples being placed in a tungsten carbide milling pot (Figure 3.11) and being milled for 3 minutes. The milling pot was cleaned in between samples by milling quartz sand for 2 minutes and using an air pressure gun and ethanol to remove any leftover sample and quartz sand before a new sample was milled.

Figure 3.10 Swing mill grinder

Figure 3.11 Tungsten carbide milling pot

3.2.3.1. Mineral digestion

The milled, air dried claw samples are digested in order to release the minerals and this was done according to the standard procedure as described by AOAC (2000). In brief, 0.5 g of each sample were weighed off in duplicate and transferred to the glass digestion tubes. 25 mL Nitric acid (65%) (HNO_3) was added to each glass tube and placed on the pre-heated block (240˚C) for 15 minutes. 10 mL Perchloric acid ($HCLO_4$) was added to each test tube and boiled for 35 minutes, allowed to cool down and a solution of 50 mL prepared by adding 50 mL deionized water.

3.2.3.2 Zinc (Zn), Copper (Cu), Calcium (Ca), Manganese (Mn)

The Zn and Cu concentrations of the digested sample solutions were read on the GBC 905 atomic absorption spectrophotometer (GBC Scientific Equipment, Braeside, Australia) at a wavelength of 213.9 nm (Giron, 1973). Sample solutions needed to be diluted five times before Zn readings could be done. Calcium concentration was read on the Perkin Elmer 5100PC atomic absorption spectrophotometer (PerkinElmer, Waltham, USA) at a wavelength of 422.7 nm and Mn readings were done on the Varian Spectra AA 50 atomic absorption spectrophotometer (SpectraLab Scientific Inc., Palo Alto, USA) at a wavelength of 324.7 nm (Giron, 1973).

3.2.3.3 Phosporus (P)

1 mL of digested claw sample solution was diluted further with 7 mL deionized water after which 2 mL of Molybdate-Vanadate reagent is added to each. Phosphorus concentrations were read using the Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena, Germany) at a wavelength of 400 nm. Readings were done in reference to five standard solutions prepared (AOAC, 2000).

3.2.3.4 Selenium (Se)

Selenium analysis of samples requires a different digestion process as for the other minerals (AOAC, 2000). 0.25 g of claw sample was weighed into tubes where after 5 mL digestion mix, consisting of 65% nitric acid (HNO_3) and 35% perchloric acid ($HCLO_4$), was added to the tubes. The tubes were put on a programmable digestion block with the following settings:

Time (hours)	Temperature (℃)
4	Room
1	Room -100
1	100
1	100-180
6	180
2	180-130
1	130

After 16 hours tubes were removed from the block and allowed to cool down. 2.5 mL hydrochloric acid (HCl) was added to each tube and placed on the digestion block for 40 minutes. The sample solutions in each test tube were made up to 20 mL with 10% HCl. The solutions were then put through a hydride generator (Vapor Generation Accessory VGA-77), using 20% HCl as oxidizing agent and sodium borohydrate (NaBH4) as reductant (0.6 g NaBH4/100 mL 0.5% NaOH). The Se readings were done using a Perkin-Elmer 2380 atomic absorption spectrophotometer (PerkinElmer, Waltham, USA) at an absorbency of 196 nm and lamp energy of 16 mA. Selenium concentrations were read in reference to standard solutions of 2, 5 and 10 parts Se per mL. Peach leaves were used as a control (AOAC, 2000).

3.2.4 Statistical methodology

The data were analysed using SAS software version 9.3 (SAS Institute, Cary, North Carolina, USA). Data was tested for normality (normal distribution) and descriptive statistics were generated, followed by a principal component analysis (PCA) on the morphological variables (LL, ML and circumference). A PCA takes relationships between factors into account. The first principal component (Prin1) described 91.42% of the variation observed and, therefore, was chosen as the representative for the three morphological measurements. A variance analysis was performed on the data using the GLM multi-factorial ANOVA procedure in order to determine the effect of colour, bioregion, AgeSex, moisture content, morphological measurements (Prin1) and six different minerals (Ca, P, Cu, Mn, Zn, Se) on the TS of the front claws (Model A). All the main effects investigated were included in the model simultaneously. The same procedure was repeated for measurements on both the front and hind claws with TS (Model B), LL (Model C), ML (Model

D) and circumference (Model E) as dependent variables in separate models. These models included all the main effects of the front claw model (Model A) without the mineral effects (since it was not determined on the hind digits) and had FrontHind and Bioregion*FrontHind interaction as additional effects (Table 3.2). It is important to note that only the main effects were included in the models and only one interaction (where applicable) (Table 3.2). Other interactions were not included due to limited data. Some of the main effects included in the models had different levels or sub-categories and are given in Table 3.3.

Table 3.2 Summary of the different dependent variables and main effects included in the respective models (A to E)

Models	Dependent Variable	Claws tested	Effects investigated
A	Tensile strength (TS) (MPa)	Only Front claws	Colour, Bioregion, AgeSex, Moisture Content, Prin1[1] and mineral effect
B	Tensile Strength (TS) (MPa)	Front and Hind claws	Colour, Bioregion, AgeSex, Moisture Content, Prin1, FrontHind, Bioregion*FrontHind[2]
C	Later Toe Length (LL) (cm)	Front and Hind claws	Colour, Bioregion, AgeSex, Moisture Content, Prin1, FrontHind, Bioregion*FrontHind
D	Medial Toe Length (ML) (cm)	Front and Hind claws	Colour, Bioregion, AgeSex, Moisture Content, Prin1, FrontHind, Bioregion*FrontHind
E	Claw Circumference (cm)	Front and Hind claws	Colour, Bioregion, AgeSex, Moisture Content, Prin1, FrontHind, Bioregion*FrontHind

[1]Prin1: Principal component 1 (lateral toe length (LL), medial toe length (ML) and circumference combined)
[2]Bioregion*FrontHind: Bioregion and claw limb position (front versus hind) interaction

Table 3.3 Different levels of certain main effects included in the multi-factorial ANOVA models

Effect	Levels	Description of levels
Colour	3	1 2 3[1]
Bioregion	3	Gm SVcb SVk[2]
AgeSex	2	YoungM Other [3]
FrontHind	2	F H [4]

[1]1: light; 2: intermediate; 3: dark
[2] Gm: Mesic Highveld Grassland bioregion; SVcb: Central Bushveld bioregion; SVk: Eastern Kalahari Bushveld
[3]YoungM: young male group; Other: older group
[4] F: front claws; H: hind claws

The categories for AgeSex distribution analyses with multi-factorial ANOVA models are given in Table 3.4. The animals in the orange block were taken as the young male group ('YoungM') and the animals in the grey blocks as the second AgeSex level or 'Other' group.

Table 3.4 Age and sex distribution of Bonsmara cattle from which claws were collected

Age	Sex		
	Female	Male	Total
1*	6	150	156
2**	20	2	22
Total	26	152	178

Animals in the orange blocks were taken as the young male group (YoungM) and the animals in the grey blocks as the 'Other" group
*1: Young (between 1 and 3 years of age)
**2: Old (older than 3 years of age)

If an effect was found to be significant (P <0.05) and had more than three levels, further investigation was carried out by means of the the Scheffe test to determine significant differences (P <0.05) between the means of variables or levels.

3.3 RESULTS AND DISCUSSION

3.3.1 Bonsmara claw pigmentation and descriptive statistics for investigated claw parameters

The colour of bovine claws and its association with quality remains a controversial subject (Douglas *et al.*, 1996; Hepburn *et al.*, 2007). Based on the colour differences observed in this study, a colour chart was developed which consisted of three colour categories: light, intermediate and dark (Figure 3.12).

Figure 3.12 Bonsmara claw colour chart indicating the three respective claw colour categories (1:light, 2:intermediate and 3: dark)

The majority of the Bonsmara claws collected for this study were classified as dark (47.19%) followed by intermediate coloured claws (33.71%) (Figure 3.13). The occurrence of light coloured claws was the lowest (19.10%) which may be due to a tendency or preference of Bonsmara cattle breeders to select for darker type claws and discriminate against lighter claws (Figure 3.13). The colour distribution of claws per bioregion also confirms this trend (Figure 3.14). The perception exists that darker pigmented claws are stronger than lighter coloured claws and not as susceptible to problems (Hepburn *et al.*, 2007) hence the preference for this claw colour. The colour variation observed in the collected claws serves as a possible reference for claw colours in Bonsmara cattle.

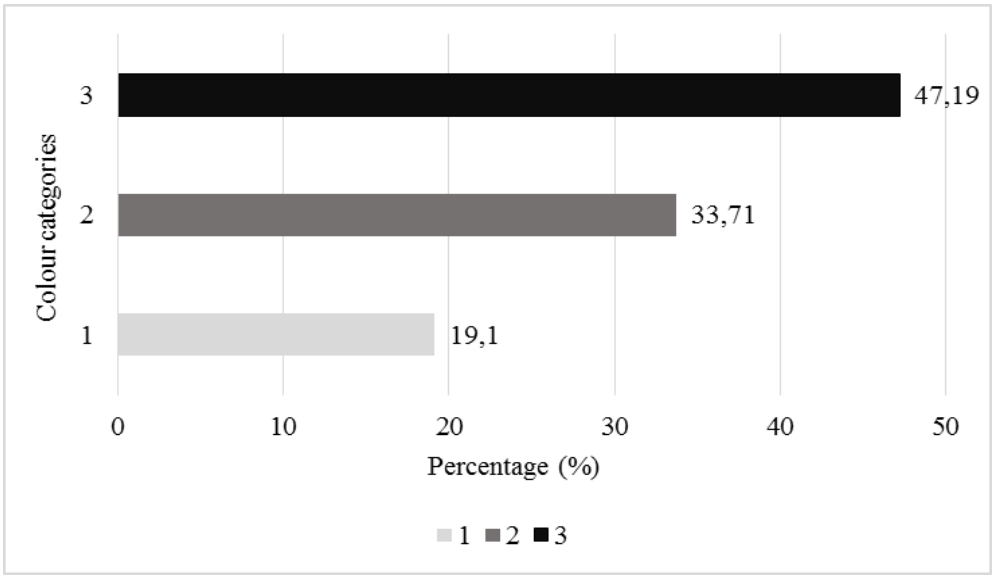


Figure 3.13 Colour distribution (%) of the 178 collected Bonsmara claws (lateral and medial claw per limb counted as one unit) according to the three respective colour categories (1: light, 2; intermediate; 3: dark)

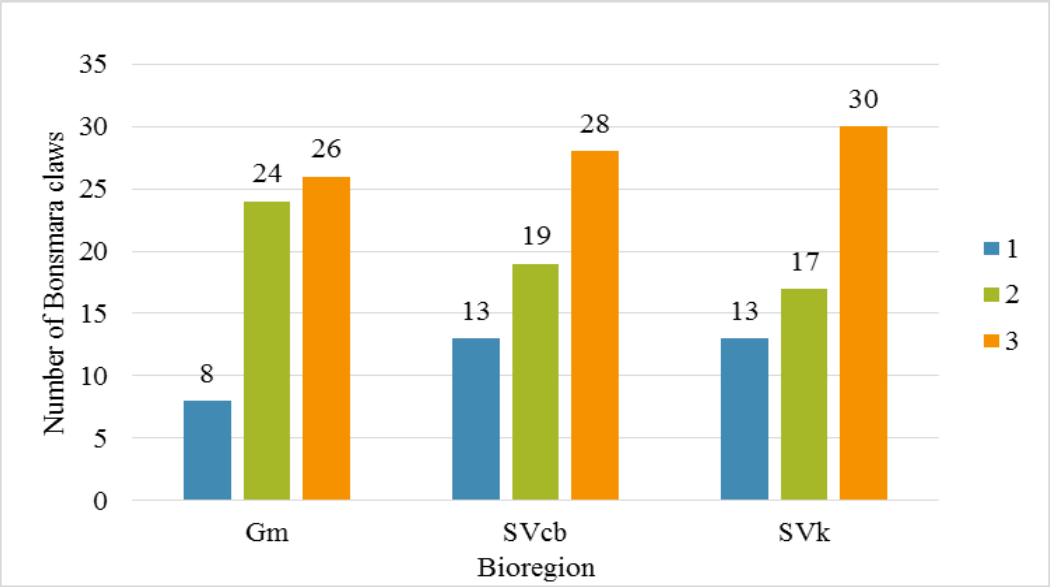


Figure 3.14 The colour distribution (1: light; 2: intermediate; 3: dark) of Bonsmara claws collected from specific bioregions (Mesic Highveld Grassland (Gm), Central Bushveld (SVcb) and Eastern Kalahari Bushveld (SVk) bioregions) predominantly associated with Bonsmara cattle

The descriptive statistics of the other claw parameters determined in this study are given in Table 3.5. The TS of the claw samples tested ranged from 4.89 to 26.23 MPa with an average strength of 16.58 ± 3.73 MPa. The minimum value for TS is quite low and could be a testing error. Douglas *et al.* (1996) indicated that the variability associated with the mechanical testing of equine hoof samples (specifically Moduli of Elasticity) could be attributed to the various challenges associated with the preparation of samples, differences in the sample dimensions as well as inherent differences associated with biological material. Moisture content of the claw samples ranged from 18.2% to 26.82% with an average of 22.59 ± 1.8%. Claws with a low moisture content could be attributed to moisture loss due to the storing of claw samples before analyses commenced. The average LL, average ML, and average claw circumference were 7.48 cm, 7.55 cm and 37.30 cm respectively. The mean Ca, P, Cu, Mn, Zn and Se levels of claw samples were 0.132 g/100g, 0.092 g/100g, 6.32 mg/kg, 1,80 mg/kg, 152.10 mg/kg and 561,16 ug/kg respectively and predominantly similar to mineral levels determined on normal claws of dairy cattle (Baggot *et al.*, 1988), feedlot cattle (Sugg *et al*., 1996) and equine hooves (Ley *et al*., 1988) with a few exceptions that will be referred to later on.

Table 3.5 Descriptive statistics on the measured claw variables

Variable	n[1]	Median	Mean	SD[2]	Minimum	Maximum
Tensile Strength (TS) (MPa)	178	16.83	16.58	3.73	4.89	26.23
Moisture Content (%)	178	22.59	22.64	1.80	18.20	26.82
Lateral toe length (LL) (cm)	178	7.20	7.48	0.82	5.90	9.80
Medial toe length (ML) (cm)	178	7.25	7.55	0.84	6.00	10.00
Circumference (cm)	178	36.40	37.30	3.45	31.30	47.10
Calcium (g/100g)	89	0.131	0.132	0.029	0.070	0.215
Phosphorus (g/100g)	89	0.091	0.092	0.015	0.061	0.126
Copper (mg/kg)	89	4.96	6.32	10.83	1.76	106.05
Manganese (mg/kg)	89	1.44	1.80	1.89	0	15.76
Zinc (mg/kg)	89	145.95	152.10	23.70	120.27	211.63
Selenium (ug/kg)	89	361.00	561.16	542.26	147.31	2546.22

Minerals levels are presented on a dry matter (DM) basis
[1]n: number of claw samples tested, measured or analysed
[2]SD: standard deviation
The units of measurement for the respective claw variables are indicated in parenthesis next to the variable

The various models that were employed to test the influence of different main effects (simultaneously) on the different dependent variables were all of overall significance (P <0.0001). The R-square values ranged from 0.33 to 0.54 for the different models, indicating that not much variation could be explained by the effects included in the model (Table 3.6). This confirms the multifactorial influence that is associated with claw structure and strength (Toussaint-Raven, 1989; Vermunt & Greenough, 1995).

Table 3.6 Summary of the respective models and the degrees of freedom (df), F Values, P Values, R-Square Values, Coefficient of Variation and means of the respective dependent variables associated with each model

Model	Dependent variables of the different models	n[6]	df[7]		F Value	Pr>F[8]	R-Square	Coeff Var[9]	Root MSE[10]	Mean
			Model	Error						
A	TS (F)[1] (MPa)	87	13	73	4.69	<0.0001	0.45	17.71	3.08	17.39
B	TS (F & H)[2] (MPa)	178	10	167	8.37	<0.0001	0.33	18.90	3.13	16.58
C	LL (F & H)[3] (cm)	178	9	168	19.32	<0.0001	0.51	7.90	0.59	7.48
D	ML (F & H)[4] (cm)	178	9	168	21.52	<0.0001	0.54	7.75	0.59	7.55
E	Circumference (F & H)[5] (cm)	178	9	168	14.84	<0.0001	0.44	7.09	2.64	37.30

[1]TS (F): tensile strength (only front claws); [2]TS (F & H): tensile strengths (front and hind claws included); [3]LL (F & H): lateral toe lengths (front and hind claws included); [4]ML (F & H): medial toe lengths (front and hind claws included); [5]Circumference (F & H): circumference of front and hind claws
[6]n: number of claw samples tested or measured; [7]df: degrees of freedom; [8]Pr>F: P-Value [9]Coeff Var: Coefficient of Variation; [10]Root MSE: Root Mean Squared Error
The units of measurement for the respective dependent variables are indicated in parenthesis next to the dependent variable

3.3.2. The effect of colour, bioregion, AgeSex, moisture content, Prin1, minerals and limb position on Bonsmara claw tensile strength (TS)

Various types of tests can be applied to various materials including claw horn in order to assess the biomechanical behaviour and structural strength or composition thereof. These tests include TS tests (Franck *et al.*, 2006), hardness tests with durometers (Hepburn *et al.*, 2007), compression tests (Douglas *et al.*, 1996), bending tests (Baillie *et al.*, 2000), fracture toughness (Bertram & Gosline, 1986) or punch tests (Winkler & Margerison, 2012). Biomechanical properties of claws in publications are predominantly described through Young's Modulus of Elasticity determined through either tensile tests, bending tests or compression tests and refers to the stiffness of the claw horn material. It is defined as the stress divided by the strain which is the elongation or contraction of the sample, divided by its original length (Franck *et al.*, 2006). Tensile strength testing performed in the present study determines the stress the moment the sample breaks and is defined as the applied force divided by the measured area of sample breakage (Franck *et al.*, 2006).

The mean TS of the Bonsmara claw samples tested in the present study was 16.58 MPa which agrees with findings of Franck *et al.* (2006) who obtained a mean TS of 16.2 MPa for bovine claw samples. These authors, however, only tested five samples and the detail of samples with regards to age, sex, claw position (front versus hind as well as lateral or medial claw) and type of bovine (dairy versus beef) were unclear. Similar TS tests in horses gave measurements that ranged from 21.70 MPa to 35.32 MPa depending on the season, year, feeding and management regimes applied (Ley *et al.*, 1998). Bertram & Gosline (1987) reported TSs of

38.9 MPa in horses. These measurements in horses were overall higher compared to Bonsmara claws in the present study and could be due to differences in sample preparation and testing time after collection, differences in the claw sample dimensions that were mechanically tested (Douglas *et al*., 1996), the orientation of the load applied to the claw sample during testing (with reference to the tubular cells) as well as species differences (Baillie & Fiford, 1996). Intrinsic differences in biological material also exist (Douglas *et al*., 1996).

The effects that were tested on the TS of the front claws (Model A) in the present study on Bonsmara cattle and their corresponding levels of significance are indicated in Table 3.7 as well as those for Model B that included both the front and hind claw TSs (without the mineral effect but the FrontHind effect as well as Bioregion*FrontHind interaction as additional effects). The significant effects (P <0.05) associated with TS highlighted by both models for the specific data recorded were bioregion and moisture content. The Ca levels and the FrontHind effect (limb position of the claws) were additionally significant for Model A and Model B respectively. Even though only factors with P <0.05 were taken as significant, it is worth mentioning that Se had a significant effect on TS at a 93.29% confidence level (P <0.10) for Model A. The effects of colour, AgeSex and Prin1 were not significant for Model A and Model B and the Bioregion*FrontHind interaction additionally non-significant only for Model B.

Table 3.7 The different main effects included in the multi-factorial ANOVA model for tensile strength (TS) of front claws (Model A) as well as for front and hind claws (Model B) and their respective df, MS, F value and significance (P <0.05)

Effect	Dependent Variable							
	Model A Tensile Strength (TS) (Front)				Model B Tensile Strength (TS) (Front & Hind)			
	Df[5]	MS[6]	F Value	Pr>F[7]	df	MS	F Value	Pr>F
Colour	2	1.31	0.14	NS[1]	2	4.89	0.5	NS
Bioregion	2	124.53	13.14	<0.0001	2	133.62	13.61	<0.0001
AgeSex	1	15.56	1.64	NS	1	11.75	1.2	NS
Moisture Content	1	130.65	13.78	0.0004	1	216.12	22.01	<0.0001
Prin1[2]	1	3.59	0.38	NS	1	14.05	1.43	NS
Calcium (Ca)	1	54.41	5.74	0.0191	-	-	-	-
Phosphorus (P)	1	5.22	0.55	NS	-	-	-	-
Copper (Cu)	1	5.64	0.6	NS	-	-	-	-
Manganese (Mn)	1	18.81	1.98	NS	-	-	-	-
Zinc (Zn)	1	7.02	0.74	NS	-	-	-	-
Selenium (Se)	1	32.76	3.46	0.0671	-	-	-	-
FrontHind[3]	-	-	-	-	1	97.07	9.88	0.002
Bioregion*FrontHind[4]	-	-	-	-	2	19.61	2	NS

Significant effects P <0.05; [1]NS: non-significant
[2]Prin1: Principal Component (lateral toe length (LL), medial toe length (ML) and circumference combined)
[3]FrontHind: front and hind claws
[4]Bioregion*FrontHind: Bioregion and claw limb position (front versus hind) interaction
[5]df: degrees of freedom; [6]MS: mean square; [7]Pr>F: P Value
- Not applicable
TS unit of measurement: MPa (megapascal)

The bioregion effect was significant with regard to TS (P <0.05) and the Scheffe test indicated that claw samples from bioregion Gm had a significantly lower TS than those from bioregions SVk and SVcb. The mean TSs did not differ significantly between claw samples collected from bioregions SVk and SVcb (Table 3.8 & Figures 3.15). Distinct climatic differences exist between bioregions whereas the climate within a specific bioregion is fairly similar (Mucina *et al*., 2006). The mean annual temperatures for bioregions SVcb and SVk, as described by Mucina *et al*. (2006), are generally about 18.4℃ and 17.8 ℃ respectively and 14.7℃ for bioregion Gm (Mucina *et al*., 2006). Climatic and seasonal effects could explain some of the observed differences in the TSs of the collected Bonsmara claws. Vermunt (1990) postulated that seasonal differences in claw quality could be due to temperature associated changes in blood supply to the claws. Colder temperatures cause the constriction of blood vessels (arterioles) and less blood with important nutrients and oxygen are subsequently available to the cells involved in the keratinization process of claw horn. This may explain why Bonsmara claws from bioregion Gm had a lower TS than those collected from bioregions SVcb

and SVk since the Gm bioregion is overall colder than the other two bioregions. Adequate blood supply is imperative for the production of good quality horn (Van Amstel & Shearer, 2006). Variation in the differentiation and keratinization of the keratinocytes of the claw is observed with different seasons (MacCallum *et al.*, 2002) with an increase in the rate of proliferation and keratinization of claw horn cells in the summer months as opposed to winter (MacCallum *et al*., 2002; Van Amstel & Shearer, 2006). MacCallum *et al.* (2002) observed that the claws of Holstein-Friesian heifers were harder in the summer compared to the winter and that hardness differed significantly between seasons. Bonsmara claws in the present study were also collected at different times of the year over a period of two years since collection was subjected to the availability of claws of stud animals from specific bioregions. Significant year, seasonal and nutritional differences in hoof wall strength were also reported by Ley *et al.* (1998) in equines without hoof defects.

Seasonal variation in the quality of the grazing or raw materials in feed could also contribute to variation observed in claw TS of animals from the different bioregions. The quality of plants and their consequent nutrient composition are influenced by species, plant maturity, season, climate and soil type (Whitehead, 2000; McDonald *et al*., 2002). Bioregions are classified by distinct differences in climate like temperature, frost occurrence and rainfall as well as differences in plant composition or vegetation type (Mucina *et al.*, 2006). The Gm bioregion is characterised by a mean annual precipitation of 726 mm whereas bioregions SVcb and SVk have annual precipitation of 559 mm and 362 mm respectively (Mucina *et al.*, 2006). Differences in the quality of grazing and feed will therefore occur between these bioregions and within the specific bioregion throughout the year and may explain the TS variation observed between bioregion Gm and the other two bioregions. Claws collected from bioregion Gm were predominantly from parts or areas characterised by sourveld and mixed veld as opposed to the mixed and sweet veld associated with the other two bioregions (SVcb and SVk) (Smith, 2006) . It is therefore crucial that breeders know the limitations of their farming region to ensure that animals receive a balanced supply of nutrients throughout the year. Where animals graze extensively, strategic supplements (licks) are crucial and therefore would also reflect the quality of management and management decisions. Seasonal variations in amino acid content in claw horn samples were also observed by Hidiroglou & Williams (1986) and ascribed to nutritional and management practices. The nutritional composition and quality of the feed and grazing material of the Bonsmara cattle from the different bioregions were however not determined in this study.

The variation in TS associated with bioregions could also be attributed to the physical walking surface that animals are exposed to, since it would determine the pressure distribution on the claws. The type of pressure distribution on the claws associated with the physical terrain will have an effect on claw horn production (Vermunt & Greenough, 1996) and on the subsequent micro architecture and structural strength of claws. Animals are adapted to certain regions and adaptation to the terrain or surface characteristics could reflect the differences between observed claw strengths. Further investigation into specific surface characteristics associated with the specific bioregions in question and their subsequent effect on the micro-

architecture of the claw is however required including potential genetic influences (Boelling *et al*., 2001b) associated with the variation observed in claw strength between the animals. It is important to take note that Bonsmara claws tested in the present study were classified as normal without any phenotypic defects at inspection but the differences in claw TS associated with specific bioregions could give an indication of problems that may develop later on due to softer claws that may be less resistant to the external stressors (Borderas *et al*., 2004).

Table 3.8 The mean tensile strengths (TSs) of claw samples (front claws as well as front and hind claws) collected from different bioregions (Gm, SVk and SVcb) and differences between the respective means (*P* <0.05)

			Model A	**Model B**
Effect	**Level of Effect**	**n[4]**	**Tensile Strength Mean (TS) (MPa)** **Front claws only**	**Tensile Strength Mean (TS) (MPa)** **Front & Hind claws**
Bioregion	Gm[1]	28	14.51[a] (±3.35)	14.28[a] (±3.18)
	SVk[2]	30	18.83[b] (±3.38)	17.62[b] (±3.89)
	SVcb[3]	29	18.68[b] (±3.23)	17.76[b] (±3.01)

[a,b,c] Column tensile strength (TS) means with different superscripts differ significantly at *P* <0.05
[1]Gm: Mesic Highveld Grassland Bioregion; [2]SVk: Eastern Kalahari Bushveld Bioregion; [3]SVcb: Central Bushveld Bioregion
[4]n: number of lateral claw samples tested
TS unit of measurement: MPa (megapascal)

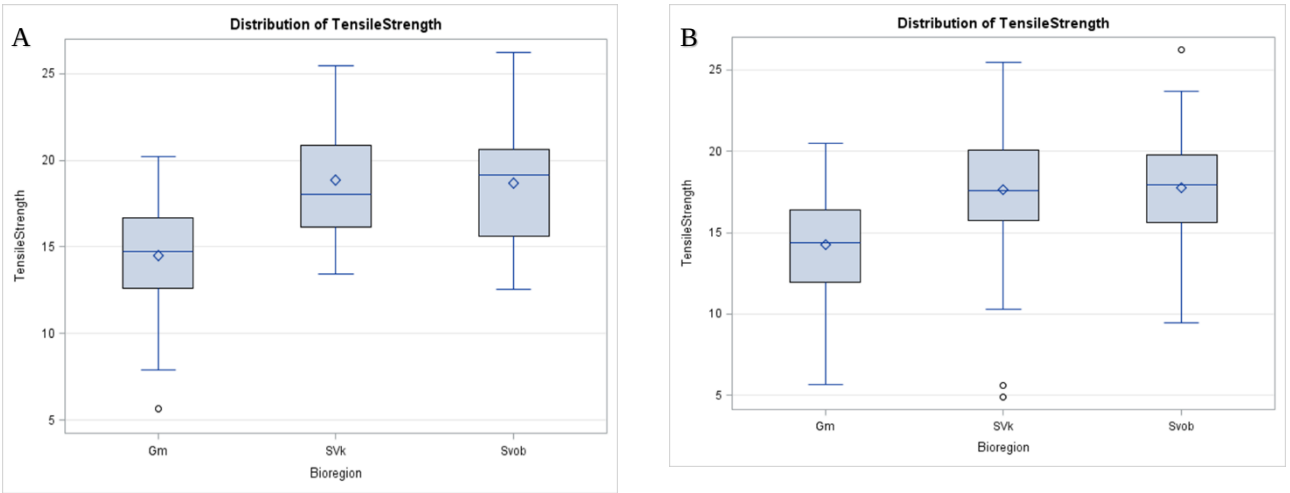


Figure 3.15 Box plots illustrating the differences between the tensile strengths (MPa) of claw horn samples of only the front claws (A) and both the front and the hind claws (B) collected from the Mesic Highveld Grassland bioregion (Gm), Eastern Kalahari Bushveld bioregion (SVk) and the Central Bushveld bioregion (SVcb) respectively

Moisture content had a significant effect on TS (P <0.004) in the present study on Bonsmara claws (Table 3.7). A negative effect was observed where a higher claw moisture content gave rise to lower claw horn TS. This is in agreement with other studies that made use of mechanical testing techniques other than TS testing to investigate the association between moisture content and the biomechanical behaviour, hardness or structural strength of claw horn (Pflug *et al.*, 1980; Bertram & Gosline, 1987; Borderas *et al.*, 2004; Winkler & Margerison, 2012). A significant negative exponential relationship between moisture content and the elastic modulus of the sole and white line claw material were observed by Winkler & Margerison, (2012) as well as negative linear decrease in the puncture resistance. Pflug *et al.* (1980) found that a higher claw moisture content resulted in increased claw abrasion and Borderas *et al.* (2004) observed reduced hardness of claws tested with a durometer. Softer claws, due to a higher moisture content, are more susceptible to excessive wear and damage and may predispose cattle to lameness (Borderas *et al.*, 2004). Other studies could however not establish a relationship between the moisture content and mechanical strength of claw material in cattle (Franck *et al*., 2006) and horses (Ley *et al*., 1998) and attributed it to low variation in moisture levels between tested samples.

The mean moisture content of the collected claws in the present study ranged from 18.20% to 26.82% with an average of 22.64% after 24 hours of drying at 105℃ (Table 3.5). This was more in the lower ranges compared to reports by other researchers where claw moisture content of claws without any defects originating from beef cattle ranged from 22.9% to 32.5% (Pflug *et al.*, 1980) and 27.46% to 29.05% (Winkler & Margerison, 2012) respectively. The moisture content of the dorsal wall of normal hooves in horses ranged from 31.16% to 33.83% (Ley *et al*., 1998) and an average moisture content of 27.9 ± 1.7% was also reported for horses (Douglas *et al*., 1996). Immediate moisture determination on the Bonsmara claw samples analysed in the present study was not always possible and may explain the lower moisture content, even though samples were sealed in plastic bags to retain moisture. Other studies confirmed that moisture content of claw samples will differ with regards to the storage method, length of storage (Winkler & Margerison, 2012) and the method of moisture determination (Reilly *et al*., 2002) and could explain the observed differences between the claw moisture content in the present study and other studies. No standard method for moisture determination in equine hooves and bovine claws exists. Reilly *et al*. (2002) observed variation in moisture content values of hooves associated with different methods applied and should therefore be taken into consideration. In addition, animals are also exposed to different environmental influences in different studies and may explain the variation in the observed moisture content (Distl *et al*., 1984).

Research on the mineral composition of beef cattle claws and specifically beef bulls is limited (Sugg *et al.*, 1996). The majority of claw research that relates to minerals and other nutrients generally investigates the effect of nutrient levels in feed and the subsequent effect on claw quality in dairy cows or horses (evaluating either the effect on claw health or various claw characteristics). Ley *et al.* (1998) related mineral content of hooves to TS in particular but the study was conducted on equine hooves and dimensions of the samples and orientation in which hoof samples were pulled (with reference to the tubular cells) differed from the present

study on Bonsmara claws. Other research compared the mineral composition of claw samples of lame and non-lame dairy cows and investigated the hardness associated with mineral composition by means of a durometer (Baggot *et al.*, 1988). Minerals play an important role in determining the structural strength of claws due to their involvement in specific biochemical pathways associated with keratin synthesis (Tomlinson *et al.*, 2004).

The only minerals that had a significant effect on claw TS in the present study on Bonsmara cattle were Ca (P <0.05) and Se (P <0.10) (Table 3.7). Even though Ca had a significant effect on TS, the parameter estimate was negative, indicating a negative relationship between TS and Ca, which is contrary to what was expected. Ca plays a role in keratin cornification through the activation of the enzyme, epidermal transglutaminase (TG) and it is therefore expected that it will result in stronger claws (Mülling *et al.*, 1999). Baggot *et al*. (1988) found that the harder keratin in dairy cow claws was associated with higher Ca levels. The usefulness of claw material as an accurate indicator of the mineral content of the claws remains uncertain (Greenough, 2007). The Ca status of other tissues (bone, blood) should be compared to claw samples to evaluate the accuracy of claw material as an indicator of the Ca status and general mineral status of animals. Kincaid (1999) stated that tissues like hair, wool and hooves as indicators of the mineral status of animals may not be as accurate since it is more easily contaminated (as opposed to blood and liver samples), their reaction to feed intake is much slower and reference standards are deficient. Selenium was also significant (P <0.10) with regard to TS and a positive relationship was observed between these two factors. This was expected since Se plays a role in protecting the ICS from oxidative damage, thereby ensuring claw horn structure of good quality through the adequate binding of keratin proteins by means of the ICS (Tomlinson *et al.*, 2004; Andrieu, 2008).

Interestingly, none of the other minerals included in the present study (essential for normal keratinization and claw integrity), had a significant effect on the TS including Zn that plays an important role in determining the structural strength of claws (Mülling *et al*., 1999) (Table 3.7). Again these claws were from Bonsmara animals that were inspected for any claw problems (according to breed standards) and the majority had no phenotypic claw defects. Variation of these minerals in association with TS was too small to detect. This probably indicates that the animals received adequate levels of all the important claw influencing minerals and therefore no problems were observed. Correspondingly, Ley *et al*. (1998) found no relationship between TS and the Zn content of normal hooves in horses.

The concentrations of the various minerals in Bonsmara claw samples obtained in the present study (Table 3.5) were within the ranges of mineral levels determined on normal healthy claws of dairy cattle (Baggot *et al.*, 1988), feedlot cattle (Sugg *et al*, 1996) and normal hooves of equines (Ley *et al*., 1998). The only exceptions (compared to the present study on Bonsmara claws) were lower Se levels in dairy cattle (Baggot *et al*., 1988), lower Zn levels in feedlot cattle (Sugg *et al*, 1996) and higher Mn levels in horses (Ley *et al*., 1998). Different environmental influences (diet and seasonal differences) could explain differences in mineral

composition observed between dairy and beef cattle claws as well as species differences between bovines and equines. Combs *et al*. (1982) indicated that various factors like season, breed, hair colour within and between breeds, sire, age and body location may influence mineral levels in hair and some of these factors could also be relevant for claws. Mineral levels also differ significantly with regards to the position (heel, sole and wall) from where claw material is obtained for the analyses (Baggot *et al.*, 1988). Mineral composition determination of claws in conjunction with other methods to ascertain and evaluate the mineral status of the animal would be more accurate.

The limb position of the claws (front versus hind limb) had a significant effect on the claw TS. The front claws had a greater TS compared to the hind claws (Table 3.9 & Figure 3.16). Regardless of this significance the mean TS of the front and hind claws (17.38 MPa and 15.78 MPa respectively) were still quite similar. Corresponding to the findings of the current study, Chmielnik *et al*. (1983) observed that front claws are harder than hind claws in Polish Lowland Black and White cattle. The variation observed with regards to front and hind claw strength can be explained by the differences in weight distribution. The front claws usually carry a slightly higher load than the hind claws and the distribution of weight is more equal and stable on the front claws compared to the hind claws and therefore of possible greater structural strength (Toussaint-Raven, 1989). The higher pressure exerted on the front claws was also confirmed by Distl *et al.* (1984) who determined the pressure on the ground surface (N/cm^2) of Simmental bulls at different ages but did not observe significant differences between the hardness of front and hind claw measured with a durometer.

Table 3.9 The mean tensile strengths (TSs) of claw samples originating from different limb positions (front versus hind) and the differences between the respective means (P <0.05)

			Model B
Effect	**Level of Effect**	**n**[2]	**Tensile Strength Mean (TS) (MPa)** **Front & Hind claws**
FrontHind[1]	Front	89	17.38[a] (±3.80)
	Hind	89	15.78[b] (±3.50)

[a,b,c] Column tensile strength (TS) means with different superscripts differ significantly at P <0.05
[1]FrontHind: Front and Hind claws
[2]n: number of lateral claw samples tested
TS unit of measurement: MPa (megapascal)

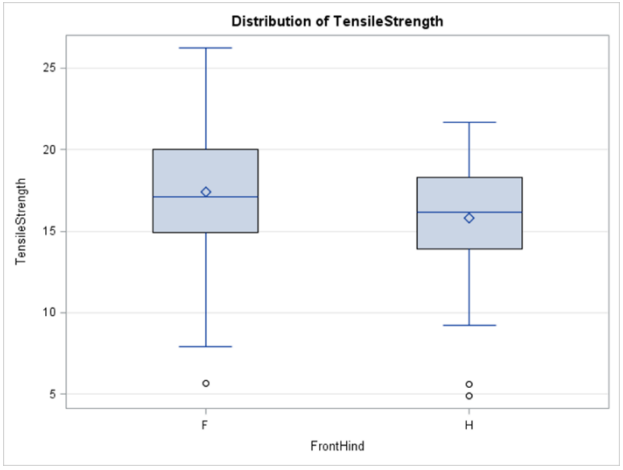


Figure 3.16 Box plots illustrating the differences between the tensile strengths (MPa) of claw horn samples from the front (F) and hind (H) limb

It is of interest to note that claw colour did not have an association with TS in the present study, which concurs with other studies performed in horses (Landeau *et al*., 1983; Bertram & Gosline, 1986; Douglas *et al*., 1996; Runciman *et al*., 2004). Based on the results of the present study conducted on Bonsmara claws, claw colour is of lesser importance in improving claw quality or ensuring beef cattle without any defects in selection programs.

3.3.3 The effect of colour, bioregion, AgeSex, moisture content and claw limb position on LL, ML and claw circumference respectively

Various morphological claw measurements exist to describe the conformation (size and shape) of claws and act as indicators for potential claw problems (Distl *et al.*, 1990). The main effects simultaneously included in the models for LL, ML and circumference and the resultant levels of significance are given in Table 3.10. The same explanatory variables were of significance for the respective morphological dependent variables (LL, ML and circumference) and somewhat expected given that these morphological parameters are correlated as seen with the PCA. Colour, bioregion, AgeSex and FrontHind were of significance (P <0.05) whereas claw moisture content and the Bioregion*FrontHind interaction was not (Table 3.10). The significant effects, with regards to the respective morphological dependent variables (LL, ML and circumference), that had more than one level are given in Table 3.11 along with the significance between their level means (per dependent variable) as determined through the Scheffe test.

Table 3.10 The different main effects (excluding the mineral effect) tested on lateral toe length (LL), medial toe length (ML) and circumference respectively of front and hind claws and their corresponding df, MS, F Value and significance (P <0.05)

Effect	Dependent Variable									
	Lateral Toe Length (LL) (cm) Model C				Medial Toe Length (ML) (cm) Model D			Circumference (cm) Model E		
	Df[2]	MS[3]	F-Value	Pr>F[4]	MS	F-Value	Pr>F	MS	F-Value	Pr>F
Colour	2	1.71	4.89	0.0086	1.05	3.06	0.0493	26.30	3.76	0.0253
Bioregion	2	4.42	12.63	<0.0001	5.47	15.97	<0.0001	132.75	18.98	<0.0001
AgeSex	1	43.69	124.86	<0.0001	45.33	132.45	<0.0001	423.73	60.59	<0.0001
MoistureContent	1	0.97	2.79	NS[1]	0.34	0.99	NS	25.84	3.69	NS
FrontHind	1	1.61	4.61	0.0333	1.56	4.57	0.0339	73.14	10.46	0.0015
Bioregion*FrontHind	2	0.15	0.43	NS	0.29	0.83	NS	3.23	0.46	NS

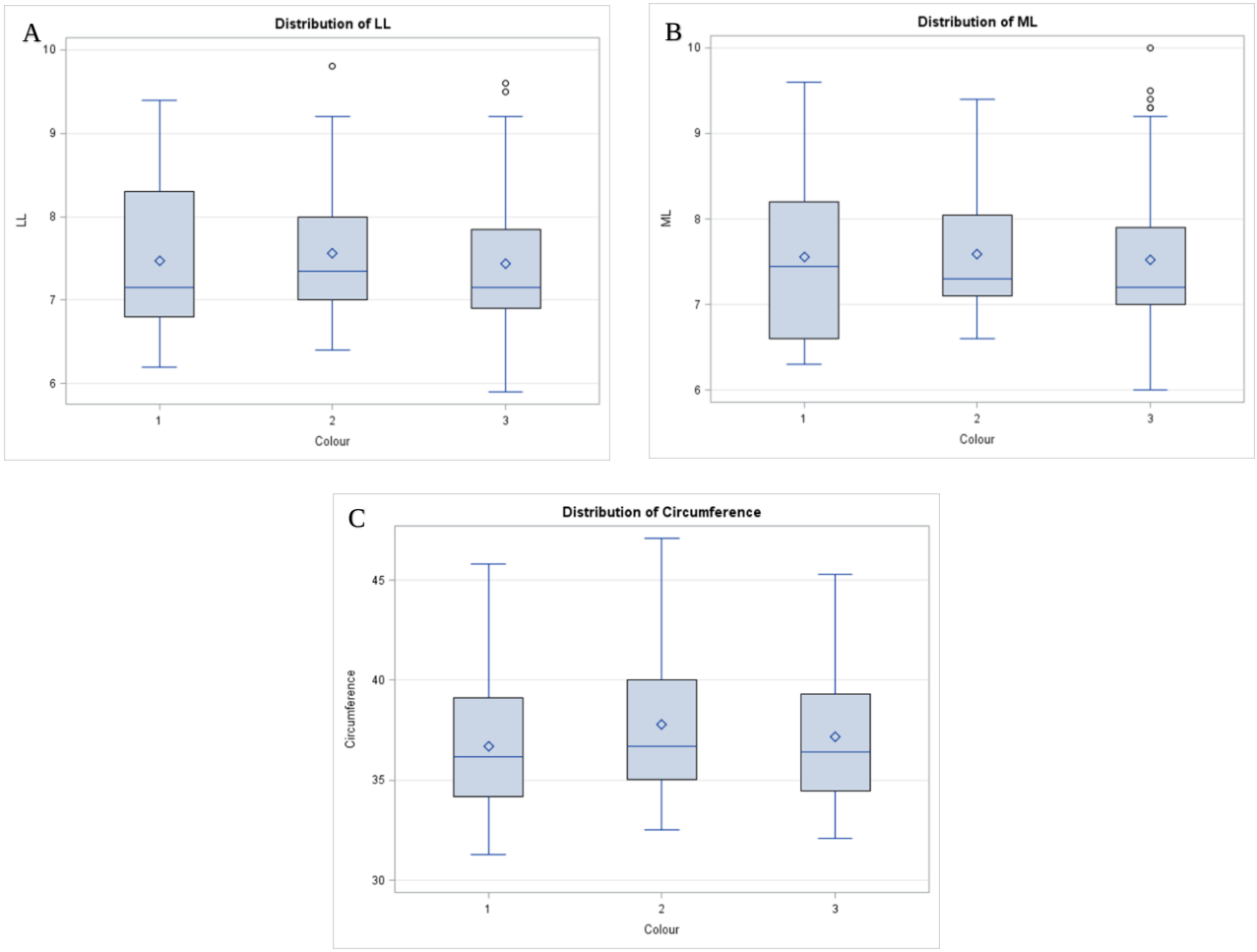
Significant effects (P <0.05); [1]NS: non-significant; [2]df: degrees of freedom; [3]MS: mean square; [4]Pr>F: P Value
Unit of measurement: cm (centimetre)

Table 3.11 The morphological measurement means (LL, ML and circumference respectively) of different levels of only the significant main effects (P <0.05) and the significant differences between these level means

		Model C		Model D		Model E	
Effect	**n[1]**	**Level of Effect**	**LL[2] Mean (cm)**	**Level of Effect**	**ML[3] Mean (cm)**	**Level of Effect**	**Circumference Mean (cm)**
Colour	34	1[4]	7.47[a] (±0.92)	1	7.55[a] (±0.96)	1	36.72[a] (±3.38)
	60	2[5]	7.57[a] (±0.76)	2	7.59[a] (±0.70)	2	37.80[a] (±3.59)
	84	3[6]	7.43[a] (±0.83)	3	7.52[a] (±0.88)	3	37.18[a] (±3.38)
Bioregion	58	Gm[7]	7.78[a] (±0.92)	Gm	7.89[a] (±0.88)	Gm	39.00[a] (±3.85)
	60	SVk[8]	7.56[a] (±0.90)	SVk	7.65[a] (±0.90)	SVk	37.53[b] (±3.59)
	60	SVcb[9]	7.13[b] (±0.42)	SVcb	7.13[b] (±0.47)	SVcb	35.44[c] (±1.44)
AgeSex	28	Other[10]	8.65[a] (±0.58)	Other	8.78[a] (±0.63)	Other	41.14[a] (±3.02)
	150	YoungM[11]	7.27[b] (±0.66)	YoungM	7.32[b] (±0.65)	YoungM	36.59[b] (±3.04)
FrontHind	89	Front	7.59[a] (±0.79)	Front	7.65[a] (±0.82)	Front	37.98[a] (±3.47)
	89	Hind	7.38[b] (±0.84)	Hind	7.45[b] (±0.84)	Hind	36.62[b] (±3.32)

[a,b,c] Different superscripts only indicate significant differences (P <0.05) between level means associated with a specific effect in a column and not the complete column, row or other effects and their respective level means
[1]n: number of claws
[2]LL: lateral toe length; [3]ML: medial toe length
[4]1: light; [5]2: intermediate; [6]3:dark
[7]Gm: Mesic Highveld Grassland bioregion; [8]SVk: Eastern Kalahari Bushveld bioregion; [9]SVcb: Central Bushveld bioregion
[10]Other: older predominantly female group; [11]YoungM: young male group
Unit of measurement: cm (centimetre)

Additional analyses using the Scheffe test confirmed no significant association between the claw colour categories (1: light, 2: intermediate and 3: dark claw colours) and the respective morphological dependent variables (Table 3.11 & Figures 3.17) even though colour was initially indicated to be significant (Table 3.10). Furthermore, claw colour was also not as significant compared to other effects (Bioregion and AgeSex) highlighted by Models C to E (Table 3.10).



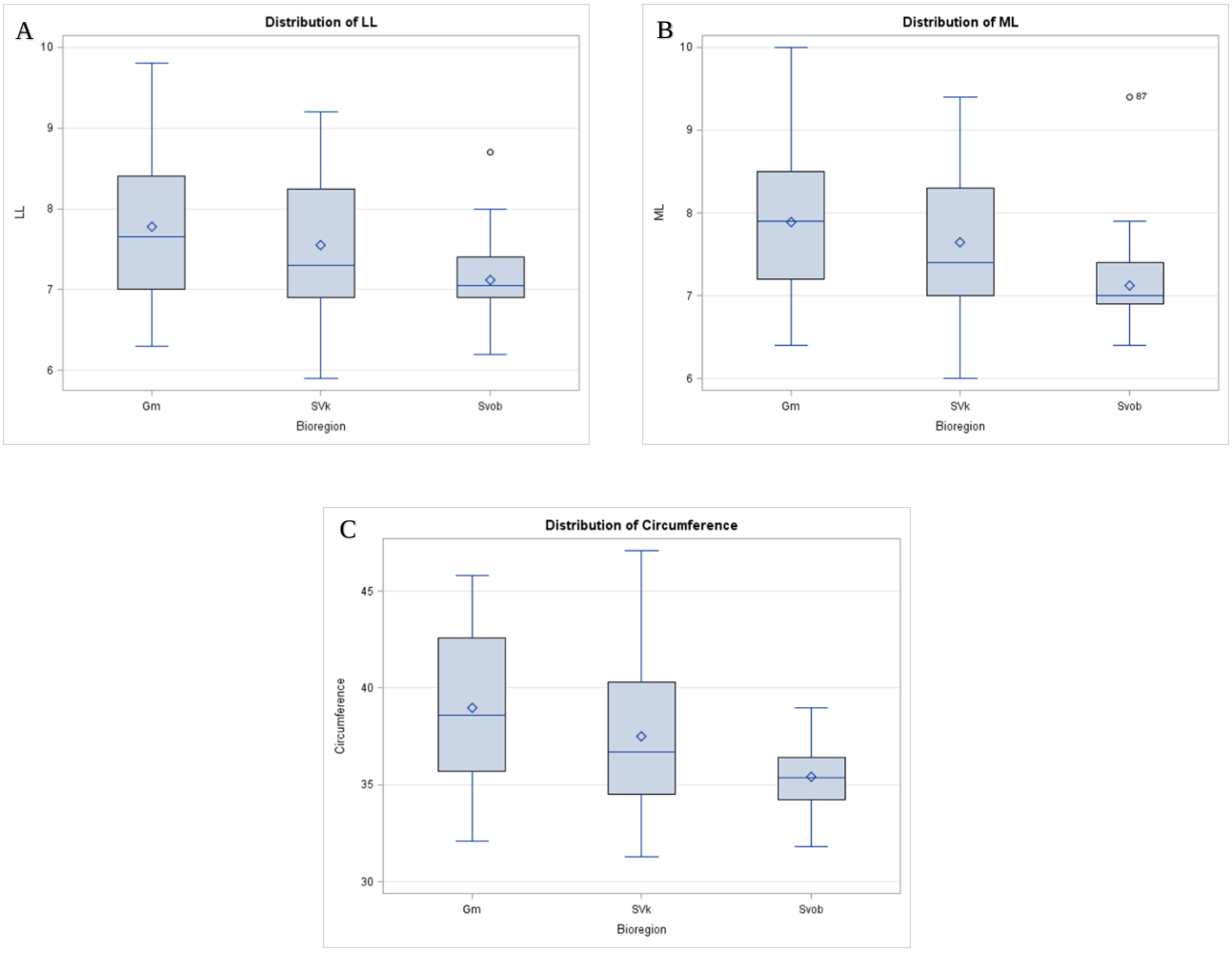
Figures 3.17 Box plots illustrating the differences between the LL: lateral toe lengths (A), ML: medial toe lengths (B) and claw circumferences (C) of different coloured claws (1: light, 2: intermediate and 3: dark colour)

Bioregion had a significant effect on the LL, ML and claw circumference measurements. The LL and ML measurement means of claws originating from bioregions Gm and SVk differed significantly from the LL and ML means obtained for bioregion SVcb but not from each other (Table 3.11). Toe lengths of claws collected from bioregion SVcb were significantly shorter compared to the other two bioregions (Gm and SVk). The LL and ML differences for the bioregion levels were however quite small and therefore the practical significance of these differences is questionable since it differed by mere millimetres and, therefore, were

nearly similar (Table 3.11). It is yet again important to take into account the fact that the Bonsmara claws analysed in the present study were from animals that were inspected by breed inspectors to be without any claw defects and extreme differences are therefore not expected. The claw circumference means were significantly different for all three the bioregions but nonetheless also quite similar (Table 3.11).

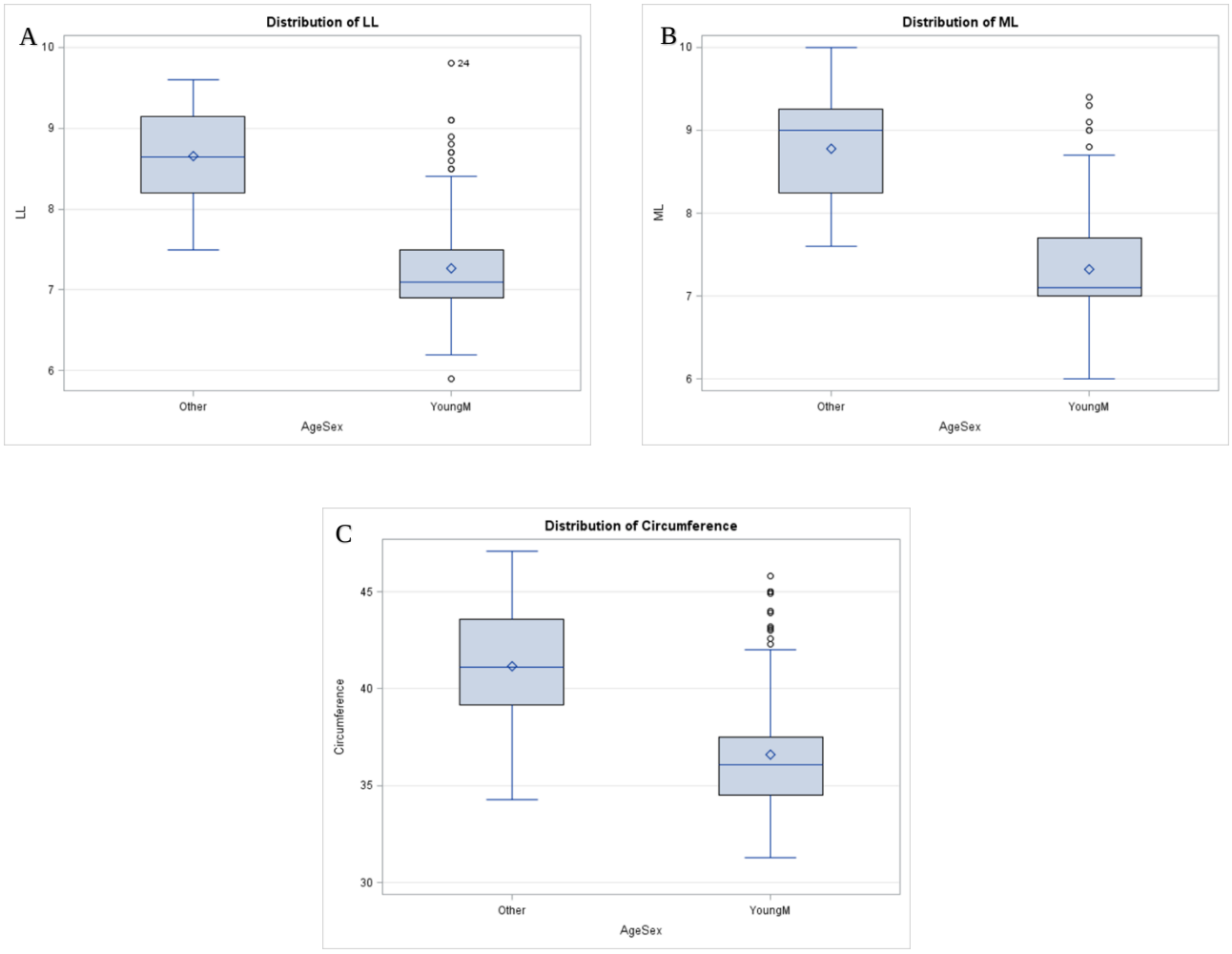
Differences in the ground surface characteristics and respective wear properties associated with the different bioregions could explain the variation in toe lengths (even though small) observed in Bonsmara cattle. Telezhenko *et al.* (2008) found that the variation in claw conformation of claws was subjected to the abrasive properties of the surface area dairy cattle are exposed to. Vermunt & Greenough (1996) noted differences in the claw conformation of dairy heifers exposed to different management systems (animals kept indoors on concrete compared to animals kept outside in a dry lot). The toe length of animals kept outside were significantly longer and lateral claws wider compared to those kept inside (Vermunt & Greenough, 1996). Bosmara cattle in the present study originated from different bioregions in South Africa, and were therefore exposed to different surface areas and ground textures. The type of ground surface Bonsmara animals are exposed to in a specific bioregion could influence the observed claw measurements, indicating slightly less abrasion associated with bioregions Gm and SVk compared to bioregion SVcb. It could be that the animals from bioregion SVcb are exposed to harder terrain with more rocks allowing for more claw abrasion than animals of bioregion Gm that may be exposed to a thicker grass layer and bioregion SVk with a sandier surface area resulting in less claw wear respectively (Map of Soil Types of South Africa, ARC-ISCW, 600 Belvedere Street, Arcadia, 008). This aspect requires further investigation.

Differences in the rate of horn growth could also be an explanation for the significant morphological claw variation in Bonsmara cattle from different bioregions, in addition to the wearing properties of ground surfaces, and is influenced by multiple factors like diet (Vermunt & Greenough, 1995) and underlying genetic influences (Quintanilla *et al*., 2006). Bioregions are characterised by distinct climatic differences and vegetation types (Mucina *et al*., 2006) and differences in the quality of grazing and associated management practices could be reflected in the morphological claw measurements from the different bioregions. In addition, differences in the lengths and sizes of the claws could be due to differences in the weight of animals (that were not included in the study). Morris & Baker (1988) observed a weight and claw size relationship in Angus steers, where larger claws were associated with heavier animals. It is yet again important to remember that the observed measurements were associated with phenotypically normal claws and therefore the differences in the measurements not excessive.



Figures 3.18 Box plots illustrating the differences between the LL: lateral toe lengths (A), ML: medial toe lengths (B) and claw circumferences (C) of claws originating from different bioregions (Gm: Mesic Highveld Grassland bioregion, SVk: Eastern Kalahari Bushveld bioregion and SVcb: Central Bushveld bioregion)

The older Bonsmara animals had longer LLs, MLs and larger claw circumferences than the younger animals (Table 3.11 & Figure 3.19) which is expected given that anatomical dimensions will increase with advancing age and associated growth or increased body weight (Boelling & Pollott, 1998; Kehler & Sohrt, 2000; Boelling *et al.*, 2001a; Boelling *et al.*, 2001b). Significant differences were observed by Boelling *et al.* (2001a) in the claw measurements (lengths, widths, circumferences) in dairy bulls at 5 months and the same bulls again at 10 months. An age associated increase in the claw measurements of these dairy bulls was observed and was due to general growth of the young bulls. In the present study on Bonsmara cattle, the AgeSex difference observed with regard to the anatomical claw measurements was predominantly due to age and not sex. As shown previously, the 'Other' group consisted predominantly of older female animals and the younger group (YoungM) predominantly of males. However, Nüske *et al.*, (2003) observed significant differences between male and female calves of similar ages with regards to claw anatomy with the male animals having larger corresponding digits.



Figures 3.19 Box plots illustrating the differences between the LL: lateral toe lengths (A), ML: medial toe lengths (B) and claw circumferences (C) of claws collected from Bonsmara cattle of different ages and sexes (Other: Older female group; YoungM: Young male group)

The limb positions of the Bonsmara claws (front versus hind limb) were also of significance with regards to the various morphological measurements. The mean LL, ML and circumferences were greater for the front claws than hind claws in the present study (Table 3.11 & Figures 3.20). These observations are in agreement with front and hind claw measurements in 70 day old calves (Nüske *et al.*, 2003) if one assumes that the relationship or ratio of these measurements stay similar throughout the animal's lifespan. Vermunt & Greenough (1996) detected significant differences between the front and hind claws with the dorsal border (toe) length longer compared to the hind claws and front claws wider compared to the hind claws in dairy heifers. The mean front and hind toe lengths of these specific dairy heifers were shorter compared to the Bonsmara bulls of similar age in the present study and may reflect sex differences but could also be due to environmental and management differences (intensive versus a more extensive approach associated with Bonsmara stud cattle). No significant differences between the dorsal wall toe lengths of claws and their limb

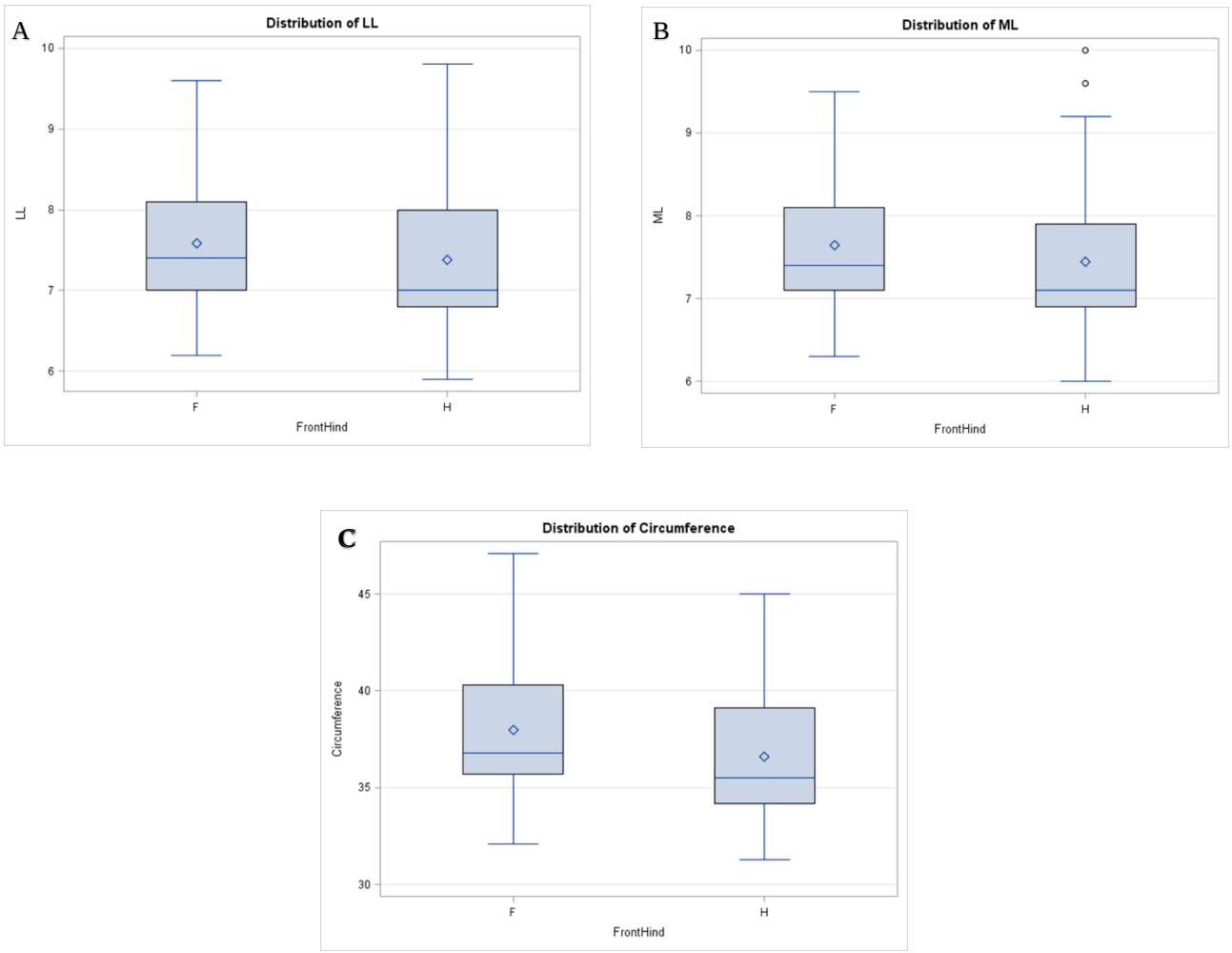
positions were detected by Distl *et al.*, (1984) and contradicts findings in the present study on Bonsmara cattle. It is worth mentioning that the differences observed between the front and hind claw toe lengths of Bonsmara cattle were not excessive. The practical significance thereof should be taken into consideration or evaluated to determine if the observed differences are meaningful in practice irrespective of their significance.

The mean front and hind claw toe lengths of Bonsmara cattle measured in the present study were however greater compared to the observations of Distl *et al.*, (1984) and could be ascribed to age differences since Bonsmara animals were older in the present study or variations in the measuring methods applied. Present results for dorsal wall toe length of lateral and medial hind claws were however more in agreement with what Becvar, (2006), (that focused only on the hind claws) observed in Angus steers of similar ages as the Bonsmara bulls. Claw length measurements of the lateral front limb and hind limb in dairy bulls (Danish Red and Danish Friesian) that were of younger age (10 months) were however greater compared to the present study but claw length measurements in Jersey bulls (10 months old) were similar compared to Bonsmara animals in the present study (Boelling *et al.*, 2001b) reflecting possible breed differences in claw traits (Nüske *et al.*, 2003).

In addition, ML measurements of the Bonsmara claws were slightly longer than the LL measurements irrespective of limb positions and, although the significance of these variations were not determined, it corresponds to what Nüske *et al.* (2003) found in calves and Becvar (2006) in Angus steers older than 12 months originating from a feedlot system. Kehler & Sohrt, (2000) found no differences between the lateral and medial hind claws of cows of various ages and dorsal wall lengths ranged from 6.5 cm to 8.2 cm with a mean of 7.6 cm. These dorsal wall lengths were however similar to the Bonsmara claw measurements in the present study (Table3.5).

Claw measurements performed on young Simmental bulls at 6 months, 9 months and 12 months of age, respectively, at three performance testing stations in Bavaria, indicated significant differences between the front and hind claw ground surface areas and circumferences (Distl *et al.*, 1984) and concur with the results obtained in the present study on claws of Bonsmara cattle where the front claws were larger compared to the hind claws. The claw circumference of Bonsmara claws were however greater than the measurements obtained by Distl *et al*. 1984, but could be attributed to older Bonsmara cattle in the present study and also differences in the measuring method related to claw circumference. Boelling *et al*. (2001a) found the circumference of the hind cannon bone to be larger than the front in dairy bulls and Scott *et al*. (1999) measured the claw volume of front claws to be 8% higher than the volume of the hind claws. The slightly heavier weight carried by the front claws compared to the hind claws could explain the variation in claw size (Toussaint-Raven, 1989). The majority of the claws in the present study came from young Bonsmara bulls that carry more weight on the front legs and associated claws and explain the differences observed between front and hind limbs with regard to size. The front feet generally carry slightly more weight than the hind feet regardless of gender (Toussaint-

Raven, 1989) but even more so in bulls that generally have a heavier fore quarter than hind quarter compared to cows.



Figures 3.20 Box plots illustrating the differences between the LL: lateral toe lengths (A), ML: medial toe lengths (B) and claw circumferences (C) of claws from different limb positions (F: front: H: hind)

3.4 CONCLUSION

This study investigated claw parameters and characteristics of normal claws in Bonsmara cattle originating from three different bioregions of South Africa and it provided baseline data for the various claw characteristics included in the study under the specific conditions. It also highlights factors that influence certain claw properties. Caution must be taken with the interpretation of the results due to the sample size tested and ideally claws from all regions should be studied. Bioregion had the greatest effect on the TS and morphological measurements (LL, ML and circumference) of Bonsmara claws tested in this study. The claw

characteristics of Bonsmara animals exposed to the respective bioregions (Gm, SVk and SVcb) possibly reflect the differences in climate, diet and variation in surface areas associated with these bioregions but requires further investigation to the specific causes. Claw moisture content, Ca, Se and claw limb position (front versus hind) had a significant influence on the TS of claws. Colour had a non-significant effect on claw TS and,therefore, based on the results of the current study, it is not an important factor to select for in order to improve claw quality in Bonsmara cattle. Claw conformation measurements (LL, ML and circumference) are significantly influenced by age, sex as well as claw limb position (front versus hind) and are relatively easy to measure. Morphological measurements were however taken post-mortem and the practicality and feasibility of these measurements on live animals should be taken into consideration. Morphological measurements however had no significant association with TS. The results of this study emphasize the complexity of claw quality since it is the aggregate result of multiple influential factors. It is not always easy to discern the main cause of observed claw characteristics and require a multifactorial approach or consideration. The value of these measurements in practice and inclusion in breeding programs would depend on the feasibility thereof and the overall need or necessity to improve specific claw traits in the Bonsmara breed (compared to other economically important traits).

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

This research project gave an insight into the occurrence of claw problems and claw characteristics in the Bonsmara breed, firstly based on inspection data and, secondly, based on the analyses of a number of claw measurements. The results serve as a benchmark for claw characteristics in Bonsmara cattle originating from different bioregions of South Africa. The study (inspection data analyses and claw characteristic descriptions) yet again confirmed the complexity associated with claw problems and claw quality. It is difficult to ascribe only a single factor as the cause of observed claw characteristics and quality, since claw quality is the result of the synergistic effect of various factors (genetic as well as non-genetic) as corroborated by this study on Bonsmara cattle originating from different environments.

Inspection data revealed that the percentage of animals exhibiting claw problems were relatively low compared to other traits inspected. It also indicated that differences in selection intensity with regards to claws exist and that some breeders are stricter in their selection policies pertaining to claw traits and not necessarily that certain animals are more prone to developing claw defects. This was probably also the case where male animals had a significantly higher claw problem occurrence than inspected female animals, but was likely due to stricter selection in bulls due to their long term genetic influence in a herd and not that they are more prone to claw problems per se. A genetic base or significant sire association with claw problems could however not be confirmed from the data but variation in the claw problem occurrence was however observed in the inspected progeny of different sires. It was clear that bioregion or the area where the animals are located had a major (significant) influence on the observed claw problems and breeder to an even greater extent. It was interesting to note that the regions indicated by the breeders as regions commonly associated with claw problems in South Africa, were not signalled as being significant in this regard, even though initial frequencies on the original inspection dataset highlighted some of these problem regions. The datasets (subsets of the original inspection dataset) were however small due to inherent data limitations and should be taken into consideration. Claw problems and possible causes would differ between farms and breeders and should be evaluated individually to acquire solutions to the problem or management adaptations to eliminate the problem.

The inspection data shows promise as an informative tool in the Bonsmara breed but various limitations of the data should be addressed in order to make it more accurate and useful for future use. Claw defects seem to be more of a problem at an older age after inspections already took place. In order to get a better indication of the claw problem incidence in the Bonsmara breed these culling reasons should also be recorded after inspections including the type of claw problem and the location of the claw problem on the limb (fore or hind and later or medial claws if applicable). Accurate recording and data capturing should be of priority to ensure efficient use and reliability. It is also imperative that the code of the inspector involved at each inspection be

recorded to account for differences between inspectors and subjectivity. It is therefore also imperative that the different claw defects should be clearly defined by the breeder society and understood by inspectors. Also, to investigate the degree of accuracy and comparability among inspectors in the identification or judging of claw traits. Trimming of claws as a management practice, in certain areas of South Africa, should also be recorded to get a fair and clear evaluation of the problem. The value of claw trimming data should be investigated since it could provide valuable or more accurate information with regards to claw problems and improve the genetic analyses and parameter estimations for various claw traits.

The evaluation of morphological claw measurements and physiological parameters indicated that there exists a significant difference between the claws of animals originating from different bioregions. The greatest significant influence on the observed claw tensile strength (TS), the lateral toe length (LL), medial toe length (ML) and claw circumferences were bioregion. These differences in claw characteristics reflect the type of environment and management animals are exposed to and emphasize yet again the complexity and extensive role of environmental influences on claw quality. Breeder knowledge of the various factors influencing claw quality is therefore crucial to limit claw problems by means of informed management decisions. This includes knowledge related to limitations associated with the quality of grazing throughout the year (relevant to the specific farming region) and subsequent supplementation of nutrients where it is required. The study also indicated that various other aspects (in addition to bioregion) play a role in determining claw strength and claw morphology. Claw moisture content, the Ca level, the Se level and claw limb position (front versus hind) had a significant effect on claw TS. Age, sex and claw limb position were significant with regard to the morphological measurements (LL, ML and circumference) of claws. Claw morphology (LL, ML and circumference) however did not have a significant influence on TS and therefore was not an important indicator of claw horn quality in this study. Interestingly, claw colour also had no significant effect on the TS of claws and therefore not that important in improving claw quality. The mineral content of claw material as an indicator of claw quality remains uncertain and should be used and evaluated in conjunction with mineral analyses on other tissues to accurately assess the mineral status of the animal. The sample size tested was small but provided baseline data regarding the claws of Bonsmara stud cattle farmed under South African conditions and is beneficial for further work.

The value and practicality of claw trait measurements (compared to other economically important traits) in beef cattle breeding programs (specifically in the Bonsmara breed) should be investigated and it is essential that the Bonsmara breeder society should set clear guidelines for routine recording of these traits. It would therefore also be beneficial to evaluate and investigate the necessity or need for these types of recordings. Objective scoring and measurements are essential to obtain data that could be included in routine genetic analyses. Future studies should focus on individual factors affecting Bonsmara claw traits in controlled environments as well as comparisons of normal claws to abnormal claws. In addition, bioregion characteristics like the abrasion properties and effect of different ground textures on claw quality associated with the

bioregions (ideally all the different bioregions) could be investigated more closely. The progeny of specific sires should be studied with regards to claw traits and evaluated through its life to determine if certain bull or sire lines in the Bonsmara breed are more prone to problems and to establish a possible genetic component associated with certain claw traits and claw problems in the breed.

The study provided insight to the extent of claw problems in Bonsmara cattle as well as valuable information pertaining to claw characteristics and the various effects influencing these characteristics in Bonsmara cattle farmed under adverse South African conditions.

ADDENDUM A

Table A1 The rejection codes or culling reasons of the Bonsmara Breeder Society of South Africa

Category	Description	Rejection / Culling Reasons
A	Performance	A1 Slaughter Clause
		A2 Minimum Breed Standards (Index)
		A3 EBV's below standard (estimated breeding values)
B	General Conformation	B1 Not Bonsmara type
		B2 Poor muscling
		B3 Poor balance (height/length)
		B4 Poor balance (front/hind quarter)
		B5 Poor constitution or poorly adapted
		B6 Pony type
		B7 Big (late matured)
		B8 Coarsely boned
		B9 Fine boned
		B10 Lack of depth
		B11 Lacks I spring of rib
		B12 Abnormal gait
		B13 Flat
		B14 Excessive muscling
C	Colour	C1 White above underline
		C2 White above switch
		C3 Not typical Bonsmara colour
D	Hair coat	D1 Long or woolly hair coat
E	Masculinity/Femininity	E1 Oxy
F	Temperament	F1 Bad temperament
		F2 Wild (difficult to handle)
G	Head	G1 Skew face
		G2 Light jaw
		G3 Undershot jaw
		G4 Overshot jaw
		G5 Compressed head
		G6 Poor eyebrow development
		G7 Narrow head
		G8 Dish face
H	Front quarter	H1 Prominent brisket (heifers)
		H2 Loosely attached shoulders
J	Mid piece	J1 Hollow back
		J2 Laterally twisted spine
		J3 Hunchback
		J4 Devil's grip
		J5 Roofy on shoulders

K	Hind quarter	K1 Rump too flat K2 Excessively sloping rump K3 Rump too roofy K4 Narrow through pin bones K5 Excessively round hind quarter K6 Flat through thighs
L	Front legs	L1 X-legged L2 Pigeon toed L3 Bandylegged L4 Stag knees L5 Knees bent backwards L6 Duck feet (Stands on inner hooves)
M	Hind legs	M1 Straight hocks M2 Excessively sickle hocked M3 Excessively cow hocked M4 Short gait M5 Bandy legged
N	Pasterns	N1 Weak pasterns N2 Upright pasterns N3 Twisted pasterns N4 Missing dew claws
P	Claws	P1 Outgrowing hooves P2 Hooves curling inwards P3 Hooves too open (pole shoe) P4 Lack in depth of heel P5 Hooves differ in size P6 Corkscrew hooves P7 Standing on outside part of hind hooves
Q	Tail	Q1 Wrytail – attached of centre Q2 Baboon tail Q3 Congenital kink in upper third of tail
R	Scrotum & Testes	R1 Scrotum twisted (>45˚) R2 Testes (scrotum) too small R3 Testes too big R4 ‘Koeksister’ shaped testes R5 Hypoplasia R6 Cryptorchidism (testes did not drop) R7 Exessively long hair on scrotum R8 Scrotum split R9 Testes ‘scoops’ forward
S	Sheath	S1 Sheath too long S2 Fleshy sheath S3 Preputial prolapse S4 Sheath opening too big S5 Navel

T	Female genitals	T1 Underdeveloped vulva T2 Vulva tends to be horizontal
V	Udder & Teats	V1 Poor udder development V2 Poor or abnormal teat development V3 Bottle teats
W	Other reasons	W1 Any other negative traits not on the list W2 Owner - culled

ADDENDUM B

Table B1 The frequency and percentage of inspected Bonsmara animals that exhibited claw problems (P1-P7 clustered together) per bioregion as determined from the original inspection dataset containing 166828 inspected animals

Bioregion Code	Bioregion Description	Claw Problems	Total Animals Inspected	% Claw Problems
NKb	Bushmanland	131	1182	11.08
AT	Albany Thicket	78	1424	5.48
Gh	Dry Highveld Grassland	1618	37185	4.35
F07	West Coast Renosterveld	2	51	3.92
SVl	Lowveld	2	53	3.77
NKu	Upper Karoo	113	3419	3.31
Gm	Mesic Higveld Grassland	1087	39921	2.72
SVcb	Central Bushveld	464	18192	2.55
SVk	Eastern Kalahari	856	33608	2.55
Missing	-	77	3588	2.15
None	-	31	1594	1.94
F06	Eastern Fynbos-Renosterveld	22	1238	1.78
SVs	Sub-Escarpment Savanna	26	1927	1.35
Gs	Sub-Escarpment Grassland	117	9924	1.18
*NAM	Namibia	96	11399	0.84
Gd	Drakensberg Grassland	11	2123	0.52
Total		**4731**	**166828**	**2.84**

*NAM was considered separately since the bioregion classification system (Mucina *et al.*, 2006) utilised in this study only focuses on South Africa and do not extend to the neighbouring countries

Table B2 The frequencies and percentages of animals inspected with claw problems per year (2000 to early 2012) as determined from the original inspection dataset containing 166828 inspected animals

Year	Claw Problems	Total Animals Inspected	% Claw Problems
2000	56	815	6.87
2001	101	3068	3.29
2002	296	8026	3.69
2003	314	10018	3.13
2004	320	11493	2.78
2005	370	10848	3.41
2006	325	13081	2.48
2007	477	17699	2.70
2008	454	19187	2.37
2009	580	22586	2.57
2010	803	24792	3.24
2011	613	23688	2.59
2012	22	1527	1.44
Total	4731	166828	2.84

Table B3 Summary of the number of inspected progeny with claw problems per sire ranging from none to 57 progeny with claw problems per sire as determined from the original inspection dataset containing 166828 inspected animals

Number of sires	Progeny with claw problems
1*	57
1	38
1	26
1	25
1	21
1	20
3**	19
1	18
1	15
3	14
6	13
4	12
3	11
8	10
11	9
14	8
25	7
40	6
60	5
129	4
230	3
447	2
1128	1
5221	0
No sire	19
7340 sires	

*One sire had 57 inspected progeny with claw problems
**Three sires each had 19 inspected progeny with claw problems respectively

Table B4 Sires with five or more inspected progeny with claw problems as determined from the original inspection dataset containing 166828 inspected animals

Specific Sire	Progeny with claw problems	Total progeny inspected per sire	% progeny with claw problems
1	57	2249	2,53
2	38	960	3,96
3	26	73	35,62
4	25	304	8,22
5	21	423	4,96
6	20	151	13,25
7	19	244	7,79
8	19	642	2,96
9	19	106	17,92
10	18	666	2,70
11	15	297	5,05
12	14	100	14,00
13	14	63	22,22
14	14	165	8,48
15	13	194	6,70
16	13	118	11,02
17	13	117	11,11
18	13	55	23,64
19	13	54	24,07
20	13	164	7,93
21	12	196	6,12
22	12	297	4,04
23	12	95	12,63
24	12	61	19,67
25	11	196	5,61
26	11	44	25,00
27	11	69	15,94
28	10	60	16,67
29	10	436	2,29
30	10	99	10,10
31	10	45	22,22
32	10	143	6,99
33	10	65	15,38
34	10	35	28,57
35	10	33	30,30
36	9	39	23,08
37	9	52	17,31
38	9	124	7,26
39	9	51	17,65
40	9	109	8,26
41	9	176	5,11
42	9	314	2,87
43	9	125	7,20
44	9	42	21,43
45	9	248	3,63
46	9	36	25,00
47	8	51	15,69
48	8	229	3,49
49	8	101	7,92
50	8	125	6,40
51	8	12	66,67
52	8	83	9,64
53	8	55	14,55
54	8	135	5,93
55	8	171	4,68
56	8	72	11,11
57	8	56	14,29
58	8	74	10,81
59	8	104	7,69
60	8	21	38,10
61	7	29	24,14
62	7	56	12,50
63	7	273	2,56
64	7	16	43,75
65	7	217	3,23
66	7	97	7,22
67	7	133	5,26
68	7	45	15,56
69	7	330	2,12
70	7	48	14,58
71	7	29	24,14
72	7	93	7,53
73	7	94	7,45
74	7	167	4,19
75	7	65	10,77
76	7	64	10,94

77	7	67	10,45
78	7	150	4,67
79	7	59	11,86
80	7	158	4,43
81	7	73	9,59
82	7	49	14,29
83	7	53	13,21
84	7	99	7,07
85	7	26	26,92
86	6	10	60,00
87	6	142	4,23
88	6	7	85,71
89	6	38	15,79
90	6	139	4,32
91	6	90	6,67
92	6	35	17,14
93	6	57	10,53
94	6	216	2,78
95	6	52	11,54
96	6	109	5,50
97	6	64	9,38
98	6	102	5,88
99	6	140	4,29
100	6	147	4,08
101	6	151	3,97
102	6	50	12,00
103	6	53	11,32
104	6	92	6,52
105	6	131	4,58
106	6	74	8,11
107	6	108	5,56
108	6	60	10,00
109	6	178	3,37
110	6	142	4,23
111	6	49	12,24
112	6	54	11,11
113	6	188	3,19
114	6	235	2,55
115	6	32	18,75
116	6	65	9,23
117	6	76	7,89
118	6	44	13,64
119	6	91	6,59
120	6	59	10,17
121	6	44	13,64
122	6	56	10,71
123	6	15	40,00
124	6	16	37,50
125	6	29	20,69
126	5	82	6,10
127	5	44	11,36
128	5	31	16,13
129	5	19	26,32
130	5	268	1,87
131	5	60	8,33
132	5	144	3,47
133	5	65	7,69
134	5	28	17,86
135	5	61	8,20
136	5	53	9,43
137	5	66	7,58
138	5	28	17,86
139	5	136	3,68
140	5	94	5,32
141	5	57	8,77
142	5	105	4,76
143	5	27	18,52
144	5	111	4,50
145	5	79	6,33
146	5	45	11,11
147	5	124	4,03
148	5	78	6,41
149	5	209	2,39
150	5	128	3,91
151	5	36	13,89
152	5	33	15,15
153	5	76	6,58
154	5	58	8,62
155	5	18	27,78
156	5	58	8,62
157	5	19	26,32
158	5	127	3,94
159	5	84	5,95
160	5	59	8,47
161	5	99	5,05
162	5	72	6,94
163	5	37	13,51
164	5	133	3,76
165	5	83	6,02
166	5	21	23,81

167	5	105	4,76
168	5	87	5,75
169	5	53	9,43
170	5	86	5,81
171	5	86	5,81
172	5	93	5,38
173	5	62	8,06
174	5	35	14,29
175	5	57	8,77
176	5	93	5,38
177	5	102	4,90
178	5	56	8,93
179	5	75	6,67
180	5	35	14,29
181	5	46	10,87
182	5	38	13,16
183	5	24	20,83
184	5	46	10,87
185	5	15	33,33
No Sire	19	1048	1,81

ADDENDUM C

Table C1 The percentage of inspected Bonsmara animals with claw problems (P1 to P7 clustered together) per province as determined from the original inspection dataset (A), Model B dataset (B) and Model C dataset (C)

A Province	Total inspected animals	Number of animals with claw problems	% Claw problems of total inspected animals per province
Northern Cape	11575	496	4.29
Free State	57507	2325	4.04
North West	36221	921	2.54
Mpumalanga	13018	290	2.23
Eastern Cape	9758	181	1.85
Western Cape	1159	21	1.81
Other	1856	33	1.78
Gauteng	2654	47	1.77
Limpopo	13133	213	1.62
Namibia	12625	133	1.05
Kwazulu-Natal	7322	71	0.97
	166828	**4731**	**2.84**

B Province	Total inspected animals	Number of animals with claw problems	% Claw problems of total inspected animals per province
Mpumalanga	197	21	10.66
Kwazulu-Natal	126	7	5.56
Free State	1354	42	3.10
Western Cape	98	3	3.06
North West	911	25	2.74
Eastern Cape	430	5	1.16
Limpopo	442	3	0.68
Northern Cape	31	0	0.00
	3589	**106**	**2.95**

C Province	Total inspected animals	Number of animals with claw problems	% Claw problems of total inspected animals per province
Mpumalanga	197	21	10.66
North West	664	23	3.46
Free State	1162	26	2.24
Limpopo	319	3	0.94
	2342	**73**	**3.12**

Table C2 The percentage of inspected Bonsmara animals with claw problems (P1 to P7 clustered together) per bioregion as determined from the original inspection dataset (A), Model B dataset (B) and Model C dataset (C)

A Bioregion	Claw Problems	Total Animals Inspected	% Claw Problems
Missing	77	3588	2.15
AT	78	1424	5.48
F06	22	1238	1.78
F07	2	51	3.92
Gd	11	2123	0.52
Gh	1618	37185	4.35
Gm	1087	39921	2.72
Gs	117	9924	1.18
NAM	96	11399	0.84
NKb	131	1182	11.08
NKu	113	3419	3.31
None	31	1594	1.94
SVcb	464	18192	2.55
SVk	856	33608	2.55
SVl	2	53	3.77
SVs	26	1927	1.35
Total	**4731**	**166828**	**2.84**

B Bioregion	Claw Problems	Total Animals Inspected	% Claw Problems
F06	3	98	3.06
Gd	2	222	0.90
Gh	15	474	3.16
Gm	62	1530	4.05
Gs	7	126	5.56
Nku	3	208	1.44
SVcb	12	650	1.85
SVk	2	281	0.71
Total	**106**	**3589**	**2.95**

C Bioregion	Claw Problems	Total Animals Inspected	% Claw Problems
Gh	14	453	3.09
Gm	47	1359	3.46
SVcb	12	530	2.26
Total	**73**	**2342**	3.12

NKb: Bushmanland
AT: Albany Thicket
Gh: Dry Highveld Grassland
F07: West Coast Renosterveld
SVl: Lowveld
NKu: Upper Karoo
Gm: Mesic Highveld Grassland
SVcb: Central Bushveld
SVk: Eastern Kalahari Bushveld
Missing: Missing Bioregion
None: No Bioregion
F06: Eastern Fynbos Renosterveld
SVs: Sub-Escarpment Savanna
Gs: Sub-Escarpment Grassland
NAM: Namibia
Gd: Drakensberg Grassland

Table C3 The percentage of inspected Bonsmara animals with claw problems per individual claw category (P1 to P7 respectively) as determined from the original inspection dataset (A), Model B dataset (B) and Model C dataset (C)

A Claw Code	Frequency	% of total inspected animals
P1[1]	2860	1.71
P2[2]	502	0.30
P3[3]	233	0.14
P4[4]	1095	0.66
P5[5]	168	0.10
P6[6]	110	0.07
P7[7]	654	0.39

B Claw Code	Frequency	% of total inspected animals
P1	65	1.81
P2	10	0.28
P3	3	0.08
P4	12	0.33
P5	6	0.17
P6	6	0.17
P7	27	0.75

C Claw Code	Frequency	% of total inspected animals
P1	47	2.01
P2	3	0.13
P3	3	0.13
P4	8	0.34
P5	4	0.17
P6	2	0.09
P7	21	0.90

[1]P1: Outgrowing hooves
[2]P2: Hooves curling inwards
[3]P3: Hooves too open (pole shoe)
[4]P4: Lack in depth of heel
[5]P5: Hooves differ in size
[6]P6: Corkscrew hooves
[7]P7: Standing on outside part of hind hooves

ADDENDUM D

Table D1 Sires used by different breeders (HDM) in different bioregions and the respective inspected progeny exhibiting claw problems (yellow blocks)

SIRE \ HDM	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Total
A	0%	0%	0%											0%	0%			0%	9.10 %	0%			0%		1.00 %
	3	60	2											3	1			37	22	80			1		209
B	0%	0%	50.00 %	0%	0%	0%		8.30 %			0%							0%							1.90 %
	6	5	2	3	54	4		12			1							16							103
C	0%		0%	0%		0%		37.50 %			0%	0%	0%	0%	0%	0%	0%							0%	4.20 %
			6	11		9		8			1	23	4	1		4	1							3	71
D	0%								5.90 %		22.20 %			0%				3.80 %				0%			3.90 %
	17								34		9			14				26				27			127
E	0%	0%		0%				0%				0%			0%	0%			15.80 %	0%					2.10 %
	82	10		6				9				1			6	2			19	10					145
F					0%	0%	0%	0%													6.70 %			0%	1.50 %
					7	31	7	4													15			4	68
G	0%	0%			0%			23.10 %	0%			0%				0%		0%	0%			0%			2.30 %
	58	18			8			13	5			1				2		11	15			2			133
H					0%		0%			0%	3.40 %		0%						0%					0%	1.70 %
					2		5			1	117		1						13					90	229
I		0%		0%	0%	0%	0%	0%	6.50 %	0%					0%					0%			0%		2.10 %
		3		5	8	19	7	12	31	1					1					8			1		96
J	0%				0%		0%				50.00 %		0%									0%	0%		1.60 %
	1				10		18				2		27									3	1		62
K				0%	6.30 %					8.30 %	0%		0%										0%	0%	2.00 %
				1	16					12	5		61										1	2	98
L	0%	7.70 %	0%	0%	3.20 %	0%	4.30 %	7.70 %	0%	10.00 %	50.00 %	0%	0%		0%	0%	0%	0%	0%			0%	0%		3.60 %
	4	26	8	2	31	23	23	26	18	20	2	6	1		1	12	2	21	9			14	1		250

M	0%	0%	0%		2.20 %	0%		0%	12.50 %	14.30 %	0%								0%	1.60 %			2.80 %
	3	17	2		89	8		16	16	14	11								8	62			246
N	2.10 %	6.30 %				2.00 %		17.20 %		11.50 %	0%		0%	1.90 %	11.10 %			2.20 %	4.20 %	0%	0%	0%	16.70 %	0%	4.30 %
	190	16				51		64		26	14		1	107	9			90	48	6	7	24	12	9	674
O			0%	0%		0%			0%			5.90 %									16.70 %	0%			2.60 %
			13	15		6			8			17									6	11			76
P	0%		0%	2.70 %		0%		0%		0%		0%		0%	0%			0%		0%	0%	0%			0.80 %
	2		6	37		12		9		1		18		4	3			7		3	4	12			118
Q	0%									0%							30.00 %			0%					4.90 %
	93									1							20			8					122
R	1.90 %					1.70 %	0%				3.10 %	0%				0%	11.10 %								1.90 %
	155					58	34				32	21				8	9								317
S			5.60 %		0%		0%		0%		8.30 %					0%	14.30 %					0%	0%	0%	5.30 %
			36		22		38		3		12					3	42						4	10	170
T				0%		0%		4.20 %	3.40 %								10.00 %				0%			0%	3.30 %
				6		12		24	203								10				4			16	275
	1.10 %	1.90 %	4.00 %	1.20 %	1.60 %	0.90 %	0.80 %	10.70 %	4.10 %	10.50 %	4.90 %	1.10 %	0.00 %	1.60 %	4.80 %	0.00 %	16.70 %	1.40 %	5.60 %	0.00 %	3.10 %	0.00 %	9.50 %	0.00 %	3.00 %
	614	155	75	86	247	233	132	197	318	76	206	87	95	129	21	31	84	208	126	123	98	93	21	134	3589

HDM: Herd Designation Mark

Grey blocks indicate HDMs that had a significant effect on the observed claw problems and sires with a possible effect on claw problems (even though the sire effect was insignificant)

Yellow blocks indicate the percentage of inspected progeny with claw problems with the total animals inspected just below it. **Green blocks** indicate inspected progeny without claw problems. For example 9.10% of a total of 22 inspected progeny of sire A with HDM S had claw problems and none (0%) of a total of 3 inspected progeny of sire A with HDM A had claw problems.