

Morphological and physiological characteristics of claw quality in South African Bonsmara cattle

E. van Marle-Köster[#], S.J. Pretorius & E.C. Webb*

Department Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa

(Received 30 January 2019; Accepted 24 July 2019; First published online 23 November 2019)

Copyright resides with the authors in terms of the Creative Commons Attribution 4.0 South African Licence.

See: <http://creativecommons.org/licenses/by/4.0/za>

Condition of use: The user may copy, distribute, transmit and adapt the work, but must recognise the authors and the South African Journal of Animal Science.

Abstract

Sound claws are essential for beef cattle, given the marked influence they have on functional longevity and subsequent performance. The aim of this study was to evaluate morphological and physiological claw characteristics of Bonsmara SA beef cattle in the major bioregions of South Africa. Normal claws of 89 Bonsmara stud animals were collected from three bioregions in which Bonsmara cattle are farmed, namely Mesic Highveld Grassland, Eastern Kalahari Bushveld and Central Bushveld bioregions. Most of these claws were from Bonsmara bulls that were slaughtered after completion of a standardized intensive feeding test and a few were from older cows. Lateral toe length (LL), medial toe length (ML), claw circumference, colour coding and tensile strength (TS) were determined on the fore and hind claws and mineral composition only on the fore claws. Multifactorial analysis of variance (ANOVA) models indicated that bioregion, moisture content, calcium (Ca), selenium (Se) and claw position (fore versus hind claws) had a significant effect ($P < 0.05$) on TS. It is clear that environmental factors need to be considered in the evaluation of claw quality. This research serves as a benchmark for claw traits in the Bonsmara breed. Recording of claw and conformation traits is essential for genetic improvement.

Keywords: bioregion, claw parameters, colour, lateral and medial claw length, mineral composition, tensile strength

[#] Corresponding author: evm.vanmarle-koster@up.ac.za

Introduction

Cow-calf production systems are found primarily under extensive farming conditions in South Africa, while steers are finished in feedlots (Webb & Erasmus, 2013). Most production systems use the Bonsmara SA, which is the most numerous breed. Production occurs in nine biomes and 35 bioregions with various types of vegetation (Mucina *et al.*, 2006). These biomes are characterized by different climatic conditions, soil types, vegetation and physical terrain. Bonsmara seed stock breeders are well represented throughout South Africa (Webb *et al.*, 2017), being most concentrated in Mesic Highveld Grassland, Eastern Kalahari Bushveld and Dry Highveld Grassland regions. Beef cattle are therefore exposed to a variety of environments and associated stressors throughout their productive life, which may affect their production efficiency and longevity. Quality claws are an attribute of cattle that affects the functional efficiency of the animal.

Claw quality has been studied mostly in dairy cattle under intensive production systems with the focus on claw health, lameness, and its effect on longevity (Haufe *et al.*, 2012; Solano *et al.*, 2016). Claw quality is also an animal welfare issue in the production of all cattle under intensive conditions. Desirable claw quality has been defined as the normal growth of the claws to ensure adequate structural strength to carry the weight of an animal (Hepburn *et al.*, 2007), resistance to external damage, and absence of defects and lesions.

Morphological measurements and histological and physical characteristics have been reported as being potential indicators of claw quality (Hahn *et al.*, 1984; Politiek *et al.*, 1986). The horn capsule of the claw consists of tubular, inter-tubular, and lamellar horn cells (keratin), which determine the structural strength, biomechanical behaviour, and resistance of claws to external stressors (Franck *et al.*, 2006). Claw morphology is described by 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 and weight distribution (Phillips *et al.*, 1996; Van der Tol *et al.*, 2002; Bonser *et al.*, 2003). Several claw defects have been identified in dairy (Volkman & Kemper, 2018) and beef cattle (Vollmar, 2016). The International Committee for Animal Recording (ICAR) atlas contains a number of common foot and claw disorders that can be used for identification (Egger-Danner *et al.*, 2015). Claw colour is under investigation for an association with claw quality, with most of the studies being done in equines (Douglas *et al.*, 1996; Hepburn *et al.*, 2007) and sheep (Scobie *et al.*, 2017).

The Bonsmara breed was developed through a well-documented scientific breeding programme, which included traits such as conformation, legs, and claws (Bonsma, 1980; Bergh *et al.*, 2010). Environmental factors that influence claw quality in cattle include the nutritional regime, production environment, and management practices. Research has indicated that several nutrients (minerals, vitamins, amino acids and fatty acids) play a role in the structural integrity of claws (Nocek *et al.*, 2000; Tomlinson *et al.*, 2004; Lean *et al.*, 2013; Van Riet *et al.*, 2013). Most of these nutrients are involved in the keratinization process, which ensures normal claw growth and structural binding of keratin proteins (Lean *et al.*, 2013). A number of studies have compared flooring systems with regard to locomotion and claw traits in dairy and beef cattle under intensive production systems (Cozzi *et al.*, 2013; Brscic *et al.*, 2015; Earley *et al.*, 2017). Although claw defects do occur in beef cattle herds in extensive production systems, there is a dearth of information because claw traits are not recorded routinely, and limited hoof trimming is performed.

The underlying genetics of claw quality are complex. Genetic parameters have been reported for claw traits in dairy cattle based on data that has been recorded in conjunction with routine hoof trimming. Heritability estimates for dairy cattle have varied from 0.01 to 0.14 and 0.06 to 0.39 when estimated with linear and threshold models, respectively (Heringstad *et al.*, 2018). Foot angle and claw set have also been studied with a scoring system in American Angus cattle, in which heritability estimates varied from 0.16 to 0.37 (Wang *et al.*, 2017). However, morphological and physiological characteristics of beef cattle claws have not been reported for beef cattle in South Africa. This presents challenges for genetic selection and improvement. The objective of this study was to evaluate morphological measurements and physiological parameters to set a benchmark for claw quality in beef cattle with special reference to Bonsmara cattle.

Materials and Methods

Ethical approval for sample collection was obtained from the Ethics Committee of the University of Pretoria (EC110620-044).

Bonsmara stud bulls were subjected to intensive growth tests, which includes visual inspection on functional traits at the end of the test period. Most of the claws that were collected for this study were from animals that had failed the growth test did not meet the standards for functional traits. Only claws without defects from bulls between the ages of 12 and 36 months and 20 older cows were included (Table 1). A total of 178 lateral and 178 medial claws from 89 Bonsmara stud animals were collected from abattoirs in which animals originated from three bioregions in SA (Figure 1). The Mesic Highveld Grassland (Gm) bioregion, Central Bushveld (SVcb) bioregion and Eastern Kalahari Bushveld (SVk) are representative of the primary bioregions in which Bonsmara cattle are farmed (Webb *et al.*, 2017). Front and hind foot (lateral and medial) claws were collected per animal, either right or left, cut at the knee and hock joints, respectively. The lateral and medial claws were removed from the leg at the pastern joint after collection using an Okto industrial meat bandsaw (Crown National, South Africa). Claws were wiped clean, placed in a plastic bag, labelled with the identification number of the animal, and stored at -20 °C at Hillcrest Experimental Farm of the University of Pretoria until further processing. Lateral and medial claws were studied as a unit (per hind or front limb) unless specified.

Table 1 Total number of Bonsmara claws (front and hind) collected from the Mesic Highveld Grassland, Central Bushveld and Eastern Kalahari Bushveld bioregions

	Bioregions					
	Mesic Highveld Grassland		Central Bushveld		Eastern Kalahari Bushveld	
Average temperature, °C	14.7		18.4		17.8	
Average precipitation, mm	726		559		362	
	Male	Female	Male	Female	Male	Female
12 to 36 months of age	50 ¹ (25) ²	None	60 (30)	None	40 (20)	8 (4)
> 36 months of age	2 (1)	6 (3)	None	None	None	12 (6)
Total claws (feet)	58		60		60	

¹The lateral and medial claw per front and hind limb are counted as one unit

²The number in brackets indicates the number of animals involved

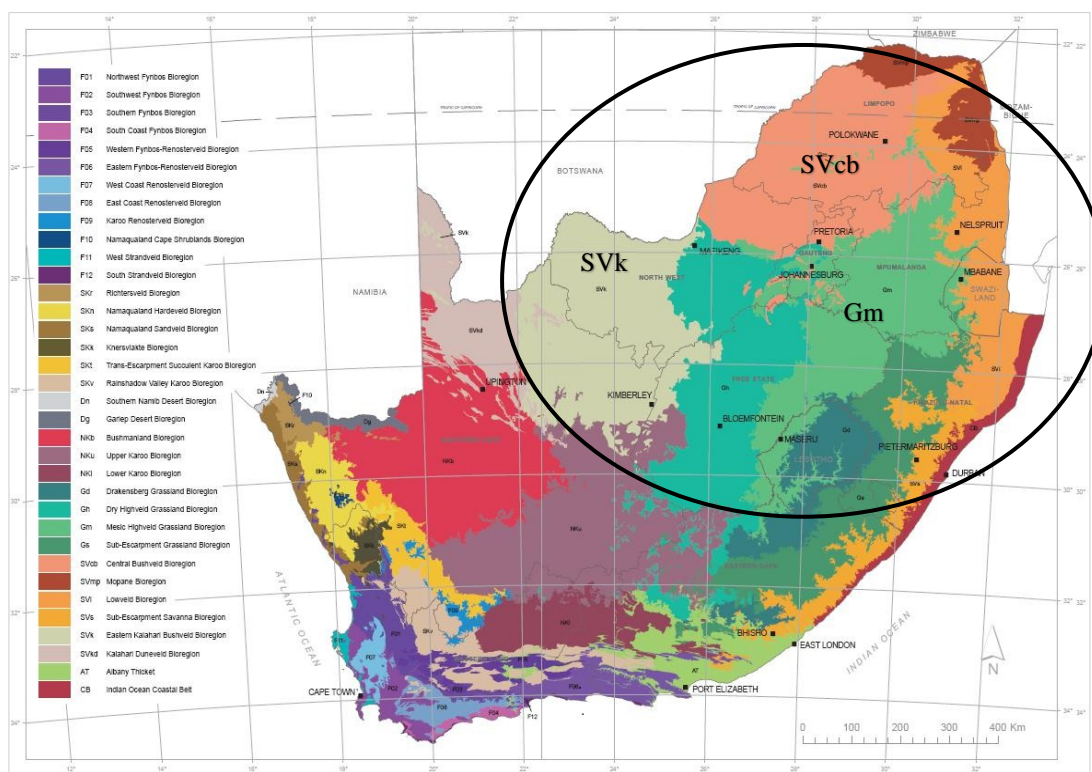


Figure 1 Mesic Highveld Grassland, Central Bushveld and Eastern Kalahari Bushveld bioregions (Mucina *et al.*, 2006) of South Africa from which claws used in this study originated

Key - Gm: Mesic Highveld Grassland, SVcb: Central Bushveld, SVk: Eastern Kalahari Bushveld

Morphological measurements included toe length, circumference, colour and hardness of the claw. Claws were defrosted and LL and ML were measured with a measuring tape (Politiek *et al.*, 1986) from the coronary band along the dorsal border to the toe of the claw (Figure 2). The circumferences of the lateral and medial claw were measured, and claws were photographed with a Canon IXY digital 910IS camera (Canon Inc., Tokyo, Japan) to describe colour variation.



Figure 2 Length of claw as measured from periople to tip of the toe

Rectangular samples (4.5 cm x 1 cm) were cut from the lateral claw wall using a Stryker 1100 oscillating saw (Stryker Corp., Michigan, USA) and a Dremel 3000 rotary multi-tool (Robert Bosch Tool Corp., Mount Prospect, Illinois, USA) for measuring tensile strength. All samples were vacuum sealed until analysis to prevent excessive moisture loss.

Tensile strength was measured in the Civil Engineering Laboratory of the Department of Civil Engineering, University of Pretoria, using a LRX Plus Series Lloyd instrument (Ametek Inc., Lloyd Materials Testing Ltd., West Sussex, UK) fitted with a 5 kN (kilonewton) standard load cell. Samples were collected from the claws at the location illustrated in Figure 3. NEXYGENPlus 3 material testing and data analysis software (Lloyd Instruments Ltd., West Sussex, UK) was used. The length and the width of each sample were measured with a digital 150 mm Vernier calliper to determine the surface area. Samples were positioned between two clamps and pulled with a speed of 3 mm/min and a preload stress speed of 21 mm/min. The maximum load (N) of each sample was measured and used to determine the TS of each sample with the formula $TS \text{ (MPa)} = \text{Force (N)} / \text{Surface area (mm}^2\text{)}$.



Figure 3 Position of rectangular claw sample on dorsal claw wall for tensile strength testing

Claws were classified (Light, Intermediate or Dark) according to colour using the standards that are shown in Figure 4 as reference.



Figure 4 Standards used to classify the colour of claws from Bonsmara cattle

Moisture content and mineral analyses were performed on all samples at the Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria, according to standard protocols (AOAC, 2000). For the mineral analyses, claws 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 hole saw. The round discs were reduced in size and further milled with a swing saw (Department of Geology, University of Pretoria). The milling pot was cleaned between samples by milling quartz sand for two minutes and using an air pressure gun and ethanol to remove leftover sample and quartz sand before a new sample was milled.

Mineral analyses included Zinc (Zn), Calcium (Ca), Copper (Cu), Manganese (Mn), Phosphorus (P), and Selenium (Se). The milled air-dried claw samples were digested according to the standard procedure as described by AOAC (2000). The Zn and Cu concentrations of the digested sample solutions were determined on a GBC 905 atomic absorption spectrophotometer (GBC Scientific Equipment, Braeside, Australia) at a wavelength of 213.9 nm. The Ca concentration was determined by a Perkin Elmer 5100PC atomic absorption spectrophotometer (PerkinElmer, Waltham, USA) at a wavelength of 422.7 nm. Mn was analysed on a Varian Spectra AA 50 atomic absorption spectrophotometer (SpectraLab Scientific Inc., Palo Alto, USA) at a wavelength of 324.7 nm. One millilitre of digested claw sample solution was diluted with 7 mL deionized water, followed by the addition of 2 mL Vanadate-Molybdate reagent. Phosphorus concentrations were measured with an Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena, Germany) at a wavelength of 400 nm. Accuracies of mineral analyses were tested against five standard reference solutions. Selenium was measured according to an AOAC (2000) protocol using a Perkin-Elmer 2380 atomic absorption spectrophotometer (PerkinElmer, Waltham, USA) at an absorbency of 196 nm and lamp energy of 16 mA. Determination of the Se concentrations was done with reference to standard solutions of 2, 5, and 10 parts Se per mL.

The data were analysed using SAS (version 9.3, SAS Institute Inc., Cary, NC, USA). Data were tested for normality, and descriptive statistics were generated, followed by a principal component analysis (PCA) on the morphological claw variables (LL, ML, and circumference). The first principal component (PC1) explained 91.42% of the variation in LL, ML and circumference together. Thus, PC1 was used as a proxy for the three morphological measurements. For the front claws, the analysis of variance model included colour, bioregion, age-sex, moisture content, PC1, and Ca, P, Cu, Mn, Zn, Se as independent variables and TS was the dependent variable (Model A). All these main effects were included in the model simultaneously and potential interactions were ignored. In analysing the TS measurements from front and hind claws, the model included colour, bioregion, age-sex, moisture content, and PC1 with the addition of effects for front versus hind leg and the interaction of that effect with bioregion (Model B). Differences between means were assessed with Scheffe's multiple range tests at a significance level of $P=0.05$.

Results

A majority (47.2%) of the claws were classified as being dark in colour, with 19.1% classified as light and 33.7% classified as intermediate. The descriptive statistics for the physical (TS) and physiological

(moisture content) traits and morphological measurements (LL, ML and circumference) are shown in Table 2. In Table 3 the mineral composition of the claws is summarised.

Table 2 Descriptive statistics for claw traits of Bonsmara cattle

Trait	N	Median	Mean	SD	Skewness	Kurtosis
Tensile strength (MPa)	178	16.83	16.58	3.73	-0.312	0.614
Moisture content (%)	178	22.59	22.64	1.80	0.127	-0.323
Lateral toe length (cm)	178	7.20	7.48	0.82	0.787	-0.136
Medial toe length (cm)	178	7.25	7.55	0.84	0.826	-0.099
Circumference (cm)	178	36.40	37.30	3.45	0.842	-0.110

[†] N: number of claws, SD: standard deviation

Table 3 Descriptive statistics for mineral analyses of claws of Bonsmara cattle

Traits	N	Median	Mean	SD
Calcium (g/100g)	89	0.131	0.132	0.029
Phosphorus (g/100g)	89	0.091	0.092	0.015
Copper (mg/kg)	89	4.960	6.320	10.830
Manganese (mg/kg)	89	1.440	1.800	1.890
Zinc (mg/kg)	89	145.95	152.10	23.700
Selenium (ug/kg)	89	361.00	561.16	542.260

[†] Mineral concentrations are presented on a dry matter (DM) basis

Model A was used to analyse the TS of front claws. The model explained 33% of the variation in TS, with the effects of bioregion, moisture content, and Ca and Se concentrations being significant (Table 4). Model B was used to analyse the TS of both front and hind claws. The mineral concentrations were not included as independent variables because they were only measured for the front claws. The difference between feet from the front and hind legs and the interaction of this effect with bioregion were not significant.

Bioregion had a significant effect on TS ($P < 0.05$), with the weaker claws being obtained from Gm compared with those from SVk and SVcb. Claws from SVk and SVcb were similar in TS (Table 5).

Discussion

Claw quality in cattle is an important trait for functional efficiency and productive herd life (Bonsma, 1980; Vollmar, 2016; Volkman & Kemper, 2018). Bonsmara SA (2019) uses an inspection system as part of breed classification and registration, which includes assessment of the claws and recording claw defects. Breeders may also regard colour as an important aspect that is associated with claw strength. In this study, three colour categories were identified. Bonsmara cattle breeders may prefer to select for darker claws. There is a perception that darker pigmented claws are stronger and less susceptible to claw lesions such as sole ulcers, dermatitis and heel erosion compared with lighter coloured claws (Hepburn *et al.*, 2007). A number of reports have suggested that darker claws in beef cattle are stronger (Dietz & Prietz, 1981; Petersen *et al.*, 1982; Chesterton *et al.*, 1989; Bosman & Scholtz, 2010). However, a recent study by Scobie *et al.* (2017) found no differences in the mechanical properties of white, grey and black hooves of sheep. The results of the present study do not indicate significant differences in the TS of claws that are attributable to colour.

Various tests have been used to assess the biomechanical behaviour and structural strength of claws. These include TS tests (Franck *et al.*, 2006), hardness tests with durometers (Hepburn *et al.*, 2007), bending tests (Baillie *et al.*, 2000), fracture toughness (Bertram & Gosline, 1986), and punch tests (Winkler & Margerison, 2012). In the present study, TS was defined as the applied force that is necessary for sample breakage divided by the measured surface area of the sample (Franck *et al.*, 2006). The mean TS of the

Bonsmara claw samples was 16.58 MPa, which is similar to the findings of Franck *et al.* (2006) on bovine claws. However, these authors tested only five samples and the sample details (age, sex, claw position) and types of bovine (dairy versus beef) were not reported. Similar tests of horse hooves resulted in measurements that were between 21.70 MPa and 35.32 MPa, depending on the season, year and feeding regime (Ley *et al.*, 1998). These measurements were generally greater compared with the values observed for Bonsmara claws. Within a species, differences between studies can be attributed to differences in sample preparation, size and testing time after collection, as well as differences in the methods (Douglas *et al.*, 1996; Baillie & Fiford, 1996).

Table 4 Analysis of variance¹ to determine factors that affect the tensile strength (megapascal) of Bonsmara claws

Independent variable ²	Model A: Front claws				Model B: Front and hind claws			
	df	MS	F	P-value	df	MS	F	P-value
Colour	2	1.31	0.14	NS	2	4.89	0.50	NS
Bioregion	2	124.53	13.14	<0.01	2	133.62	13.61	<0.01
Age-sex	3	15.56	1.64	NS	1	11.75	1.20	NS
Moisture content	1	130.65	13.78	<0.01	1	216.12	22.01	<0.01
PC1	1	3.59	0.38	NS	1	14.05	1.43	NS
Calcium	1	54.41	5.74	0.02	-	-	-	-
Phosphorus	1	5.22	0.55	NS	-	-	-	-
Copper	1	5.64	0.60	NS	-	-	-	-
Manganese	1	18.81	1.98	NS	-	-	-	-
Zinc	1	7.02	0.74	NS	-	-	-	-
Selenium	1	32.76	3.46	0.07	-	-	-	-
Front /hind claw	-	-	-	-	1	97.07	9.88	<0.01
Bioregion*front/ hind claw	-	-	-	-	2	19.61	2.00	NS

¹ df: degrees of freedom; MS: mean square; F: ratio of effect MS to residual MS; NS: (*P*-value > 0.05)

² Bioregion: Mesic Highveld Grassland, Central Bushveld and Eastern Kalahari Bushveld; Age-sex: males and females either less or more than 36 months of age; PC1: first principal component (lateral toe length (LL), medial toe length (ML) and circumference combined); claw from front or hind leg

Table 5 Least squares mean tensile strengths (mean ± SE, megapascal) of claws from Bonsmara cattle from three bioregions and from claws of the front versus hind legs

Classification ¹	n	Tensile strength (Mpa)	
		Front claw	Hind claw
Gm bioregion	29	14.71 ^a ± 0.614	14.28 ^a ± 0.572
SVk bioregion	30	18.83 ^b ± 0.617	17.62 ^b ± 0.737
SVcb bioregion	29	18.64 ^b ± 0.579	17.76 ^b ± 0.473
Front Leg			17.38 ^a ± 0.384
Hind Leg			15.78 ^b ± 0.370

¹ Gm: Mesic Highveld Grassland bioregion; SVk: Eastern Kalahari Bushveld bioregion; SVcb: Central Bushveld bioregion

The bioregion and production environment had a highly significant effect on the TS of the claws. The mean annual temperatures in SVcb and SVk vary between 18.4 °C and 17.8 °C, respectively (Mucina *et al.*, 2006), The Gm bioregion is cooler, with an average mean annual temperature of 14.7 °C (Mucina *et al.*,

2006). Colder temperatures cause the constriction of blood vessels (arterioles) and less blood and consequently less available oxygen and vital nutrients to the cells that are involved in the keratinization process of claw horn. This may explain why Bonsmara claws from the cooler Gm bioregion had less TS compared with those collected from the warmer bioregions of SVcb and SVk. Although not directly comparable with the cooler climatic regions in South Africa, Canadian studies have observed seasonal differences in claw quality attributable to temperature-associated changes in blood supply to the claws (Vermunt, 1990). Variations in the differentiation and keratinization of the keratinocytes of the claws were observed in 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 summer than in winter and that the hardness differed significantly between seasons.

In addition, the differences in the quality and quantity of grazing and supplementary feeding may contribute to the observed differences in claw TS. The Gm bioregion consists predominantly of Sourveld and mixed veld, while the SVcb and SVk bioregions consist primarily of mixed and Sweetveld (Smith, 2006). Further, soil mineralization is known to differ between these regions (Webb *et al.*, 2017). However, these factors were not directly assessed in this study.

The Bonsmara claws that were tested in the present study were classified as normal and without phenotypic defects at inspection. The differences in claw TS that are associated with specific bioregions could give an indication of problems that may develop later because softer claws are less resistant to external stressors (Borderas *et al.*, 2004). The variation in TS that is associated with bioregions could also be attributed to the physical walking surface to which animals are exposed, since it influences surface pressure distribution on the claws. Differences could also be a reflection of adaptation to the terrain and types of surface. Informal observations suggest that cattle raised in the Gm bioregion and moved to SvK, which has a sandier terrain, often tend to exhibit more claw problems, such as corkscrew, scissors claw and overgrown claws. Observations from the present study suggested that natural wear and tear of claws tended to be less in sandy regions.

The mean moisture content of the claws ranged from 18.20% to 26.82% with an average of 22.64% after 24 hours of drying at 105 °C. These values are marginally less than other observations of claw moisture content, which ranged from 22.9% to 32.5% (Pflug *et al.*, 1980) and from 27.46% to 29.05% (Winkler & Margerison, 2012). Immediate determination of claw moisture content of the Bonsmara claw samples that were analysed in the present study was not always possible and this delay may explain the lower moisture content, even though samples were sealed in plastic bags to retain moisture. Others found that the moisture content of claw samples differed depending on the storage method and length of storage (Winkler & Margerison, 2012), and the method of moisture determination (Reilly *et al.*, 2002).

Moisture content had a significantly negative association with TS ($P < 0.0001$) in the present study, indicating that claws with a higher claw moisture content had a lower claw horn TS. This is in agreement with other studies that used mechanical techniques other than TS testing to investigate the association between moisture content and biomechanical behaviour, hardness and structural strength of claw horn (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 was observed by Winkler and Margerison (2012) and a negative linear decrease in the puncture resistance. Softer claws, because of higher moisture content, are more susceptible to wear and damage, and may predispose cattle to lameness (Borderas *et al.*, 2004).

Minerals play an important role in determining the structural strength of claws owing to their involvement in specific biochemical pathways that are associated with keratin synthesis (Tomlinson *et al.*, 2004). Among the minerals examined in this study, only the Ca concentration showed an influence ($P < 0.05$) on claw TS. 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. Because Ca influences keratin cornification increased Ca was expected to be associated with stronger claws (Mulling *et al.*, 1999). Calcium also plays a role in keratin cornification through the activation of the enzyme epidermal transglutaminase. Baggot *et al.* (1988) found that higher Ca concentrations in the claws in dairy cows were associated with hardness. However, the usefulness of claw material as an accurate indicator of the mineral content of the claws remains uncertain (Greenough, 2007). Kincaid (1999) stated that tissues such as hair, wool and hooves as indicators of the mineral status of animals may not be as accurate as blood or liver samples, since these tissue samples are more easily contaminated, their reaction to feed intake is much slower, and reference standards are deficient. The positive relationship of Se with TS tended toward significance ($P < 0.10$). This was expected since Se plays a role in protecting the intercellular cement substance (ICS) from oxidative damage, thereby ensuring claw horn structure of good quality through the adequate binding of keratin proteins by the ICS (Tomlinson *et al.*, 2004; Andrieu, 2008). None of the other

minerals had a significant effect on the TS, including Zn, which has been shown to play an important role in determining the structural strength of claws (Mülling *et al.*, 1999). The results of the mineral content of the claws in the current study were based on a small sample size and further investigation is required.

The front claws usually carry a greater load than the hind claws and the distribution of body weight is more equal and stable on the front claws compared with the hind claws (Toussaint-Raven, 1989). Studies in dairy cattle indicate that front limbs are responsible for supporting between 54% and 60% of the total bodyweight (Pastell *et al.*, 2008; Van Nuffel *et al.*, 2015). In this study, the limb position of the claws had a significant effect on the claw TS. The front claws had a greater TS compared with the hind claws. Although significant, the difference in TS between the front and hind claws (17.38 MPa and 15.78 MPa, respectively) was numerically small. Chmielnik *et al.* (1983) also observed that front claws were harder compared with the hind claws in Polish Lowland Black and White cattle. The difference in strength observed between front and hind claws can be explained by the differences in body weight distribution. In the Bonsmara SA, emphasis has been placed on increased growth and muscling in the hindquarters, which results in greater weight bearing on the hind legs and claws. Future research in Bonsmara cattle should assess the limb movement in association with claw quality and health measurements.

Conclusion

This study represents the first attempt to study morphological and physiological characteristics of claws in South African beef cattle and it provides reference data for further investigations on claw quality in Bonsmara cattle. No significant differences in the tensile strength of claws could be attributed to differences in colour. Bioregion and moisture were responsible for significant differences in tensile strength.

Acknowledgements

The authors would like to thank the South African Bonsmara Breeders Society, and The National Research Foundation (THRIP grant: TP2010070500004) for the financial support for the project.

Authors' Contributions (Orcid ID)

EVMK (0000-002-6976) and ECW (0000-0001-5648-6319) conceptualized and designed the study, while SJP collected the data for the study. SJP did the laboratory work and statistical analysis as part of her MSc degree. SJP and EVMK drafted the manuscript, and EVMK and ECW provided critical reviews of the manuscript.

Conflict of interest

All authors declare that they have no actual or potential conflict of interest, including financial, personal and other relationships with other people and organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence the current work.

References

- Andrieu, S., 2008. Is there a role for organic trace element supplements in transition cow health? *Vet. J.* 176, 77-83.
- AOAC, 2000. Official methods of analysis. 17th edition. Volume I. Association of Official Analytical Chemists, Inc., Maryland, USA.
- Baggot, D.G., Bunch, K.J. & Gill, K.R., 1988. Variations in some inorganic components and physical properties of claw keratin associated with claw disease in the British Friesian cow. *Br. Vet. J.* 144, 534-542.
- Baillie, C. & Fford, R., 1996. The three-dimensional structure of cow hoof wall. *Biometrics* 4, 1-22.
- Baillie, C., Southam, C., Buxton, A. & Pavan, P., 2000. Structure and properties of bovine hoof horn. *Adv. Comp. Letters.* 9, 101-113.
- Bergh, L., Gerhard, R., Scholtz, M.M. & Mamabolo, M.J., 2010. Introduction to the information on beef and dual-purpose breeds in South Africa. In: M.M. Scholtz. *Beef breeding in South Africa*. 2nd edition. Agricultural Research Council (ARC), Pretoria. pp 179-181.
- Bertram, J.E.A. & Gosline, J.M., 1986. Fracture toughness design in horse hoof keratin. *J. Exp. Biol.* 125, 29-47.
- Bonser, R.H.C., Farrent, J.W. & Taylor, A.M., 2003. Assessing the frictional and abrasion-resisting properties of hooves and claws. *Bio. Eng.* 86, 253-256.
- Bonsma, J., 1980. *Livestock production – A global approach*. 1st ed. Tafelberg, Cape Town, South Africa. p. 201.
- Bonsmara SA, 2019. <https://bonsmara.co.za/wp-content/uploads/2019/03/Codes.pdf>.
- Borderas, T.F., Pawluczuk, B., De Passille, A.M. & Rushen, J., 2004. Claw hardness of dairy cows: Relationship to water content and claw lesions. *J. Dairy Sci.* 87, 2085-2093.
- Bosman, D.J. & Scholtz, M.M., 2010. Selecting cattle for functional efficiency. In: M.M. Scholtz. *Beef breeding in South Africa*. 2nd edition. Agricultural Research Council (ARC), Pretoria. pp 33-52.
- Brcsic, M., Ricci, R., Prevedello, P., Lonardi, C., De Nardi, R., Contiero, B., Gottardo, F. & Cozzi, G., 2015. Synthetic rubber surface as an alternative to concrete to improve welfare and performance of finishing beef cattle reared on fully slatted flooring. *Anim.* 9, 1386-1392.
- Chesterton, R.N., Pfeiffer, D.U., Morris, R.S. & Tanner, C.M., 1989. Environmental and behavioural factors affecting the prevalence of foot lameness. *NZ Vet. J.* 37, 135-142.

- Chmielnik, H., Jakubiec, J., Bukaluk, E. & Labiszak, R., 1983. An evaluation of the hardness of the claw of the Polish Low-Land Black and White and their cross breeds with the Holstein-Friesian cattle. Proc. 34th Annual Meeting of the Study Commission EAAP, Spain.
- Cozzi, G., Tessitore, E., Contiero, B., Ricci, R., Gottardo, F. & Brscic, M., 2013. Alternative solutions to the concrete fully-slatted floor for the housing of finishing beef cattle: Effects on growth performance, health of the locomotor system and behaviour. *The Vet. J.* 197, 211-215.
- Dietz, O. & Prietz, G., 1981. Quality and status of cattle hoof horn. *Monatsheft Veterinarmedizin* 36, 419-422.
- Distl, O., Koorn, D.S., McDaniel, B.T., Peterse, D., Politiek, R.D. & Reurink, A., 1990. Claw traits in cattle breeding programs: Report of the E.A.A.P Working Group Claw Quality in Cattle. *Livest. Prod. Sci.* 25, 1-13.
- Douglas, J.E., Mittal, C., Thomason, J.J. & Jofriet, J.C., 1996. The modulus of elasticity of equine hoof wall: implications for the mechanical function of the hoof. *J. Exp. Bio.* 199, 1829-1836
- Earley, B., McNamara, J.D., Jerrams, S.J. & O'Riordan, E.G., 2017. Effect of concrete slats, three mat types and out-wintering pads on performance and welfare of finishing beef steers. *Acta Vet. Scand.* 59, 34
- Egger-Danner, C., Cole, J.B., Pryce, J.E., Gengler, N., Heringstad, B., Bradley, A. & Stock, K.F., 2015. Invited review: Overview of new traits and phenotyping strategies in dairy cattle with a focus on functional traits. *Anim.* 9, 191-207.
- Franck, A., Cocquyt, G., Simoens, P. & De Belie, N., 2006. Biomechanical properties of bovine claw horn. *Biosystems Eng.* 93, 459-467.
- Greenough, P.R., 2007. Bovine laminitis and lameness: A hands-on approach. 1st edition. Saunders Elsevier, Philadelphia, USA. pp. 311.
- Hahn, M.V., McDaniel, B.T. & Wilk, J.C., 1984. Genetic and environmental variation of hoof characteristics of Holstein cattle. *J. Dairy Sci.* 67, 2986-2998.
- Haufe, H.C., Gygas, L., Wechsler, B., Stauffacher, M. & Friedli, K. 2012. Influence of floor surface access to pasture on claw health in dairy cows kept in cubicle housing systems. *Prev. Vet. Med.* 105, 85-92
- Hepburn, N.L., Kinninmonth, L. & Galbraith, H., 2007. Pigmentation, impression hardness and the presence of melanosomes in bovine claw tissue. *J. of Agric. Sci.* 145, 283-290.
- Heringstad, B., Egger-Danner, C., Charfeddine, N., Pryce, J.E., Stock, K.F., ..., Nielsen, P., 2018. Invited review: Genetics and claw health: Opportunities to enhance claw health by genetic selection. *J. Dairy Sci.* 101, 4801-4821.
- Kincaid, R.L., 1999. Assessment of trace mineral status of ruminants: A review. *Proc. Amer. Soc. Sci.* 1-10.
- Lean, I.J., Westwood, C.T., Golder, H.M. & Vermunt, J.J., 2013. Impact of nutrition on lameness and claw health in cattle. *Livest. Sci.* 156, 71-87.
- Ley, W.B., Pleasant, R.S. & Dunnington, E.A., 1998. Effects of season and diet on tensile strength and mineral content of the equine hoof wall. *Equine Vet. J. Suppl.* 26, 46-50.
- MacCallum, A.J., Knight, C.H., Hendry, K.A.K., Wilde, C.J., Logue, D.N. & Offer, J.E., 2002. Effects of time of year and reproductive state on the proliferation and keratinisation of bovine hoof cells. *Vet. Rec.* 151, 285-289.
- Mucina, L., Rutherford, M.C. & Powrie, L.W., 2006. Biomes and bioregions of southern Africa. In: *The vegetation of South Africa, Lesotho and Swaziland*. In: L. Mucina, L. & M.C. Rutherford, SANBI, Pretoria. pp 31-51.
- Mülling, C.K.W., Bragulla, H.H., Reese, S., Budras, K.D. & Steinberg, W., 1999. How structures in bovine hoof epidermis are influenced by nutritional factors. *Anat. Hist. Embryol.* 28, 103-108.
- Nocek, J.E., Johnson, A.B. & Socha, M.T., 2000. Digital characteristics in commercial dairy herds fed metal-specific amino acid complexes. *J. Dairy Sci.* 83, 1553-1572.
- Pastell, M., Hautala, M., Poikalainen, V., Praks, J., Veermaeb, I., Kujalac, M. & Ahokasa, J., 2008. Automatic observation of cow leg health using load sensors. *Computers and Electronics in Agriculture* 62, 48-53.
- Petersen, P.H., Nielsen, A.S., Buchwald, E. & Thysen, I., 1982. Genetic studies on hoof characters in dairy cows. *Z. Tierz. Zuchtungsbio.* 99, 286-291.
- Pflug, W., Osterhoff, D.R., Kräusslich, H., Osterkorn, K., 1980. The adaptability of Simmentaler cattle in South and South West Africa with special reference to their claws. *S. Afr. J. Anim. Sci.* 10, 91-97.
- Phillips, C.J.C., Patterson, S.J., AP Dewi, I. & Whitaker, C.J., 1996. Volume assessment of the bovine hoof. *Res. Vet. Sci.*, 61, 125-128.
- Politiek, R.D., Distl, O., Fjeldaas, T., Heeres, J., McDaniel, B.T., Nielsen, E., Peterse, D.J., Reurink, A. & Strandberg, P., 1986. Importance of claw quality in cattle: Review and recommendations to achieve genetic improvement. Report of the E.A.A.P Working Group on Claw Quality in Cattle. *Livest. Prod. Sci.* 15, 132-152.
- Reilly, J.D., Newlyn, H., Cope, B., Latham, R.J., Collin, S. & Hopegood, L., 2002. A comparison of different moisture-loss methods for measuring hoof wall moisture content. Proc. 12th International Symposium on Lameness in Ruminants. 9-13 January 2002, Orlando, FL, USA. p. 193.
- Scobie D.R., Makela, A.G., Van Koten, C. & D O'Connell, D., 2017. Mechanical properties of black, grey, and white hoof material of sheep. *Proceedings of the New Zealand Society of Animal Production* 2017. 77, 154-158
- Smith, B., 2006. Veld management. In: *The farming handbook*. University of Kwazulu-Natal Press, Scottsville, South Africa. pp 60-88.
- Solano, L., Barkema, H.W., Mason, S., Pajor, E.A., LeBlanc, S.J. & Orsel, K., 2016. Prevalence and distribution of foot lesions in dairy cattle in Alberta, Canada. *J. Dairy Sci.* 99, 6828-6841
- Tomlinson, D.J., Mulling, C.H. & Fakler, T.M., 2004. Invited Review: Formation of keratins in the bovine claw: Role of hormones, minerals and vitamins in functional claw integrity. *J. Dairy Sci.* 87, 797-809.
- Toussaint-Raven, E., 1989. Cattle foot care and claw trimming. 3rd impression. Farming Press Books, Ipswich, UK. pp127.

- Van Amstel, S. & Shearer, J., 2006. Manual for treatment and control of lameness in cattle. 3rd impression. Blackwell, Iowa, USA. pp212.
- Van der Tol, P.P.J., Metz, J.H.M., Noordhuizen-Stassen, E.N., Back, W., Braam, C.R. & Weijs, W.A., 2002. The pressure distribution under the bovine claw during square standing on a flat substrate. *J. Dairy. Sci.* 85, 1476-1481.
- Van Nuffel, A., Zwervaegher, I., Pluym, L., Van Weyenberg, S., Thorup, V.M., Pastell, M., Sonck, B. & Saeys, W., 2015. Lameness detection in dairy cows: Part 1. How to distinguish between non-lame and lame cows based on differences in locomotion or behavior. *Animals* 5, 838-860.
- Van Riet, M.M.J., Millet, S., Aluwé, M. & Janssens, G.P.J., 2013. Impact of nutrition on lameness and claw health in sows. *Livest. Prod. Sci.* 156, 24-35.
- Vermunt, J.J., 1990. Lesions and structural characteristics of claws of dairy heifers in two management systems. MSc thesis, University of Saskatchewan, Saskatoon.
- Volkman, N. & Kemper, N., 2018. Claw condition and claw health in dairy cows: How important is access to pasture? *The Veterinary Record*, London, 182, 76-78.
- Vollmar, K., 2016. Survey of prevalence of structural defects in feedlot receiving cattle in the United States, MSc dissertation. Colorado State University, Fort Collins, Colorado.
- Wang, L., Miller, S.P., Retallick, K.J. & Moser, D.W., 2017. Genetic parameter estimation for foot structure in American Angus cattle. *Journal for Animal Science* 95, Suppl. 4, 100.
- Webb, E.C., 2015. A critical review of the South African carcass classification systems, *S. Afr. J. Anim. Sci.* 45, 229-233.
- Webb, E.C. & Erasmus, L.J., 2013. The effect of production system and management practices on the quality of meat products from ruminant livestock, *S. Afr. J. Anim. Sci.* 43, 413-423.
- Webb, E.C., Visagie, P., Van der Westhuizen, J. & Snyman, H.A. 2017. The influence of the production environment and environmental factors on the growth, size and reproduction of Bonsmara cows, *S. Afr. J. Anim. Sci.* 47, 542-552.
- Winkler, B. & Margerison, J.K., 2012. Mechanical properties of the bovine claw horn during lactation. *J. Dairy Sci.* 95, 1714-1728.