

Comparison of shear force tenderness, drip and cooking loss, and ultimate muscle pH of the loin muscle among grass-fed steers of four major beef crosses slaughtered in Namibia

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(Received 8 May 2015; Accepted 30 August 2016; Published online 27 October 2016)

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Abstract

The authors investigated the effects of breed (Brahman, Bonsmara, Simbrah and Simmental crosses) and post-mortem ageing on meat tenderness, purge, cooking loss and ultimate pH of the *longissimus* muscle under commercial production and slaughter conditions of the Namibian beef export industry. Fifty steers of each breed cross, at an average age of 2½ years and with an average subcutaneous fat cover of 2 mm over the 9th–10th thoracic vertebrae, were included in this study. The Brahman (BRX) differed significantly ($P < 0.05$) from all other breed crosses in all ageing treatments, recording higher Warner-Bratzler shear force values. The Bonsmara (BNX) steers showed the highest rate of tenderization and maintained this advantage up to day 30 post mortem. Purge and cooking loss increased initially and then tapered off over ageing time. BNX steers recorded the highest cooking loss.

Keywords: beef, breeds, cooking loss, grass-fed, purge, tenderness

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Introduction

The eating quality of beef is best described as a combination of flavour, juiciness and tenderness (Shackelford *et al.*, 1995; Koohmaraie *et al.*, 2003; Verbeke *et al.*, 2010). However, various studies have found that inconsistent tenderness is the most important factor in determining consumer dissatisfaction (Brooks *et al.*, 2000; Koohmaraie *et al.*, 2003; Chambaz *et al.* 2003; Hanzelkoá *et al.*, 2011).

Free-range beef production in Namibia poses multiple challenges in terms of climate, parasites and predators, to name a few. For this reason, resilient breeds and breed crosses that are able to produce and reproduce under these conditions are used extensively. The four main breed crosses (Bonsmara, Brahman, Simbrah, and Simmental) that are slaughtered at Windhoek Export Abattoir of the Meat Corporation of Namibia (MEATCO) generally reflect these requirements. The Bonsmara, as a locally developed composite breed (composite *B. taurus africanus*), Brahman (*B. indicus*) and Simbrah (*B. indicus taurus composite*) breeds are well adapted to the sub-tropical conditions in Namibia. Although the Simmental breed (*B. taurus*) is considered less adapted in the tropics, it is the oldest farmed cattle breed in Namibia after the indigenous Sanga animals (*B. taurus africanus*). The first Simmental animals were introduced to Namibia in 1893 (Anonymous, 2009a) and have been adapted to local environmental challenges for more than a century.

Although meat tenderness and other meat quality characteristics depend on a number of inherent factors (e.g. breed, age, sex, muscle type, marbling) and environmental factors (e.g. nutrition, ante-mortem stress conditions, slaughter processes and chilling conditions, and ageing), research has shown that the production advantages of *B. indicus* and *B. indicus* x *B. taurus* composite breeds in harsher environments are partially negated by problems with beef tenderness and other quality characteristics (Strydom, 2008; Ferguson *et al.*, 2000; Jerez-Timaure & Huerta-Leidenz, 2009).

Namibia is a net exporter of beef, with South Africa, European Union, and Japan being its major markets (Bowles *et al.*, 2005), while Norway was recently added to the list. All these markets are discerning about the quality of the beef that they import. Because Namibia has a small feedlot industry, most of the export beef originates from older (2–3 years) animals that are finished on natural pastures, which may result

in tougher beef than that of younger feedlot finished animals. In addition, because of variations in the duration of shipping and cold storage for the various markets and particular client specifications, meat may be exposed to post-mortem ageing periods of five weeks or more. All these factors may affect the quality of the final product.

The aim of this investigation was to measure and compare the meat quality characteristics of the loin muscle of the four most prominent beef breeds farmed extensively on natural pasture for the Namibian export market. In addition, the study investigated the effect of extended post mortem ageing on tenderness and other quality parameters in order to overcome possible quality defects caused by breed and production system conditions.

Materials and Methods

Namibian carcass classification is similar to the South African classification system and is based mainly on differentiation of age, according to dentition, carcass fatness and conformation, determined subjectively (Anon 1999b). Table 1 presents a summary of the South African and Namibian beef classification system with regards to age and fatness. Fifty steers of each of the four major breed crosses slaughtered in Namibia, Bonsmara (BNX), Brahman (BRX), Simbrah (SBX), and Simmental (SX), were selected in the lairage of the export Windhoek MEATCO Abattoir. After slaughter only carcasses of age class B (2–2½ years old) (Lawrence *et al.*, 2001) with a fat code of 2 (1–4 mm subcutaneous fat) were included in this study.

Table 1 Summary of the age and fat classification codes used to classify Namibian beef

Age (p.i.) description	Age classification code	Fat description	Thickness of subcutaneous fat layer (mm)	Fat class code
0 p.i.	A	No fat	0	0
1–2 p.i.	AB	Very lean	<1	1
3–6 p.i.	B	Lean	1–4	2
7–8 p.i.	C	Lean	4.1–7	3
		Fat	7.1–9	4
		Over-fat	9.1–11	5
		Excessively over-fat	> 11	6

p.i.: permanent incisors

Animals originated from various production areas in Namibia as well as different producers. All animals in this study were raised on natural pasture.

The animals were killed according to the standard slaughter procedures of the export abattoir, that is, stunning by captive bolt, hoisting by the hind leg, dead weight determination, exsanguination, dressing, evisceration, carcass classification, hot weight determination and being placed in the cooler (4 °C). No electrical stimulation was applied.

After 48 hours the carcasses were removed from the coolers and deboned. A portion of the *longissimus* muscle (LD) was removed from the three-rib cut of the left side of identified carcasses, cut into six 15-mm thick steaks, which were then vacuum-packed individually. The weight of each steak was recorded as well as the pH at 48 hours post mortem (pH₄₈). The pH was determined with a hand-held pH meter (Testo-205, Scientific Laboratories Supplies, UK). Steaks were randomly allocated to various ageing treatments (2, 9, 16, 23, 30 and 37 days of ageing) packed in boxes and stored at 4 °C until they were evaluated.

These physical measurements were carried out on the individual steaks:

- Purge: Purge refers to weep/water accumulating in vacuum bag of packed meat over time. The individually packed steaks were removed from their bags after the relevant ageing period, gently dried between absorbent tissues, and weighed. Percentage purge was calculated as the weight loss expressed as a percentage of the original sample weight as demonstrated by Strydom & Hope-Jones (2014).
- Cooking loss: The steaks used to determine purge were weighed and then heated in sealed plastic bags in a water bath at 80 °C for 60 min. The cooked samples were cooled down under running water to room temperature (ca. 25 °C), dried and weighed again. Cooking loss was calculated as

total fluid lost and collected in the bag during cooking, expressed as percentage of the uncooked sample weight (adapted from Honikel, 1998).

- Warner Bratzler shear force (WBSF) (mechanical measurement of tenderness) was performed on the steaks that had been used to determine cooking loss. Five cylindrical samples (12.7-mm core diameter) were cored parallel to the grain of the meat, making sure that the whole steak area was covered. Each of the five cores were sheared perpendicular to the fibre direction using a Warner-Bratzler shear attachment (with a circular cross-section of 1.27 cm \varnothing blade) fitted to an electrical scale programmed to measure maximum weight/resistance. The reported value in kilograms represented the average of the peak force measurements of each of the five cores (Hoffman *et al.*, 2009). For further analysis, samples were categorized into three tenderness groups based on their WBSF values according to threshold levels reported by Shackelford *et al.* (1991), Voisinet *et al.* (1997), and Shackelford *et al.* (1999): 'tender' (< 3.9 kg), 'intermediate' (3.9–4.6 kg) and 'tough' (> 4.6 kg).

Statistical analysis was done with Proc GLM of SAS Enterprise Guide 3.0 (SAS, 2006). The data of purge loss, cooking loss, pH and Warner Bratzler shear force (WBSF) were subjected to analysis of variance (ANOVA), with post-mortem ageing (2, 9, 16, 23, 30 and 37 days) and breed (BNX, BRX, SBX, and SX) as the main effects. Means were separated with Bonferroni's multiple comparison method to determine least significant differences (LSD) at 5% level (Snedecor & Cochran, 1980).

Results

General statistics for the four measured quality traits are presented in Table 2. Least square means for these traits are summarized in Table 3 with superscripts identifying means, which differed significantly among breed crosses within and between individual days of ageing.

Table 2 General statistics showing the effects of post-mortem ageing and breed on purge, cooking loss, pH and Warner Bratzler shear force (WBSF) of the *longissimus* muscle

Trait	DF	Purge loss (%)	Cooking loss (%)	pH	WBSF
% Contribution to R ² of model					
R ² model (%)		24.36	7.65	20.99	19.03
Days post mortem	5	23.96***	2.64***	19.10***	13.73***
Breed cross	3	0.10	1.82***	0.49*	2.11***
Days post mortem*Breed cross	15	0.14	0.06	0.03	0.22*
Other statistics					
Mean		3.43	35.12	5.69	3.80
CV		60.92	5.35	8.98	26.89

The significance of the effect of each factor (breed cross, days aged and interaction) in the ANOVA are indicated together with contribution of the factor to R² as * $P < 0.05$, ** $P < 0.001$ and *** $P < 0.0001$; DF: degrees of freedom

Although breed cross had no influence on purge, it had a significant influence on pH and a highly significant influence on cooking loss and WBSF. Days post mortem had a highly significant influence on all four quality traits.

A significant interaction was recorded for WBSF ($P < 0.05$) between breed cross and days post mortem. As expected, WBSF values decreased over the ageing period, reaching equilibrium around 23 days (Figure 1). BRX recorded consistently higher WBSF values compared with the other three breed crosses for the duration of the ageing period. At two days, no differences were found between BNX, SBX and SX, but between 9 and 30 days, BNX recorded lower WBSF values than the other groups (Table 3). In addition, SBX recorded numerically lower WBSF values on day 2 post mortem compared with SX. This was reversed at 16 days' post mortem, indicating that the rate of post-mortem tenderization was higher in the SX.

Table 3 Least square means (\pm s.e.) for purge, cooking loss, pH and Warner-Bratzler shear-force (WBSF) values by breed at respective days of ageing

Days p.m.	Breed cross	N	Purge loss (%)	N	Cooking loss (%)	N	pH	N	WBSF (kg)
2	BNX	50	0.80 \pm 0.04	50	33.5 \pm 0.27 ^b	50	5.4 \pm 0.03 ^{bc}	50	4.5 \pm 0.085 ^{bw}
	BRX	52	0.85 \pm 0.04	52	35.3 \pm 0.27 ^a	52	5.5 \pm 0.03 ^{ab}	52	5.2 \pm 0.083 ^{aw}
	SBX	53	0.92 \pm 0.04	53	34.4 \pm 0.27 ^{ab}	53	5.3 \pm 0.03 ^c	53	4.5 \pm 0.082 ^{bw}
	SX	50	0.87 \pm 0.04	49	34.6 \pm 0.28 ^a	49	5.6 \pm 0.03 ^a	50	4.8 \pm 0.085 ^{bw}
	Mean	205	0.86 \pm 0.02	204	34.4 \pm 0.14	204	5.4 \pm 0.02	205	4.8 \pm 0.043
9	BNX	50	2.9 \pm 0.10	49	34.5 \pm 0.26 ^b	50	5.5 \pm 0.02 ^b	50	3.6 \pm 0.076 ^{cx}
	BRX	51	2.9 \pm 0.10	52	35.6 \pm 0.26 ^a	52	5.6 \pm 0.02 ^b	52	4.5 \pm 0.074 ^{ax}
	SBX	53	2.7 \pm 0.10	52	34.9 \pm 0.26 ^{ab}	53	5.3 \pm 0.02 ^c	53	4.0 \pm 0.074 ^{bx}
	SX	41	2.8 \pm 0.11	42	34.6 \pm 0.28 ^{ab}	42	5.6 \pm 0.03 ^a	42	3.9 \pm 0.083 ^{bx}
	Mean	195	2.8 \pm 0.05	195	34.8 \pm 0.17	197	5.56 \pm 0.01	197	4.0 \pm 0.040
16	BNX	50	3.7 \pm 0.14	50	34.9 \pm 0.26 ^b	50	5.449 \pm 0.03 ^b	50	3.4 \pm 0.073 ^{cx}
	BRX	50	3.6 \pm 0.14	52	36.0 \pm 0.25 ^a	52	5.5 \pm 0.03 ^a	52	4.2 \pm 0.072 ^{ay}
	SBX	52	3.4 \pm 0.13	53	34.9 \pm 0.25 ^b	53	5.4 \pm 0.03 ^b	53	3.8 \pm 0.071 ^{bx}
	SX	49	3.7 \pm 0.14	50	35.4 \pm 0.26 ^{ab}	50	5.5 \pm 0.03 ^a	50	3.65 \pm 0.073 ^{bcy}
	Mean	201	3.6 \pm 0.07	205	35.3 \pm 0.13	205	5.5 \pm 0.01	205	3.7 \pm 0.038
23	BNX	49	3.6 \pm 0.13	50	35.1 \pm 0.28	50	5.4 \pm 0.03 ^b	50	3.1 \pm 0.062 ^{cy}
	BRX	50	3.9 \pm 0.13	52	35.6 \pm 0.27	52	5.5 \pm 0.03 ^{ab}	52	3.9 \pm 0.061 ^{ayz}
	SBX	53	3.9 \pm 0.13	53	34.8 \pm 0.27	53	5.4 \pm 0.03 ^b	52	3.5 \pm 0.061 ^{byz}
	SX	49	4.0 \pm 0.13	50	35.1 \pm 0.28	50	5.6 \pm 0.03 ^a	50	3.4 \pm 0.062 ^{by}
	Mean	201	3.9 \pm 0.08	205	35.2 \pm 0.14	205	5.4 \pm 0.02	204	3.5 \pm 0.032
30	BNX	50	4.2 \pm 0.14	48	34.8 \pm 0.29 ^b	50	5.5 \pm 0.03 ^b	50	3.2 \pm 0.061 ^{cy}
	BRX	52	4.1 \pm 0.14	52	36.1 \pm 0.27 ^a	52	5.5 \pm 0.03 ^{ab}	52	3.7 \pm 0.060 ^{az}
	SBX	52	4.1 \pm 0.14	52	35.6 \pm 0.27 ^{ab}	50	5.3 \pm 0.03 ^c	52	3.4 \pm 0.060 ^{bz}
	SX	49	4.4 \pm 0.15	49	35.3 \pm 0.28 ^{ab}	49	5.6 \pm 0.03 ^a	49	3.3 \pm 0.062 ^{bcy}
	Mean	203	4.2 \pm 0.07	201	35.5 \pm 0.14	201	5.5 \pm 0.02	203	3.4 \pm 0.031
37	BNX	50	4.4 \pm 0.15	49	34.8 \pm 0.24 ^b	50	5.5 \pm 0.03 ^b	50	3.3 \pm 0.064 ^{by}
	BRX	50	4.9 \pm 0.15	51	36.1 \pm 0.24 ^a	51	5.6 \pm 0.03 ^{ab}	51	3.8 \pm 0.063 ^{az}
	SBX	52	4.6 \pm 0.15	53	35.3 \pm 0.23 ^{ab}	52	5.5 \pm 0.03 ^b	53	3.4 \pm 0.062 ^{bz}
	SX	50	5.0 \pm 0.15	50	35.4 \pm 0.24 ^{ab}	50	5.7 \pm 0.03 ^a	50	3.3 \pm 0.064 ^{by}
	Mean	202	4.7 \pm 0.08	203	35.4 \pm 0.12	203	5.6 \pm 0.02	204	3.4 \pm 0.032

^{a,b,c} Column means for breed crosses within different days of ageing with different superscripts differ ($P < 0.05$)

^{w,x,y,z} Column means for breed crosses between different days of ageing with different superscripts differ ($P < 0.05$)

Where: BNX = Bonsmara, BRX = Brahman, SBX = Simbrah and SX = Simmental

The amount of purge increased significantly in a curvilinear way over ageing time (Table 3), with most of the losses occurring between 2 and 9 days. A similar trend was observed for cooking loss, although the effect was less pronounced and no differences occurred between 16 and 36 days. However, in contrast to purge, there were consistent breed differences for cooking loss throughout the ageing period, although the magnitude of the differences were small. BNX recorded lower cooking losses ($P < 0.05$) than BRX throughout the ageing period, except on day 23, while the other two breeds showed values intermediate to BRX and BNX. BRX recorded higher pH_u values (i.e. after rigor mortis) compared with the other three breeds at two days' post mortem. This difference was maintained throughout the ageing period. pH values initially declined slightly and increased again between 30 and 37 days' post mortem.

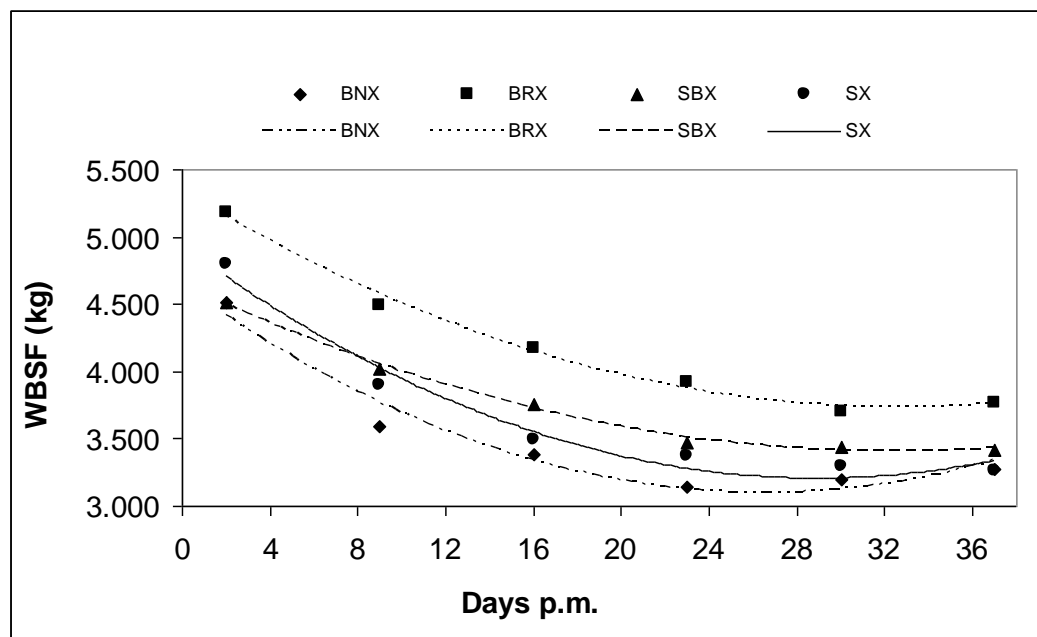


Figure 1 Changes in Warner-Bratzler shear-force (WBSF) of the *longissimus* muscle of four breed crosses over an ageing period of 37 days' post mortem
Where: p.m = post mortem, BNX = Bonsmara, BRX = Brahman, SBX = Simbrah and SX = Simmental

The data depicted in Figure 1 were fitted with polynomial models. The resulting equations (Table 4) were used to calculate the days post mortem to reach 'intermediate' (4.6 kg) and 'tender' (3.9 kg) WBSF values on average. BNX and SBX reached 'intermediate' WBSF values before day 2, while SX reached these values around 3 days' post mortem and the BRX around 9 days. It took the BNX, BRX, SBX and SX 7, 22, 12 and 11 days of ageing, respectively, to reach 'tender' WBSF values.

The changes in tenderness class within breed crosses over the ageing period of 37 days are shown in Figure 2a and b. The most noticeable change took place between days 2 and 9 post mortem with the percentage of animals moving from 'tough' (> 4.6 kg) to 'intermediate' (3.9–4.6 kg) and 'tender' (< 3.9 kg). Furthermore, the rate of tenderizing of the BNX group was much higher compared with the other breed crosses. Tenderness improved up to 30 days' post mortem and then stabilised.

Table 4 Polynomial equations fitted to Warner-Bratzler shear-force (WBSF) values, describing the improvement of tenderness (y) over ageing time (x; days)

Breed cross	Polynomial equation	R ²	Days until WBSF 4.6 kg	Days until WBSF 3.9 kg
BNX	$y = 0.0022x^2 - 0.1161x + 4.6379$	0.9579	-	7.38
BRX	$y = 0.0015x^2 - 0.0984x + 5.3384$	0.9921	8.51	21.89
SBX	$y = 0.0012x^2 - 0.0764x + 4.6465$	0.9947	-	11.91
SX	$y = 0.0021x^2 - 0.1192x + 4.9378$	0.9704	2.90	10.73

Where: BNX = Bonsmara, BRX = Brahman, SBX = Simbrah and SX = Simmental

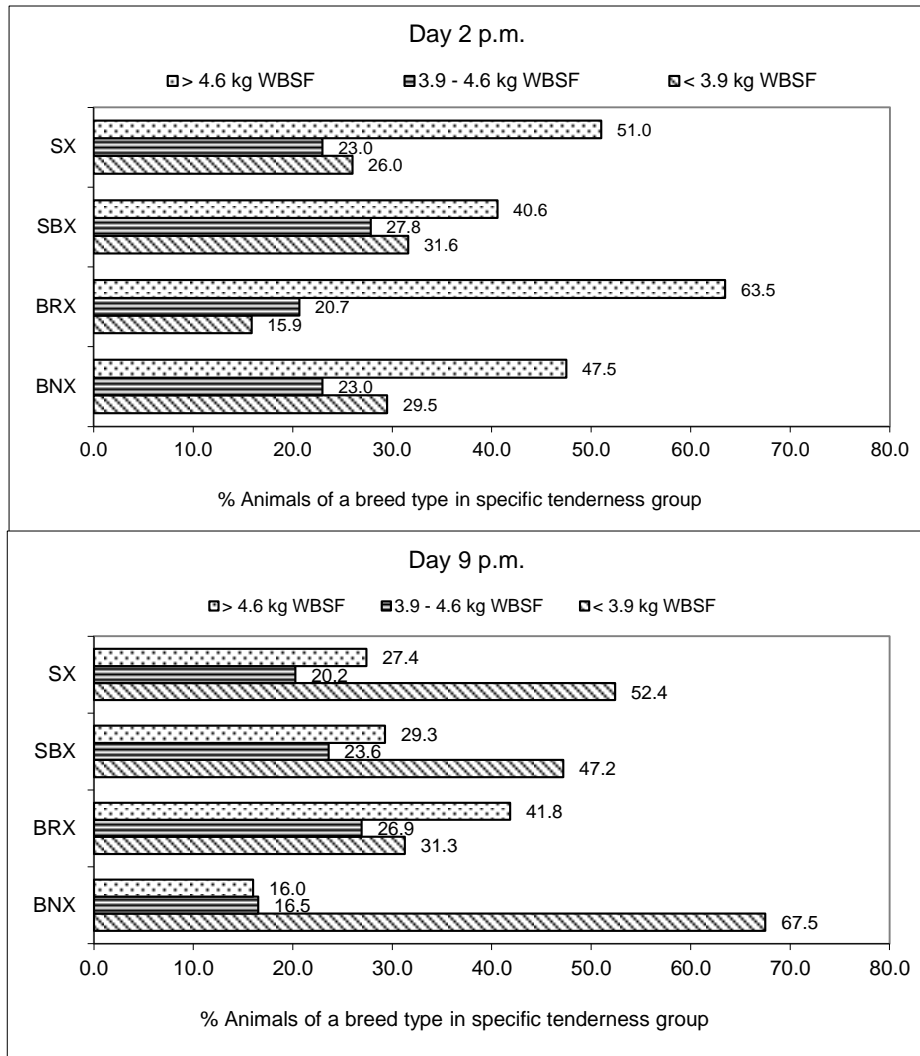


Figure 2a Change in tenderness class for four breed crosses for days 2 and 9 post mortem
 Where: WBSF = Warner-Bratzler shear-force, p.m = post mortem, BNX = Bonsmara, BRX = Brahman, SBX = Simbrah, and SX = Simmental

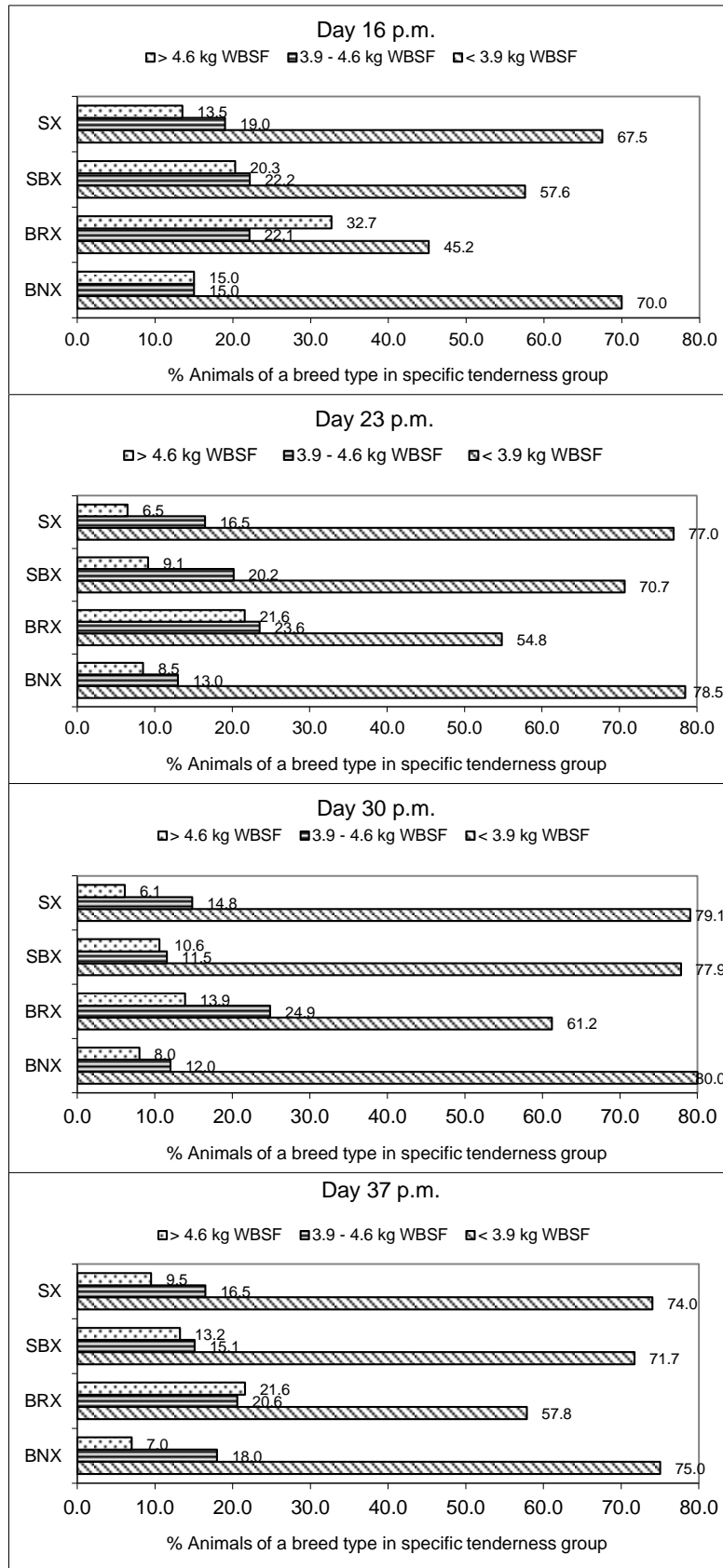


Figure 2b Change in tenderness class for four breed crosses for days 16, 23, 30 and 37 post mortem
 Where: WBSF = Warner-Bratzler shear-force, p.m = post mortem, BNX = Bonsmara, BRX = Brahman, SBX = Simbrah,
 and SX = Simmental

Discussion

Juiciness is one of the three sensory attributes that determine overall eating satisfaction of meat (Shackelford *et al.*, 1995; Aaslyng *et al.*, 2003), the others being tenderness and flavour. The amount of water captured and retained in meat before and after cooking influences its juiciness and therefore palatability, as well as the saleable weight of the product. Water is lost from the meat in the form of purge during storage and in thawing of frozen meat, and during cooking through evaporation and drip loss (stock) (Den Hertog-Meischke *et al.*, 1998; Aaslyng *et al.*, 2003). Water exists in muscle in three forms, namely water bound to proteins (this fraction is small, is not affected by freezing and is not lost during conventional cooking); entrapped water (held by steric effects and/or by attraction to bound water), and free water (Huff-Lonergan & Lonergan, 2005). The fraction that is most affected by the conversion of muscle to meat or rigor is the entrapped water. During the rigor process, muscle pH decreases, mainly because of the anaerobic conversion of glycogen to lactic acid. The pH ultimately reaches the iso-electric point of the main muscle proteins (myosin: pH = 5.4), reducing the net charge of these proteins to zero. This means that the attraction of water is reduced, and the repulsion of structures within myofibrils is diminished, allowing the components to move nearer to one another (lateral shrinkage) (Huff-Lonergan & Lonergan, 2005; Pearce *et al.*, 2011). This effectively reduces the space available for water, and the water manifests as drip or purge (purge loss describes the water that is visible in vacuum-packed meat). Low pH leads to partial denaturation of the myosin head, which could contribute to shrinkage of the lateral space. These changes take place soon after death, leading to relatively high levels of purge over the first days post mortem.

There were differences in pH_u (pH after rigor mortis was reached) among the breed groups, with pH_u of SX being 0.3 units (day 2) above the iso-electric point of meat proteins. That of SBX is closest to the isoelectronic point. However, since the values were in the range for normal meat (pH 5.4 to 5.7) (Renner, 1990), there was probably little effect on water-holding capacity and therefore on purge, which agrees with the results of Muchenje, *et al.* (2008) and Du Plessis & Hoffman (2007) for pasture-raised animals. Contradictory results were reported by Jama *et al.* (2008), who found a decrease in drip loss over an ageing time of 21 days. Despite significant breed cross effects being recorded for cooking loss over the duration of ageing, the actual differences were at the most 1.5 percentage units. BRX cuts showed the highest cooking losses for the duration of the ageing period. According to Huff-Lonergan & Lonergan (2005), impaired post-mortem ageing contributes to lateral shrinkage of the muscle cells and creates drip channels, in which more moisture flows into extracellular space and increases moisture losses. Because the BRX group recorded the toughest meat throughout the ageing period, it is plausible that this led to increased moisture losses during cooking, although it is surprising that this effect did not increase the amount of purge as well. Increased purge and cooking loss over time of ageing were expected (Table 3). Kristensen & Purslow (2001) and Straadt *et al.* (2007) noted that there is initially a continuous release of water from meat over time during ageing and this may stabilise, as in our study. Since cytoskeletal protein forms 10% of muscle protein (Labeit & Kolmerer, 1995), water is released continuously as the meat ages as a result of cytoskeletal structure degradation.

Connective tissue content, sarcomere length and myofibrillar breakdown are the primary sources of meat tenderness variation. Connective tissue components are believed to be responsible for the variation observed in background toughness, in particular the organization of the perimysium (Strandine *et al.*, 1949; Koohmaraie & Geesink, 2006). Background toughness was defined by Marsh & Leet (1966) as 'the resistance to shearing of the muscle before shortening occurred' and is a factor that exists at slaughter and does not change during ageing (Koohmaraie & Geesink, 2006). These effects are more prominent in high connective tissue cuts, and probably less so in the *longissimus* muscle (Rhee *et al.*, 2004)

The toughening phase starts with rigor mortis development and is caused by sarcomere shortening (Koohmaraie *et al.*, 1996; Hanzelková *et al.*, 2011). This phase is similar in carcasses handled under similar processing conditions (Luciano *et al.*, 2007), as in the current study. The tenderizing phase starts directly after slaughter and may vary greatly in rate and extent among breeds, in particular where *B. indicus* is involved. This variation causes the inconsistency in tenderness observed at consumer level (Koohmaraie & Geesink, 2006). Proteolysis of key myofibrillar and myofibrillar-associated proteins forms the basis of the tenderizing phase (Koohmaraie & Geesink, 2006; Muchenje *et al.*, 2009). The primary proteolytic enzyme system involved in post mortem tenderization of aged beef is the calpain system, which consists of two calcium requiring enzymes, μ -calpain and *m*-calpain, as well as an inhibitor, calpastatin (Koohmaraie, 1996; Ibrahim *et al.*, 2008). Other factors such as temperature, pH and calcium ion concentration can influence this process (Takahashi, 1996).

The difference in tenderness between *B. indicus* and *B. taurus* is well documented. It appears that it is mainly the result of calpastatin activity in post-mortem muscle. The lower tenderness observed in the BRX (Figure 1; Table.2) is in accordance with the findings of Crouse *et al.* (1989), Whipple *et al.* (1990), Johnson

et al. (1990a,b), O'Connor *et al.* (1997), Pringle *et al.*, 1997), Voisinet *et al.* (1997), Ferguson *et al.* (2000) and Ibrahim *et al.* (2008). O'Connor *et al.* (1997) and Pringle *et al.* (1997) measured calpastatin activity and concluded that the increased calpastatin activity found in *B. indicus* breeds would be the major reason for the higher WBSF of BRX group at three days and the lower extent of ageing over the subsequent 34 days (Figure 1). Similar effects between breed x ageing time were reported by Johnson *et al.* (1990b). Since the animals in this study were of commercial origin, the percentage of *indicus* blood was not known and identification of crosses was based on phenotypes. O'Connor *et al.* (1997) and Ibrahim *et al.* (2008) found that biological type interacted with ageing and reported that as the percentage Brahman inheritance increased, the rate and extent of tenderization decreased. Johnson *et al.* (1990b) showed that differences in tenderness became significant only when the percentage Brahman breeding reached fifty per cent, while Stolarski *et al.* (2006) found that calpastatin levels were highest in the *longissimus* muscle in animals with 50% *B. indicus* breeding. As well as from the significant effect of *indicus* influence on WBSF of BRX group, SBX cuts were less tender than BNX at each stage of ageing, except for the final WBSF on day 37. The magnitude of the differences however, was less than between BNX and BRX. Of further interest is the higher WBSF of SX animals compared with BNX at 2, 9 and 23 days (Table 3). SX and BNX did not differ at any stage during ageing. In agreement with these trends, Frylinck & Heinze (2003) reported higher WBSF values for pure Brahman and Simmental compared with Hereford, Afrikaner, Bonsmara and Nguni animals. These differences were supported by higher calpastatin levels in Brahman cuts compared with the other more tender breeds, but higher WBSF was not reflected in the calpastatin levels of the Simmental cuts.

The Bonsmara breed is made up of 5/8 Afrikaner and 3/8 Hereford and Shorthorn. It might be because of its *B. taurus* inheritance that this breed cross showed the lowest shear values throughout the trial period. Strydom *et al.* (2000) reported favourable tenderness results for *B. taurus africanus* breeds, such as the Afrikaner, and therefore the influence of this breed contributed to the tenderness results of the BNX group. Most comparisons of tenderness between *B. indicus* and *B. taurus* breeds named here were done on grain-fed younger cattle, while the current study showed similar trends for older grass-fed animals. Du Plessis & Hoffman (2007) reported numerically higher WBSF values for loin cuts of grass-fed Simmental crosses of between 0.6 and 0.9 kg compared with Nguni and Bonsmara crosses.

The display of WBSF distribution in the three tenderness categories in Figures 2a and b confirms that the BNX produced the best quality meat of all the breed crosses investigated. Although the SX and SBX groups lagged behind the BNX in terms of number of samples in the 'tender' class during the initial stages of ageing, the differences were diluted as ageing progressed. However, considering the cost involved in storage of meat, using the BNX group means that meat develops an acceptable level of tenderness earlier than meat from SBX and SX breed crosses and much earlier than meat from BRX. SBX will probably lag behind SX in this regard, while both groups will take fewer ageing days to produce acceptable levels of tenderness than the BRX group. Even after 37 days, between 7% and 22% (i.e. 4 to 11) of the 50 or so samples within a group still measured more than 4.6 kg WBSF.

Conclusion

Clear breed differences were found for cooking loss and tenderness among the four main breed crosses slaughtered in Namibia. Tenderness differences between breeds are in accordance with previous research, performed mostly under grain-fed systems. Ageing clearly improved tenderness in all breeds. Under the conditions of this study, it seems that BNX animals produce loin muscle cuts that age faster and therefore reach acceptable levels of tenderness sooner than the other breeds, while the loins of BRX animals take the longest.

Acknowledgments

The help of the staff from the abattoir in Windhoek is appreciated. This work is based on research supported by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation of South Africa (Grant: 84633). Opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and the National Research Foundation does not accept liability.

Authors' Contributions

Conception and design - LCH; Data collection, analyses and drafting of paper - JL; Critical revision – PS & CK; critical revision and final approval of version to be published – LCH.

Conflict of Interest Declaration

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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