A review of factors affecting goat meat quality and mitigating strategies

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Highlights

- Breed and age at slaughter are the main biological factors for goat meat quality.
- Pre-slaughter conditioning can improve carcass and meat quality of goats.
- Minimising *ante-mortem* stress is important for goat meat quality.
- Appropriate slaughter conditions should be applied for enhanced goat meat quality.
- Ageing for 4–6 days may further improve goat meat tenderness.

Abstract

Goat meat is increasing in popularity worldwide due to a growing demand for lean and nutritious meat. It is important to have an understanding of factors affecting goat meat quality in order to ensure the best possible quality acceptable to consumers. This paper reviews current knowledge on key factors and strategies for improving goat meat quality. Among animal factors, the breed/genetics and age at slaughter are key to goat meat quality. Conditioning of goats destined for slaughter can improve the quality of meat through more desirable carcass fat content. It has been established that goat carcasses have low glycolytic potential and

consequently yield higher pH meat, therefore, minimising ante-mortem stress is important for goat meat quality. Goat carcasses are very small and lean, therefore, chilling conditions should be carefully monitored in order to minimise the risk of cold shortening. Electrical stimulation of carcasses has been reported to improve goat meat tenderness. Pelvic suspension of goat carcasses may result in improved meat tenderness compared to Achilles-hung carcasses. Post-slaughter ageing can further improve the tenderness of goat meat. Several efforts have been made to address the concerns pertaining to goat meat quality, but the challenge now is to promote the consumption of goat meat among diverse consumers and establish it as a dietetically acceptable red meat source.

Keywords: Ageing; Goat meat quality; Slaughter conditions; Stress

1. Introduction

Goats are widely distributed across the world with an estimated total of one billion heads (FAO, 2017). About 98 % of goat population and 76 % of goat breeds are in developing countries (Devendra, 2010). In many parts of the world, meat is the common product and the consumption of goat meat is increasing worldwide. Goat meat is marketed as either capretto or chevon depending on local custom and preference. Capretto is obtained from goat kids with carcass weight of 6−8 kg and it is popular in France, Latin America and the Mediterranean region (Webb, 2014). In these areas, the demand for capretto is high during Christmas and Easter holiday periods. Chevon is obtained from older goats with carcass weight of 16−22 kg and is particularly preferred in most parts of Africa and India.

Meat quality is a critical issue as it determines the acceptability and continued interest in the product by consumers. Meat quality is usually defined in terms of eating quality or processing quality, depending on usage (Webb et al., 2005). Nonetheless, the consumer's

perception of meat quality is also important. Consumers generally expect meat to be nutritious, wholesome, fresh, lean, tender, juicy and flavoursome (Hoffman and Wiklund, 2006).

Increased health consciousness of consumers has led to a demand for alternative healthy meat types, with many people opting for low fat products. Goat meat could play a major role as an alternative red meat source because of its salubrious fatty acid profile in comparison to beef and lamb (Webb and O'Neill, 2008). However, there are some quality concerns that negatively affect the acceptability of chevon by consumers. For instance, goat meat is often perceived by consumers as tough, stringy and strongly flavoured (Webb et al., 2005). Sensory studies with a trained panel have also shown that there is a preference for lamb/mutton to goat meat, in terms of tenderness, juiciness and flavour (Schönfeldt et al., 1993a, 1993b). It is therefore necessary to develop guidelines for quality chevon production, in order to promote the consumption of goat meat, particularly in cultures that prefer lamb/mutton.

Research has established that the quality concerns of chevon are largely due to the use of unsuitable animals, inadequate nutrition and inappropriate pre-, peri- and post-slaughter handling procedures. For instance, the chevon market is usually dominated by older cull goats and meat from such older goats should be processed into value added products rather than sold as fresh meat as it is tough (Webb et al., 2005). In addition, goats are known to be highly susceptible to ante-mortem stress, possibly due to their excitable nature (Casey and Webb, 2010). It is known that stress limits the acidification of meat during the transformation of muscle to meat, resulting higher pH meat. Higher pH meat is undesirable as it is darker in colour and has a low degree of tenderisation even after ageing (Simela et al., 2004). Thus, the susceptibility of goats to ante-mortem stress also contributes to the unappealing dark colour and increased toughness, the common misconceptions regarding the quality chevon. Another known fact is that goat carcasses are very small and lean, and these characteristics increase the risk of cold shortening resulting in very tough meat (Kannan et al., 2014).

It is important to have a better understanding of how production, pre-, peri- and post slaughter factors affect chevon quality. This paper highlights critical factors that affect chevon quality, from farm to chilled carcasses and how these factors can be managed for enhanced quality.

2. Biological factors affecting chevon quality

2.1 Breed/genetics

Breed/genotype is a key factor of carcass quality, which is important for meat quality. Breed/genetic effects on carcass quality and subsequent meat quality are mostly linked to the amount and location of fat deposition. An example of this genetic influence is reflected by the results of Dhanda et al. (2003) in their study of six goat genotypes. These authors showed that the Boer × Feral genotype had greater subcutaneous fat (2.6 mm *vs.* 1.6 mm) and their muscles showed significantly lower shear force values (36.3 N *vs.* 45.1 N), implying more tender meat than the Saanen × Feral genotype. These genetic differences were also distinguished by some sensory tests, where the Boer × Feral genotype had higher sensory scores for juiciness (6.6 *vs.* 5.7) and overall acceptability (6.4 *vs*. 5.9) than the Saanen × Feral genotype. The results of Dhanda et al. (2003) agree with the notion that meat breeds such as the Boer goat and its crosses tend to deposit more subcutaneous and intermuscular fat, hence, they have better eating quality than other breeds (Ding et al., 2010).

Another known fact is that breeds/genotypes vary in their stress responsiveness, which may affect meat quality. For instance, Kadim et al. (2004) studied meat quality of three Omani goat breeds, namely the Batina, Dhofari and Jabal Khaddar goat breeds. A characteristic of the Batina goat breed was its significantly higher pH than other breeds, in all studied muscle types (*longissimus dorsi*, *biceps femoris*, *semitendinosus* and *semimembranosus*). In a later study, Kadim et al. (2006) reported that the Batina goat breed had higher stress hormone

concentrations (cortisol, dopamine, adrenaline and nor-adrenaline), which gives a clear indication of its greater susceptible to stress than the Dhofari and Jabal Khaddar breeds. Stress affects the acidification of meat, resulting in higher pH meat that is associated with lower lightness values (darker meat), higher shear force values and higher water holding capacity (Kadim et al., 2014). It has been described that goats are generally susceptible to stress due to their nervous/excitable nature (Casey and Webb, 2010), so establishing a handling system that minimises stress is important for goat meat quality.

The Boer goat has received considerable attention worldwide for its superior meat production traits, and it has been used in many crossbreeding programs to improve the local breeds. However, research on crossbreeding of goats has largely been unsuccessful because of environmental stress and under-nutrition (Simela and Merkel, 2008). Research conducted in South Africa highlighted the importance of promoting the unimproved local goat breeds for chevon production. For example, Pophiwa et al. (2017) evaluated meat quality of Boer and non-descript indigenous goats of South Africa. These authors found that key objective meat quality characteristics such as ultimate pH, water holding capacity, cooking losses, shear force values, colour and myoglobin redox forms were not significantly different between the two goat breeds, in both the *longissimus dorsi* and s*emimembranosus* muscles. In earlier work, Simela et al. (2008) showed that indigenous South African goats, slaughtered at about two years or younger can yield chevon of acceptable quality. The studies of Simela et al. (2008) and Pophiwa et al. (2017) show that unimproved indigenous goats of South Africa have a potential to yield chevon of acceptable quality provided that the animals of an appropriate age are slaughtered, and they are handled and fed well during the production and slaughter phases. These results are important for the unimproved South African indigenous goats which have an anecdotal reputation of being inferior to Boer goats. In this regard, there should be incentives

to reward producers of indigenous goat breeds in order to promote their utilisation and conservation.

The choice of breed is critical for chevon quality, although it may be less important than other factors. It is imperative for producers to choose a breed with characteristics of a meat producing animal, well adapted to the environment and resistant to endemic diseases, among other characteristics (Casey and Webb, 2010).

2.2 Age at slaughter

Age at slaughter is important in the meat industry as it is one of the criteria used in many carcass classification/grading systems (Strydom, 2011). In the current South African carcass classification system, the overall class designation is based on age and level of fatness although criteria such as sex, conformation and bruising are also considered (Soji and Muchenje, 2016). Carcasses of animals in the A-age class (no permanent incisors) with a fat score of 2 or 3 (1−5 mm subcutaneous fat thickness) have a better market value as they are presumed to be tender (Brand et al., 2018).

The effect of age as a factor of goat meat quality is not well documented. However, Simela et al. (2004) found that *semimembranosus* muscle of 2-teeth goats had lower shear force values (59.9 N *vs.* 77.4 N) than that of 8-teeth goats, in their study with unimproved indigenous goats of South Africa. Pratiwi et al. (2007) showed negative correlations between slaughter weight and sensory scores such as flavour (−0.59), tenderness (−0.84), juiciness (−0.82) and overall acceptability (−0.82) of cooked *longissimus thoracis* muscle, in their study with Feral goats slaughtered at 5, 10, 20, 30, 40, 50, 60 and 70 kg. These researchers recommended 40 kg as the heaviest slaughter weight before deterioration of meat quality. Saccà et al. (2019) studied meat quality traits and expression of tenderness related genes in *longissimus lumborum* of young goats. These authors found that meat of suckling goats (5 weeks of age) was more tender

than that of post-puberal goats (34 weeks of age), while meat from goats slaughtered at 17 weeks had intermediate shear force values. These authors concluded that variation in meat tenderness between suckling kids and post-puberal goats was due to different expression of heat shock proteins and the expression of these genes can change with age. According Lomiwes et al. (2014) heat shock proteins modulate aptosis in muscle and ultimately influence meat quality.

The aforementioned studies confirm the fact that meat from older goats tend to be less valued by consumers due to increased toughness. This could explain the negative perception of goat meat marketed in South Africa, which is mainly from older goats. As previously mentioned, meat from older goats is more suitable for processing into value added products rather than being sold as fresh meat (Webb et al., 2005). Several authors have shown that meat from older goats can be successfully processed into products acceptable by consumers (Guerra et al., 2011; Leite et al., 2015; Paulos et al., 2015).

The issue of age as an indicator of goat meat tenderness is debatable as observed in the study Borgogno et al. (2015) who found that meat from kids slaughtered at 3–4 months was more tender and had less cooking losses than meat from both milk fed kids (1–1.5 months old) and older kids (4–6 months old). Simela et al. (2008) compared the consumer acceptability of meat from goat kids (milk teeth) and old does (fully erupted permanent teeth). A consumer panel in that study found no significant differences in sensory quality (aroma, tenderness, flavour and overall acceptability) of goats' *longissimus dorsi* muscle, between the two dentition groups. In an earlier study, the 2-teeth group had better shear force values than both the milk teeth and 8-teeth groups (Simela et al., 2004). Smith et al. (1978) reported that yearling Spanish and Angora goats yielded more tender, juicier and flavourful meat to that of 3 to 5-month old kids. It was concluded that the increased toughness of meat from goat kids was related to the effects of chilling on small and very lean carcasses.

The above-mentioned results show that there is a lower preference for meat from very young goats, which can be linked to their carcass quality. Goats deposit fat in preferential order and carcass fat only reaches appreciable levels when goats are near or at their mature body weight (Webb et al., 2005). Hence the risk of cold shortening during carcass chilling and consequently tough meat, is higher in very young or small goats compared to older goats with better subcutaneous fat cover. In addition, very young goats have lower intramuscular fat, a characteristic associated with sensory attributes such as juiciness and flavour (Schönfeldt et al., 1993a, 1993b).

Another important aspect is that goat kids are very susceptible to pre-slaughter stress, leading to high pH with possible consequences on meat quality (Sañudo et al., 2012). As previously mentioned, stress has profound effects on several key meat quality attributes such as ultimate pH, tenderness, colour, water holding capacity and cooking loss (Kadim et al., 2014).

It is clear that the use of animal age as an indicator of goat meat quality as it is used for sheep carcasses, is not reliable and it should be re-considered in goat carcass classification/grading systems. In countries or cultures where chevon is preferred over capretto, it is recommended to slaughter goats between the age of one and two years, or between 25 and 40 kg, in order to obtain better meat quality (Simela et al., 2004; Pratiwi et al., 2007; Simela et al., 2008). Future studies should focus on the age at which meat quality begins to deteriorate for different muscles in order to re-define the goat carcass classes/grades.

3. Pre-slaughter management of goats

3.1 Pre-slaughter conditioning

Typically, goat carcasses are very lean with more than 60 % dissectible lean meat and 5–14 % dissectible fat (Hogg et al., 1992). As previously mentioned fat accretion in goats occurs

in preferential order and most fat is deposited in the visceral rather than carcass depots (Webb et al., 2005). Deposition of less subcutaneous fat cover increases the susceptibility of goat carcasses to moisture loss (shrinkage) and cold shortening during the chilling process (Webb et al., 2005). This has increased the interest in feeding practices that improve the degree of carcass fat deposition and subsequent body condition of goats prior to slaughter.

Simela et al. (2004; 2011) studied the effect of pre-slaughter conditioning on live animal, carcass characteristics and meat quality of unimproved indigenous South African goats, ranging from weaned kids to 8-teeth does. The goats were kept on a commercial diet and slaughtered within two months of purchase (non-conditioned) or within six to ten months of purchase (conditioned). The results of that research showed the advantages of pre-slaughter conditioning of goats in quality chevon production. The conditioned goats had better carcass yield, increased intermuscular and subcutaneous fat, slower carcass chilling rates and longer sarcomere lengths than the non-conditioned goats (Table 1). The results of Simela et al. (2004) further indicated that the *semimembranosus* muscle of the conditioned goats had lower shear force values at 24 hours and after ageing for 96 hours than that of the non-conditioned group.

The foregoing results indicate that improved nutrition is important for a good body condition, better carcass yields and quality meat production. The only potential conflict arising from increasing the level of carcass fatness through pre-slaughter conditioning is the current consumer perception regarding dietary fat (Webb and O'Neill, 2008).

Table 1
Effect of pre-slaughter conditioning on live weight and selected characteristics associated with eating quality of goat meat.
Source: [1]Simela et al. (2011); [2]Simela et al. (2004)

	Pre slaughter conditioning		*P*-value
	Non-conditioned	Conditioned	
Slaughter weight (kg)[1]	31.9 ± 6.08	35.9 ± 5.86	***
Cold carcass weight (kg)[1]	12.1 ± 2.81	15.7 ± 2.66	***
Dressing percentage[1]	37.9 ± 3.61	43.9 ± 2.78	***
Chilling losses (%)[1]	3.1 ± 1.05	2.2 ± 0.73	***
Intermuscular fat[1]	6.8 ± 3.11	13.7 ± 3.77	***
Subcutaneous fat[1]	3.4 ± 1.74	6.0 ± 1.96	***
Carcass temperature (°C) @ 3 h p.m[2]	13.5	19.5	***
Sarcomere length (μm)[2]	1.6	1.9	***

*** $P < 0.001$.

3.2 On-farm handling

Rearing livestock in adverse environmental conditions predispose the animals to stress which could affect meat quality. However, there is limited information on the effect of farm management practices and environmental factors on animal physiology and subsequent meat quality of goats.

Kruger et al. (2016) studied the effects of routine handling procedures, management practices and environmental factors on stress in South African unimproved indigenous goats. The results of that research showed that routine procedures such as vaccination and dosing resulted in increased serum cortisol concentration, an indication of acute stress response, in contrast to environmental stressors such as heat exposure and feed/water deprivation (Table 2) The psychological stress suffered by goats exposed to routine handling stress was due to stimuli such as noise, strenuous exercise and even physical force when moving animals from the grazing camp to the handling facility. The study of Kruger et al. (2016) confirmed the fact that goats are fearful towards unfamiliar humans, novel environments or threatening situations (Zimerman et al., 2011). Minimising fear during animal handling is therefore an important step in reducing stress-associated effects on goat meat quality. There is a need for further research

Table 2
Serum cortisol levels (nmol/L) for different stress treatments in goats.
Source: Kruger et al. (2016)

Time (min)	Handling stress	Heat stress	Food deprivation stress	Water deprivation stress	Heat and handling stress	Heat, food and water deprivation stress
0	314.2^{a}	$133.4^{b,c}$	$35.0^{c,d}$	$86.5^{b,c}$	203.8^{b}	$168.6^{b,c}$
15	229.0^{b}	$76.7^{c,d}$	$67.8^{c,d}$	$95.6^{b,c}$	$191.5^{b,c}$	$165.5^{b,c}$
30	$161.9^{b,c}$	$61.5^{c,d}$	$94.0^{b,c,d}$	$98.2^{b,c}$	$181.5^{b,c}$	$133.1^{b,c}$
45	$129.1^{b,c}$	$63.5^{c,d}$	$56.2^{c,d}$	$70.1^{b,c}$	$150.3^{b,c}$	$125.0^{b,c}$
60	199.3^{b}	$73.3^{c,d}$	$69.2^{c,d}$	$58.7^{c,d}$	$152.5^{b,c}$	202.9^{b}
90	$97.9^{b,c,d}$	$105.4^{b,c,\ d}$	$36.4^{c,d}$	45.2^{d}	$129.1^{b,c}$	$157.6^{b,c}$

^{a,b,c,d} Means within the same row with different superscripts are significantly different ($P = 0.05$).

on the relationship between on-farm handling and stress responsiveness, in order to identify farm management practises that minimise stress in goats and improve meat quality.

3.3 Transportation and lairage conditions

The transportation of goats from farm to abattoir results in both physical and psychological stress. Long and stressful journeys of 2 h at an average ambient temperature of 37 °C, from farm to abattoir have been reported to elicit acute stress response in goats (higher plasma cortisol, adrenaline, nor-adrenaline, and dopamine concentrations) and negatively affected meat quality (higher ultimate pH, expressed juice, cooking loss percentage, shear force and lower sarcomere length, L*, a*, and b*values) (Kadim et al., 2006). Kannan et al. (2000) indicated that goats recover from transportation stress within 3 h. It is, therefore, recommended to allow goats a resting period of at least 3 h prior to slaughter, for better meat quality.

In South Africa, a waiting period at the abattoir facilities is compulsory to allow the animals to rest and recover from transport stress prior to slaughter (Meat Safety Act no. 4 of, 2000). During the lairage period, feed is normally withdrawn to reduce carcass contamination with gut contents (Gregory, 1998). However extended lairage periods of more than 18 h without feed leads to economic losses due to increased stress and live weight shrinkage (Kannan et al., 2000, 2002). In this regard, aspects such as shorter lairage periods or provision of feed and water are critical factors for goat meat quality.

4. Slaughter and post–slaughter conditions

4.1 Chilling

Carcasses of livestock slaughtered under commercial conditions are quickly chilled at 0−4 °C for 24 h to prevent proliferation of microbial organisms. However, research has shown that goat carcasses undergo cold shortening if rapidly chilled, resulting in very tough meat

(King et al., 2004; Simela et al., 2004; Kadim et al., 2014). Cold shortening has been identified as a major problem in the goat meat industry worldwide (Kannan et al., 2014).The reason being that goat carcass are relatively small and very lean and these characteristics allow carcass temperature to decrease rapidly, inducing cold shortening and consequently tough meat (Webb et al., 2005).

Controlling pH-temperature combination at the onset of rigor mortis is deemed to be important in counteracting the effects of cold shortening and enhancing the resultant meat quality attributes (Hannula and Puolanne, 2004). Locker and Hagyard (1963) demonstrated that minimum shortening occurs when pre-rigor muscles are held at 14−19 °C until the onset of rigor mortis. Thus, delaying the chilling of carcasses until the onset of rigor mortis has received attention as a way of minimising the risk of cold shortening and improving meat quality traits in other species (Savell et al., 2005; Fernández and Vieira, 2012). However, the use of delayed chilling in preventing cold shortening of goat carcasses is not well documented, although it is believed to be practised in informal settings.

Pophiwa et al. (2017) highlighted the usefulness of delayed chilling (10−15 °C for 6 h, 0−4 °C until 24 h) as a strategy on minimising cold shortening in goat carcasses and improving meat quality. The onset of rigor mortis (pH∼ 6) occurred at elevated temperatures between 13.1 °C and 17.1 °C. The measured sarcomeres were longer than 2 μm, in both *longissimus dorsi* and *semimembranosus* muscles of goats, which gives an indication that cold shortening did not occur under the chilling conditions set for the study. The study of Pophiwa et al. (2017) further showed that *longissimus* muscle had presumably an acceptable degree of tenderness at 24 h post mortem, with an average shear force value of 42.8 ± 1.5 N, while *semimembranosus* muscle was tough with an average shear force value of 88.5 ± 3.8 N. The increased toughness of *semimembranosus* muscle was not necessarily related to cold shortening, but possibly due

to increased connective tissue or a higher calpastatin activity that inhibits the action of calpains in mediating proteolysis (Nagaraj et al., 2002).

Delayed chilling of carcasses seem to be a cheaper and simpler technique of preventing cold shortening in goat carcasses and improving the subsequent quality of meat. However, its practicality under commercial slaughter conditions should be considered to ensure that it does not disrupt the flow of abattoir processes or compromise food safety standards. Another alternative that needs to be investigated is skin-on chilling, which is practiced in some African countries.

4.2 Electrical stimulation

Electrical stimulation is one technology being used in the meat industry to accelerate the rate of pH decline with beneficial effects on meat quality, particularly tenderness. Several studies have confirmed the efficiency of electrical stimulation in improving the quality of goat meat (Savell et al., 1977; Gadiyaram et al., 2008; Pophiwa et al., 2016) even in stressed goats (Kadim et al., 2014). Electrical stimulation improves goat meat tenderness by preventing cold shortening, some disruption of the myofibrillar and connective tissue structures and/or acceleration of proteolysis (Savell et al., 1978; Biswas et al., 2007; Gadiyaram et al., 2008).

King et al. (2004) found that low voltage (20 V) electrical stimulation did not improve meat tenderness of young goats. In that study, shear force value of 71.2 N for *gluteobiceps* muscle after electrical stimulation with low voltage was significantly higher than 58.5 N for high voltage (550 V) electrical stimulation. Biswas et al. (2007) found that medium voltage electrical stimulation (330 V) was more effective in improving meat quality traits than lower voltages (both 35 V and 110 V) or higher voltages (both 550 V and 1100 V). The research of King et al. (2004) and Biswas et al. (2007) highlight the potential quality problems related to under-stimulation or over-stimulation of goat carcasses. This emphasises the importance of

carefully monitoring the application of electrical stimulation in order to achieve the required pH-temperature combination.

Research has clearly shown that electrical stimulation is beneficial for improving the eating quality of goat meat, even in carcasses with low glycolytic potential. The only disadvantage with electrical stimulation is that it is expensive and difficult to install and maintain and hence it may not be readily adopted by small abattoirs.

4.3 Carcass suspension

Another way of improving meat tenderness is by alternative carcass suspension methods that restrain muscles from shortening during the chilling process. Tender-stretch was first reported in beef carcasses by Hostetler et al. (1972) and is achieved by suspending carcasses from aitch bone (*obturator foramen*) in split carcass or pelvis in full carcasses. Research in goats conducted by Basinger et al. (2019) showed that tender-stretch effectively stretched the sarcomeres and improved meat tenderness, compared to the traditional vertical suspension byAchilles tendon, tender cut or tender cut carcasses with a 2.3 kg weight attached to the neck (Table 3). Additionally, there was less variation in tenderness between muscles when tender-stretch was applied. The findings of Basinger et al. (2019) are consistent with prior research in beef, where tender-stretch has been studied widely (Bayraktaroglu and Kahraman, 2011; Ahnström et al., 2012; Liu et al., 2016).

Pelvic suspension is clearly a mitigating strategy for optimal goat meat quality and it is recommended for small abattoirs. However, pelvic suspended carcasses require more chilling and storage space and it may cause slight alterations in muscle shape, compared to Achilles-hung carcasses (Ahnström et al., 2012).

Table 3
Effects of pre-rigor tension treatment on characteristics related to eating quality of goat meat.
Source: Basinger et al. (2019)

	Pre rigor treatments				SEM	F-test
	AT[1]	TS[2]	TC[3]	TC +W[4]		
LM Sarcomere length	1.51[b]	1.68[b]	1.57[b]	–	0.03	< 0.001
LM WBSF	62.3[a]	38.0[b]	73.7[a]	–	4.80	< 0.001
LM Sarcomere length	1.55[b]	1.71[a]	–	1.75[a]	0.05	0.042
SM Sarcomere length	1.46	1.65	–	1.64	0.09	0.059
LT WBSF	50.9[a]	25.2[b]	–	23.4[b]	3.81	< 0.001
LL WBSF	71.9[a]	36.0[b]	–	61.5[a]	4.96	< 0.001
SM WBSF	47.3[a]	22.1[b]	–	42.5[a]	1.92	< 0.001

[a,b] Means within the same row with different superscripts are significantly different ($P = 0.05$).
Pre rigor tension treatments: [1]Conventional suspension by Achilles tendon; [2]pelvic suspension; [3]tender cut; [4]tender cut with a 2.3 kg weight attached to the neck.
LM = longissimus thoracis et lumborum; SM = semimembranosus; LT = longissimus thoracis LL = longissimus lumborum.
WBSF = Warner Bratzler Shear force.

4.4 Ageing

Research on post mortem ageing of goat meat is very limited, probably because of its shorter shelf life compared to other meat types (Strube, 1991 cited by Kannan et al., 2014). Simela et al. (2004), found that a 96 -h ageing period improved goat meat tenderness by about 12 %. Kadim et al. (2004) reported a 15–37 % increase in tenderness of four muscles (*longissimus dorsi*, *biceps femoris*, *semitendinosus* and *semimembranosus*) of three Omani goat breeds during a 6-day ageing period (Table 4). However, there seem to be limited benefits in ageing electrically stimulated goat carcasses (King et al., 2004; Gadiyaram et al., 2008).

Although ageing can further improve goat meat tenderness, it could also be critical for the visual appearance of meat. Researchers have reported a tendency for goat meat to discolour within 4–8 days of post mortem storage (Kannan et al., 2001; Kadim et al., 2004). This could result in economic losses as consumers prefer bright red meat. Future studies should focus on

Table 4
Warner-Bratzler shear force values for three Omani breeds at 1 or 6 days ageing.
Source: Kadim et al. (2004)

	Breed						Significance		
	Batina		Dhofari		Jabal Khaddar		Breed	Ageing	Interaction
	1-day ageing	6-day ageing	1-day ageing	6-day ageing	1-day ageing	6-day ageing			
LD	70.6[b]	44.1[a]	72.6[b]	52.0[a]	75.5[b]	53.0 [a]	ns	***	ns
BF	75.5[b]	52.0 [a]	78.5[b]	58.8 [a]	78.5[b]	58.8 [a]	ns	***	ns
ST	46.1[b]	38.2[a]	55.9[b]	46.1[b]	56.9[b]	47.1[b]	***	***	ns
SM	96.1[b]	63.8[a]	95.1[b]	75.5 [a]	98.1[c]	72.6 [a]	ns	***	ns

[a,b,c] Means within the same row with different superscripts are significantly different ($P = 0.05$). [***] $P < 0.001$.

LD = longissimus dorsi; BF = biceps femoris; ST = semitendinosus; SM = semimembranosus.

colour stability of different muscles as this aspect is important for export market and retailers who sell goat meat after long term storage.

5. Recommended critical control points for improved eating quality of goat meat

The quality of goat meat quality can be improved if most factors that affect meat quality are properly managed. Research findings presented in this paper have been translated into critical control points for improved eating quality of goat meat (Fig. 1). Producers and abattoirs needs to compare their management practices to recommended critical control points and determine whether their current practices can be improve.

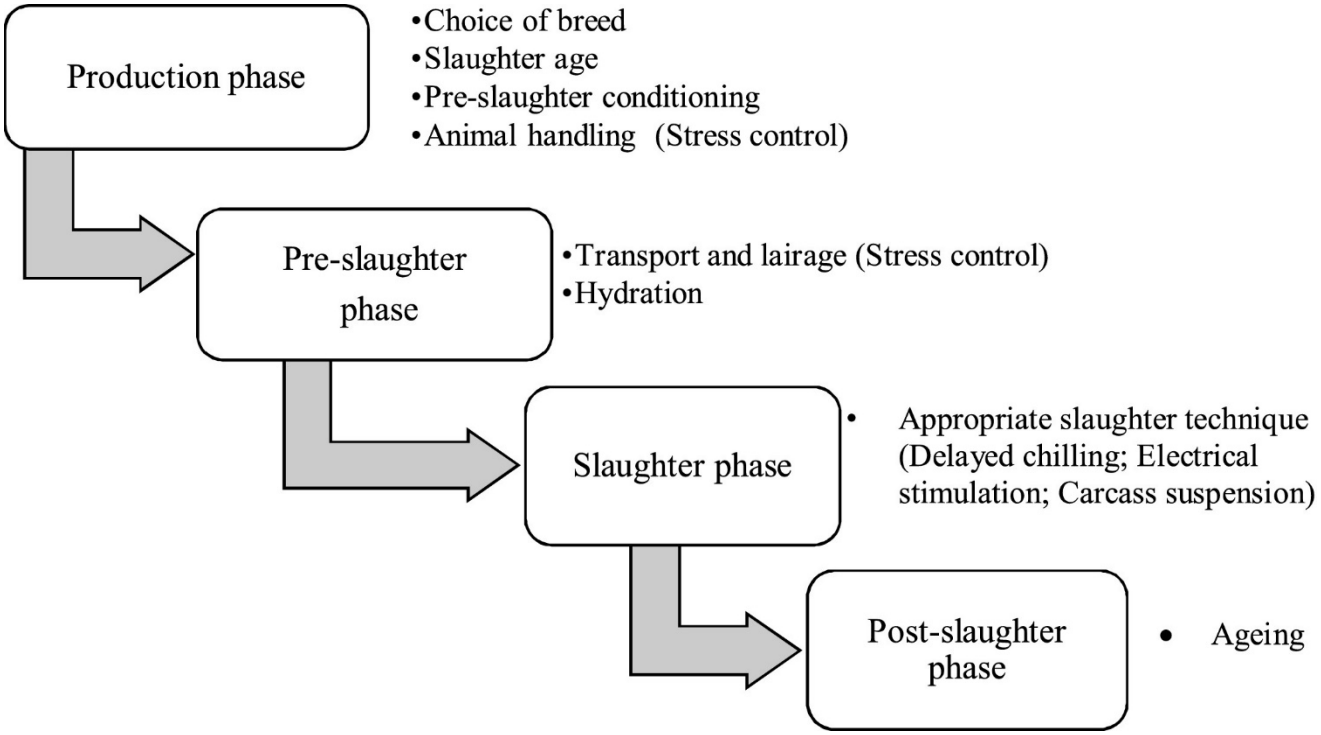

Fig. 1. Recommended critical control points for goat meat quality.

6. Conclusions and future priorities

Low glycolytic potential of goat carcasses coupled with their susceptibility to cold shortening, support the anecdotal suggestion that goat meat is inferior to other types of meat. Minimising ante mortem stress, electrical stimulation, delayed chilling, pelvic suspension and ageing may be of practical value in improving the quality of goat meat.

With emerging global markets for goat meat, there is a critical need for breeds that are well adapted to the environment and resistant to diseases with a potential for quality meat production, meat quality enhancement techniques and development of value-added products in order to continually meet the expectations of diverse consumers. An integrated approach should be established to facilitate the exchange of knowledge between researchers, producers, abattoirs processors and consumers. Structures that link small scale producers with larger markets are essential in promoting the global trade of goat meat. Future priorities should focus on marketing and social awareness of goat meat and its products.

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