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A review of some aspects of goat meat quality: future research recommendations

Archana Abhijith[A], Robyn D. Warner[A], Frank R. Dunshea[A,B], Brian J. Leury[A], Minh Ha[A] and Surinder S. Chauhan[A,*]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Surinder S. Chauhan
School of Agriculture and Food, The University of Melbourne, Parkville, Vic. 3010, Australia
Email: ss.chauhan@unimelb.edu.au

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ABSTRACT

The global goat meat sector is advancing and contributes to long-term food security, especially in meeting the protein demands of the growing human population in developing countries. Spanning all countries, Australia, is the largest exporter of goat meat, although it has negligible consumption. However, Australia does potentially have a secure future as an innovative, profitable, and resilient world leader in goat production, provided some challenges are addressed. These challenges facing the goat meat sector require suitable strategies and interventions for better profitability and acceptance of goat meat consumed in Australia and as an export product. Limited research on goat meat quality and the lack of an adequate grading system for goat meat quality are two of the major issues that need attention from the industry and researchers. Some of the most critical areas that need further research to enable growth of the goat meat industry are the influence of genetics and age of animals on meat quality, standardisation of the ageing period of various goat meat cuts, cooking innovations, consumer acceptance and sensory analysis of goat meat (both farmed and rangeland goats). This paper reviews the status of the goat meat sector and identifies the opportunities for the goat meat sector, particularly in Australia. In addition, we highlight several key issues requiring further research and interventions to enhance the growth of the goat meat industry.

Keywords: chevon, cold-shortening, cooking temperature, farmed goats, feral, glycogen, muscle fibre, sensory.

Introduction

Goat meat is consumed globally by more people than is red meat derived from other species, and has no religious or cultural restrictions on production, slaughter or consumption (except for the specific halal slaughter requirement by the Muslim community; GICA 2015). It is a major source of protein in developing countries, where the production and consumption of goat meat is high (Webb 2014). The growing global goat population, estimated to be ~7.7 billion, is mainly in Asia and Africa (90%), with significant numbers in individual countries including China (39%), India (9%), Pakistan (6%), Nigeria (4%), Bangladesh (4%), Australia (1%), and other (38%) (MLA 2020). In developing countries with abundant goat production, the adaptabilities of animals to different climatic conditions and diets are important traits of goats. Although goat meat contributes to long-term food security and possesses health benefits (Ivanović *et al.* 2016), there are several industry-related issues that need to be addressed, especially in developed countries. This paper reviews the critical factors influencing goat meat quality, which need to be addressed to enhance the consumption of goat meat, with a particular focus on the Australian domestic market. Additionally, this paper highlights several opportunities requiring intervention, and identifies key areas requiring further research, to enhance the growth of the goat meat industry globally.

Goat meat industry in Australia

Australia is the leading exporter of goat meat globally, contributing to 34% of global export value, although it is a small producer that provides only 0.4% to global goat meat production compared with other countries (MLA 2020). The total value of goat meat exported from Australia was A$145.5 million in 2020, down 38% from the value in 2019 (MLA 2020). Consumption of goat meat in Australia is negligible compared with other red meat (approximately 10% of goat meat produced is consumed in Australia), although one-third of Australian consumers would consider consuming goat meat (GICA 2015). The 'over-the-hooks' price for goat meat has increased over the past few years from A$3.71/kg cwt (carcass weight) at the beginning of 2015 to a peak of A$6.83/kg cwt in July 2017, with a further increase to A$9.05/kg cwt by April 2022 (NLRS 2022). The Australian goat meat export market has proven to be a lucrative enterprise, with 19 046 t slaughter weight reported in 2021 (MLA 2022). The meat is exported predominantly to the USA (57%) and Taiwan (12%), followed by South Korea (6%), Canada (4%), and Trinidad and Tobago (5%) (AgriFutures 2016). Australia has established a reputation as a trusted and consistent goat meat supplier. Malaysia is the major destination for live export of goats, which accounted for only 3% of total export value of goats/goat meat of A$7.0 million in 2019 (16 059 head in 2019) (MLA 2020).

In contrast to the export market, the Australian domestic goat meat market growth is considerably slower, and goat meat is still a peripheral part of the Australian consumer's diet. The domestic destination for the Australian goat meat is supermarkets, wholesale and retail butchers, and restaurants (GICA 2015). The major constraints for the Australian domestic market include the lack of availability of a consistent supply of quality goat meat. For the aforementioned reasons, a quality assurance scheme similar to Meat Standards Australia (MSA) established for beef and sheep (MLA 2018) may contribute to expanding domestic demand. However, commercial exporters/processors may have less interest in a fresh quality-grading program, because this may not be financially beneficial; they export frozen whole carcass or as six-way cuts. Another practical challenge in grading goat meat quality is that most goat meat is harvested from the wild and comprises rangeland goats, contributing up to 90% of Australian goat meat production (MLA 2020). Rangelands are mainly indigenous lands which are mainly grasses, herbs and shrubs suitable for grazing and browsing, and where the land is managed as a natural ecosystem, whereas farmed areas may be premoninantly improved pastures (MLA 2006). The rangeland goat is typically a mix of different breeds rather than representing a specific breed themselves. These feral populations are descended from domesticated goats, which have interbred with each other, and some of the domesticated goat breeds that have contributed to the feral goat populations in Australia include British Alpine, Ango-Nubian and Toggenburg, Boer and Australian Cashmere (MLA 2006). The greatest numbers are present in the semi-arid pastoral areas of Western Australia, western New South Wales, southern South Australia, and central and south-western Queensland (Jones 2012). These goats have adapted to the harsher rangeland environments and no longer resemble the original breeds of domesticated goats introduced with the European settlement (GICA 2015). There is no control over the pre-slaughter nutrition with wild goats and less than desirable control over management from paddock to slaughter. The National Livestock Identification System (NLIS) in Australia ensures lifetime movements of sheep and goats by NLIS-accreditd tag/device before movement (NLIS 2020). However, rangeland and dairy goats have tagging exemptions in some states and territories. This could challenge the traceability of these goats. Additionally, processors are reluctant to provide individual carcass data back to the producers, which could limit any improvements.

Rangeland goat constitutes a major source of animals for the goat meat processing industry (GICA 2015). The remaining goats slaughtered in Australia are farmed Boer goats and their crosses. A survey conducted in New South Wales and Queensland, Australia, in 2016 reported the existence of the following breeds: Australian rangeland goats, Boer (White and Red), Anglo-Nubian, Toggenburg, Saanen and Savannah. Pastoral regions were dominated by rangeland goats and Boer-cross goats, while high-rainfall regions had purebred Boer goats for stud breeding. Other breeds were kept by 35% of producers interviewed in the survey (Nogueira et al. 2016). Producers reported introducing Boer goats into the rangeland goat herd to improve bodyweights and carcass weights. There are about 4–6 million rangeland goats and ~200 000 farmed meat goats in Australia (AgriFutures 2016). Table 1 provides information on the breeds/types and numbers of goats in Australia. There are few reports on the Australian consumer perceptions of goat meat. Robust studies focusing on consumer perceptions could enable, or even drive, innovations in the Australian goat meat industry. Table 2 provides a guide to the specifications for a range of goat meat market segments in Australia.

Table 1. The breed/type and number of goats in Australia.

Breed type	Category	Estimated population
Rangeland goats	Uncertain	2.6 million
Domestic farmed goats	Dairy goats	25 000
	Fibre goats	155 000 Angora 10 000 Cashmere
	Meat goats	<200 000
	Estimated total	450 000

The values are only estimates (Swain 2011).

Table 2. Australian goat meat domestic and export market specifications.

Market	Customers	Age/size	Breed	Sex	Other requirements
Live trade	Malaysia	>40 kg live weight	All	All	Prefer heavier goats
	Middle East	• >25 kg live weight • Prefer young goats, but will take all	All	All	–
	Saudi Arabia	• >25 kg live weight • No more than 2-tooth	Prefer farmed Boer goat bloodlines, but will accept all	All	Must be farmed
Capretto	Domestic food-services sector	• <12 kg hot carcass weight, must have pale pink meat colour on the internal flank muscle • 12–20 weeks of age	• Usually unwanted male kids of dairy herds or specialty meat such as Boer goats • Dairy goats, especially Nubian types, are the least desirable.	All. No secondary sexual characteristics in the case of males	Lean, tender, juicy meat from young milk-fed unweaned kid
Chevon	Domestic food-services sector; Export – European and USA markets	• Female, male or castrate	Boer bloodlines	All. In case of males and castrate males, no evidence of secondary sexual chararacteristics	Must be farmed. Prefer milk-teeth and fat score 2–3
Commodity goat meat	Taiwan, USA, Canada, Carribean	Range of age and size	Range of breeds	–	Taiwan and Chinese community in USA have demand for skin-on product. Shorter-haired breeds or shorn goats are preferred for this product. Rangeland, Boer and Boer goat crosses are suitable

Source: MLA (2021).

Major drivers of goat meat consumption in Australia

Consumption of goat meat depends on consumer demographics, where factors such as religion, nationality, heritage, region, and gross income play important roles (Sans and Combris 2015). The major consumers of goat meat in Australia comprise people of Hispanic, Muslim and Caribbean backgrounds (MLA 2020). Traditional perceptions that goat meat is associated with off-smells, off-flavours, unappealing colour, and perceived toughness are some reasons for the low preference for goat meat despite the health benefits of goat meat recognised by consumers from other demographics (Mandolesi *et al.* 2020). In addition, many cultures are unfamiliar with consuming goat meat and are less likely to either try or purchase it.

Animal age is an important determinant of meat quality and consumer preference for goat meat (Basinger 2016; Mehjabin *et al.* 2016). In 2005, it was observed that Hispanics prefer kids (goats of 4–8 weeks of age), weighing 6–12 kg live weight and young goats usually termed as chevon (6–9 months age) weighing about 23 kg. In contrast, Muslims favour heavier goats and consume male and non-castrated goats of ~32 kg liveweight (Knight *et al.* 2006). Furthermore, Jamaicans, Haitians, West Africans and African Americans prefer meat from intact male and adult goats above 2 years of age (Pinkerton *et al.* 1994). The negative quality attributes associated with goat meat could be strongly influenced by past experiences, when goat meat from older animals (above 2 years age) was sold in markets and age had a noticeable deleterious impact on tenderness and caused a gamey flavour (Mandolesi *et al.* 2020). However, there is an increasing trend for goat kid meat globally (Brand *et al.* 2018).

Goat meat possesses unique flavour and aroma (Madruga *et al.* 2000) and these attributes are influenced by breed (Dhanda *et al.* 2003), age (Smith *et al.* 1978; Sheridan *et al.* 2003; Saccà *et al.* 2019), subcutaneous fat thickness (Schönfeldt *et al.* 1993) (Table 3, Item 6), sex (Rodrigues and Teixeira 2009), diet (Oliveira *et al.* 2015), and method of cooking (Liu *et al.* 2013) (Table 3, Item 11). Previous studies showed that goat meat flavour is either rated acceptable (Griffin *et al.* 1992) or less desirable (Pike *et al.* 1973) than that of lamb or mutton, depending on the familiarity of the consumers and their ethnicity. Branched-chain fatty acids (BCFAs) contribute to the typical sheep (Watkins *et al.* 2014) and goat (Johnson *et al.* 1977) flavour. Short-chain BCFAs, deposited in fat, typically contribute to the species-specific flavour of sheep and goat meat, which is higher in sexually mature male animals, and animals fed on a concentrate-based diet (Watkins *et al.* 2021). Consumers in different countries have different preference for goat meat (Karakuş and Yıl 2006). It is important to understand the factors that influence the flavour of

Table 3. Summary of studies on antemortem and postmortem factors or treatments influencing goat meat quality, defined by objective methods and sensory evaluation.

Factor	Breed	Muscle	Description[A]	Sensory evaluation	Objective meat quality	References
1. Slaughter age (2-year-old goats vs 12 young 6–9-month-old goats), muscle (*longissimus thoracis et. lumborum* and *semimembranous*) and ageing (1 and 13 days)	Boer	LL, SM	24 wether goats: (n = 12/group)		Ageing for 14 days reduced shear force in both age groups. 2-year-old goats exhibited higher lipid oxidation than the 6-9-month-old goats. Total muscle glycogen concentration was lower in both age groups compared to the optimum glycogen level required in muscles pre-slaughter (45–57 mmol glycogen/kg muscle) sufficient for normal pH decline.	Abhijith et al. (2021*a*)
2. Muscle fibre type in two age groups (18 month vs 9-month old)	Korean native black	LL, PM, SM, GM	10 castrated male goats (n = 5/group)		Positive correlation between type IIb fibre and shear force. Shear force and collagen content, Type IIb was higher, and Myofibrillar Fragmentation Index (MFI) and sarcomere length was lower in 18 month old goats	Hwang et al. (2019)
3. Slaughter weight (7.5 and 11.5 kg) and breed (Blanca Andaluza; Blanca Celtibérica; Moncaína; Negra Serrana 73 Castiza; Pirenaica)	Blanca Andaluza, Blanca Celtibérica, Moncaína, Negra Serrana–Castiza and Pirenaica	LL	141 male kids from 5 breeds and 2 slaughter weight (n = 15/group)	Trained panel: light goat meat was more tender and juicier and with less odor than meat from heavy ones; Blanca Andaluza and Pirenaica had most tender and juicy meat	L*, b* and h diminished and C and a* was higher in goats with 11.5 kg than 7.5 kg slaughter weight	Ripoll et al. (2011)
4. Live weight (6 and 10 kg) and diet (reared with their dams and the other group were reared with milk replacer)	Majorera breeds: two diets: suckled on dam or milk replacer and two liveweights at slaughter: 6 and 10 kg	LL, SM, TB	Kids of 2 live weight (n = 10/group)		High shear force in SM and TB of 10 kg kids. Moisture percentage significantly lower in 10 kg goats	Argüello et al. (2005)
5. Breed and slaughter weight (60 days old kids with <11 kg and 90 days old kids with >11 kg slaughter weights)	Criollo Cordobes (CC) and Anglonubian suckling kids	LL	n = 10/group	Trained panel: meat from CC kids showed better scores for tenderness and juiciness	Shear force was higher in the goats with >11 kg slaughter weight	Peña et al. (2009)
6. Breed	Angora and Boer	LL, SM	Kids with no permanent incisors (n = 9/group)	Trained panel: Angora goat meat was juicier compared to Boer goat meat	Higher cooking loss in both muscles of Boer than Angora goats. Angora SM showed greater thawing loss than Boer	Schönfeldt et al. (1993)
7. Rearing system (Traditional system; Intensive Feeding System without Concentrate and Intensive Feeding System with Concentrate)	Crossed Parda Alpina × undefined breed	LL	New-born kids with 3.35 ± 0.65 kg BW and slaughtered at 12 kg; 3 rearing systems (n = 7/group)	Trained panel: IS + C and IS presented better flavour, juiciness, aroma scores and higher overall acceptability	IS + C and IS had higher intramuscular fat content, lower shear force	Santos et al. (2020)
8. Nutrition (Control treatment with vitamin E plus others containing 50, 150, and 450 mg dl-α-tocopherol acetate/kg dry matter)	Boer–Saanen goats	LL	Age: 122.1 ± 3.6 days; 21.6 ± 2.9 kg body weight (n = 8/group)	Untrained consumers: 8.97%, 21.98%, and 28.28% longer acceptance for meat colour from goats fed with diets supplemented with 50, 150, and 450 mg vitamin E, respectively, compared with control group.	Inclusion of 450 mg vitamin E/kg DM in diets for Boer–Saanen goat kids significantly reduces the lipid oxidation	Possamai et al. (2018)

(Continued on next page)

Table 3. (*Continued*).

Factor	Breed	Muscle	Description[A]	Sensory evaluation	Objective meat quality	References
9. Diet (Cassava peel + urea, cassava peel plus broiler litter, cassava peel plus cassava forage and cassava peel plus sweet potato forage for 90 days)	West African dwarf bucks (5 months old)	Thigh and forearm	n = 3/group	Untrained consumers: overall acceptance of goat meat was higher for meat from animals fed cassava peel diet supplemented with cassava foliage	No significant impact on nutritional composition (dry matter, ash content, nitrogen free extract and other minerals)	Eneji *et al.* (2015)
10. Cooking method (boiling (100–160°C), oven-drying (250°C) or micro-waving (180–200°C) for 35 min)	West African dwarf bucks (5 months old)	Thigh and forearm	n = 6/group	Untrained consumers: boiling (100–160°C) appeared to be preferred than micro-waving and oven-drying for overall acceptance		Eneji *et al.* (2012)
11. Cooking temperature (raw, 50°C, 55°C, 60°C, 65°C, 70°C, 75°C, 80°C, 85°C and 90°C)	Not specified	SM	Vacuum-packed strips were heated to one of nine end-point temperatures (n = 15/treatment)		Cooking losses and shear force increased, at cooking temperature up to 80°C.	Liu *et al.* (2013)
12. Breed and heat stress (exposed to natural heat stress for 45 days; temperature–humidity index was 86.5)	Osmanabadi and Salem Black (indigenous breeds)	LL	Osmanabadi control, Osmanabadi heat stress, Salem Black control and Salem Black heat stress; (n = 6/group)	Trained panel: Salem Black goat meat had better appearance and heat stress had no effect on sensory parameters	Heat stressed animals had high ultimate pH and shear force	Archana *et al.* (2018)
13. Heat stress (exposed to natural heat stress for 45 days; temperature–humidity index was 86.5) vs control (animals kept inside shed)	Malabari goat (indigenous)	LL	Control and heat stress (n = 6/group)	Trained panel: appearance and flavour showed lower scores in heat stress group	High pH and shear force in heat stress group	Abhijith *et al.* (2021*b*)
14. Heat stress vs transportation stress (transported at high ambient temperature 37°C)	Male Omani goats; male Dhofari goats	LL, BF, ST	Transported and non-transported goats (n = 10/group)		Transported goats (with heat stress) had higher ultimate pH, cooking loss, lower sarcomere length, and shear force.	Kadim *et al.* (2006, 2014)

LL, *longissimus thoracis et lumborum*; BF, *biceps femoris*; GM, *gluteus medius*; PM, *psoas major*; SM, *semimembranosus*; ST, *semitendinosus*; TB, *triceps brachii*.
[A]Kids, male or female goat that has 0 permanent incisor teeth and male shows no secondary sexual characteristics; wether, castrate or entire male that has up to 8 permannet incisor teeth and shows secondary sexual characteristics.

goat meat, which would accordingly help producers develop management strategies.

Shear-force values and tenderness of goat meat are generally acceptable when meat is from goat kids (Webb *et al.* 2005). Karthik *et al.* (2017) showed untrained consumers in India preferred tender goat meat from kids (4–6 months) to tougher meat from adult goats (aged > 12 months). Rodrigues and Teixeira (2009) showed through a trained sensory panel evaluation that meat from male goat kids had greater juiciness, flavour quality, and overall acceptability, than did meat from females.

Ageing of meat is another factor that is as equally important as is the age of the animal for improving tenderness. Ageing in beef, especially wet and dry ageing, are established ways of improving tenderness, flavour and overall acceptability of beef. Dry-aged beef is considered a premium product in restaurants and retail outlets (Stenström *et al.* 2014; Park *et al.* 2018). The limited work on dry ageing in sheep meat (lamb, hogget and mutton) has reported an increase in tenderness (Hastie *et al.* 2022), roasted and buttery flavours, and decreased negative traits such as bloodiness, boiled, livery and metallic flavours (Burvill 2016). However, most goat carcasses have very little subcutaneous fat, and therefore dry ageing could be a challenge. Wet ageing is consequently an alternative that warrants further research. The similarities in sensory attributes of lamb and goat kid meat when fed the same diet (Sheridan *et al.* 2003) imply that challenges in consumer acceptability faced by both types of meat are relatively similar.

The greatest constraint to goat meat consumption in Australia is the consumer's unfamiliarity with preparing goat meat before cooking (MLA 2020). Consumers in western countries are usually unfamiliar with the preparation of goat meat and tend to prepare and cook goat meat using methods similar to those used for lamb. Thus, when exploring goat meat usage, consumers tend to make an inappropriate selection of goat meat cuts in relation to the proposed cooking method, which results in a poor eating experience. Currently, there is no MSA cut/cook pathway or protocols available for goat meat. Consumers generally seek a recipe that is quick and requires a few ingredients. Hence, further research looking at different cooking methods and consumer responses is needed.

Importance of grading meat quality

In the 1990s, the Australian red meat industry developed a grading scheme for sheep meat and beef as an innovative approach to tackle changing markets and evolving consumer demands. The Meat Standards Australia (MSA) system evolved from a large research effort to guarantee consumers a consistent eating quality and add value to the entire supply chain (Watson *et al.* 2008). The MSA program is supported by Meat and Livestock Australia (MLA), which works in partnership with the red meat industry and the federal government, with the core purpose of fostering the red meat industry. However, there is no similar grading scheme for goat meat, which could be mainly because of the current low demand for goat meat in the Australian domestic market.

Grading the eating quality of meat requires extensive experimentation to identify the ideal combination of conditions (age, sex, weight, fat depth and intramuscular fat, to name a few) that yield goat meat of acceptable quality. The MSA system identifies critical control points (CCPs) from the paddock to the plate, which is one of the keystones of this program that affect palatability. It considers the production, pre-slaughter, processing, and value-adding aspects of the supply chain, which has been achieved through large-scale sensory panel tests using untrained consumers. Further, the MSA-licensed processors grade meat in the abattoir before boning. The major determinants used during the grading of beef carcasses include carcass weight, sex, tropical breed content, eye-muscle area, hanging method, hump height (to determine *Bos indicus* content), ossification (to determine the maturity of the animal), marbling, rib fat, meat colour and fat colour, and eye-muscle area (MLA 2018). In sheepmeat, the traits used in grading are mainly carcass weight, nutrition and finishing, and sheep carcass class (minimum weight requirements are ≥16 kg hot carcass weight (HCW) for sucker (milk fed lamb) and ≥18 kg HCW for all weaned lambs, hogget and mutton. The cut and cooking method combination is a vital factor in optimising sheep meat eating quality. For example, muscle such as *semimembranosus* will have a high collagen and connective tissue content, which will be partially broken down through casserole (wet) cooking methods using low heat and moisture over a period of time, whereas for tender cuts such as loin, grilling is recommended. Selecting the appropriate cooking method will optimise the eating quality of these cuts (MLA 2019). Hence, the MSA grading system is a quality-assurance system that has proven capability of managing and predicting beef and sheep meat palatability, not only in Australia but also in other countries (Bonny *et al.* 2018). There are no standards established for presenting goat meat to consumers. The general trend in commercial production is to use cuts similar to those used for lamb (Webb *et al.* 2005; Webb 2014), which is debatable since the two species differ significantly in the inter- and intra-muscular subcutaneous fat content (Casey 1983). Therefore, it is important to focus studies on goats to develop a standardisation/classification system. Some of the important goat meat quality attributes are discussed in the next sections.

Meat pH, tenderness and flavour are the most important quality attributes

pH and temperature decline

The sensitivity of goats to pre-slaughter stress and consequent effects on the conversion of muscle to meat is one of the crucial areas requiring further research to better understand the relationship to goat meat quality (Kadim *et al.* 2010; Kumar *et al.* 2023). Generally, ultimate pH values of goat *longissimus* tend to be higher, ranging from 5.8 to 6.2, than for other species (Simela *et al.* 2004; Kannan *et al.* 2014; Archana *et al.* 2018 (Table 3, Item 12); Abhijith *et al.* 2020). Meat with pH values >6 is generally considered unsuitable for storage because this favours the development of pathogenic and spoilage microorganisms and reduced shelf-life (Aymerich *et al.* 2002). The high pH values associated with goat meat suggest that goats are generally more susceptible to stress than are other species because stress depletes muscle glycogen in the animal and low glycogen at slaughter is a common (not only) cause of high pH meat (Chauhan and England 2018). Low postmortem muscle concentrations of glycolytic metabolites strongly indicate pre-slaughter stress (Simela *et al.* 2004) and this has been previously related to the excitable nature of goats (Pophiwa *et al.* 2017). It is likely that the sensitivity of goats to pre-slaughter stress is similar to that seen in the Merino breed of sheep (Gardner *et al.* 1999) and warrants further investigation. The role of muscle glycogen in postmortem muscle glycolysis, and hence meat pH, is critical (Pethick *et al.* 1995). The critical threshold concentrations of glycogen needed to drop ultimate pH to 5.5–5.6 are between 45 and 57 mmol glycogen/kg muscle in ruminants and non-ruminants (Tarrant 1989; Warriss 1990; Pethick *et al.* 1995). In our (Abhijith *et al.* 2020) recent study on Boer goats, we observed that muscle glycogen concentration was as low as 27.4 and 11.6 μmol/g in young (6–9 months) and adult (2 years) goats. Similarly, glycogen concentration of 33 μmol/g occurred in muscle samples collected pre-slaughter in a study with a goat herd of mixed sex and age, and ante-mortem stress which includes transportation stress was identified as the cause (Simela 2007). Higher ultimate pH is usually associated with dark cutting and a variable degree of tenderisation even after ageing (Simela *et al.* 2004).

Muscle glycogen concentrations vary seasonally (Knee *et al.* 2004), linking feed quality and quantity with muscle glycogen concentration. Low glycogen concentrations may be a significant issue for goats because they are often maintained on poor-quality pasture. Moreover, there are reports of goats that have depleted muscle glycogen due to several stress factors such as transportation in hot environments, handling stress and high stocking density during transportation (Kannan *et al.* 2003; Nikbin *et al.* 2016). Studies on beef have shown that high-energy-supplement diets improved muscle glycogen concentration at slaughter and reduced the incidence of dark cutting/dark firm dry (DFD) meat (Knee *et al.* 2004, 2007). The authors proposed that supplying high-energy diets could be implemented as a preslaughter strategy 'on-farm' to reduce the incidence of dark cutting in beef; this raises the possibility that the same principles could be applied to goats. In fact, Brand *et al.* (2018) compared different levels of dietary energy content in Boer goats and concluded that goats can be slaughtered at liveweights between 30 and 50 kg and still present a lean carcass with a favourable yield. Moreover, it is known that in both cattle and sheep, a low plane of nutrition on the farm can contribute to low muscle glycogen at slaughter and a higher ultimate pH (Knee *et al.* 2004, 2007). Hence, MSA recommends that sheep dispatched for slaughter must have the weight gain of about 100–150 g/day for 2 weeks pre-slaughter, so as to ensure good nutrition and minimal problems with ultimate pH (MLA 2011). However, there are no such guidelines available for goats and further research is needed to define the optimal nutritional requirements of goats during their finishing phase, to ensure optimum muscle glycogen concentrations at the time of slaughter.

The influence of muscle fibre-type composition on muscle pH and meat quality is well documented (Lefaucheur 2010; Ithurralde *et al.* 2017). In a recent study in 14-month-old sheep, by using 15 muscles, larger fast-glycolytic fibres with reduced oxidative activity were associated with a lower ultimate pH, higher L* values, lower a* values and longer sarcomeres (Ithurralde *et al.* 2017). Another study in beef reported that *psoas major* with a higher proportion of Type I fibres than in *semitendinosus* and *longissimus thoracis*, showed a faster pH decline rate than did the other two muscles from 1 h to 6 h postmortem, but there was no difference among the muscles from 6 h to 24 h (Lang *et al.* 2020). Picard and Gagaoua (2020) suggested that the rate and extent of pH decline can be higher in meat with a greater percentage of fast-twitch glycolytic fibres than in the meat with a greater percentage of oxidative fibres. Further, Chauhan *et al.* (2019) demsonstrated that glycolysis and pH decline of oxidative muscles terminate prematurely at a higher ultimate pH, even in the presence of excess glycogen across livestock species. England *et al.* (2014) highlighted the critical role of phosphofructokinase (PFK) activity in the cessation of pH decline in cattle, poultry and pigs. PFK activity starts to decline near pH 5.9 and becomes completely inactive at pH 5.5, which causes cessation of the postmortem pH decline. England *et al.* (2016) later showed that oxidative muscles in pigs had a higher ultimate pH regardless of glycogen concentration. They suggested that there are other inherent muscle factors that control the extent of pH decline in porcine muscles. However, detailed studies looking at factors influencing postmortem muscle glycolysis and its role in goat meat quality are very few.

Tenderness

Tenderness of meat is important for consumer satisfaction (Grunert *et al.* 2004). Tenderness can be evaluated either through mechanical devices such as TPA (texture profile analysis) and Warner–Bratzler shear force (WBSF) or with trained taste panels or untrained consumer panels (Watson *et al.* 2008). The major factors influencing meat tenderness include breed, age, nutrition, muscle and cooking method (Goetsch *et al.* 2011), some of which are listed in the publications summarised in Table 3. Investigation of the factors influencing meat tenderness is important for goat meat in particular, because of its perceived lower tenderness than lamb/mutton and beef (Savell *et al.* 1977). However, Sheridan *et al.* (2003) reported that Boer goat kids compare favourably with Merino lambs in terms of water-holding capacity, colour and shear-force values when raised under similar feedlot conditions and slaughtered at a similar age.

Age at slaughter

Age of the animal is an important determinant of goat meat quality (Bakhsh *et al.* 2019). In developed countries, animals above 2 years of age are usually traded in the goat market (MLA 2020). The influence of age on goat meat quality is not well documented. However, Saccà *et al.* (2019) found that meat of Angora suckling kids (5 weeks of age) was more tender than that of post-pubertal goats (34 weeks of age). Likewise, Simela *et al.* (2004) reported in their study on indigenous South African goats, that the *semimembranosus* of two-tooth goats had lower shear-force values (59.9 N vs 77.4 N) than that of eight-tooth goats. Negative correlations between slaughter weight and sensory scores evaluated using a 9-point hedonic scale such as flavour (r = –0.59), tenderness (r = –0.84), juiciness (r = –0.82) and overall acceptability (r = –0.82) of cooked *longissimus thoracis* muscle of rangeland goats were reported (Pratiwi *et al.* 2007) and a cut-off of 40 kg liveweight was recommended before deterioration of meat quality. The inverse relationship between tenderness and age of goats (Smith *et al.* 1978; Peña *et al.* 2009) (Table 3, Item 5) is primarily due to the development of mature insoluble cross-links in the collagen (Purslow 2014, 2018). Yearling Spanish and Angora goats yielded more tender, juicier and flavourful meat than that of 3–5-month-old kids (Smith *et al.* 1978). Sheridan *et al.* (2003) showed increasing drip loss and cooking loss in Boer goats with an increase in slaughter age. However, adult goat meat (2–4 years old) is juicy and flavourful and highly preferred by some consumers (Dhanda *et al.* 2003). During chewing, the in-mouth lipid processing by saliva acts as a means of lubrication, improving the meat juiciness (Forrest *et al.* 1975; Schönfeldt *et al.* 1993). Water retained in cooked meat contributes to meat juiciness. The above factors underpin the need for slaughter age cut-offs to be defined to ensure the quality of goat meat, which is acceptable and desired by consumers, particularly when the focus is for the goat meat to be prepared and consumed as fresh meat cuts rather than as cubes for slow cooking, as is the more common use for goat meat.

Muscle and fibre type

A substantial amount of research has demonstrated that muscle/fibre type influences meat quality, especially water-holding capacity and tenderness (instrumentally and sensorially assessed). Although there are few reports on the influence of muscle/fibre type on goat meat tenderness, inferences can be drawn from studies on other ruminants such as cattle and sheep (Totland and Kryvi 1991; Rhee *et al.* 2004; Sazili *et al.* 2005; Şirin *et al.* 2017). Numerous studies have shown the relationship between muscle fibre type and tenderness in beef (Calkins *et al.* 1981; Geesink *et al.* 1995; Hwang *et al.* 2010). With the exception of the studies of Kadim *et al.* (2010) and Hwang *et al.* (2019), no other studies were found on goats muscle fibre type in relation to meat quality. Hwang *et al.* (2019; Table 3, Item 2) reported a positive correlation between the fibre-number percentage and fibre-area percentage of Type IIb fibres and WBSF in goats.

Several studies have studied the effect of muscle fibre type in relation to cooked meat quality in other species (Kim *et al.* 2013; Vaskoska 2020). Vaskoska (2020) showed a higher WBSF in bovine *cutaneous trunci* than in *masseter* and explained it by the fact that myosin from Type II fibres creates firmer gels than did myosin from Type I fibres. Changes in the tenderness and WHC during heating or cooking are driven by protein denaturation (Martens *et al.* 1982; Hamm 1996; Tornberg 2005). Therefore, investigating the effect of fibre type on tenderness and cooking loss in relation to protein denaturation during cooking is an area of great interest. A significant amount of research has been conducted on protein denaturation during cooking in bovine and porcine muscles regarding tenderness and cooking (Vaskoska *et al.* 2021). Nevertheless, only a few studies on thermal analysis of goat meat, such as Liu *et al.* (2013), have been published.

Cooking method

The method of cooking meat and end-point temperature play a critical role in the eating quality of goat meat (Xazela *et al.* 2011; Liu *et al.* 2013; Oz *et al.* 2017). Moist and slow cooking methods, such as roasting, braising or moist cooking in a curry, are usually preferred for cubed goat meat from older goats (MLA 2020). Goat meat can be prepared in various ways, depending on the country and region where it is consumed. A low intramuscular fat content in goat meat is consistant with the present-day consumers' demands for leaner meat; however, there is a general agreement that lower level of intramuscular fat is responsible for the low juiciness and tenderness of goat meat (Adeyemi *et al.* 2015). Thus, fast cooking methods such as grilling or pan-frying used for sheep or lamb meat would be inappropriate for goat meat. Goat meat usually requires long and slow cooking at a lower temperature rather than fast cooking methods such as grill, to prevent it becoming dry and tough (Jenkinson 2017). Low temperature–long-time sous-vide cooking is an innovative approach that gives better control of degree of doneness, tenderness, and colour than traditional cooking methods (Ismail *et al.* 2019). Using this technique, raw food is vacuum-sealed in food grade, heat-stable pouches, and the pouches are cooked under controlled, low temperatures (Baldwin 2012). The sous-vide cooking method allows heat transfer evenly from water bath to meat, providing juicier, and more tender meat for any cut (Baldwin 2012), provided a quick grilling process is used prior to consumption to esure Maillard reaction occurs (essential for good flavour) on the meat surface. Significant reduction of toughness was reported in *biceps femoris* and *gluteus medius* muscles of goat meat when they were subjected to stepped sous-vide cooking (45°C for 3 h followed by 60°C for 3 h) compared with single-stage sous-vide treatment (60°C for 6 h) (Ismail *et al.* 2019).

Goat meat requires careful seasoning with spices such as onions, garlic, black pepper, chilli powder, paprika, and cumin to balance the gamey flavour of the meat (Rhee *et al.* 2003; Putra *et al.* 2017). Putra *et al.* (2019) observed reduced shear force, lipid oxidation, and a decrease in gamey odor/flavour of refrigerated Saanen-crossbred goat in ginger-marinated meat compared with non-marinated meat. Likewise, meat from 7-year-old dairy Saanen goats marinated with either pineapple juice for 60 min or barbecue sauce containing 3% sodium bicarbonate for 60 min, had a lower cooking loss and hardness as well as higher scores for all sensory attributes than did the non-marinated meat (Kaewthong *et al.* 2021).

The influence of cooking method is usually dependent on the rate at which thermal energy (heat) is applied. Thermal processing of meat greatly influences the cooking yield, protein solubility and other quality attributes, such as tenderness, juiciness, colour and flavour, associated with eating quality and consumer acceptance (Murphy and Marks 2000; Liu *et al.* 2013; Schwartz *et al.* 2022). Schwartz *et al.* (2022) comprehensively reviewed the influence of increasing cooking temperatures on physiochemical and sensory properties of red meat. Liu *et al.* (2013) showed that increasing end-point cooking temperatures to >60°C led to a significant increase in cooking loss and collagen solubility in *semimembranosus* muscle of goats. The authors reported a four-phase change in shear force with an increase in end-point temperature from 50°C to 90°C. They also observed a decrease in sarcoplasmic protein solubility between 55°C and 90°C. In a study with goat and lamb meat, roasting in a domestic oven was compared to industrial microwave heating methods (Yarmand and Homayouni 2009). Roasted samples of *semimembranosus* muscles, which were cooked conventionally in a domestic oven (700 W) to an internal temperature of 70°C, had greater fat retention for both species than did the goat and lamb meat cooked in an industrial oven to 70°C (12 000 W). Although the effects of thermal processing on meat quality have been conducted in many studies including in beef (Bertola *et al.* 1994; Vasanthi *et al.* 2007), pork (Bejerholm and Aaslyng 2004) and chicken (Murphy and Marks 2000; Wattanachant *et al.* 2005), very few studies have been conducted using goat meat.

The other factors contributing to poor goat meat quality are low subcutaneous fat cover, low carcass weight and cooling/freezing being applied prior to rigor onset, all of which are well known to increase the likelihood of cold-shortening and toughening in the carcass musculature. When exposed to typical chilling temperatures of 1–4°C, cold-shortening in rapidly chilled carcasses and toughening is a known problem in the goat meat industry. Pophiwa *et al.* (2017) proposed delayed chilling (10–15°C for 6 h, 0–4°C until 24 h) as a strategy to minimise cold-shortening in goat carcasses. Research has clearly shown that medium voltage (330 V) electrical stimulation is beneficial for enhancing the postmortem glycolysis, pH decline and tenderness in goat meat (King *et al.* 2004; Biswas *et al.* 2007). However, the installation cost restricts small-scale processing plants from adopting the technology.

While there is limited research on ageing and goat meat quality, 6 days of ageing improved tenderness by about 12% in *semimembranosus* muscle (Simela *et al.* 2004) and 15–37% in four muscles (*longissimus thoracis et lumborum, biceps femoris, semitendinosus, semimembranosus*) in three Omani goat breeds (Kadim *et al.* 2004).

Flavour

Meat flavour is a fundamental sensory characteristic in meat that influences the eating quality and, thus, consumer acceptance (Arshad *et al.* 2018). In goats and sheep, flavour and aroma are complex attributes that can be affected by breed (Ivanović *et al.* 2020), age (Smith *et al.* 1978; Sheridan *et al.* 2003; Saccà *et al.* 2019), backfat depth (Schönfeldt *et al.* 1993), sex (Rodrigues and Teixeira 2009), diet (Oliveira *et al.* 2015; Ivanović *et al.* 2020), and cooking methods (Murphy and Marks 2000; Liu *et al.* 2013). Branched-chain fatty acids (BCFA) contribute to the typical sheep and goat species flavour (Johnson *et al.* 1977). The robust species-related flavour in goat and sheep meat is associated with the specific fatty acid 4-ethyloctanoic acid (Madruga *et al.* 2000). Goat meat has a 'gamier', metallic and liver-odour flavour compared with lamb (Mandolesi *et al.* 2020). In a recent study by Ivanović *et al.* (2020) in three goat breeds, alpha-linolenic (n-3 fatty acid) and linoleic acids were found predominantly in Balkan goat meat, while Alpine goat meat had the highest amounts of linoleic acid among the three goat breeds. Also, the overall sensory acceptability was higher for Balkan goat meat. Previously, it was reported that long-chain fatty acids (8–10 carbon length) and 4-methyl-BCFAs, specifically 4-Me-8:0 (methyl octanoic acid) and 4-Me-9:0 (methyl nonanoic acid), were responsible for the distinct mutton flavour (Wong *et al.* 1975*a*; Young *et al.* 1997). In another study in goats, Wong *et al.* (1975*b*) showed that concentration of 4-Me-8:0 and 4-Me-9:0 was higher in goat and barley-fed mutton than in non-grain-fed mutton. The sensory tests also showed higher scores for 'goatiness' in minced samples spiked with 4-Me-8:0 and 4-Me-9:0, than in samples without added 4-Me-8:0 and 4-Me-9:0 (Wong *et al.* 1975*a*). Watkins *et al.* (2014) showed that the 'overall liking' and 'liking of smell' scores of grilled lamb assessed by the Australian consumers was negatively influenced by the concentration of 4-Me-8:0 and 4-Et-8:0 (ethyl octanoic acid). Watkins *et al.* (2014) also showed that due to the very low odour sensory threshold of consumers for 4-Me-8:0 and 4-Et-8:0, these compounds have very strong effects on consumer liking of flavour at very low concentrations. Similarly, Castada *et. al* (2017) reported that the higher concentrations of 4-Me-8:0, 4-Me-9:0 and 4-Et-8:0 corresponded with greater lamb flavour intensity rating by US consumers. The limited data described above emphasise the limitations in understanding the flavour chemistry of goat meat, hence further research is required.

Constraints to improving eating quality consistency of goat meat

One of the critical issues being faced by the goat meat industry is the lack of consistency in meat quality, and the lack of standardised slaughter weight and age. For example, it is unknown whether the meat of heavier goats (>40 kg) is acceptable to consumers (Brand *et al.* 2018). The temperature at which the loin muscle enters rigor (pH 6.0) can be used to predict the meat quality (Thompson *et al.* 2005). If the carcass temperature falls too rapidly before rigor mortis sets in, then cold-shortening occurs, which results in meat toughness (Tornberg *et al.* 1994). Goat carcasses are especially prone to cold-shortening-induced toughness because of their leaner carcass, resulting in a higher surface area to volume ratio. This is particularly relevant for kid carcasses, which are very light-weight carcasses, hence the rate of temperature decline in the muscle is much faster than for adult goats of 2 years (Abhijith *et al.* 2020). Electrical stimulation is a well established processing technique to improve meat quality (Devine *et al.* 2001; King *et al.* 2004; Kadim *et al.* 2010), but the adoption of this technique among goat-processing plants is minimal. Toohey and Hopkins (2007) suggested that the implementation of electrical stimulation in goat-processing plants could prevent carcasses from entering rigor at low temperatures. Future research should focus on this fundamental concept and evaluate the adoption of electrical stimulation in goat-meat processing plants for better eating quality. Assuring adequate on-farm nutrition is important for the beneficial effect of electrical stimulation to be achieved in goat meat quality, because electrical stimulation can hasten postmortem glycolysis only if glycogen concentration is sufficiently high and above a threshold of 45–55 mmol/g (Devine *et al.* 2001; Warner *et al.* 2005). Thus, electrical stimulation may not be able to prevent cold-shortening if the muscle glycogen concentration is

Table 4. Recommendations to improve the goat meat industry in Australia relevant to producers, processors and government departments/agencies.

Recommendation	Relevant sector	Beneficial outcome	Current status
1. Implementation of carcass tracking by using identification systems such as NLIS regardless of age and breed of animal	State and territory government Departments of Agriculture or Primary Industries and key agencies such as MLA	• Processors can record carcass characteristics, and carcass defect information and provide this information to producers through either the NLIS database or the Livestock Data Link system managed by Integrity Systems Company (ISC), or as part of feedback sheets sent directly to producers, which would assist producers in breed improvement	• Harvested rangeland goats, Saanen, British Alpine, Toggenburg, Anglo Nubian, Melaan, Australian Brown, Lamancha and Nigerian Dwarf dairy goat breeds, and miniature goat breeds are exempt from tagging requirements
2. Development of semi-intensive feeding systems with high-energy diets or feed-lotting of rangeland goats	Producers	• This is an on-farm pre-slaughter strategy that would ensure optimum nutrition	• Limited research on feed-lotting in rangeland goats warrants further research
3. Development of an industry-wide standard to distinguish different types of goat meat (defining age, sex, breed, carcass weight etc.) similar to MSA grading to inform consumers on the quality of purchased meat cuts	Primarily researchers and producer agencies such as MLA	• This limits the bad eating experience for first-time consumers who are not familiar with eating goat meat • Provides consumers with clear reference points from their previous meat consumption (similar to cooking grass vs grain fed steak on the BBQ)	• Lacks proper grading/classification system
4. Adoption of stress-free transportation • Select a transport firm with clean trucks, trained stockmen and drivers • Handle goats with the least stress from the holding paddock and loading onto trucks	Producers, livestock transport companies, and processors	• Reduces the pre-slaughter glycogen depletion	• Needs to make it mandatory and also educate the abattoir workers on the importance of proper handling in the abattoir
5. Implementation of electrical stimulation of whole carcasses pre-rigour and standardisation of post-mortem ageing period	Primarily abattoir owners and operators in collaboration with industry organisations such as MLA, research institutions, government agencies, and technology providers	• Electrical stimulation has the potential to provide consistent meat quality by attaining the optimum pH–temperature window and reducing the incidence of cold-shortening • Postmortem ageing can significantly reduce the toughness of goat meat	• Electrical stimulation is currently practised in sheep, lamb and beef, but not in goats • There is no standardised aging requirement specifically for goat meat, as there is for beef
6. Development of cooking innovation methods such as sous-vide cooking	Chefs, culinary experts, food researchers and meat scientists	• Better use of labour and equipment through centralised production • Reduced need for flavour enhancers, better preservation of vitamins, retention of juiciness, • Better tenderness and consistent eating experience	• Long cooking times required for innovative cooking methods often makes it uneconomical, which perhaps explains why it is not widely adopted in the meat industry
7. Development of MSA cut and cooking-method combinations	Primarily researchers and government agencies such as MLA	• Avoids bad eating experiences for inexperienced consumers	• Recently developed in sheep, not developed in goats

below this threshold (Monin 1981; Warriss 1990). Dutson *et al.* (1981) showed no change in ultimate pH following electrical stimulation, when heifers were stressed antemortem, which resulted in a high ultimate pH of 6.6.

The effect of type of goat (rangeland vs farmed), ageing rate, type of ageing and ageing duration of goat meat on meat quality also warrants research. Wet-ageing, which is an innovative method for improving tenderness and has been recently recommended to increase mutton consumption (Hastie *et al.* 2022), must be explored to improve the tenderness of goat meat. Although Australian goats are rarely finished in semi-intensive production systems and/or feedlots and are mostly reared in extensive rangeland systems, goat production by intensive feeding may improve quality; hence, the influence of the energy content requirement of the diet should be clearly understood. Recently, Dieters *et al.* (2021) reported that meat-quality characteristics of lot-fed Australian rangeland goats were unaffected by liveweight at slaughter. In this study, the goats were fed Mitchell grass (*Astrebla lappacea*) hay and a commercially available finisher pellets *ad libitum* for 42 days. Feedlotting of boer goats has been researched in some depth by Brand *et al.* (2018) in South Africa. The palatability and chemical composition of *longissimus lumborum* muscles from 24 castrate Boer goats weaned from their dams at an average age of ~18 weeks of age, finished on diets varying in energy content (9.7, 10.2 and 10.6 MJ ME/kg feed), and slaughtered at an average live bodyweight of 48 kg, were evaluated. The study reported that the energy content of the finisher diet had no effect on the sensory attributes, or physical or chemical properties of the meat.

Consumers have some unique perceptions about goat meat, which are not easily changed, such as the toughness and poor flavour (Sheridan *et al.* 2003). However, innovation in the industry and the supply chain can play a key role in increasing domestic acceptance and consumption of goat meat. Potential post-slaughter innovations include how the meat is cooked, muscle-specific cooking methods, and value-adding methods such as ageing. Age and weight of goats for slaughter, considering the eating quality of meat rather than just the dressing percentage and carcass yield, needs to be determined. Recently, consumer taste-testing results showed that the Australian goat meat has a high acceptance among domestic consumers (MLA 2022). The consumers scored goat meat on average over 50 points, which is considered as a 'good every-day product'. This report also suggested the need for more cut-by-cook research for goat meat, which has the potential to improve the domestic demand for goat meat. Table 4 summarises some of the relevant recommendations to overcome the current barriers for the goat meat industry in Australia.

Conclusions

There are numerous gaps in knowledge regarding market potential and demand for the goat meat sector. Some key factors to be addressed by the goat industry so as to improve meat eating quality and consistency are as follows:

1. The need for producers to supply processors with consistent lines of goats and producer understanding of market requirements are essential for growing the goat production industry.
2. Developing standard practices for grading goat meat similar to those for MSA sheep meat is recommended, including identification of suitable interventions in goat feeding, handling and processing practices to achieve consistent goat meat quality.
3. It is critical to manage and reduce ante-mortem stress, including transportation and handling stress, to ensure minimal glycogen depletion pre-slaughter and thereby achieving an optimum meat ultimate.
4. Adoption of industrial technology such as electrical stimulation will significantly increase the yield of consistent meat quality.
5. Changing from extensive to semi-intensive farming/feedlot systems would allow producers to effectively manipulate nutrition and ensure that goats have a sufficient muscle glycogen concentration prior to slaughter.
6. Cooking methods such as slow and moist cooking should be promoted to enhance the eating experience, especially for non-ethnic consumers unfamiliar with goat meat. In addition, promoting sous-vide cooking provides the opportunity to provide consumers with juicier, more tender and more flavourful meat than the dry and tough meat regularly found with faster cooking methods.

References

Abhijith A, Warner RD, Ha M, Dunshea FR, Leury BJ, Zhang M, J Aleena, Osei-Amponsah R, Chauhan SS (2020) Effect of Boer goat age on meat quality. In 'Proceedings of the 66th International Congress of Meat Science and Technology and the 73rd Reciprocal Meat Conference', pp. 81–82. (American Meat Science Association, Orlando, Florida, USA)

Abhijith A, Warner RD, Ha M, Dunshea FR, Leury BJ, Zhang M, Joy A, Osei-Amponsah R, Chauhan SS (2021*a*) Effect of slaughter age and post-mortem days on meat quality of longissimus and semimembranosus muscles of Boer goats. *Meat Science* **175**, 108466. doi:10.1016/j.meatsci.2021.108466

Abhijith A, Sejian V, Ruban W, Krishnan G, Bagath M, Pragna P, Manjunathareddy GB, Bhatta R (2021*b*) Summer season induced heat stress associated changes on meat production and quality characteristics, myostatin and HSP70 gene expression patterns in indigenous goat. *Small Ruminant Research* **203**, 106490. doi:10.1016/j.smallrumres.2021.106490

Adeyemi KD, Ebrahimi M, Samsudin AA, Sabow AB, Sazili AQ (2015) Carcass traits, meat yield and fatty acid composition of adipose tissues and *Supraspinatus* muscle in goats fed blend of canola oil and palm oil. *Journal of Animal Science and Technology* **57**(1), 1–14. doi:10.1186/s40781-015-0076-y

AgriFutures (2016) Meat goats. AgriFutures Australia. Availabe at https://www.agrifutures.com.au/farm-diversity/meat-goats/ [Posted 24 May 2017]

Archana PR, Sejian V, Ruban W, Bagath M, Krishnan G, Aleena J, Manjunathareddy GB, Beena V, Bhatta R (2018) Comparative assessment of heat stress induced changes in carcass traits, plasma leptin profile and skeletal muscle myostatin and HSP70 gene expression patterns between indigenous Osmanabadi and Salem Black goat breeds. *Meat Science* **141**, 66–80. doi:10.1016/j.meatsci.2018.03.015

Argüello A, Castro N, Capote J, Solomon M (2005) Effects of diet and live weight at slaughter on kid meat quality. *Meat Science* **70**, 173–179. doi:10.1016/j.meatsci.2004.12.009

Arshad MS, Sohaib M, Ahmad RS, Nadeem MT, Imran A, Arshad MU, Kwon J-H, Amjad Z (2018) Ruminant meat flavour influenced by different factors with special reference to fatty acids. *Lipids in Health and Disease* **17**, 223. doi:10.1186/s12944-018-0860-z

Aymerich MT, Garriga M, Costa S, Monfort JM, Hugas M (2002) Prevention of ropiness in cooked pork by bacteriocinogenic cultures. *International Dairy Journal* **12**, 239–246. doi:10.1016/S0958-6946(01)00143-1

Bakhsh A, Hwang Y-H, Joo S-T (2019) Effect of slaughter age on muscle fiber composition, intramuscular connective tissue and tenderness of goat meat during post-mortem time. *Foods* **8**(11), 571. doi:10.3390/foods8110571

Baldwin DE (2012) Sous vide cooking: a review. *International Journal of Gastronomy and Food Science* **1**(1), 15–30. doi:10.1016/j.ijgfs.2011.11.0

Basinger KL (2016) Age end-point effects on performance, carcass measurements, and tenderness in goats. MSc thesis, University of Arkansas, USA.

Bejerholm C, Aaslyng MD (2004) The influence of cooking technique and core temperature on results of a sensory analysis of pork—depending on the raw meat quality. *Food Quality and Preference* **15**, 19–30. doi:10.1016/S0950-3293(03)00018-1

Bertola NC, Bevilacqua AE, Zaritzky NE (1994) Heat treatment effect on texture changes and thermal denaturation of proteins in beef muscle. *Journal of Food Processing and Preservation* **18**, 31–46. doi:10.1111/j.1745-4549.1994.tb00240.x

Biswas S, Das AK, Banerjee R, Sharma N (2007) Effect of electrical stimulation on quality of tenderstretched chevon sides. *Meat Science* **75**, 332–336. doi:10.1016/j.meatsci.2006.08.002

Bonny SPF, O'Reilly RA, Pethick DW, Gardner GE, Hocquette J-F, Pannier L (2018) Update of Meat Standards Australia and the cuts based grading scheme for beef and sheepmeat. *Journal of Integrative Agriculture* **17**, 1641–1654. doi:10.1016/S2095-3119(18)61924-0

Brand TS, Van Der Merwe DA, Hoffman LC, Geldenhuys G (2018) The effect of dietary energy content on quality characteristics of Boer goat meat. *Meat Science* **139**, 74–81. doi:10.1016/j.meatsci.2018.01.018

Burvill T (2016) 'Dry aged lamb proof of concept stage 2.' (Meat & Livestock Australia: Sydney, NSW, Australia)

Calkins CR, Dutson TR, Smith GC, Carpenter ZL, Davis GW (1981) Relationship of fiber type composition to marbling and tenderness of bovine muscle. *Journal of Food Science* **46**, 708–710. doi:10.1111/j.1365-2621.1981.tb15331.x

Casey NH (1983) Carcass and growth characteristics of four South African sheep breeds and the Boer goat. Doctoral dissertation, Universiteit van Pretoria, South Africa.

Castada HZ, Polentz V, Barringer S, Wick M (2017) Temperature-dependent Henry's Law constants of 4-alkyl branched-chain fatty acids and 3-methylindole in an oil-air matrix and analysis of volatiles in lamb fat using selected ion flow tube mass spectrometry. *Rapid Communications in Mass Spectrometry* **31**, 2135–2145. doi:10.1002/rcm.8007

Chauhan SS, England EM (2018) Postmortem glycolysis and glycogenolysis: insights from species comparisons. *Meat Science* **144**, 118–126. doi:10.1016/j.meatsci.2018.06.021

Chauhan SS, LeMaster MN, Clark DL, Foster MK, Miller CE, England EM (2019) Glycolysis and pH decline terminate prematurely in oxidative muscles despite the presence of excess glycogen. *Meat and Muscle Biology* **3**(1), 254–264. doi:10.22175/mmb2019.02.0006

Devine CE, Wells R, Cook CJ, Payne SR (2001) Does high voltage electrical stimulation of sheep affect rate of tenderisation? *New Zealand Journal of Agricultural Research* **44**, 53–58. doi:10.1080/00288233.2001.9513462

Dhanda JS, Taylor DG, Murray PJ, Pegg RB, Shand PJ (2003) Goat meat production: present status and future possibilities. *Asian–Australasian Journal of Animal Sciences* **16**, 1842–1852. doi:10.5713/ajas.2003.1842

Dieters LSE, Meale SJ, Quigley SP, Hoffman LC (2021) Meat quality characteristics of lot-fed Australian Rangeland goats are unaffected by live weight at slaughter. *Meat Science* **175**, 108437. doi:10.1016/j.meatsci.2021.108437

Dutson T, Savell J, Smith G (1981) Electrical stimulation of ante mortem stressed beef. In 'The problem of dark-cutting in beef'. (Eds DE Hood, PV Tarrant) pp. 253–268. (Springer: Netherlands)

Eneji CA, Kalio GA, Oko OOK (2012) Sensory evaluation of meat of west African Dwarf goats fed crop by-products in Cross River State, Nigeria. *Journal of Agricultural Science* **4**, 201–208. doi:10.5539/jas.v4n4p201

Eneji CA, Kalio GA, Kennedy-Oko O (2015) Carcass composition of West African Dwarf (WAD) goats fed cassava peel-based diets. *Journal of Food Research* **4**(1), 168. doi:10.5539/jfr.v4n1p168

England EM, Matarneh SK, Scheffler TL, Wachet C, Gerrard DE (2014) pH inactivation of phosphofructokinase arrests postmortem glycolysis. *Meat Science* **98**(4), 850–857. doi:10.1016/j.meatsci.2014.07.019

England EM, Matarneh SK, Oliver EM, Apaoblaza A, Scheffler TL, Shi H, Gerrard DE (2016) Excess glycogen does not resolve high ultimate pH of oxidative muscle. *Meat science* **114**, 95–102. doi:10.1016/j.meatsci.2015

Forrest JC, Aberle ED, Hedrick HB, Judge MD, Merkel RA (1975) 'Principles of meat science.' p. 417. (WH Freeman and Co.: UK)

Gardner GE, Kennedy L, Milton JTB, Pethick DW (1999) Glycogen metabolism and ultimate pH of muscle in Merino, first-cross, and second-cross wether lambs as affected by stress before slaughter. *Australian Journal of Agricultural Research* **50**(2), 175–182. doi:10.1071/A98093

Geesink GH, Koolmees PA, van Laack HLJM, Smulders FJM (1995) Determinants of tenderisation in beef *Longissimus dorsi* and *Triceps brachii* muscles. *Meat Science* **41**(1), 7–17. doi:10.1016/0309-1740(94)00066-G

GICA (2015) Goat meat and livestock Industry Strategic Plan 2020. Goat Industry Council of Australia. Available at https://www.goatindustrycouncil.com.au/project-policies/research [Verified 7 June 2023]

Goetsch AL, Merkel RC, Gipson TA (2011) Factors affecting goat meat production and quality. *Small Ruminant Research* **101**(1–3), 173–181. doi:10.1016/j.smallrumres.20

Griffin CL, Orcutt MW, Riley RR, Smith GC, Savell JW, Shelton M (1992) Evaluation of palatability of lamb, mutton, and chevon by sensory panels of various cultural backgrounds. *Small Ruminant Research* **8**(1–2), 67–74. doi:10.1016/0921-4488(92)90008-R

Grunert KG, Bredahl L, Brunsø K (2004) Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat science* **66**(2), 259–272. doi:10.1016/S0309-1740(03)00130-X

Hamm R (1996) The influence of pH on the protein net charge in the myofibrillar system. *Fleischwirtschaft* **76**(12), 1335–1337.

Hastie M, Ha M, Jacob RH, Hepworth G, Torrico DD, Warner RD (2022) High consumer acceptance of mutton and the influence of ageing method on eating quality. *Meat Science* **189**, 108813. doi:10.1016/j.meatsci.2022.108813

Hwang Y-H, Kim G-D, Jeong J-Y, Hur S-J, Joo S-T (2010) The relationship between muscle fiber characteristics and meat quality traits of highly marbled Hanwoo (Korean native cattle) steers. *Meat Science* **86**, 456–461. doi:10.1016/j.meatsci.2010.05.034

Hwang Y-H, Bakhsh A, Lee J-G, Joo S-T (2019) Differences in muscle fiber characteristics and meat quality by muscle type and age of Korean native black goat. *Food Science of Animal Resources* **39**, 988–989. doi:10.5851/kosfa.2019.e92

Ismail I, Hwang YH, Joo ST (2019) Interventions of two-stage thermal sous-vide cooking on the toughness of beef semitendinosus. *Meat Science* **157**, 107882. doi:10.1016/j.meatsci.2019.1

Ithurralde J, Bianchi G, Feed O, Nan F, Ballesteros F, Garibotto G, Bielli A (2017) Variation in instrumental meat quality among 15 muscles from 14-month-old sheep and its relationship with fibre typing. *Animal Production Science* **58**(7), 358–1365. doi:10.1071/AN16013

Ivanović S, Pavlović I, Pisinov B (2016) The quality of goat meat and it's impact on human health. *Biotechnology in Animal Husbandry* **32**, 111–122. doi:10.2298/BAH1602111I

Ivanović S, Pavlović M, Pavlović I, Tasić A, Janjić J, Baltić MŽ (2020) Influence of breed on selected quality parameters of fresh goat meat. *Archives Animal Breeding* **63**, 219–229. doi:10.5194/aab-63-219-2020

Jenkinson D (2017) 'Value adding meat for domestic consumers.' (Meat & Livestock Australia: Sydney, NSW, Australia)

Johnson CB, Wong E, Birch EJ, Purchas RW (1977) Analysis of 4-methyloctanoic acid and other medium chain-length fatty acid constituents of ovine tissue lipids. *Lipids* **12**, 340–347. doi:10.1007/BF02533636

Jones A (2012) Rangeland goat production in western NSW. Orange Agricultural Institute, NSW, Australia.

Kadim IT, Mahgoub O, Al-Ajmi DS, Al-Maqbaly RS, Al-Saqri NM, Ritchie A (2004) An evaluation of the growth, carcass and meat quality characteristics of Omani goat breeds. *Meat Science* **66**, 203–210. doi:10.1016/S0309-1740(03)00092-5

Kadim IT, Mahgoub O, Al-Kindi A, Al-Marzooqi W, Al-Saqri NM (2006) Effects of transportation at high ambient temperatures on physiological responses, carcass and meat quality characteristics of three breeds of Omani goats. *Meat Science* **73**, 626–634. doi:10.1016/j.meatsci.2006.03.003

Kadim IT, Mahgoub O, Al-Marzooqi W, Khalaf S, Al-Sinawi SSH, Al-Amri I (2010) Effects of transportation during the hot season, breed and electrical stimulation on histochemical and meat quality characteristics of goat *longissimus* muscle. *Animal Science Journal* **81**, 352–361. doi:10.1111/j.1740-0929.2009.00722.x

Kadim IT, Mahgoub O, Khalaf S (2014) Effects of the transportation during hot season and electrical stimulation on meat quality characteristics of goat *Longissimus dorsi* muscle. *Small Ruminant Research* **121**, 120–124. doi:10.1016/j.smallrumres.2014.01.010

Kaewthong P, Wattanachant C, Wattanachant S (2021) Improving the quality of barbecued culled-dairy-goat meat by marination with plant juices and sodium bicarbonate. *Journal of Food Science and Technology* **58**, 333–342. doi:10.1007/s13197-020-04546-8

Kannan G, Kouakou B, Terrill TH, Gelaye S (2003) Endocrine, blood metabolite, and meat quality changes in goats as influenced by short-term, preslaughter stress. *Journal of Animal Science* **81**(6), 1499–1507. doi:10.2527/2003.8161499x

Kannan G, Gutta VR, Lee JH, Kouakou B, Getz WR, McCommon GW (2014) Preslaughter diet management in sheep and goats: effects on physiological responses and microbial loads on skin and carcass. *Journal of Animal Science and Biotechnology* **5**, 42. doi:10.1186/2049-1891-5-42

Karakuş F, Yıl Y (2006) Consumer preferences on sheep and goat meat in the world. In '57th EAAP Annual Meeting'. p. 208. (European Association for Animal Production, Antalya, Turkey)

Karthik J, Abraham RJJ, Rao VA, Parthiban M, Babu RN (2017) A survey on preferred slaughter age of goats in Tamil Nadu, India. *International Journal of Current Microbiology and Applied Sciences* **6**, 285–287. doi:10.20546/ijcmas.2017.610.035

Kim G-D, Jeong J-Y, Jung E-Y, Yang H-S, Lim H-T, Joo S-T (2013) The influence of fiber size distribution of type IIB on carcass traits and meat quality in pigs. *Meat Science* **94**, 267–273. doi:10.1016/j.meatsci.2013.02.001

King DA, Voges KL, Hale DS, Waldron DF, Taylor CA, Savell JW (2004) High voltage electrical stimulation enhances muscle tenderness, increases aging response, and improves muscle color from cabrito carcasses. *Meat Science* **68**, 529–535. doi:10.1016/j.meatsci.2004.05.003

Knee BW, Cummins LJ, Walker P, Warner R (2004) Seasonal variation in muscle glycogen in beef steers. *Australian Journal of Experimental Agriculture* **44**, 729–734. doi:10.1071/EA03044

Knee BW, Cummins LJ, Walker PJ, Kearney GA, Warner RD (2007) Reducing dark-cutting in pasture-fed beef steers by high-energy supplementation. *Australian Journal of Experimental Agriculture* **47**, 1277–1283. doi:10.1071/EA05362

Knight EP, House L, Nelson MC, Degner RL (2006) An evaluation of consumer preferences regarding goat meat in the South. *Journal of Food Distribution Research* **37**, 88–96.

Kumar P, Abubakar AA, Ahmed MA, Hayat MN, Kaka U, Pateiro M, Sazili AQ, Hoffman LC, Lorenzo JM (2023) Pre-slaughter stress mitigation in goats: prospects and challenges. *Meat Science* **195**, 109010. doi:10.1016/j.meatsci.2022.109010

Lang Y, Zhang S, Xie P, Yang X, Sun B, Yang H (2020) Muscle fiber characteristics and postmortem quality of *longissimus thoracis*, psoas major and semitendinosus from Chinese Simmental bulls. *Food Science & Nutrition* **8**, 6083–6094. doi:10.1002/fsn3.1898

Lefaucheur L (2010) A second look into fibre typing – relation to meat quality. *Meat Science* **84**, 257–270. doi:10.1016/j.meatsci.2009.05.004

Liu F, Meng L, Gao X, Li X, Luo H, Dai R (2013) Effect of end point temperature on cooking losses, shear force, color, protein solubility and microstructure of goat meat. *Journal of Food Processing and Preservation* **37**, 275–283. doi:10.1111/j.1745-4549.2011.00646.x

Madruga MS, Arruda SGB, Narain N, Souza JG (2000) Castration and slaughter age effects on panel assessment and aroma compounds of the 'mestiço' goat meat. *Meat Science* **56**, 117–125. doi:10.1016/S0309-1740(00)00025-5

Mandolesi S, Naspetti S, Arsenos G, Caramelle-Holtz E, Latvala T, Martin-Collado D, Orsini S, Ozturk E, Zanoli R (2020) Motivations and barriers for sheep and goat meat consumption in Europe: a means–end chain study. *Animals* **10**, 1105. doi:10.3390/ani10061105

Martens H, Stabursvik E, Martens M (1982) Texture and colour changes in meat during cooking related to thermal denaturation of muscle proteins. *Journal of Texture Studies* **13**, 291–309. doi:10.1111/j.1745-4603.1982.tb00885.x

Mehjabin S, Amin MR, Faruque MO, Sarker MB (2016) Effect of age and sex on meat quality and quantity of Black Bengal goat. *Bangladesh Journal of Animal Science* **45**, 19–24. doi:10.3329/bjas.v45i1.27483

MLA (2006) 'Going into goats.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2011) 'National procedures and guidelines for intensive sheep and lamb feeding systems.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2018) 'How MSA beef is graded.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2019) 'The effect of cut and cooking method on sheepmeat eating quality.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2020) 'Global snapshot: goat meat.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2021) 'Going into goats: profitable producers' best practice guide – module 8 – marketing.' (Meat & Livestock Australia: Sydney, NSW, Australia)

MLA (2022) 'Goatmeat put to the taste test.' (Meat & Livestock Australia: Sydney, NSW, Australia)

Monin G (1981) Muscle metabolic type and the DFD condition. In 'The problem of dark-cutting in beef'. (Eds DE Hood, PV Tarrant) pp. 63–85. (Springer)

Murphy RY, Marks BP (2000) Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. *Poultry Science* **79**, 99–104. doi:10.1093/ps/79.1.99

National Livestock Identification Service (NLIS) (2020) NLIS sheep and goats standards. Available at nlis-sheep-and-goat-standards-booklet.pdf (integritysystems.com.au)

National Livestock Reporting Service (NLRS) (2022) Over the hooks report. Available at https://www.mla.com.au/prices-markets/oth/ [Verified 6 July 2022]

Nikbin S, Panandam JM, Sazili AQ (2016) Influence of pre-slaughter transportation and stocking density on carcass and meat quality characteristics of Boer goats. *Italian Journal of Animal Science* **15**, 504–511. doi:10.1080/1828051X.2016.1217752

Nogueira DM, Gummow B, Gardiner CP, Cavalieri J, Fitzpatrick LA, Parker AJ (2016) A survey of the meat goat industry in Queensland and New South Wales. 2. Herd management, reproductive performance and animal health. *Animal Production Science* **56**, 1533–1544. doi:10.1071/AN14794

Oliveira RL, Palmieri AD, Carvalho ST, Leão AG, de Abreu CL, Ribeiro CVDM, Pereira ES, de Carvalho GGP, Bezerra LR (2015) Commercial cuts and chemical and sensory attributes of meat from crossbred Boer goats fed sunflower cake-based diets. *Animal Science Journal* **86**, 557–562. doi:10.1111/asj.12325

Oz F, Aksu MI, Turan M (2017) The effects of different cooking methods on some quality criteria and mineral composition of beef steaks. *Journal of Food Processing and Preservation* **41**, e13008. doi:10.1111/jfpp.13008

Park B, Yong HI, Choe J, Jo C (2018) Utilization of the crust from dry-aged beef to enhance flavor of beef patties. *Korean Journal for Food Science of Animal Resources* **38**, 1019. doi:10.5851/kosfa.2018.e35

Pethick D, Rowe J, Tudor G (1995) Glycogen metabolism and meat quality. *Recent Advances in Animal Nutrition in Australia* **7**, 97–103.
Peña F, Bonvillani A, Freire B, Juárez M, Perea J, Gómez G (2009) Effects of genotype and slaughter weight on the meat quality of Criollo Cordobes and Anglonubian kids produced under extensive feeding conditions. *Meat Science* **83**, 417–422. doi:10.1016/j.meatsci.2009.06.017
Picard B, Gagaoua M (2020) Muscle fiber properties in cattle and their relationships with meat qualities: an overview. *Journal of Agricultural and Food Chemistry* **68**, 6021–6039. doi:10.1021/acs.jafc.0c02086
Pike MI, Smith GC, Carpente ZL (1973) Palatability ratings for meat from goats and other meat animal species. *Journal of Animal Science* **37**, 61826–7410.
Pinkerton F, Harwell L, Drinkwater W, Escobar N (1994) 'Consumer demand for goat meat.' (Virginia Department of Agriculture and Consumer Sciences, USA)
Pophiwa P, Webb EC, Frylinck L (2017) Carcass and meat quality of Boer and indigenous goats of South Africa under delayed chilling conditions. *South African Journal of Animal Science* **47**, 794–803. doi:10.4314/sajas.v47i6.7
Possamai APS, Alcalde CR, Feihrmann AC, Possamai ACS, Rossi RM, Lala B, Claudino-Silva SC, Macedo FdAF (2018) Shelf life of meat from Boer-Saanen goats fed diets supplemented with vitamin E. *Meat Science* **139**, 107–112. doi:10.1016/j.meatsci.2018.01.011
Pratiwi NMW, Murray PJ, Taylor DG (2007) Feral goats in Australia: a study on the quality and nutritive value of their meat. *Meat Science* **75**, 168–177. doi:10.1016/j.meatsci.2006.06.026
Purslow PP (2014) New developments on the role of intramuscular connective tissue in meat toughness. *Annual Review of Food Science and Technology* **5**, 133–153. doi:10.1146/annurev-food-030212-182628
Purslow PP (2018) Contribution of collagen and connective tissue to cooked meat toughness; some paradigms reviewed. *Meat Science* **144**, 127–134. doi:10.1016/j.meatsci.2018.03.026
Putra AA, Wattanachant S, Wattanachant C (2017) Potency of culled Saanen crossbred goat in supplying raw meat for traditional Thai butchery. *Media Peternakan* **40**, 128–135. doi:10.5398/medpet.2017.40.2.128
Putra AA, Wattanachant S, Wattanachant C (2019) Sensory-related attributes of raw and cooked meat of culled Saanen goat marinated in ginger and pineapple juices. *Tropical Animal Science Journal* **42**, 59–67. doi:10.5398/tasj.2019.42.1.59
Rhee KS, Myers CE, Waldron DF (2003) Consumer sensory evaluation of plain and seasoned goat meat and beef products. *Meat Science* **65**, 785–789. doi:10.1016/S0309-1740(02)00283-8
Rhee MS, Wheeler TL, Shackelford SD, Koohmaraie M (2004) Variation in palatability and biochemical traits within and among eleven beef muscles. *Journal of Animal Science* **82**, 534–550. doi:10.2527/2004.822534x
Ripoll G, Alcalde MJ, Horcada A, Panea B (2011) Suckling kid breed and slaughter weight discrimination using muscle colour and visible reflectance. *Meat Science* **87**, 151–156. doi:10.1016/j.meatsci.2010.10.006
Rodrigues S, Teixeira A (2009) Effect of sex and carcass weight on sensory quality of goat meat of Cabrito Transmontano. *Journal of Animal Science* **87**, 711–715. doi:10.2527/jas.2007-0792
Saccà E, Corazzin M, Bovolenta S, Piasentier E (2019) Meat quality traits and the expression of tenderness-related genes in the loins of young goats at different ages. *Animal* **13**, 2419–2428. doi:10.1017/S1751731119000405
Sans P, Combris P (2015) World meat consumption patterns: an overview of the last fifty years (1961–2011). *Meat Science* **109**, 106–111. doi:10.1016/j.meatsci.2015.05.012
Santos NL, Sousa WHd, Gomes MdGC, Batista ASM, Ramos JPFd, Cartaxo FQ, Lira AB, Cavalcante ITR (2020) Meat quality of suckling goat raised in differents feeding systems. *Acta Scientiarum. Animal Sciences* **42**, e46547. doi:10.4025/actascianimsci.v42i1.46547
Savell JW, Smith GC, Dutson TR, Carpenter ZL, Suter DA (1977) Effect of electrical stimulation on palatability of beef, lamb and goat meat. *Journal of Food Science* **42**, 702–706. doi:10.1111/j.1365-2621.1977.tb12583.x
Sazili AQ, Parr T, Sensky PL, Jones SW, Bardsley RG, Buttery PJ (2005) The relationship between slow and fast myosin heavy chain content, calpastatin and meat tenderness in different ovine skeletal muscles. *Meat Science* **69**, 17–25. doi:10.1016/j.meatsci.2004.06.021
Schwartz M, Marais J, Strydom PE, Hoffman LC (2022) Effects of increasing internal end-point temperatures on physicochemical and sensory properties of meat: a review. *Comprehensive Reviews in Food Science and Food Safety* **21**, 2843–2872. doi:10.1111/1541-4337.12948
Schönfeldt HC, Naude RT, Bok W, van Heerden SM, Sowden L, Boshoff E (1993) Cooking-and juiciness-related quality characteristics of goat and sheep meat. *Meat Science* **34**, 381–394. doi:10.1016/0309-1740(93)90085-V
Sheridan R, Hoffman LC, Ferreira AV (2003) Meat quality of Boer goat kids and Mutton Merino lambs 2. Sensory meat evaluation. *Animal Science* **76**, 73–79. doi:10.1017/S1357729800053339
Simela L (2007) Meat characteristics and acceptability of chevon from South African indigenous goats. PhD thesis, University of Pretoria, South Africa.
Simela L, Webb E, Frylinck L (2004) Post-mortem metabolic status, pH and temperature of chevon from indigenous South African goats slaughtered under commercial conditions. *South African Journal of Animal Science* **34**, 204–206.
Şirin E, Aksoy Y, Uğurlu M, Çiçek Ü, Önenç A, Ulutaş Z, Şen U, Kuran M (2017) The relationship between muscle fiber characteristics and some meat quality parameters in Turkish native sheep breeds. *Small Ruminant Research* **150**, 46–51. doi:10.1016/j.smallrumres.2017.03.012
Smith GC, Carpenter ZL, Shelton M (1978) Effect of age and quality level on the palatability of goat meat. *Journal of Animal Science* **46**, 1229–1235. doi:10.2527/jas1978.4651229x
Stenström H, Li X, Hunt MC, Lundström K (2014) Consumer preference and effect of correct or misleading information after ageing beef *longissimus* muscle using vacuum, dry ageing, or a dry ageing bag. *Meat Science* **96**, 661–666. doi:10.1016/j.meatsci.2013.10.022
Swain B (2011) 'Australian goat meat supply profile.' (Meat & Livestock Australia: Sydney, NSW, Australia)
Tarrant P (1989) Animal behaviour and environment in the dark-cutting condition in beef-a review. *Irish Journal of Food Science and Technology* **13**, 1–21.
Thompson JM, Hopkins DL, D'souza DN, Walker PJ, Baud SR, Pethick DW (2005) The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture* **45**, 561–573. doi:10.1071/EA03195
Toohey E, Hopkins D (2007) 'Meat electronics for goats.' (Meat & Livestock Australia: Sydney, NSW, Australia)
Tornberg E (2005) Effects of heat on meat proteins – implications on structure and quality of meat products. *Meat Science* **70**, 493–508. doi:10.1016/j.meatsci.2004.11.021
Tornberg E, Von Seth G, Göransson Å (1994) Influence of ageing time, storage temperature and percentage lean on the eating quality of pork and its relationship to instrumental and structural parameters. *Sciences Des Aliments* **14**, 373–385.
Totland GK, Kryvi H (1991) Distribution patterns of muscle fibre types in major muscles of the bull (Bos taurus). *Anatomy and Embryology* **184**, 441–450. doi:10.1007/BF01236050
Vasanthi C, Venkataramanujam V, Dushyanthan K (2007) Effect of cooking temperature and time on the physico-chemical, histological and sensory properties of female carabeef (buffalo) meat. *Meat Science* **76**, 274–280. doi:10.1016/j.meatsci.2006.11.018
Vaskoska R (2020) Structural determinants of the quality of cooked meat. PhD thesis, University of Melbourne, Vic., Australia.
Vaskoska R, Ha M, Ong L, Chen G, White J, Gras S, Warner R (2021) Myosin sensitivity to thermal denaturation explains differences in water loss and shrinkage during cooking in muscles of distinct fibre types. *Meat Science* **179**, 108521. doi:10.1016/j.meatsci.2021.108521
Warner RD, Ferguson DM, McDonagh MB, Channon HA, Cottrell JJ, Dunshea FR (2005) Acute exercise stress and electrical stimulation influence the consumer perception of sheep meat eating quality and objective quality traits. *Australian Journal of Experimental Agriculture* **45**, 553–560. doi:10.1071/EA03270
Warriss PD (1990) The handling of cattle pre-slaughter and its effects on carcass and meat quality. *Applied Animal Behaviour Science* **28**, 171–186. doi:10.1016/0168-1591(90)90052-F

Watkins PJ, Kearney G, Rose G, Allen D, Ball AJ, Pethick DW, Warner RD (2014) Effect of branched-chain fatty acids, 3-methylindole and 4-methylphenol on consumer sensory scores of grilled lamb meat. *Meat Science* **96**, 1088–1094. doi:10.1016/j.meatsci.2012.08.011
Watkins PJ, Jaborek JR, Teng F, Day L, Castada HZ, Baringer S, Wick M (2021) Branched chain fatty acids in the flavour of sheep and goat milk and meat: a review. *Small Ruminant Research* **200**, 106398. doi:10.1016/j.smallrumres.2021.106398
Watson R, Gee A, Polkinghorne R, Porter M (2008) Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture* **48**, 1360–1367. doi:10.1071/EA07176
Wattanachant S, Benjakul S, Ledward DA (2005) Microstructure and thermal characteristics of Thai indigenous and broiler chicken muscles. *Poultry Science* **84**, 328–336. doi:10.1093/ps/84.2.328
Webb EC (2014) Goat meat production, composition, and quality. *Animal Frontiers* **4**, 33–37. doi:10.2527/af.2014-0031
Webb EC, Casey NH, Simela L (2005) Goat meat quality. *Small Ruminant Research* **60**, 153–166. doi:10.1016/j.smallrumres.2005.06.009
Wong E, Johnson CB, Nixon LN (1975*a*) The contribution of 4-methyloctanoic (hircinoic) acid to mutton and goat meat flavour. *New Zealand Journal of Agricultural Research* **18**, 261–266. doi:10.1080/00288233.1975.10423642
Wong E, Nixon LN, Johnson CB (1975*b*) Volatile medium chain fatty acids and mutton flavor. *Journal of Agricultural and Food Chemistry* **23**, 495–498. doi:10.1021/jf60199a044
Xazela NM, Muchenje V, Marume U (2011) Effects of different cooking methods on the consumer acceptability of chevon. *African Journal of Biotechnology* **10**, 12671–12675. doi:10.5897/AJB11.598
Yarmand MS, Homayouni A (2009) Effect of microwave cooking on the microstructure and quality of meat in goat and lamb. *Food Chemistry* **112**, 782–785. doi:10.1016/j.foodchem.2008.06.033
Young OA, Berdagué J-L, Viallon C, Rousset-Akrim S, Theriez M (1997) Fat-borne volatiles and sheepmeat odour. *Meat Science* **45**, 183–200. doi:10.1016/S0309-1740(96)00100-3

Data availability. Authors confirm that that there no data were generated in this review article. All research findings included in this review have been cited appropriately. The data that support the findings of this review are openly available.

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Author affiliations
[A]School of Agriculture and Food, The University of Melbourne, Parkville, Vic. 3010, Australia.
[B]Faculty of Biological Sciences, The University of Leeds, Leeds LS2 9JT, UK.