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Review paper

Intrinsic and extrinsic factors impacting fresh goat meat quality: An overview

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A b s t r a c t: Goat meat, known also as chevon or caprine meat, is an important source of protein and essential nutrients in many regions worldwide. To ensure high-quality goat meat production, it is crucial to understand the intrinsic and extrinsic factors that influence its sensory, technological and nutritional properties. This review aims to provide an overview of the factors affecting goat meat quality throughout the production and processing chain. The importance of different factors influencing goat meat quality were described. First, the focus was made on the intrinsic factors, including the effects of age at slaughter, gender (sex), breeds, slaughter weight, and the contractile and metabolic properties of the muscle by discussing their impact in terms of their influence on important intrinsic quality traits such as tenderness, flavor, color and overall quality of goat meat. Furthermore, the extrinsic factors such as production systems, husbandry practices, feeding strategies, types of feed and roughages, antioxidants, feeding systems, climate, season, and environmental conditions were examined in addition to the pre-slaughter treatments, transport conditions, and stress experienced by goats at the time of slaughter. Overall, this review synthesizes current knowledge on both the intrinsic and extrinsic factors affecting goat meat quality. The findings emphasize the importance of a better understanding and optimizing of these factors at each stage of production and processing to ensure the consistent delivery of high-quality goat meat. Further research in these areas will contribute to the development of improved practices and technologies in the goat meat industry.

Keywords: *Meat; Goat meat quality; Meat quality variation; Production and farming systems; Farm-to-fork factors.*

1. Introduction

Goat meat is popular globally due to its lean meat and favorable nutritional qualities. Further, it is an alternative source of low-fat content red meat with a healthy fatty acid profile compared to lamb and beef (*Rajkumar et al.,* 2015). There are different terms used for goat meat, based on the carcass weight. In France, Latin America, and the Mediterranean region, "capretto" is a term used to refer to goat carcasses weighing between 6–8 kg that are famous for their tenderness, juiciness, and flavor (*Pophiwa et al.*, 2020). In South Mediterranean countries, tender and fatless milk-fed kids weighing approximately 7–10 kg are preferred for grilling or roasting the whole carcass in traditional festivals like Easter and Christmas (*Rodrigues & Teixeira*, 2009). On the other hand, matured goat carcasses weighing between 16–22 kg are favored in South Africa and India, and this meat is known as chevon.

The quality of goat meat for consumption, as for other meat sources, is influenced by a variety of factors, both intrinsic and extrinsic, which encompasses the entire production and processing chain. In recent years, there has been a growing demand for goat meat due to its unique taste, perceived health benefits, and cultural preferences. As a result, ensuring high-quality goat meat production has become a key focus for producers, researchers, and consumers. Understanding

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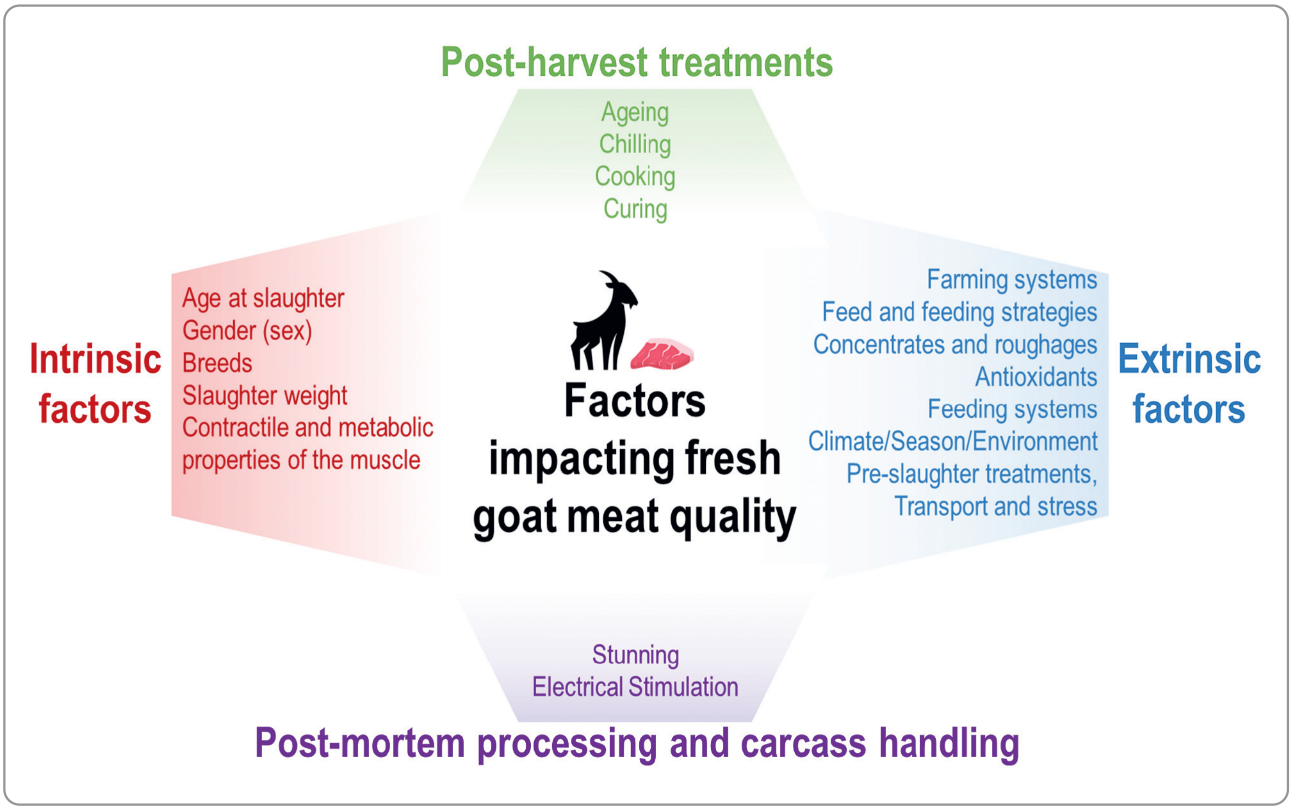

Figure 1. Multiple farm-to-fork factors impacting fresh goat meat quality

the factors at interplay and their impacts on meat quality is essential for producers and industry stakeholders to meet consumer expectations and maintain market competitiveness. This review aims to explore and synthesize current knowledge on both the intrinsic and extrinsic factors affecting goat meat quality (Figure 1).

Intrinsic factors affecting goat meat quality

The concept of "meat eating quality" is complex and multifaceted, and involves several dimensions, when we refer to the intrinsic qualities, these being sensory, nutritional, technological, safety, and many others (*Prache et al*., 2022). Several factors including feeding and rearing practices, genetic background, pre-slaughter stress of the animals and their handling, and post-mortem muscle processing and biochemical alterations, all interactively can influence the final quality of goat meat (*Gagaoua et al.*, 2022). The consumers' sense of smell play a significant role in determining meat eating quality *(Das & Rajkumar, 2010; Goetsch et al.*, 2011; *Pophiwa et al.*, 2020; *Webb et al.*, 2005). Despite goat meat being of satisfactory eating quality, it is not as preferred as other meat species (*Lamri et al.* 2022). For example, chevon is not preferred over lamb/mutton and beef due to its tough texture and strong peculiar flavor, particularly in western countries (*Webb et al.,* 2005). The acceptance of goat meat is also hindered by religious and caste dogma (*Webb et al.*, 2005). So, it is necessary to produce quality goat meat to promote its beneficial part among reluctant consumers *(Pophiwa et al., 2020; Lamri et al.* 2022). In the following sections, the main intrinsic factors that impact goat meat quality are described.

Effect of age at slaughter

Age is one of the most crucial parameters and indicators driving the final quality of goat meat, especially in terms of meat tenderness. Consumers generally have a hypothetical concept about slaughter age and meat-eating quality parameters, where they assume that meat from younger kids is better (more tender and palatable) than meat from older goats. Tenderness is one of the most critical sensory criteria for consumer acceptance, and it also determines the market value of meat animals (*Gagaoua et al.*, 2018a; 2019a,b). Numerous research studies have been conducted to reveal the age-associated integrated factors that influence meat tenderness or toughness. Intramuscular connective tissue and myofibers are main structural integrated factors that were intensively related to meat tenderness (*Listrat et al.*, 2020a,b). It was observed that the perimysium's (intramuscular connective tissue sheath of fascicles) quantity (90%), thickness and persistent organization are positively correlated with age and meat toughness (*Bakhsh et al.*, 2019). Other experiments in different species of meat like pork, horse etc. supported such statements (*Ke et al.*, 2019; *Roy et al.*, 2018). According to *Bakhsh et al.* (2019), the tenderness of post-mortem muscles is affected by the types of muscle fibers, their percentage, and their covered area. Muscle fibers undergo continuous changes up to the post-rigor condition to adapt to physiological changes. The authors found that the percentage of *Longissimus thoracis* muscle fiber type I increased with age, while type IIA and type IIB fibers decreased from the 9th to the 18th month of the experimental period. Fiber type I and perimysium thickness showed a positive correlation with the age of goats. Similar experiments conducted in South Africa suggest that 2-teethed goat kids had lower shear force values compared to 8-teethed matured goats, indicating greater tenderness in younger goats (*Simela et al.*, 2004).

Collagen is associated with age and has a significant influence on meat tenderness (*Listrat et al.*, 2020c). Matured animals have increased crosslinks in collagen fibrils, resulting in less solubility of collagen and toughening of meat after moist cooking. This factor is important in judging the tenderness of meat, and young animals are known to produce more tender meat than yearlings and older animals (*Schönfeldt et al.*, 1993). *Pratiwi et al.* (2007) found negative correlations between sensory scores for different taste attributes, including tenderness, juiciness, and slaughtered weight of carcass. However, in some countries, such as those that prefer chevon over capretto, the marketable slaughtered age should be between 1 and 2 years with a body weight of 25–40 kg to achieve better palatability. A carcass weight above 40 kg indicates lower quality characteristics of meat and lower appreciation by consumers.

Although aged does are preferred in some countries for preparing restructured and value-added processed meat products (*Webb et al.*, 2005), it has been reported that slaughtered goat kids between the ages of 3–5 months old are more tender, juicy, and flavorful compared to milk-fed kids (1–1.5 months) and older does (4–6 months) (*Borgogno et al.,* 2015; *Simela et al.*, 2004). Some studies suggest that younger kids produce less tenderness than mature ones. This may be because early age slaughter can lead to severe stresses that produces higher pH and consequently impacts cooking loss, shrinkage, color defects, etc. (*Kadim et al.*, 2014). Additionally, the deposition of intramuscular and subcutaneous fat is mainly seen in the mature body weight of goats. As a result, defects during carcass chilling, such as cold shortening, are common in young kids (*Pophiwa et al.*, 2020) due to a lack of subcutaneous fat. Intramuscular fat also contributes to the flavorful eating quality of meat (*Gagaoua et al.*, 2019c; 2020). Further scientific studies are required to investigate this debate on age and goat meat quality characteristics.

Effect of gender (sex)

Gender plays a significant role in the carcass composition and different quality characteristics of goat meat. However, after a thorough review of various scientific literature, it was observed that gender does not affect carcass dissected composition much, yet female goats tend to have more preferential internal fat deposition compared to males (*Todaro et al.*, 2004). In their study, *Santos et al.* (2007) found that female kids had significantly ($P < 0.05$) higher fat deposition, but dissected muscle and bone percentage were more for male kids. Pelvic limb tissue composition after dissection showed more muscle percentage in females, although the live animal weight, slaughter weight, and carcass weight were more for male goats (*Todaro et al.*, 2004). Flank firmness, streaking, feathering, and marbling are higher valued in females and sometimes in castrated goats rather than in intact males, and this trend may be due to the influence of the sex hormone testosterone in intact males (*Johnson et al.,* 1995). However, meat quality attributes are not always affected by sex alone; rather, a correlation was noticed with genotype and age. It was observed that the PUFA:SFA ratio was greater in males than females from different age groups and breed types (*Santos et al.,* 2007; *Todaro et al.,* 2004).

Cooking losses were found to be higher in meat from female kids due to less water holding capacity, whereas meat from male kids showed minimal cooking losses and more water holding capacity. These properties are linked to higher pH in male animals and more fat deposits in females (*Todaro et al.,* 2004). However, these differences have little effect on the acceptance range of quality characteristics in meat. Sex has very insignificant effect in texture attributes of meat, where males are preferred over females. This may be influenced more by extensive or intensive rearing management systems and feeding variations. Different researchers also concluded that Warner-Bratzler shear force values for meat from male or castrated males were lower compared to females indicating more tenderness in female goat meat except in *Semitendinosus* muscle (*Johnson et al.*, 1995).

Gender has a considerable importance for goat meat flavor and odor (*Carlucci et al.,* 1998). *Xazela et al.* (2011) found that the scores of aroma, flavor, juiciness, amount of connective tissue residue etc were higher for cooked meat in female goat meat, when compared to male under trained sensory panelists. The meat from female goat scored higher because of more intramuscular fat deposition and this marbling is directly associated with the juiciness, flavor and tenderness sensory traits of meat (*Xazela et al.,* 2011). Regarding aroma and flavor in cooked goat meat, interaction between slaughter age and castration has also a crucial role. After thorough experiments, *Madruga et al.* (2000) reported that meat from younger goat was tender, flavorful, juicy with a desirable aroma. But with aged animals, more goaty off flavor and stringy consistency of muscle fibers were detected in sensory analysis. Some branched chain fatty acids *i.e.* 4-methyloctanoic and 4-methylnanoic acids were the main goaty aroma producing components present in adipose tissue of goat. The fat deposition in castrated goats is greater than intact goats, therefore after thermal treatment, dissociation or fatty acid oxidation is more likely to produce different volatile hydrocarbons that actually enhances the goaty aroma in castrated goats (Zamiri et al., 2012; *Paengkoum et al.,* 2013).

Effect of breeds

Meat quality parameters like tenderness, texture, fatty acid profile and chemical composition may also differ within breeds or genotypes. *Stankov et al.* (2002) reported that crossbred of different native breeds of goat had higher amount of intramuscular fats and adipose tissue in muscles that correlates with better palatability, tenderness but less with moisture content. It was also noticed that local breeds and crossbreeds tended to narrow the proportion of unsaturated fatty acids with age. Meat quality variations of different breeds are related to age, diets and extensive or intensive management system (*dos Santos Souza et al.*, 2019). After extensive research in this particular area, *Johnson et al.* (1995) described that breed type has very minimal effects on carcass quality attributes such as carcass weight, fat and bone percentages. On the other hand, dressing percentage, water-holding capacity, especially flavor, Warner-Bratzler shear force value etc. were slightly affected by genotypes. Producers need to choose obligatory breeds with quality meat producing ability, resistance to emerging diseases and well accommodated to environmental disparity.

Goats are usually more prone to stress due to their anxious nature. Few breeds (Batina goat breed) are reported to have more responsiveness higher stress hormone concentrations (cortisol, adrenaline and nor-adrenaline) that indicate imbalances of acidification of different muscles (*Kadim et al.*, 2006). Ultimately this condition affects the quality of meat in terms of higher pH of muscle, darker meat, higher shear force value etc (*Kadim et al.*, 2014; *Pophiwa et al.*, 2020). Boer goats are considered the choicest supreme quality breed for quality meat production. This breed is preferred for genetic quality improvement of indigenous unproductive breeds by crossbreeding. Sometimes unimproved native goat breeds also produce acceptable quality attributes of chevon, especially at early ages of maturation. Therefore, it may be advised to producers to conserve and exert the indigenous breeds (*Pratiwi et al.*, 2007).

Effect of slaughter weight

Slaughter weight or carcass weight is another paramount factor that impacts the meat-eating quality (*Gagaoua et al*. 2018b). In the case of goat, both factors influence the dressing percentage, body compactness including carcasses size and conformation (*Martelo et al.*, 2020; *Rajkumar et al.*, 2014). Conducting research with different age groups of male and female goats, *Teixeira et al.* (2011) found that with the enhancement of ages and slaughter weight, carcass length, hot carcass weight, carcass width were also enhanced. The authors further reported that with the advancement of ages and slaughtered body weight, chump and breast weight, loin proportion, kidney and pelvic fat, especially in female were increased in significant proportion. Alternatively, leg, shoulder, fore ribs and bone proportions were diminished inversely with body weight. They also observed the carcass weight had a significant effect on muscle color, as reduced brightness and increased redness were noticed with enhancement of the body weight.

Interestingly, carcass weight has a significant role in shear force values of goat meat. It was noticed that with the increased body weights, shear force values dropped down notably. With the matured carcass weight, cutting forces also reduced down unlikely other studies that confirmed more shear force cutting values observed with higher carcass weights (*Argüello et al.,* 2005; *Santos et al.*, 2007). Specially in female goats, due to more deposition of body fats, cutting forces were significantly lower indicating more tenderness and flavorful meat (*Johnson et al*., 1995; *Teixeira et al.,* 2011). *Pratiwi et al.* (2007) described a negative correlation between sensory scores and carcass weight, and it was found that above 40 kg body weight, quality parameters start deteriorating sharply.

Effect of contractile and metabolic properties of the muscle

In goat meat, almost 60% is dissectible lean muscle tissue, and up to 15% dissectible fat. However, because of their low subcutaneous and intermuscular fat deposits surrounding the carcass, there may be severe drip loss and cold shortening during the chilling process. This problem can be solved by improved nutrition management or conditioning before slaughter to deposit more subcutaneous and intermuscular fat over the carcass and viscera, leading to less shear force values and more sarcomere length (*Simela et al.,* 2011; *Webb et al.,* 2005). Pre-slaughter factors such as on-farm management practices, pre-slaughter transportation, and physiological and heat stress can lead to significant physiological and biochemical changes in the muscular components and hormonal imbalances of goats. Stress management is, therefore an essential part of minimizing glycogen depletion, shrinkage issues, and ensuring meat quality (*Pophiwa et al.,* 2020). These pre-slaughter factors are equally important in determining the contractile and metabolic properties of muscle fibers in the post-slaughtered condition (*Picard et al.*, 2014; *Picard and Gagaoua*, 2020, *Terlouw et al.*, 2021).

Skeletal muscle fiber types, intramuscular connective tissue, intramuscular fat and stored glycogen etc. are directly associated with post-mortem changes of muscle biology (*Listrat et al.*, 2016; *Gagaoua et al.*, 2015; *Gagaoua et al.*, 2016a*; Picard and Gagaoua*, 2020). After slaughter, carcasses are usually kept under refrigerated conditions for specific periods of time (not always the case in poor or developing countries) for facilitating post rigor resolution and natural conditioning of muscles. In this period, changes of sarcomere length, alteration of actomyosin cross bridges, ultrastructural changes of myofibrils and connective tissue or alteration of metameric organizations, myofibrillar fragmentation index, proteolytic deviations are foremost associated reasons for integrating the most desirable olfactory quality characteristics in meat (*Gagaoua et al.,* 2021; *Gagaoua et al.*, 2022). Enzymatic changes start soon after the killing process of the animal to restore the contractile and metabolic activity of skeletal muscles under deficiency of oxygen (*Ouali et al.,* 2013). Post-mortem glycolysis, pH decline and chill temperature and its decline in the carcasses are related consequences to initiate *rigor mortis* followed by complete depletion of creatine phosphate and ATP, the main energy sources for muscle contraction. A reduction in the efficiency of the calcium pump causes an increase in the net efflux of calcium ions from the sarcoplasmic reticulum, which activates the contractile mechanisms. This situation activates the endogenous proteolytic enzymes (calpain, caspases, cathepsin etc.) that can induce the morphological changes of proteins in muscle tissue and/or connective tissues (*Gagaoua et al.,* 2021). Ultimately the Z line ultrastructure of myofilaments, responsible for muscle stiffening, goes through the *rigor mortis* resolution by splitting it and collagen solubilization is also seen after cooking (*Purslow et al.*, 2021). In this period, major sensory attributes like tenderness, water-holding capacity, color and firmness are determined as ultimate meat quality parameters (*Listrat et al.*, 2016). The appearance of meat is primarily influenced by the oxidation and reduction of natural pigments, such as myoglobin, or their chemical state (*Purslow et al.*, 2021).

One of the challenges in preserving the quality of meat is cold shortening, which can occur during the rapid chilling process of animal carcasses. This results in tough meat with significant drip loss. To prevent cold shortening in goat carcasses, delayed chilling at temperatures of 10–15°C for 6 hours, followed by further cooling at 0–4°C for up to 24 hours, has been shown to be effective (*Kadim et al.*, 2014; *Simela et al.*, 2004). Another method to prevent cold shortening is by using electrical stimulation (ES) with medium voltage, which induces accelerated pH drop and proper temperature combination, thereby avoiding glycolytic potential and quality defects development. The application of ES technique to improve goat meat quality is addressed later in this review.

Extrinsic Factors affecting goat meat quality

Goat meat quality can be affected by different extrinsic factors, such as the system of rearing (extensive, intensive, semi-intensive, and organic), feeding strategies, environmental conditions (e.g., origin/region of production and climate/season), animal welfare (including pre-slaughter treatments, transport, and stress), and processing or post-harvest conditions (such as chilling, ageing, cooking, packaging, and storage). These extrinsic factors can significantly impact the final quality of goat meat *(Bernués et al., 2003; Dashdorj et al., 2015; Poveda-Arteaga et al.*, 2023). Information on extrinsic factors affecting goat meat quality is crucial for consumers concerned about credence quality issues such as safety, health, and ethical considerations. This information can help consumers make informed decisions about the goat meat they consume. Therefore, understanding the impact of extrinsic factors on goat meat quality is essential for ensuring high-quality goat meat products that meet consumer expectations (*Northen*, 2000; *Bernués et al.* 2003a, and *Corazzin et al.* 2019). Various extrinsic factors affecting goat meat quality are described here in the following sections.

Production or Husbandry or Farming systems

Production, husbandry or farming systems viz., extensive, intensive, semi-intensive and organic system of rearing have a great influence on goat meat quality traits (*Corazzin et al.,* 2019). Different farming systems can result in differences in growth rates, yields and various carcass quality parameters of goats (*Assan,* 2012; *Toplu,* 2014). For example, *Liotta et al.* (2020) conducted a study to investigate the effect of production system on the growth performances and meat traits of suckling Messinese goat kids. The researchers divided a total of 102 suckling kids into two homogeneous groups and reared them under two different systems: the extensive system (ES) and semi-extensive system (SES). The animals reared under SES were fed exclusively on spontaneous pasture diet and kept in the farm during the evening, while those reared in ES were fed exclusively on spontaneous pasture diet and kept exclusively outdoors. The study found that the production system did not affect the weight of kids at birth, but there was a significant difference in the performance of kids in relation to the breeding system. The chemical composition of the *Longissimus thoracis* muscle was not significantly affected by the production system. However, the ES group showed some differences in meat traits compared to the SES group. Specifically, the ES group showed lower final pH, hue angle values (color), and higher values of cooking loss and shear force affecting the texture and color of the meat. Furthermore, the production system significantly influenced the fatty acid composition of the meat. The meat from the ES group had the highest values of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), as well as the lowest ω-6/ω-3 ratio and thrombogenic index. These findings suggest that the production system can affect the nutritional quality of goat meat, which can have implications for human health. In summary, Liotta et al. (2020) showed that the production system can affect the performance, texture, color, and nutritional quality of goat meat. These findings highlight the importance of considering the production system when evaluating the quality of goat meat and making informed decisions about goat meat consumption.

Yalcintan et al. (2018) compared the carcass and meat quality traits of Saanen goat kids raised under natural rearing and artificial rearing systems. The artificial rearing kids were separated from their dams immediately after birth and fed with commercial milk replacer, while the natural rearing kids were fed milk from their does. The rearing type did not affect the average daily gain, slaughter weight, hot carcass weight, empty body weight, dressing %, subjective conformation and fatness scores of kids. It was also observed that the rearing type had no effect on instrumental meat quality traits, except for meat lightness (L^*) and hue angle (h°) values. Meat from natural rearing kids had higher L^* and $h°$ values at 1 hour and 24 hours after cutting than those of artificial rearing kids. From the sensory evaluation results, it was concluded that meat from natural rearing kids was more tender and juicier than that of artificial rearing kids.

In another study, *De Marzo et al.* (2018) reported that extensive farming represents the best system for goats living in Mediterranean environment, despite the fact that the productive potential is partly achieved, but the rusticity and frugality of goats reach their maximum. The researchers observed that extensive farming allows the maximum use of environmental resources enabling the two Italian goat breeds viz., Garganica and Girgentana reared in two different regions of Italy, to produce primarily milk and secondarily meat.

Quaresma et al. (2016) studied the meat lipid profile of suckling goat kids from three certified and one non-certified production system obtained from an intensive dairy farm. Goat reared in certified system displayed lower lipid contents (1.0 vs. 1.9 g/100 g of meat) but higher contents of total cholesterol (61 vs. 48 mg/100 g meat). Certified system goats displayed higher CLA content, α-tocopherol content, more than twice the total PUFA content and more than triple content of n-3 PUFA than of the non-certified systems.

Ozcan et al. (2014) documented that Gokceada kids reared under an extensive production system had lower meat lightness, high scores for meat color intensity evaluated by redness (a^*), flavor intensity and overall acceptability as compared to kids reared under semi-intensive systems. The pre-slaughter weight (17.44 and 12.51 kg), cold carcass weight (8.66 and 5.53 kg) and cold dressing % (54.9 and 49.28%) were always higher in animals reared under extensive than semi-intensive system, respectively. This study concluded that an extensive system of rearing was more appropriate than semi-intensive system for kid meat production.

Zurita-Herrera et al. (2013) determined the effect of three management systems on meat quality of 61 goat kids. Kids from the extensive management system displayed pink meats than intensive systems with natural and artificial rearing management. The type of management system had no effect on the pH, chemical composition and sensory evaluation. Intensive combined with artificial rearing system goat meat had the lowest capacity to retain water. Intramuscular fat deposits from the kids reared under extensive management system showed the lowest percentage of C14:0 fatty acid and the highest percentage of C18:1. The researchers observed that a strong influence of physical activity and trough grazing in extensive management system led to production of healthier kids with lower atherogenicity index of intramuscular fat.

Jambrenghi et al. (2007) conducted a study on the effect of goat production system on meat quality and CLA content in suckling kids. Twenty male Ionica suckling kids fed only on maternal milk were subdivided into two groups. One group (G1) was raised under dams reared by intensive system whereas the other group (G2) was raised under dams grazing on pasture. Upon slaughtering the animals on 45 days, it was found that the goat production system had no effect on kid's growth rates, slaughtering yield and other carcass characteristics. The animals under G1 had significantly higher pH of *Longissimus thoracis* muscle obtained after 45 minutes of slaughter. The conjugated linoleic acid (CLA) content, cooking loss and tenderness values of meat in G2 were higher, but the meat color was lighter and had greater yellowness and chroma values. However, the meat chemical composition of both groups did not differ in raw as well as cooked meats.

Feed and feeding Strategies

Feed and feeding strategies can have a significant impact on the quality of goat meat. The composition of goat meat can be influenced by the type and quantity of feed provided to the animals. Goats that are fed a balanced diet, with a proper ratio of carbohydrates, proteins, and fats, tend to produce meat with higher nutritional value and better sensory characteristics. Feeding of animals may influence the carcass and meat composition, muscle pH decline and the rate of post-mortem carcass cooling. Also, there is a requirement of dietary protein and energy for increased muscle maturity (*Kannan et al.*, 2014). It is also observed that dressing % can be improved by increasing the level of high nutritious diet, which can increase the proportion of muscle and fat as compared to bone in small ruminants (*Corazzin et al.*, 2019; *Das et al.*, 2008; *Gürsoy et al.,* 2011).

Feeding strategies such as grazing, browsing, and supplementation can also affect the meat quality of goats. Goats that are raised on pasture or allowed to graze freely tend to produce leaner meat with higher levels of omega-3 fatty acids and CLA, which are beneficial to human health. On the other hand, goats that are fed a high-grain diet, such as in intensive feeding systems, tend to produce meat with higher fat content and lower levels of CLA. In addition to the type of feed, the duration of feeding can also influence meat quality. Goats that are fed for a longer period of time tend to have meat with a richer flavor and higher levels of marbling, which is highly valued by consumers.

Overall, the feed and feeding strategies used in goat production can have a significant impact on the quality and nutritional value of the meat. Therefore, it is important for producers to carefully consider their feeding practices and make the necessary adjustments to ensure that their goats produce high-quality meat that meets consumer expectations.

Concentrates and roughages

Da Silva Pereira et al. (2020) studied the effect of diets containing cunha hay (CH) and forage cactus meal (CM) on carcass traits, fatty acid profile and meat quality of Boer crossbred goat. Carcass yield, fatty acid profile and commercial cut weights were higher in the animals fed CH and CM at any concentration than the control groups. Animals fed with CM feed resulted in better proportion of unsaturated fatty acids, desirable fatty acids, omega 6/omega 3 ratio and hypo-/hypercholesterolemic index.

Guzmán et al. (2020) studied the use of by-products of orange, *i.e.,* dehydrated orange pulp (DOP) at 0%, 40% and 80% levels in goat feed and its effect on physico-chemical, textural, fatty acid, volatile compounds and sensory characteristics of meat of suckling kids of Payoya breed. Meat from kids in the DOP-40 and DOP-80 groups exhibited characteristics favorable for human health, including the thrombogenicity index, PUFA/SFA ratio, and n-6/n-3 PUFA ratio. The meat also exhibited reduced MUFA content. In another study, *Hwang et al.*(2018) determined the effect of alfalfa feeding (ALF) and conventional commercial concentrate (CCP) pellets on meat quality and fatty acid profile of Korean native black goats. There were no significant differences in proximate chemical composition, collagen and myoglobin content, meat color, WHC and tenderness of meat between ALF and CCP groups. However, the proportion of oleic acid was significantly higher in ALF goats whereas, proportions of linoleic and arachidonic acids were significantly higher in CCP goats. These results suggested that Korean native black goats fed with alfalfa could result in meat with desirable fatty acids. In yet another study, *Ebrahimi et al.* (2018) investigated the effects of n-6: n-3 PUFA ratios in concentrate on meat quality, carcass characteristics, tissue fatty acid profiles and expression of lipogenic genes in growing Boer goats. This study concluded that the optimal n-6: n-3 fatty acid ratio of 2.27:1 exerted beneficial effect on meat fatty acid profiles, leading to enrichment in n-3 PUFA and CLA in goat intramuscular fat. In a separate study, *Abuelfatah et al.* (2016) studied the effect of n-3 PUFA supplementation (0, 10 and 20%) in diet of Boer bucks on meat quality, sensory evaluation and lipid oxidation at different post-mortem ageing times. The authors observed no difference in cooking loss, WBSF value and color of meat from all three groups on the first day of ageing. After 7 days of ageing, the color of meat was affected. The tenderness, juiciness and overall acceptability of groups supplemented with 20% n-3 PUFA rated better than other groups. No difference was observed in color, flavor and aroma of meats from all the three groups. In this experiment, the lipid oxidation in meat was positively correlated with the level of n-3 PUFA and ageing time.

Brand et al. (2018) suggested that the energy density of feedlot diets can be varied to produce chevon with uniform and desirable quality characteristics. Conducting a study in Boer goat castrates finished on diets varying in energy content (9.7, 10.2 and 10.6 MJ ME/kg feed), the authors noticed no significant differences in proximate composition and sensory parameters like flavor, aroma, texture etc. amongst the three goat groups. *Lee et al.* (2017) evaluated the quality characteristics of goat meat as influenced by condensed tannins-containing pine bark. In this case, Kiko crossbred male goats were grazed randomly and assigned to either Bermuda grass (BG) hay or pine bark (PB) supplementation for 55 days. No differences were found in average daily gain, proximate composition, WBSF values, cooking loss and TBARS values of meats of both groups. Further, no differences were found in L^* and yellowness (b^*) color values. However, the a^* values of BG group were higher than that of PB group. Further, the PB group had lower CLA and PUFA contents and higher EPA content than the BG group. This study suggested that wood derived condensed tannins in PB might not impact the nutrient composition, eating quality and fatty acid profile of chevon. Similarly in other study, *Brassard et al.* (2017) studied the effect of inclusion of barley and corn in the ratio (100:0; 50:50 and 0:100) in the diet of concentrate-fed male Boer kids on growth performance, meat quality and muscle fatty acid composition. The researchers noticed that inclusion of barley in diet linearly increased concentrate intake and average daily gain, whereas no significant differences were observed in carcass traits and meat quality among the three treatments.

Moyo et al. (2014) and *Xazela et al.* (2012) observed that feeding Moringa (*Moringa oleifera*) leaf meal and sunflower cake, respectively, resulted in higher physico-chemical and sensory properties of goat meat as compared to meat of other test groups. *Marinova et al.* (2005) reported that fish oil supplementation in the diet of goats influenced the physico-chemical meat quality and led to higher deposition of body fat. Even *Rao et al.* (2003) found that feeding neem seed kernel cake improved the fatty acid content, decreased the cholesterol content of goat meat without affecting the meat quality.

Antioxidants

Chevon is prone to rapid lipid oxidation on refrigerated storage because of its high unsaturated fatty acid content (*Das et al.*, 2009; *Kannan et al.*, 2014). Dietary supplementation of antioxidants to goats has the potential to retard lipid oxidation. *Wang et al.* (2017) studied the effect of α-lipoic acid (LA) in different concentrations (0, 300 and 600 mg/kg) on carcass characteristics, antioxidant capability and meat quality in Hainan black goats. It was recorded that the goats fed with diet containing 600 mg/kg LA had a significantly higher average daily gain and feed conversion rate compared to control group fed on basal diet without LA. There was no difference in carcass characteristics, pH and intramuscular fat of all the three groups of goats. The meat from group of goats fed on 600 mg/kg LA had a significantly higher antioxidant enzymes like SOD, GSH-Px, catalase and higher T-AOC etc. This group had the lowest MDA concentration, low drip loss and lower WBSF values. This study indicated that diet supplemented with LA may influence the antioxidant capacity, meat quality and growth performance in goats. Likewise, dietary supplementation of seaweed extract has also been reported to affect the antioxidant activity and meat quality characteristics in goats *(Galipalli et al., 2004; Kannan et al.*, 2007).

Feeding Systems

The carcass composition and meat quality can also be affected by the feeding systems (*Corazzin et al.*, 2019). Confined feeding mainly with concentrate can affect various carcass characteristics resulting in heavier goats and higher fat levels than grazing goats (*Goetsch et al.*, 2011; *Ryan et al.*, 2007; *Toplu*, 2014). It is also observed that meat from animals fed on pasture grazing system is darker than that of concentrate feeding systems *(Priolo et al., 2001; Rodrigues et al.*, 2011). *Santos et al.* (2020) evaluated the effect of three feeding systems on the organoleptic and physico-chemical properties of goat meat. The three feeding systems included traditional System (TS), intensive feeding System without concentrate (IS) and intensive feeding System with concentrate (IS+C). The meat of goats under IS+C and IS presented higher intramuscular fat content and better flavor and aroma scores. The goats that received IS+C showed meat with more intense red color, high moisture, low fat, more tender and juicier than other groups. Overall, the meat from IS+C group of goats showed better attributes than others. *Kamatara et al.* (2014) reported that goats supplemented with non-molasses based and molasses-based concentrates produced higher carcass weights and carcass quality characteristics than that of goats fed on grazing system only. *Pearce et al.* (2010) reported that goats reared in saltbush-based pasture systems had higher meat quality and high vitamin E content.

Climate/Season/Environment

Goats are highly adaptable animals that can thrive in a wide range of climatic conditions, from arid desert areas to tropical rainforests. They have the largest ecological distribution of all domesticated animals and are well-suited for harsh environments. In fact, goats are the most beneficial animal to be reared in areas where almost uncultivable land is the main source of feed, such as resource-constrained environments with water scarcity and nutrient deficiencies (*Erasmus*, 2000; *Shinde,* 2000). This is exemplified by the Boer goat meat production in the arid and semi-arid regions of South Africa (*Webb & Pophiwa*, 2018). Asia and Africa are home to 88% of the world's goat population, with 80% of them living in the tropics and sub-tropics. Therefore, the goat is an important animal for meat production in these regions.

The climate change is seen as a significant threat to sustainability of many species including goats in many parts of the world, mainly due to its impacts on the availability of pasture and productive performance of goats (*Nardone et al.*, 2010), hence affecting the reproduction, disease, health and meat quality of goats. Further, various kinds of stress viz., physical, nutritional, chemical, psychological, and most importantly heat stress under the changing climate can affect the meat quality (*Gupta et al.*, 2013). In general, climate change could affect goat meat quality in two ways. First, affecting the organs and muscle mechanism directly pre-slaughter, which persists even after slaughter. Second, the changes in husbandry practices in response to climate change could indirectly lead to changes in meat quality (*Gregory,* 2010). For example, changing to heat-tolerant breeds of animals could lead to tougher, less juicy meat with less marbling. Also, pre-conditioning animals to heat stress may lead to more viable ultimate pH of meat (*McKee & Sams*, 1997; *Wheeler et al.*, 2001). Moreover, the impact of climate on meat quality varies between regions. High ambient climate can favor greater muscle marbling and internal fat depot of subcutaneous fat (*Gregory,* 2010). With the changing climatic conditions, the adaptive local breeds can be better alternatives as an appropriate bio-resource to sustain goat meat production (*Joy et al.*, 2020).

Several researchers have studied the impact of climate, season, temperature and environment on meat quality and adaptability of different livestock species. *Chergui et al.* (2017) studied the seasonal effects of plasma cortisol concentrations in Bedouin buck, native to Algerian Sahara Desert to understand the mechanism of adaptation to extreme climates. Another earlier study allowed better understanding the cellular stress response in terms of heat shock protein (HSP70, HSP27) gene expression against heat and cold challenge in goat peripheral blood mononuclear cells (*Jagan Mohanarao et al.*, 2014). *Archana et al.,* (2018) compared the impact of heat stress on meat production characteristics of Osmanabadi and Salem black breed goats based on changes in carcass characteristics, meat quality attributes, plasma leptin concentration, skeletal muscle myostatin and heat shock protein 70 (HSP70) gene expression patterns. The results of this study suggested that Salem black breed had a better resilience capacity as compared to Osmanabadi goats in maintaining meat production during heat stress. This study further established plasma leptin and HSP70 genes to be the ideal biomarkers to reflect the impact of heat stress on meat characteristics in indigenous goats. Another study investigated the effect of heat stress on blood parameter, carcass and meat quality of Black Bengal goat (*Rana et al.*, 2014). This study suggested that heat stress significantly affected the blood parameters, cooking loss, pH, by-product content of goats rather than non-heat stressed group of goats. *Kadim et al.*, (2008) studied the effect of seasonal temperatures on meat quality characteristics of hot-boned, *Psoas major* and *Psoas minor* muscles from Omani goats and Somali goats. Muscles collected during hot season had significantly higher ultimate pH, darker color and high myofibrillar fragmentation index than those collected during cool seasons. However, the meat collected during cool season had higher expressed juice than hot season meat. These results indicated that high ambient temperature had significant effects on meat quality.

Pre-slaughter treatments, transport and stress at slaughter

Animals perceive any unusual manipulation including transportation, fasting, slaughtering as stressful and these may ultimately have a negative impact on meat quality (*Biobaku et al.,* 2016; *Kannan et al.,* 2014; *Terlouw et al.,* 2021; *Terlouw and Gagaoua*, 2023). Transportation, involving handling, loading and unloading is an unfamiliar and threatening event in the life of an animal (*Terlouw et al.,* 2021). This can lead to distress, injury or even death of animal affecting the animal welfare and meat quality adversely (*Minka & Ayo*, 2010; *von Borell et al.*, 2007). The depletion of glycogen in muscle due to long-term pre-slaughter stress and the resultant elevated meat pH negatively affect meat quality (*Kannan et al.*, 2014; *Terlouw et al.*, 2021). Short-term acute stress, such as excitement or fighting immediately prior to slaughter produces lactic acid from the breakdown of glycogen. This results in meat with a lower meat pH, lighter color, reduced WHC and higher toughness. Psychological stressors, viz., excitement and fighting will often have a more detrimental effect on meat quality than pre-slaughter physical stressors like transportation, fasting and cold weather (*Grandin*, 1980; *Terlouw et al.*, 2021). Some of the available literature about pre-slaughter treatments, transport and stress at slaughter and their effect on goat meat quality are described in the following.

Biobaku et al. (2016) assessed the meat quality of Sahel bucks treated with ascorbic acid (400, 300, 200 and 0 mg/kg orally) and exposed to long term transportation stress during harmattan period. The animals were transported using high and low stocking density and ascorbic acid was administered prior to and midway of the journey. The group of goats treated with 400 mg/kg orally ascorbic acid had significantly higher dressing %, ultimate pH, excitatory score as compared to other groups of goats. Similarly, there were significantly higher dressing %, ultimate pH, excitatory score in high stocking density as compared to low stocking density. This study concluded that there was an interaction between the dose of ascorbic acid and the stocking density. Further, it showed that ascorbic acid could be used as an anti-stress agent to improve food animal welfare and chevon quality.

Alcalde et al. (2017) assessed the effect of on-farm management (high and low welfare-friendly) and transport duration on physiological responses and meat quality parameters in goat kids. Measuring carcass parameters like pH, color, WHC, shear-force value revealed that despite the marked stress status of kids during transportation, *Longissimus thoracis* muscle quality parameters were not much affected, but some pre-slaughter transportation stress effects were observed in fat cover and color of the kid carcasses.

Nikbin et al. (2016) investigated the effects of transportation and stocking density on carcass characteristics and meat quality traits of *Longissimus thoracis* and *Semimembranosus* muscles in Boer goats. The transported goats had significantly lower carcass shrinkage, glycogen content, drip loss, tenderness, lightness, yellowness, hue angle and chroma values as compared to non-transported goats. In contrast, transported goats showed significantly higher cooking loss and redness than the non-transported group. Goats transported in higher stocking density had significantly higher live-weight loss and lower dressing %. This study also reported that pre-slaughter transportation increased shrinkage loss and deteriorated meat quality of goats.

Kadim et al. (2014) studied the effect of transportation during hot season (42°C day temperature) on meat quality characteristics of *Longissimus thoracis* muscle of twenty male Dhofari goats. The transported goats had significantly higher plasma cortisol, adrenaline, nor- adrenaline and dopamine concentrations than non-transported goats. The meat from transported goats had significantly higher ultimate pH (5.84 *vs.* 5.67), expressed juice (40.2 *vs.* 36.8), shear force value (7.85 kg *vs.* 5.55 kg) but significantly ($p<0.05$) lower sarcomere length (1.53 μm *vs.* 1.60 μm). This study indicated that transporting goats for 6 hours during hot season can cause physiological responses and deteriorate meat quality characteristics. Moreover, *Kadim et al.* (2006) evaluated the effect of transportation during hot season on carcass and meat quality of three breeds of Omani goats. The meat from goats subjected to transportation had significantly higher ultimate pH, expressed juice, cooking loss %, shear force value but significantly lower sarcomere length, L^*, a^* and b^* color values.

Kannan et al. (2003) determined the effects of short-term (2 hours) pre-slaughter stress on meat quality of different age groups of goats. The transported groups of goats had higher plasma cortisol, glucose and non-esterified fatty acid concentrations, but had lower muscle glycogen reserve, *a** value and chroma of meat color. The pH, WHC, cooking loss and shear force values were not affected by stressor environment. These results indicated that short-term pre-slaughter transportation can cause noticeable changes in stress response and muscle metabolism in goats without affecting the ultimate pH of meat even with a significant glycogen breakdown.

Kannan et al. (2002) determined the effects of pre-slaughter isolation and feed withdrawal duration on physiological responses and shrinkage in Spanish goats. The results indicated that the novelty of environment during pre-slaughter holding and social isolation may be more potent stressors affecting meat quality than feed deprivation in goats, although shrinkage may increase the increasing feed withdrawal time.

Post-mortem processing and carcass handling: stunning and electrical stimulation methods

Stunning

According to the EU council directive (EU, 1993) and council regulations (EC No. 1099/2009), animals must be stunned at the point of slaughter to render them unconscious and insensible to distress and pain from the act of slaughter. Among various stunning techniques used in meat industry, the electrical stunning by passage of sufficient electrical current is most widely used in sheep and goats (*Robins et al.*, 2014). Stunning and slaughter procedures have great impact on meat quality as well as animal welfare (*Bourguet et al.*, 2011; *Terlouw et al.*, 2021; *Terlouw and Gagaoua*, 2023)

Bakhsh et al. (2018) assessed the effects of non-stunning (NS) and head-only electrical stunning (HOES) on meat quality traits of *Longissimus lumborum* muscle from Korean black goat. The results indicated that NS and HOES had no significant difference on blood loss%, the rate of pH decline, meat color properties and WHC. However, a marginal difference in WBSF values and sarcomere lengths were observed. It was concluded that, neither NS nor HOES during slaughter of goats resulted in poor quality meat. *Lokman et al.* (2016) compared the carcass and meat quality in Boer crossbred goats that were subjected to pre-slaughter head-only electrical stunning (HOES) (1A, 3 sec at 50Hz) and non-stunning (NS). The results indicated that no differences were observed in meat quality traits between NS and HOES goat carcasses. However, carcasses obtained from HOES goats had higher incidence of hemorrhages than NS goats. This study indicated that HOES prior slaughter increased carcass hemorrhages without adversely affecting meat quality traits of the studied goats.

Electrical Stimulation

Goat carcasses often have a high ultimate pH and low glycolytic potential, resulting in tougher meat that can be stringy and less desirable to consumers (*Webb & Pophiwa*, 2018; *Lamri et al.,* 2023a). To address this issue, technologies like electrical stimulation (ES) are used to improve the conversion of muscle into meat more effectively. ES can prevent cold shortening, accelerate proteolysis, and disrupt muscle fiber structures, leading to improved tenderness of the meat (*Kadim et al.*, 2010; *King et al.*, 2004). Various types of ES systems, including high, intermediate, and low voltage systems, have been studied extensively to enhance meat tenderness and prevent cold shortening (*Kannan et al.*, 2014). ES can also help to dissociate the myofibrillar and connective tissue structures, as well as accelerate proteolysis, resulting in increased tenderness and juiciness after cooking (*Biswas et al.*, 2016; *Pophiwa et al.*, 2020). However, high or very low voltage should be avoided as they may lead to improper stimulation and undesirable sensory attributes in meat. Studies have shown that electrical stimulation improves shear force values and water-holding capacity in muscles, which are indicators of tenderness and juiciness, respectively *(Gadiyaram et al.*, 2008).

In a study by *King et al.* (2004), the effects of high (550V) and low (20V) voltage ES and post-mortem storage on the tenderness and lean color of Carbito Boer cross kid carcasses were examined. Sixty carcasses were used, with half receiving ES and the other half serving as the control group. The authors observed no differences in muscle temperature, myofibrillar fragmentation index, and sarcomere length at any time measured. However, the high-voltage ES group had the fastest pH decline, higher instrumental color (in terms of *L**, *a**, and *b** values), increased aging responses, and greater tenderness 3 days post-mortem compared to the control group. In another study by *Kadim et al.* (2014), the effects of low voltage ES (90V, 60 seconds at 20 minutes post-mortem) on the physiological and meat quality characteristics of *Longissimus dorsi* muscle in twenty male Dhofari goats were investigated. The meat from electrically stimulated goat carcasses had significantly lower ultimate pH (5.68 *vs.* 5.84), higher expressed juice (39.5 *vs.* 37.45), lower shear force value (5.05 kg *vs.* 8.35 kg), longer sarcomere lengths (1.67 µm *vs.* 1.46 µm), and higher myofibrillar fragmentation index (77.25 *vs.* 71.45) than the non-stimulated goat carcasses. This study suggested that low-voltage ES may reduce the negative effects of transportation for 6 hours during the hot season on the meat quality characteristics of goats.

Cetin et al. (2012) investigated the effect of various ES voltages (50, 100 and 250V, 90 seconds, 50Hz frequency) on meat quality of 3–5 years old goats. The stimulated carcasses were examined for their textural, physico-chemical and sensorial characteristics as compared to non-stimulated carcasses. ES decreased pH values of goat meat and accelerated significantly *rigor mortis*. Additionally, ES enhanced water activity, water-holding capacity and drip loss of goat meat. Further, ES caused improvement in instrumental color parameters (L^*, a^* and b^* values), sensory characteristics and tenderness, thereby improving goat meat quality as compared to the non-stimulated carcasses. In an earlier study, *Gadiyaram et al.* (2008) studied the effects of post-mortem high voltage ES (580 V at 5s intervals during 120 seconds) on meat quality in two breeds of goats viz., uncastrated Spanish goats and crossbreds (Boar x Spanish females x Kiko males) as compared to non-stimulated carcass parts. The meat from electrically stimulated halves of goat carcasses had significantly higher (quadratically) pH decline to reach lower ultimate pH, higher (cubic) 24h-temperature decline and lower shear force value (3.0 kg *vs.* 4.2 kg) as compared to the control (non-stimulated goat carcass halves). The sarcomere lengths and instrumental color values were not affected by ES. The heated calpastatin activities were not influenced by ES, but the activities were lower at day 4 compared to day 1 of ageing. No significant effects were noticed on the myofibrillar protein concentrations (myosin, myomesin, desmin, actin and troponin-T; $p>0.05$). However, the desmin concentration of ES applied meat tended to decrease at day 4 of ageing. This study indicated that ES significantly accelerated post-mortem glycolysis and improved tenderness of goat meat.

Finally, in a study by *Biswas et al.* (2007), the authors studied the effect of ES (35, 110, 330, 550, 1100 V with fixed 50 Hz and 10 pulses/s for 3 min.) on quality of tender stretched chevon sides of 5–8 years old male Black Bengal goats. Changes in different quality parameters like decreased fiber diameter, WHC and pH, increased sarcomere lengths, increased tenderness as per taste panel scores and stable microbial counts were observed in electrically stimulated chevon as compared to the non-stimulated control chevon. The 330V, 50Hz and 10 pulses/s treatment showed superiority above other treatments in most of the quality parameters of chevon.

Post-harvest treatments

Ageing and Chilling

"Ageing" or "conditioning" or "maturation" of meat refers to the holding of meat cuts and carcasses under controlled refrigeration/chilling conditions just above the freezing point (2–3°C) in order to improve palatability traits (*Khan et al.*, 2016; *Gagaoua et al.*, 2022; *Lamri et al.*, 2023b). Ageing greatly alters the biological environment of meat by hydrolytic and proteolytic enzyme activity including changes in the taste-active compounds, which consequently lead to flavor and tenderness changes (*Dashdorj et al.,* 2015; *Kannan et al.*, 2014). The improvement of meat flavor may involve the release of free amino acids and peptides and breakdown of ribonucleotides to yield IMP, GMP, inosine and hypoxanthine during postharvest ageing (*Koutsidis et al.*, 2007). Different studies have been conducted on ageing of goat meat and its effect on palatability and other meat quality parameters.

Xiao et al. (2022) noticed changes in color, cooking loss, texture, protein, amino acids and the expression of 17 meat quality-related genes in *Longissimus thoracis* from goats during post-mortem ageing of 0, 12, 24 and 48 h at 4°C. With the development of *rigor mortis*, shear force value, texture and cooking loss had the highest value after 12 hours of ageing. Both myofibrillar and sarcoplasmic proteins were degraded 12 h onwards producing the degraded products like myosin heavy chain, troponin-T, desmin and actin. The expression of 17 genes peaked at 12–24 h. The color and contents of aspartic acid, serine, tyrosine, phenylalanine changed significantly within 24 h of ageing.

Lamri et al. (2023b) used a high-throughput shotgun proteomics approach to decipher the post-mortem changes in the *Semitendinosus* muscle young male goats of the Saanen x *Naine de Kabylie* crossbred reared under extensive production system in Kabylia region, Algeria. The evolution and comparison of the muscle proteome over three post-mortem times (1, 8, and 24 h) was assessed. The temporal proteomics profiling revealed several changing proteins that belong to myriad interconnected pathways. Briefly, binding, transport and calcium homeostasis, as well as muscle contraction and structure, exhibited an equivalent contribution during post-mortem, demonstrating their central role. Catalytic, metabolism and ATP metabolic process, and proteolysis were active pathways from the first hours of animal bleeding. Conversely, oxidative stress, response to hypoxia and cell redox homeostasis along chaperones and heat shock proteins accounted for the large proportion of the biochemical processes, more importantly after 8 h post-mortem. Overall, the conversion of goat *Semitendinosus* muscle into meat is largely orchestrated by energy production as well as mitochondrial metabolism and homeostasis through calcium and permeability transition regulation. The study further evidenced the role of ribosomal proteins in goat post-mortem muscle, signifying that several proteins experiencing changes during storage, also undergo splicing modifications, which is for instance a mechanism known for mitochondrial proteins. Thanks to the in-depth bioinformatics analyses and a new approach in studying meat tenderization by means of temporal shotgun proteomics, the authors evidenced for the first time the dynamic time-course changes and molecular signatures underpinning the conversion of goat muscle into meat. Twelve proteins (FHOD1, PDCD6IP, SIRT2, SLC25A3, GPD2, SPR, UCHL3, RPS3A, SGTA, MYOZ2, GSTM3, and NDRG2) were changing in their abundance throughout the storage period, from 1 h until 24 h post-mortem. Eleven of these proteins are suggested as candidate biomarkers to monitor the changes taking place in the goat muscle proteome during the tenderization phase (*Lamri et al.,* 2023b).

Pophiwa et al. (2017) evaluated the carcass and meat quality of Boer goats and unimproved indigenous goats of South Africa under delayed chilling conditions. This study shows that delayed chilling could be a useful strategy in improving the color and tenderness of goat meat. *Abuelfatah et al.* (2016) studied the effects of enriching Boer goat meat with n-3 PUFA on meat quality, sensory evaluation and lipid oxidative stability at different post-mortem ageing times (1–7 days). Although there were no effect on cooking loss, shear force and color at 1-day of ageing, the color of meat was affected at 7-day of ageing. The tenderness, juiciness and overall acceptability of 20% PUFA enriched groups were rated better. No differences in color, flavor and aroma was observed after 7 days of ageing by sensory evaluation. However, lipid oxidation increased with increasing PUFA content and post-mortem ageing time in goat meat.

Nagaraj et al. (2006) evaluated the effect of post-mortem ageing on pH, temperature, drip loss, sarcomere length, myofibrillar fragmentation index, myofibrillar protein solubility, released calcium and myofibrillar ATPase activity in different goat muscles stored at 5°C up to 20 days post-mortem. The results indicated that the rate of pH decline, temperature, myofibrillar ATPase activity and sarcomere length decreased during ageing. However, a significant increase in drip loss, myofibrillar fragmentation index and myofibrillar ageing was observed with increasing ageing period. Thus, the degree of ageing affected various biochemical indices of goat meat.

Kannan et al. (2006) determined the effects of different dietary treatments and post-mortem ageing on meat quality characteristics in castrated dairy goats. A decrease in pH and temperature of goat carcasses with increasing ageing time was observed, irrespective of treatments. The Warner-Bratzler shear force values, collagen solubility and cooking loss of goat meat aged 1-, 3- or 6-days post-mortem were not influenced by treatments. In conclusion, the diet did not influence meat quality characteristics, and shear force values of chevon did not decrease due to post-mortem ageing. Rapid heat dissipation from goat carcass during rapid chilling could have caused cold shortening and the meat did not respond to ageing properly.

Curing

The curing of meat involves the addition of nitrite and/or nitrate salts together with sodium chloride for improvement in oxidative stability, sensory attributes (color and flavor) and microbiological quality and stability (*Pegg & Honikel*, 2014; *Gagaoua and Boudechicha*, 2018). Several studies have investigated the effect of curing on goat meat quality. Teixeira *et al.* (2017) evaluated the physico-chemical and sensory characteristics of goat cured legs. The pH and water activity of cured meat was found to be adequate with respect to microbial growth to control meat deterioration, promoting safety and stability to shelf-life of products. The high protein, low cholesterol content, lower TBARS values and low fat of the goat cured legs showed the effect of salting and ripening processes. Physico-chemical and sensory characteristics indicated that producing cured goat legs from cull animals can be an interesting way to add value to animals with very low commercial prices or potential. In the frame of the evaluation of the influence of sodium nitrite inclusion on the quality parameters of restructured chevon jerky, *Lee et al.* (2017a) found increased redness, flavor scores, decreased TBARS values and fatty acid content. This study concluded that curing protected against lipid oxidation of chevon jerky. In another study, *Ortega et al.* (2016) compared the physical properties and color parameters in goat and sheep blanket "mantas" obtained after salting and air drying. Significant differences in physical characteristics of meat were obtained, as texture, color and WHC of goat "mantas" were most influenced by salting and ageing.

Cooking

The effect of cooking depends on the method, time and temperature and the response of muscles to heat treatment is influenced by pre- and post-mortem conditions (*Webb et al.*, 2005; *Gagaoua et al.*, 2016b; *Gagaoua et al.*, 2019d). Generally, cooking temperatures below 100ºC affect palatability, but have no severe effect on nutritive value of meat (*Casey et al.*, 2003). Cooking changes the composition of animal fat, increases energy density, improves sensory attributes like tenderness, juiciness, texture, flavor and appearance *(Forrest et al., 1975; Gagaoua et al.*, 2016b). Cooking further reduces enzyme activities, prevent against lipid oxidation and microbial spoilage of meat (*Domínguez et al.,* 2019). However, prolonged cooking results in production of cook-outs or cooking loss and damages the sensory and nutritional qualities of meat (*Guerrero et al.*, 2013; *Webb et al.*, 2005; *Lamri et al.*, 2023a).

Narayan et al. (2015) studied the effects of pressure-cooking, marination with citric acid and *cucumis* powder spray on quality attributes of goat meat curry. Significant differences were observed in protein and collagen content of meat cooked under pressure cooking as compared to other treatments and control. The pressure-cooked goat meat produced lower shear force value and higher sensory scores as compared to the control and other treatments. This study found that pressure-cooked goat meat curry was highly preferred followed by *cucumis* powder, citric acid treated samples and control.

Guerrero et al. (2014) compared the consumer preferences for laboratory-based and home-based cooking of Spanish goat meat. Sensory analysis was made by trained panelists where goat meat was cooked on a grill, without any condiments whereas, consumer testing was done at home conditions after conventional cooking of leg meat of goat in an oven with condiments, salt and oil. The differences in method and time of cooking of goat meat affected flavor, texture and consumer preferences. It was concluded that sensory scores were higher for conventional home cooked (oven) meat than laboratory cooked (grilled) goat meat.

Conclusion

The quality of goat meat is a consequence of factors standing from the farm level to the fresh and/or cooked meat (continuum from farm-to-fork). This review evidenced that the intrinsic factors refer to the inherent characteristics of the goat itself that influence meat quality. One such factor is the age at slaughter, which affects the tenderness, flavor, and composition of the meat. Younger goats generally produce more tender meat, while older goats may exhibit increased levels of connective tissue and a stronger flavor profile. The effect of gender, or sex, on meat quality is another crucial aspect to consider. Males and females can differ in terms of growth rate, carcass composition, and meat attributes. Breeds also play a significant role, as different goat breeds exhibit variations in meat quality. Additionally, the slaughter weight of goats can impact meat quality, with heavier animals potentially having tougher meat due to increased connective tissue development. The contractile and metabolic properties of the muscle are essential parameters at the muscle level that affect goat meat quality. These properties are related to the biochemical and physiological characteristics of the muscle fibers and energy metabolism pathways. Differences in muscle fiber type, myofibrillar protein composition, and enzymatic activities can influence the tenderness, juiciness, and flavor of goat meat.

Extrinsic factors, on the other hand, encompass various aspects related to goat production, handling, and processing. Production or husbandry systems, including grazing practices, housing conditions, and overall management, can significantly impact meat quality. The type and quality of feed, feeding strategies, and the ratio of concentrates to roughages in the diet also play a crucial role in determining meat attributes. Antioxidants, both natural and synthetic, have been studied for their potential to improve meat quality by mitigating oxidative stress and preserving color stability. The feeding systems implemented, such as pasture-based systems or intensive feeding systems, can influence goat meat composition, fatty acid profile, and overall sensory attributes. Climate, season, and environmental conditions are additional extrinsic factors that can impact goat meat quality. Extreme temperatures, humidity, and changes in forage availability may affect animal welfare, feed intake, and subsequently, meat quality. Pre-slaughter treatments, transport conditions, and stress experienced by goats during handling and at the time of slaughter can have significant effects on meat quality. Post-mortem processing and carcass handling practices also play a crucial role in determining goat meat quality. Electrical stimulation, a common post-mortem technique, has been shown to enhance meat tenderness by accelerating the post-slaughter glycolysis process. Stunning methods used during slaughter can affect the stress response of goats and subsequent meat quality attributes. Finally, post-harvest treatments, such as ageing and chilling, have a considerable impact on meat quality. Ageing, a process that involves storing the carcass at refrigeration temperatures, allows for enzymatic processes to improve tenderness and flavor development. Curing techniques, including dry-curing and brine-curing, are employed to enhance the flavor, color, and preservation of goat meat. Cooking methods and related parameters, such as temperature, cooking time, and moisture levels, greatly influence the sensory attributes and palatability of goat meat.

Overall, this review is the first to provide insights into both the intrinsic and extrinsic factors influencing goat meat quality throughout the production and processing chain. It highlighted the importance of understanding and optimizing multiple factors to ensure a consistent delivery of high-quality goat meat to consumers. However, despite the existing knowledge, there are still important research gaps and future perspectives to explore. First, we need to investigate the interactions between different factors and their cumulative effects on goat meat quality. For instance, understanding the combined influence of breed, feeding regime, and age at slaughter on meat attributes would provide valuable insights for optimizing production systems and achieving consistent meat quality. Second, more research is required to explore the potential use of natural antioxidants and innovative feeding strategies, in the frame of circularity, to enhance the nutritional profile and oxidative stability of goat meat. The effects of climate change on goat production systems and meat quality also warrant further investigation, as changing environmental conditions may impact animal welfare, feed availability, and subsequent meat attributes. Last but not least, advancements in post-mortem processing techniques and the use of omics tools (likely transcriptomics proteomics, metabolomics, lipidomics, …etc) and their integration should be explored to optimize goat meat quality and reduce its variability. Continued research on post-harvest treatments, including ageing, chilling, and curing methods, can further enhance the sensory attributes and shelf-life of goat meat.

Unutrašnji i spoljašnji faktori koji utiču na kvalitet svežeg kozjeg mesa: Pregled

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A p s t r a k t: Kozje meso, poznato i kao „chevon“, važan je izvor proteina i esencijalnih hranljivih materija u mnogim regionima širom sveta. Da bi se obezbedila proizvodnja kozjeg mesa visokog kvaliteta, ključno je razumeti unutrašnje i spoljašnje faktore koji utiču na njegova senzorna, tehnološka i nutritivna svojstva. Ovaj rad ima za cilj da pruži pregled faktora koji utiču na kvalitet kozjeg mesa u celom lancu proizvodnje i prerade. Opisan je značaj različitih faktora koji utiču na kvalitet kozjeg mesa. Prvo, fokus je stavljen na unutrašnje faktore, uključujući uticaj starosti prilikom klanja, pola, rase, težine pre klanja, uzimajući u obzir i kontraktilna i metabolička svojstva mišića, razmatrajući njihov uticaj na važne unutrašnje kvalitetne osobine kao što su mekoća, ukus, boja i ukupan kvalitet kozjeg mesa. Štaviše, spoljašni faktori, kao što su proizvodni sistemi, uzgojne prakse, strategije ishrane, vrste stočne i kabaste hrane, antioksidansi, sistemi hranjenja, klima, sezona i uslovi životne sredine su ispitani pored tretmana pre klanja, uslova transporta i stresa, koje koze doživljavaju u vreme klanja. Sve u svemu, ovaj pregled sintetizuje trenutno znanje o unutrašnjim i spoljašnim faktorima koji utiču na kvalitet kozjeg mesa. Rezultati naglašavaju važnost boljeg razumevanja i optimizacije ovih faktora u svakoj fazi proizvodnje i prerade kako bi se obezbedila dosledna isporuka visokokvalitetnog kozjeg mesa. Dalja istraživanja u ovim oblastima doprineće razvoju unapređenih praksi i tehnologija u industriji kozjeg mesa.

Ključne reči: *meso; kvalitet kozjeg mesa; varijacije kvaliteta mesa; proizvodni i poljoprivredni sistemi; faktor od „njive do trpeze“*

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