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Review: Factors affecting sheep carcass and meat quality attributes

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ABSTRACT

Sheep meat comes from a wide variety of farming systems utilising outdoor extensive to indoor intensive with animals of various ages at slaughter. In Europe, slaughter may occur from 4 weeks of age in suckling light lambs to adult ages. More than any other animal species used for meat production, there are strong country-specific preferences for sheep meat quality linked to production system characteristics such as dairy or grassland-based systems. This article critically reviews the current state of knowledge on factors affecting sheep carcass and meat quality. Quality has been broken down into six core attributes: commercial, organoleptic, nutritional, technological, safety and image, the latter covering aspects of ethics, culture and environment associated with the way the meat is produced and its origin, which are particularly valued in the many quality labels in Europe. The quality of meat is built but can also deteriorate along the continuum from the conception of the animal to the consumer. Our review pinpoints critical periods, such as the gestation and the preslaughter and slaughter periods, and key factors, such as the animal diet, via its direct effect on the fatty acid profile, the antioxidant and volatile content, and indirect effects mediated via the age of the animal. It also pinpoints methodological difficulties in predicting organoleptic attributes, particularly odour and flavour. Potential antagonisms between different dimensions of quality are highlighted. For example, pasture-feeding has positive effects on the image and nutritional attributes (through its effect on the fatty acid profile of meat lipids), but it increases the risk of off-odours and off-flavours for sensitive consumers and the variability in meat quality linked to variability of animal age at slaughter. The orientation towards more agro-ecological, low-input farming systems may therefore present benefits for the image and nutritional properties of the meat, but also risks for the commercial (insufficient carcass fatness, feed deficiencies at key periods of the production cycle, irregularity in supply), organoleptic (stronger flavour and darker colour of the meat) and variability of sheep carcass and meat quality. Furthermore, the genetic selection for lean meat yield has been effective in producing carcasses that yield more meat, but at a penalty to the intramuscular fat content and eating quality of the meat, and making it more difficult to finish lambs on grass. Various tools to assess and predict quality are in development to better consider the various dimensions of quality in consumer information, payment to farmers and genetic selection.

Implications

This article critically reviews the current state of knowledge on factors affecting sheep carcass and meat quality. Quality has been defined by the set of attributes that allow the product to satisfy end-user needs, which cover organoleptic, nutritional, safety, commercial, technological and image attributes. This article pinpoints critical periods and key factors of the production chain, and potential antagonisms between the attributes that constitute quality, which necessitates to search for trade-offs. It highlights research questions that still need to be addressed.

Introduction

Sheepmeat in Europe is farmed through a diverse array of systems, largely driven by the main output (meat or milk) and pedo-climatic conditions, and spanning a gradient from extensive to intensive (Sañudo et al., 1998; Berge et al., 2003). These different contexts condition the breeds and on-farm practices employed, therefore the product quality (Sañudo et al., 1998; Montossi et al., 2013). The attributes consumers value also differ between

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countries and what is seen as a desirable attribute by consumers in Northern Europe may be seen objectionable by consumers in Southern Europe (Sañudo et al., 2007).

EU regulation (N° 1308/2013) differentiate two age categories for sheep as under (lambs) or over (sheep) a year old, and distinguish light from heavy lambs (carcass weight below and above 13 kg, respectively). Light lambs are typical in Mediterranean country production systems (Sañudo et al., 1998; Berge et al., 2003); their meat is pale with subtle flavour (Carrasco et al., 2009). This category contains the very young suckling lambs from dairy-purpose herds that are slaughtered at 25–45 days (Sañudo et al., 1998). These lambs are prized in Southern Europe where there is a large proportion of dairy ewes. Heavy lambs are slaughtered at between 3 and 12 months of age (usually before 8 months) (Berge et al., 2003). This is the main type of lamb produced in Northern Europe, where they can be pasture-fed when the climate is adequate (age at slaughter will generally be 4–8 months). In areas where conditions make pasture-finishing difficult or in farms that cultivate crops and have little or no grasslands, the lambs are often stall-fed (age at slaughter will be 3–5 months) (Berge et al., 2003). A proportion of the heavy, stall-fed lambs in France come from dairy farms, as the Lacaune breed is a mixed breed (milk and meat). Sheep are eaten mainly in Anglosphere countries but also feature highly in the halal market; their meat is bright red with an intense flavour.

The quality of a product is defined by the set of attributes that allow it to satisfy the stated or implicit end-user needs. It has been broken down into six core attributes: organoleptic, nutritional, safety, commercial, technological and image, the latter covering: cultural, ethical and environmental dimensions associated with food production, including origin, all of which play a role in shaping consumer perceptions and are mobilised in product quality labelling schemes.

Factors affecting sheep carcass and meat quality attributes and their effects

Many factors influence each quality attribute, and one factor can affect several quality attributes. The factors of variation in the core dimensions of quality and their importance are rolled up into Table 1.

Commercial quality attributes

There are two different schemes for lamb classification in the UE depending on whether the carcass weight is above or below 13 kg. The conformation score is not considered in the latter, only weight, fat class and meat colour (Sañudo et al., 2000; Campo et al., 2016). In heavy lambs, carcasses are classified and priced on three core criteria: weight, conformation and fatness. As sheep carcasses are not trimmed and retail cuts can encompass several muscles, fat cover and intermuscular are of particular importance. In heavy lambs, the carcass yield most often ranges between 40% and 52% of the BW and increases with BW and fatness (Schreurs and Kenyon, 2017a). Carcass yield also depends on breed, increasing proportionally, at a given BW, in breeds that have higher fatness, higher muscling or muscle-to-bone ratio (Hegarty et al., 2006), or less non-carcass tissues. The sex effect is age-dependent. Once they reach puberty, uncastrated males have around 1% less carcass yield than same-weight females, due to the testicle weight and less fat on the carcass. However, males often turn out higher yield due to superior muscling (Hegarty et al., 2006). The diet influences carcass yield via a direct effect on gut content (Thériez et al., 1992) and an indirect effect on fatness. Suckling lambs have carcass yields that are 2–4% higher than weaned lambs (Litherland et al., 2010) and diets that are more digestible create less gut fill and greater carcass yields (Somasiri et al., 2015).

Carcass composition and fatness

Muscle tissue grows steadily after birth, at the same pace as the frame, whereas the fat depots are later to develop, in the order internal > intermuscular > subcutaneous > intramuscular fat. This means, as the animal grows towards maturity, there is an increasing fat percentage and muscle-to-bone ratio (Perez et al., 2002; Hopkins et al., 2007). The proportion of muscle in the carcass decreases and the proportion of fat increases as BW increases (Schreurs and Kenyon, 2017a). Tissue biochemical composition also changes, with muscle gaining lipid and losing water, with advancing maturity. The extent of the development of carcass fat as the sheep grows depends on potential adult BW which varies with breed, sexual type and birth weight. At a given BW, there will be less fat in heavy or later-maturing breeds, and in entire males than in females, with castrates intermediate (Schreurs and Kenyon, 2017a; Ye et al., 2020). Lambs that were lighter at birth have also been noted to be fattier at any given BW (Villette and Thériez, 1981). Each type of animal thus has an optimal slaughter BW beyond which the animals will show over-fatness.

Selection to increase growth rate and decrease fat accretion can accelerate muscle growth (Schreurs and Kenyon, 2017a). Breeds like Texel, which have been selected for muscling, show greater loin eye surface and higher muscle development. Genetic selection over the past decade has managed to increase muscling, carcass weight and yield, and decrease fat accretion. Genotypes carrying mutations in the *Callipyge* and *Carwell* genes responsible for muscle hypertrophy show higher muscle-to-bone ratio and larger rib-eye area and less fat accretion (Schreurs and Kenyon, 2017a).

Feed-energy restriction during gestation can affect lamb carcass quality. When submitting ewes to feed restriction in mid-gestation followed by *ad libitum* re-feeding, Piaggio et al. (2018) found no effect on lamb weight or carcass fatness but lower weights of the frenched rack and leg. Male lambs born to feed-restricted ewes from day 30 of gestation followed by *ad libitum* feeding during lactation showed slower growth and lower-quality carcass, these effects being not observed in female lambs indicating a sex-dependent response (Ithurralde et al., 2019). The authors explained these sex differences as an evolutionary strategy to protect females when diet is restricted. A study on nutrient restriction in ewes over the last 6 weeks of gestation followed by *ad libitum* re-feeding during lactation showed negative effects on lamb birth and carcass weights and on growth. Bone growth was also reduced, which may compromise the animal robustness (Tygesen et al., 2007). Prenatal programming studies remain however rare and their results inconsistent. Some studies report an increased carcass fatness and a lower muscle-to-fat ratio in lambs born to feed-restricted ewes (Greenwood et al., 2010), whereas other studies do not (Piaggio et al., 2018), some studies report a decrease in lamb birth and carcass weight (Tygesen et al., 2007), whereas other studies do not (Piaggio et al., 2018; Ithurralde et al., 2019). These conflicting results may reflect differences in the restriction level, in the gestation stage when feed restriction is applied, in the extent of body condition for the ewe to buffer nutritional restriction, in differences in the variables measured and in the number of animals under study.

In suckling lambs, increasing dietary energy intake increases fat accretion. In weaned lambs, there is no effect of type or method of distribution of the feed on commercial quality attributes, but feed restriction leads to lower fatness (Sañudo et al., 1998; Hegarty et al., 2006; Hopkins et al., 2007). Undersupply of feed nitrogen increases fatness (Hegarty et al., 1999). The effect of a compensatory growth on carcass composition is debated, some authors reporting that body-gain composition is similar to that in a 'nor-

Table 1
Summary of the effects of factors that influence sheep carcass and meat quality attributes.

	Commercial	Organoleptic	Nutritional	Technological	Safety	Image
Muscle/cut		+++	+++	–		
Animal characteristics						
Breed	+++	+	+	–	–	+
Age	+++	+++	+++	–	+	+
Sexual type	+++	++	+	–	–	–
Birth weight	++	–	–	–	–	–
On-farm and preslaughter						
Feeding restriction of the dam	+	–	–	–	–	+
Diet	+	++	+++	+++	+	+
Castration	++	++	+	–	–	++
Stress	–	+++	–	+	–	+++
Carcass processing						
Chilling	–	+++	–	–	++	–
Electrical stimulation	–	++	–	–	–	–
Storage						
Ageing	–	+++	+	+++	++	–
Packaging		+++		+++	+	–

No effect (–), low effect (+), moderate effect (++), high effect (+++).

mal' growth setting (Schreurs and Kenyon, 2017a), whereas others report slightly less fat and more muscle and bone (Atti and Ben Salem, 2008). Grain-fed lambs tend to be fatter at a given BW than pasture-fed lambs (Thériez et al., 1992; Priolo et al., 2002a), which has been attributed to a higher ruminal propionic: acetic acid ratio and the combination of higher intake and lower energy expenditure (Priolo et al., 2002a). Weaning can modulate fatness: lambs weaned at 45 or 75 days have been shown to present less fat at slaughter (120 days) than unweaned lambs (Ekiz et al., 2016).

Carcass tissue distribution

Fat content varies hugely among cuts, being lowest in the leg and highest in the breast (Campo et al., 2016). Fat partitioning in the different deposition sites varies with breed and sex (Schreurs and Kenyon, 2017a). Likewise, breeds selected for muscling have a slightly higher proportion of muscle tissue in the leg (Schreurs and Kenyon, 2017a). The proportion of muscle in table cuts (shoulder, loin, leg) has been shown to be heritable enough to selectively breed muscle tissue towards particular carcass sites (Campbell and McLaren, 2007).

Conformation

The most important factor in carcass conformation is age, the carcass becoming thicker and more compact as the animal grows and gets older. There is a long-known breed effect, as the breeds selected for muscularity tend to have more compact rounded bodies (Navajas et al., 2008). However, a study including various breeds showed that conformation score shared little correlation with amount of muscle in the carcass, unlike in cattle (Kempster, 1981).

Firmness and colour of fat cover

After chilling, the fat cover may present two defects: lack of firmness and undesirable colour (Prache et al., 1990; Normand et al., 2001). The lack of firmness is mostly found in stall-fed lambs that have fat that holds more water and contains low-melting-point fatty acids (**FA**s), particularly less even medium-chain saturated FAs (**SFAs**) and more odd- and branched-chain FAs (Berthelot et al., 2012). High-concentrate diets decrease pH in the rumen and increase the production of propionate, which is pivotal to the synthesis of odd- and branched-chain SFAs (Normand et al., 2001). The effect of sexual type is important, the frequency of defects being in the order entire males > castrates > females (Normand et al., 1997). This defect can be reduced by limiting concentrate intake to increase forage intake in late-finishing, by feeding whole-grain cereals and by castration (Normand et al., 1997), but the type of concentrate has little effect (Normand et al., 2001). Longer suckling has a beneficial effect, as milk lipids are rich in even SFAs. In pasture-fed lambs, forage type can influence fat cover firmness, as the proportion of legumes modulates polyunsaturated fatty acids (**PUFAs**)-to-SFA ratio (Lourenço et al., 2007). Grazing legume-rich swards can thus lead to fat that is less firm, which is an important consideration for organic farming where legumes are prized (Prache et al., 2011).

Fat colour defects have a diet and a genetic origin but can also be associated with animal health issues. Pasture-fed lambs have lighter and yellower fat cover than stall-fed lambs (Priolo et al., 2002a), due to accretion of the carotenoids found in herbage. Switching pasture-fed lambs to stall finishing decreases fat carotenoid content, through a dilution process (Huang et al., 2015). However, supplementing pasture-fed lambs with barley has no effect on fat carotenoid concentration (Devincenzi et al., 2019). Macari et al. (2017) showed between-breed differences in the ability to store carotenoids in the fat. Using lambs from two breeds that were individually penned and fed similar dietary levels of lucerne (as a source of carotenoid pigments), they found that the plasma and fat carotenoid contents at slaughter were higher in the Romane breed than in the Limousine breed. Furthermore, a mutation in the *beta-carotene oxygenase 2* (*BCO2*) gene has been associated with yellow fat in lamb (Vage and Boman, 2010). Fat tissue carotenoid concentration also increases with animal age, probably as the ingested pigments accumulate (Vage and Boman, 2010). The accumulation of bilirubin in fat may be due to haemolysis and/or liver problems (Prache et al., 1990; Thériez et al., 1997). The brown fat defect is predominantly observed in intensively reared male lambs fed high-grain diets (Prache et al., 1990; Berthelot et al., 2012). It has been attributed to an excessive accumulation of haem pigments and end-products of PUFA peroxidation (Prache et al., 1990). As for firmness, this defect can be reduced by limiting concentrate intake to increase forage intake in late-finishing, by feeding whole-grain cereals, and by castration (Thériez et al., 1997).

Organoleptic quality attributes

Meat colour

Meat colour can make or break a purchase decision, through both its intensity and any colour instability or alteration. The colour of fresh meat is shaped by its myoglobin content and its pH. For a given piece of meat, it depends on its proportions of slow-twitch and fast-twitch fibres and their metabolism and on its lipid content (Berthelot and Domange, 2018). Animal age, farming practices (chiefly diet) and preslaughter conditions (chiefly stress) are key factors of variation. Light suckling lambs have light coloured meat due to low myoglobin content (Berge et al., 2003). Muscle myoglobin content and consequently redness increase with advancing age, but the effect is not linear; it is strong in the first 120 days of life, then slows from day 120 to day 270 (Berge et al., 2003; Calnan et al., 2016). There is generally no discernible effect of sex if the animals are slaughtered at the same age and fatness (Sañudo et al., 1998; Calnan et al., 2016; Ye et al., 2020). The breed effect is debated. Some authors reported that lambs sired by Merino rams produced darker meat than lambs sired by Hampshire Down, Ile-de-France, Poll Dorset, Southdown, Suffolk and Texel rams, due to a higher myoglobin content (Calnan et al. 2016), but this effect was not confirmed in other studies (Jacob and Pethick, 2014; Monaco et al., 2015). Preslaughter stress causes a depletion of muscle glycogen stores that leads to high ultimate pH, which causes darker meat (Sheath et al., 2001), so factors such as transport conditions from farm to abattoir are important considerations (Miranda-de la Lama et al., 2012). Pasture-fed animals give darker meat than animals fed a concentrate-based diet (Priolo et al., 2002a). This effect is multifactorial, with direct factors tied to diet and physical activity, and indirect factors (age at slaughter and intramuscular fat (**IMF**) content). Physical exertion shifts the muscle fibres towards a more oxidative metabolism, with an increase in myoglobin content (Hopkins and Nicholson, 1999). Pasture-fed animals also have a propensity to produce meat with a high ultimate pH, which further darkens the meat (Calnan et al., 2016), this being due to lower glycogen stores at slaughter and/or greater sensitivity to preslaughter handling-related stresses (Sheath et al., 2001). These differences between pasture-fed and stall-fed animals can be compounded by differences in age at slaughter and IMF content: pasture-fed lambs tend to be slaughtered at an older age (Berge et al., 2003), which decreases lightness and increases redness of the meat. Pasture-fed lambs also often have a lower IMF content, which further reduces meat lightness (Warner et al., 2010). Feeding different forage diets does not generally induce differences in meat colour (De Brito et al., 2016), but studies observed less intense meat colour when lambs grazed tannin-rich forages (Priolo et al., 2002b and 2005). It is important to note that grazing conditions and lamb growth rate can vary widely with a grass-based diet (Prache and Thériez, 1988), which may add to the variability of meat colour in animals from grassland-based systems.

Eating quality

Eating quality for sheepmeat is judged the most heavily for flavour followed by tenderness and then juiciness (Watkins et al., 2013). Consumer preferences are tied to cultural background. A large part of the variability in consumer liking of lamb across six countries (Greece, Italy, Spain, France, the United Kingdom and Iceland) is explained by the production system, and European sheepmeat consumers can be collapsed into two categories: 'Mediterranean' consumers who prefer lambs fed either milk or concentrate-based diets, with mild flavour, and Northern-European consumers who prefer pasture-fed lamb, which has a more intense flavour (Sañudo et al., 2007). These preferences are connected to the traditional farming systems practised in these countries, and thus to their cultural foodways, which explains why certain consumers are not accustomed to the 'pastoral' flavour of pasture-fed lamb and prefer concentrate-fed lamb, and *vice versa*. A study (Font-i-Furnols et al., 2009) involving consumers from four European countries (Spain, Germany, the United Kingdom and France) who taste-tested three types of Uruguayan lamb (stall-fed, pasture-fed, and pasture-fed with concentrate supplement) showed that Spanish, German and French consumers preferred the taste of stall-fed lamb, British consumers preferred the taste of lamb from mixed grazing and concentrate systems, and there were 'clusters' of consumers that showed specific preferences but none of them preferred exclusively pasture-fed lamb. There is conflicting literature on the effect of animal genotype on eating quality of the meat. Pannier et al. (2018) highlighted that these divergences stemmed from the fact that many studies have used small sample populations, some studies used trained panels while others used untrained consumers, and production factors were frequently combined that made it difficult to get robust comparisons. Several studies concluded that there was little breed effect on eating quality (Arsenos et al., 2002; Ye et al., 2020). However, in the United Kingdom, lamb meat from the Scottish Blackface breed was judged more tender and had better overall liking than lamb from the Texel breed (Navajas et al., 2008). Genotypes carrying mutations in the *Callipyge* and *Carwell* genes responsible for muscle hypertrophy have meat with less IMF and of lower tenderness (Warner et al., 2010). Studies that did find between-breed differences however often considered the breed of minor influence on eating quality in comparison to other factors (like diet for example). Surprisingly, while certain compounds involved in off-flavour show high interindividual variability for animals under the same management (Devincenzi et al., 2014 and 2019; Rivaroli et al., 2019), there are still no data on the heritability of sheepmeat flavour or odour and the associated compounds (Watkins et al., 2013) and no studies reporting sire selection for odour/ flavour heritability. Sexual type has a weak effect, with eating quality generally ranking in the preference order of females > castrates > males (Arsenos et al., 2002; Navajas et al., 2008; Pannier et al., 2014; Gravador et al., 2018). These differences are often attributed to IMF content, but not always (Pannier et al., 2014). Some studies failed to find a sexual type effect, but they were performed with light lambs that are less prone to flavour issues (Teixeira et al., 2005; Tejeda et al., 2008). Based on a systematic review, Pannier et al. (2018) considered that the effect of sexual type was relatively minor compared to IMF content or diet. Focusing specifically on tenderness, Sales (2014) meta-analysed 55 studies and concluded that castrates generally outperform males. Concerning flavour/odour, there are few differences between ram lambs, ewe lambs and wethers (Schreurs and Kenyon, 2017b). Older animals have less desirable eating quality (Hopkins et al., 2006). The age effect on tenderness is muscle-dependent, as muscles with less collagen show less impact of age (Pannier et al., 2018). The flavours are more intense and off-flavours are more marked in older animals (Gravador et al., 2018). The 'mutton' flavour gets stronger with age, which is attributed to an increase in fat content of short-chain and branched-chain fatty acids (**BCFAs**) (Watkins et al., 2013).

The meat tenderness, juiciness, flavour, and overall liking are positively related to IMF content, even though these relationships can vary between countries (Pannier et al., 2018). When animals get older, carcass fat percentage increases, and so IMF content increases too. This can have a bigger impact on tenderness than the concomitant reduction in collagen solubility (Hopkins et al., 2006). In the end, a compromise between organoleptic and commercial properties needs to be found, i.e. enough IMF to guarantee good eating quality, but not too much to avoid penalising carcass composition (commercial quality attributes) and dietary health. Australian studies recommend an IMF of 5% or greater in the *Longissimus lumborum* to achieve a 'better than every day' score for liking (Pannier et al., 2018), while an IMF level less than 3% is thought to negatively impact eating quality ratings (Watkins et al., 2013) but is recommended for a 'low fat' claim (Pannier et al., 2018). Negative effects on eating quality traits by selecting for lean meat yield and loin eye muscle depth and against cover fat have been observed (Pannier et al., 2014). There is therefore a compromise to be found for a balanced selection pathway combining the two antagonistic attributes of lean meat yield and meat fat content (Pannier et al., 2018). Methods are in development to predict eating quality at the abattoir for product segmentation and transition into a quality value-based payment system for farmers (Pannier et al., 2018). Accompanying this are investigations into rapid online methods to measure IMF (Guy et al., 2011). In addition to the role of IMF for eating quality, subcutaneous fat and intermuscular fat act as thermal insulation for carcasses in the chiller and limit the risks of cold shortening, which affects meat tenderness (Berthelot and Domange, 2018). Electrical stimulation can deplete the muscle glycogen stores and snap-chill the carcass without risk of cold shortening (Schreurs and Kenyon, 2017a).

Sheepmeat has a unique flavour, distinct from other red meats and consumers tend to be polarised for their liking of sheepmeat flavour relative to other meats (Watkins et al., 2013). Large variation in flavour liking and sensitivity between groups of consumers and between sensory panellists assessing the same meat samples is evident in the literature (Prescott et al., 2001; Farouk et al., 2007; Schreurs and Kenyon, 2017b) and this is one of the reasons that research into the impact of diet on sheepmeat flavour has produced inconsistent responses. The review by Watkins et al. (2013) showed that the diet effect was far from simple and that there was still no consensus on which volatiles are essential for desirable sheepmeat flavour and how they differ compared to other red meats. It also stressed that outside volatile compounds, comparatively little work has focused specifically on the non-volatile taste components of lamb flavour, and that there is still an unaddressed need for an integrated approach encompassing animal traits, on-farm practices and consumer practices to fully explain and predict the traits that shape sheepmeat flavour. Historically, the focus of attention for sheepmeat flavour has been given to 'mutton' and 'pastoral' flavours. The 'mutton' flavour increases with age of the animal (Watkins et al., 2013). It is at least partly due to BCFAs, which are typically associated with concentrate-based diets, but there have already been reports of higher BCFA levels in pasture-finished lambs (Watkins et al., 2013). The 'pastoral' flavour is linked to pasture-feeding and is attributed to 3-methylindole (or skatole) produced by ruminal degradation of the amino acid tryptophan, and oxidation products of alpha-linolenic acid (**ALA**) that form when the meat is cooked (Sheath et al., 2001; Schreurs et al., 2008; Watkins et al., 2013). These, however, are not the only characteristic flavour notes reported in sheepmeat: brassicas, for example, contain glucosinolates which are considered to impart an offensive odour to lamb meat (Watkins et al., 2013).

Farming practices influence eating quality through direct effects on the components of meat flavour (Watkins et al., 2013), and indirect effects, chiefly IMF content and age at slaughter (Ye et al., 2020). Meat from weaned lambs is generally not as juicy as meat from unweaned lambs, which has been attributed to the weaning effect on fat mobilisation (Ye et al., 2020). Meat from lambs finished on grass has a different flavour to meat from lambs finished on concentrate-based diets, the difference being perceptible by trained panels, but not always by untrained consumers (Resconi et al., 2009; Watkins et al., 2013; Devincenzi et al., 2019; Rivaroli et al., 2019). Grass-fed lamb often also has inferior tenderness (Priolo et al., 2002a; Resconi et al., 2009). Furthermore, as pasture-feeding intrinsically adds variability in slaughter age (Prache and Thériez, 1988), there is greater variability in the flavour, odour and tenderness of pasture-fed lambs compared to stall-fed lambs. Rousset-Akrim et al. (1997), for example, showed that flavour and odour gained little intensity when lambs were slaughtered after 90 days after being on pasture but were dramatically enhanced in pasture-fed lambs slaughtered after 215 days. As the compounds responsible for pastoral flavour vary with pasture composition, pasture-finished lamb shows seasonal variation in flavour, with more intense 'pastoral' flavour when the grass is younger and therefore contains more nitrogen and ALA (Watkins et al., 2013). Young grass, which is protein-rich and has a high ratio of soluble protein to rapidly fermentable carbohydrates, leads to high skatole synthesis (Schreurs et al., 2008). As a rule, meat from pasture-fed lamb has higher skatole levels and more off-flavours (Resconi et al., 2009), more intense 'mutton' flavour and more rancid, acidic or liver flavour notes (Priolo et al., 2002a; Resconi et al., 2009) than stall-fed lamb. It also has a higher ALA content (Aurousseau et al., 2007; Berthelot and Gruffat, 2018) that, once cooked, gives the oxidation products partly responsible for pastoral flavour. Forage type has an important effect on sheepmeat flavour. Off-flavours have been recorded on white clover, alfalfa and phalaris, as well as rape (Schreurs and Kenyon, 2017b). Legumes like white clover and alfalfa are effectively rich in rapidly degradable proteins, thus increasing the formation of skatole and indole in the rumen (Schreurs et al., 2008) and consequently the concentration of these odour compounds in the fat (Devincenzi et al., 2014) compared to grass. As organic farming systems value legumes, there is an increased risk of off-flavours in organically farmed lamb meat (Prache et al., 2011). Various nutritional strategies have been tested to mitigate intense flavours of pasture-fed lambs. Fat concentrations of skatole and indole can be reduced using condensed tannins found in certain legumes (sainfoin, birdsfoot trefoil, sulla, mimosa, tara) or other plants (quebracho, grape seed, chesnut) that can be offered in fresh, powder or extract forms (Schreurs et al., 2008; Girard et al., 2016; Rivaroli et al., 2019; Del Bianco et al., 2021). The condensed tannins inhibit the ruminal synthesis of skatole and indole by complexing the proteins. However, subsequent sensory assessments sometimes prove disappointing, with little (Girard et al., 2016) or no effect (Schreurs et al., 2008; Rivaroli et al., 2019) on flavour, possibly because skatole and indole concentrations were not reduced enough. Devincenzi et al. (2019) tested barley supplementation in lambs grazing alfalfa with the idea of rebalancing the ratio of protein to rapidly fermentable carbohydrates in the rumen, but the practice proved inconclusive. However, Resconi et al. (2009) managed to decrease the intensity of off-odours and rancid and acidic flavours by increasing the proportion of concentrate in the diet of grazing lambs. Furthermore, Gkarane et al. (2019) observed that finishing pasture-fed lambs on a concentrate-based diet reduced the in-meat concentrations of skatole and indole but did not translate into any effect on the intensity of flavour parameters, possibly as the reduction in volatile compounds were not enough. The use of EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid)-rich algae as feed supplement did positively improve meat nutritional properties by increasing EPA and DHA content in the meat (Chikwanha et al., 2018), but it also gave rise to foreign and rancid flavour.

Preslaughter stress translates into darker and less tender meat, and reduces shelf life (Sheath et al., 2001). A curvilinear relationship between meat ultimate pH and tenderness has been reported, with the highest shear force values recorded for pH values in the 5.8–6.2 range. Miranda-de la Lama et al. (2012) showed that long-stay transport before slaughter and transport in harsh cold climate conditions created stress that significantly depleted muscle glycogen reserves, leading to higher ultimate pH and darker and tougher meat. Lambs reared indoors are less stress-sensitive as they are more accustomed to proximity with congeners and often have more frequent contact with humans. Finally, letting meat mature improves tenderness, and it is recommended to let meat from heavy lambs or adult sheep mature for at least 5 days (Pannier et al., 2018).

Nutritional quality attributes

Sheep meat is a good source of dietary protein (around 20 g/100 g of lean) that is rich in highly digestible essential amino acids in balance to human requirements; it is also a good source of nutritionally valuable micronutrients (iron, zinc, selenium, vitamins B3, B6 and especially B12) (Prache and Bauchart, 2015). Haem iron and vitamin B concentrations vary with muscle fibre metabolism, whereas lipid content varies with meat cut (Prache and Bauchart, 2015). However, there is only scant scientific literature addressing the effect of on-farm factors on these nutritional quality attributes. Protein content is relatively consistent between breeds and between meat cuts, and animal diet is not a lever for modifying meat amino acid composition (Berthelot and Domange, 2018). Meat from light suckling lambs contains less iron than meat from weaned heavy lambs (Berge et al., 2003) and is even considered as 'white meat' (Berthelot and Domange, 2018). A 100 g portion of lamb (weaned) provides 10–20% of the recommended daily allowance of iron, zinc, selenium and vitamin B6, 40% of the recommended daily allowance for vitamin B3 and 100–200% for vitamin B12 (Montossi et al., 2013). However, medical nutritionists consider that its FA profile is too rich in pro-atherogenic FAs (chiefly C16:0) and poor in the n-3 PUFAs essential to supporting the body's defences against chronic diseases. Furthermore, the n-3 PUFAs are extensively peroxidisable, which means they can form oxidised compounds toxic to consumer health. Sheepmeat essentially contains medium-to-long-chain FAs as well as lower concentrations of (volatile) short-chain, odd-chain and branched-chain FAs. Compared to beef, sheepmeat contains a higher proportion of n-3 PUFAs (Berthelot and Gruffat, 2018) and conjugated linoleic acid (**CLA**), including the *c*9*t*11 isomer (rumenic acid) that can potentially help prevent disease (Chikwanha et al., 2018). This is due to both a lower ruminal biohydrogenation and a more selective behaviour. Sheepmeat is also characterised by a higher content of BCFAs that were recently shown to have beneficial health effects in animal models (Chikwanha et al., 2018). From the human health standpoint, certain SFAs (primarily palmitic acid, C16:0) and most *trans*-monounsaturated FAs are thought to be associated with increased risk for cardiovascular diseases while opinions are split over whether naturally sourced *trans*-monounsaturated FAs are also involved in cardiovascular diseases (Chikwanha et al., 2018). On the upside, n-3 PUFAs, BCFAs and certain PUFA biohydrogenation intermediates demonstrate an array of potential beneficial effects for human health. In particular, the vaccenic (C18:1 t11) and CLA rumenic (C18:2 c9t11) acids and BCFAs could have beneficial protective effects against cancer and inflammation (Chikwanha et al., 2018).

Sheepmeat FA composition may vary with breed (Willems et al., 2014), fatness, muscle type and lipid content, but diet is the primary influencer (Berthelot and Gruffat, 2018). When fatness decreases, triglyceride content decreases whereas phospholipid content remains relatively unchanged, which means that given the compositional differences in FAs between these two fractions, leaner animals have higher proportions of PUFAs. Given the centrality of diet as a route to modulate meat FA composition, it is mostly diet-based strategies that have been evaluated for their potential to enrich sheepmeat with valuable FAs for human health.

Effect of diet and the wider feeding system

Suckling lambs are considered monogastrics in terms of digestive function, and their fat FA profile reflects the feed-milk FA profile. Adding extruded flaxseed to ewe diet has been shown to improve the nutritional properties of meat from their lambs, as it increased the meat content of C18:3, C20:5 and C22:5 (but not C22:6); it appeared to be even more effective during late-gestation but had negative effects on lamb growth rate and carcass weight (Nudda et al., 2015). These authors also observed milk-to-tissue transfers of C18:1 *t*11 and C18:2 *c*9*t*11 which contribute to improve the nutritional quality of the meat. In weaned sheep, the dietary FA composition has less influence on muscle and fat FA composition than in monogastrics, due to the low lipid content of the diets and ruminal biohydrogenation. However, increasing C18:3 intake also increases the amount deposited in muscles and n-3 PUFA-rich feeds can be used to increase meat n-3 PUFA content from 1% up to 3.5% of total FAs (Berthelot and Gruffat, 2018).

Berthelot and Gruffat (2018) reviewed 25 studies assessing feeding system effects on heavy lamb meat FA composition. They considered five groups: suckling lambs on pasture or with a concentrate supplement, weaned lambs on pasture or with a concentrate supplement, and weaned lambs stall-fed a concentrate-based diet. In suckling lambs, there was little difference between both groups. For weaned lambs, pasture-fed lamb was less fatty and had a better FA profile than stall-fed lamb, i.e. lower C16:0 and monounsaturated FA and higher n-3 PUFA, CLA and C18:0 proportions, together with a lower n-6 PUFA/n-3 PUFA ratio. Fattening on pasture rather than with concentrate doubled the n-3 PUFA proportion and reduced n-6 PUFA/n-3 PUFA ratio three-fold (2.7 vs 7.7). This is because grass is rich in ALA, an essential FA and precursor of long-chain n-3 FAs. Cereal grains are comparatively rich in linoleic acid (**LA**), the parent molecule of the n-6 FA family, which counteract the beneficial effect of n-3 PUFA when the n-6 PUFA/n-3 PUFA ratio is high. Pasture concentration of ALA depends on grazing conditions and varies with herbage maturity stage and pasture management. It is higher in new growth. Furthermore, a high herbage allowance has been shown to improve the health value of lamb FAs by increasing n-3 PUFA and CLA content and decreasing SFA content relatively to a low herbage allowance (Bauchart et al., 2012). Another important factor is the nature of the herbage. Lambs that grazed botanically diverse pastures featuring phenolics-rich plants gave a meat that was richer in PUFA (+18–42%), ALA (+20–87%) and LA (+26–58%) than lambs that grazed intensively managed lowland pastures with the concentration of these FAs in the meat being linearly related to the phenolic content of the pasture (Willems et al., 2014). Phenolics partially inhibit biohydrogenation, which also explained the lower CLA content of the meat. Grazing legume-rich pastures produces meat that is richer in ALA and LA than grazing grasses, likely due to faster rumen outflow rate and therefore less advanced ruminal biohydrogenation (Lourenço et al., 2007). The presence of plant secondary metabolites (polyphenol oxidase, flavonoids, tannins, essential oils and saponins) improved meat FA profile through higher accretion of PUFA (Girard et al., 2016; Campidonico et al., 2016). High concentrations of these compounds can be found in grassland and shrubland legumes and in certain agricultural by-products (grape, pomegranate) (Chikwanha et al., 2018). Campidonico et al. (2016) showed that silage mixtures including red clover (rich in polyphenol oxidase) and sainfoin (rich in condensed tannins) had positive synergistic effects on lamb meat n-3 PUFA content. As a rule, the diets that are rich in phenolic compounds increase the meat content of n-3 and n-6 PUFA and decrease the meat content of SFA (Frutos et al., 2020; Girard et al., 2016; Lourenço et al., 2007; Vasta and Luciano, 2011). The form of herbage offered is also an important factor, as fresh green and ensiled herbage results in a better FA profile than dry herbage (Chikwanha et al., 2018).

Concentrate supplementation at pasture erodes some of the advantages of pasture-fed lamb: monounsaturated FA content increases and n-3 PUFA content decreases (Berthelot and Gruffat, 2018) and this effect is greater when more concentrate is included in the diet (Montossi et al., 2013). Even though pasture grazing clearly enhances the nutritional properties of the meat, it is not always a possible option, especially in drought-prone areas. Grazing lambs are also sometimes grain-finished to increase their growth rate and IMF content. Postgrazing grain-finishing has been shown to progressively diminish the nutritional value benefits of pasture-feeding, the effect depending on the duration of the grain-finishing period (Aurousseau et al., 2007; Scerra et al., 2011).

Lambs fed starchy concentrate-rich rations have high lipid proportions of C18:1, especially the C18:1 *t*10 isomer. The proportional rise of C18:1 *t*10 (reaching 1–7% of total FA depending on focal tissue) is associated with a proportional decrease in C18:1 *t*11 and together this reduces the nutritional value of the FA composition, as C18:1 *t*11 is nutritionally better and serves for the synthesis of CLA rumenic (C18:2 *c*9*t*11) acid in body tissue (Berthelot and Domange, 2018). One nutritional strategy to improve the FA profile of stall-fed lamb is to supplement the concentrate with n-3 PUFA-rich feedstuffs (oilseed, oil or part-deoiled meal, algae oils that carry the advantage of adding long-chain n-3 PUFAs, including C22:6) (Berthelot and Domange, 2018; Chikwanha et al., 2018; Gruffat, 2018). Adding extruded flaxseed or flaxseed oil increases the meat content of C18:3, C20:5, C22:5 and C22:6 and improves its n-6/n-3 ratio, but algae are still prohibitively expensive to use (Gruffat, 2018). There are also technology development projects to protect dietary lipids against rumen degradation, including chemical or thermal seed/oil treatments and oil encapsulation techniques (Gruffat, 2018). Little work has been done on the nutritional properties of organic sheepmeat, but the few studies showed a higher n-3 PUFA level and a lower n-6 PUFA/n-3 PUFA ratio (Srednicka-Tober et al., 2016).

Technological quality attributes

Technological quality attributes relate to meat oxidation and shelf life. When fresh meat is exposed to air, the iron atom in the myoglobin molecule oxidises, causing the meat to turn an undesirable brown colour. Furthermore, lipid peroxidation processes lead to the formation of peroxidised products. A moderate peroxidation has a beneficial effect on sheepmeat flavour, but extensive peroxidation results in a decline in quality (Gruffat, 2018), releasing objectional odours/flavours (rancidity). Lipid oxidation products can also degrade the health value of the meat via the production of toxic compounds that play a proven causative role in colorectal cancer (Surya et al., 2016; WCRF et al., 2018). The key factors limiting the shelf life of fresh meat are therefore colour change, microbial spoilage and lipid oxidation. The oxidisability of meat is related to antioxidant–prooxidant balance. There is an interplay with animal diet through modulation of levels of PUFA (which are sensitive to oxidation), iron (pro-oxidative) and antioxidants. Sheepmeat has been shown to have a shorter shelf life than beef due to its higher PUFA content (Kasapidou et al., 2012). The on-farm and preslaughter phases also have an effect through pH: high pH meat is more susceptible to oxidation and lower microbial stability (Sheath et al., 2001).

Packaging and storage conditions are important for their ability to influence pro-oxidative factors (light, cutting, contact with oxygen) (Gruffat, 2018). The shelf life of meat depends on packaging technology. Packing under high-oxygen modified atmosphere can hold the bright red colour and inhibit the growth of pathogenic anaerobes, but it also promotes lipid oxidation. Packing under modified atmosphere containing 10–20% CO_2 has been shown to inhibit the growth of aerobic spoilage microorganisms, but a 30% CO_2 level can accelerate discolouration (Lauzurica et al., 2005). Vacuum-packing offers the longest shelf life (Berthelot and Domange, 2018).

The presence of intrinsic or added antioxidants can counter the oxidation processes and thus maintain shelf life. Meat from pasture-fed lambs has been shown to offer better oxidative stability than meat from concentrate-fed lambs (Gruffat et al., 2020). Pasture herbage has a high concentration of vitamin E, which provides antioxidant activity to counter lipid peroxidation. Forage type has been shown to modulate this effect, the meat being more colour-stable when lambs were finished on ryegrass or plantain compared to clover, alfalfa, or chicory (Kim et al., 2013). There are tannins found naturally in forage or added to feed that can improve the oxidative stability of meat (Vasta et al., 2008). Supplementing feed rations with PUFA-rich oilseeds did not raise meat antioxidant status enough to counter lipid peroxidation, which has prompted research to investigate reformulating with added dietary antioxidants (vitamin E and polyphenol-dense plant extracts) (Gruffat, 2018). Added vitamin E curbed the development of objectional odours/flavours (Muiño et al., 2014). Plant extract antioxidants like rosemary essential oil, red wine extract and *Ascophyllum nodosum* seaweed have been tested with varying degrees of success (Muiño et al., 2014; Ortuño et al., 2016).

Safety quality attributes

Sheepmeat may be affected by many microbiological hazards, including several bacteria (notably *Escherichia coli* carrying shiga-toxins, *Salmonella*, *Campylobacter*) and a parasite, *Toxoplasma gondii*. *Escherichia coli* carrying shiga-toxins and *Toxoplasma gondii* are considered as the most significant hazards (EFSA Panel on Biological Hazards, 2013). On-farm risk factors for *Escherichia coli* carrying shiga-toxins carriage are difficult to identify, but the presence of cattle on the same farm seems to be a risk factor (Urdahl et al., 2001). For *Toxoplasma gondii*, the prevalence is lower in lambs than in adults (Halos et al., 2010). The slaughtering includes operations that may affect microbiological contamination from the fleece and visceral contents. Good hygiene practices and the application of Hazard Analysis Critical Control Point system principles allow prevention and control of carcass contamination. Removal of the skin, evisceration, application of steam or washing with hot water, cooling, refrigerated or frozen storage are all potential critical points for microbial contamination of the carcass (Milios et al., 2011). Carcass and meat transport conditions are also important elements of control. Consumers also have an important role in preventing foodborne diseases associated with sheepmeat. The consumption of undercooked meat is a risk factor for sporadic cases of toxoplasmosis (Thebault et al., 2020). For *Escherichia coli* carrying shiga-toxins, the degree of cooking of meat determines the level of risk.

Image quality attributes

Sheepmeat has high symbolic, cultural and ritual value (Sañudo et al., 1998; Prache and Bauchart, 2015). Ethical consumerism and demand for local supply are steadily expanding (Montossi et al., 2013). Consumer beliefs, perceptions and expectations are pivotal factors, but they do vary over time and between consumer segments, and there are sometimes differences between what consumers say and what they purchase (Montossi et al., 2013). A study on Spanish, French and British consumers showed that all express a preference for pasture-fed lamb (vs grain-fed), considering that it is healthier, more natural and tastier, and that the farming system is more respectful of the environment and animal welfare (Font-i-Furnols et al., 2011). Another conjoint analysis on Italian and Norwegian consumers showed that they preferred lamb grazed on mountain (vs lowland) pasture as they considered that the corresponding farming systems use specific plant and animal resources which confer specificity to lamb meat (Hersleth et al., 2012). Extrinsic attribute messages and information on product origin or production system influence the acceptability of meat for certain segments of consumers and can be used as vectors for differentiation. Geographic origin is an important cue, as consumers prefer meat farmed locally or in their own country as they consider it fresher and tastier and better for the local or national economy (Font-i-Furnols et al., 2011; Hersleth et al., 2012; Montossi et al., 2013). However, these 'stated' preferences are sometimes disconfirmed when consumers 'blind-taste' the meat (Font-i-Furnols et al., 2011). Official signs of quality and origin offer a way to communicate on production system and/or origin values and differentiate the products, and logos are quality benchmarks for consumers. They are backed up by certification and traceability schemes that bring added reassurances and help to foster and forge a relationship of trust between seller and buyer. The EU counts 48 different Protected Designation of Origin or Protected Geographical Indication quality logos that cover every type of sheepmeat (Erasmus et al., 2017), but some of them may span a broad spectrum of farming conditions.

Meat environmental impact assessment requires farm-system-wide studies, which so far remain rare, especially for sheep. Benoit and Meda (2017) asserted that gross greenhouse gas emissions per kg of carcass output were much the same between conventional and organic lamb, but accounting for grassland carbon sequestration led to 7% lower net greenhouse gas emissions with organic lamb. The fact that organic systems prohibit the use of synthetic pesticides and fertilisers and limit the recourse to veterinary health products helps to preserve water and biodiversity resources and rules out potential knock-on effects on human health (Benoit and Meda, 2017).

Tensions between quality attributes and stakeholders

The various dimensions that constitute quality can be in tension, as can the interests of the different stakeholders, which highlights the need to seek trade-offs or solutions to overcome negative effects. Illustrative examples follow.

Selection for lean muscle and against fat cover

Intramuscular fat content shapes the key organoleptic quality attributes of the meat (tenderness, juiciness and flavour). However, too much IMF can be problematic for dietary health and promoting purchase. A compromise is required to get enough IMF to express good organoleptic attributes but also maintain nutritional and commercial quality attributes. Selecting for lean muscle and against cover fat has downgraded the organoleptic quality attributes of meat (Pannier et al., 2014). Moreover, it makes more difficult to finish lambs to a set level of fatness at pasture to take advantage of the nutritional and image quality attributes of pasture-fed lamb. Here again, there is a compromise to be found for a balanced selection pathway combining these antagonistic quality attributes (Pannier et al., 2018).

Pasture-fattening vs grain-fattening

There are positive effects of pasture-finishing lambs for nutritional (meat FA profile), technological (meat oxidative stability), image and certain commercial quality attributes (firmness and lightness of fat cover). On the other hand, there are negative effects of this farming practice on colour and flavour of the meat (darker meat, higher risk of intense flavour and of off-flavours) and an increased risk of insufficient carcass fatness (Table 2). Furthermore, there is often more variability in the quality attributes of pasture-fed lamb due to the greater variability in age at slaughter, and the output of pasture-fed lamb is seasonal, whereas the downstream commodity chain wants a regular year-round supply to a predictable procurement schedule and regular carcass and meat quality. A compromise can be found by supplementing grazing lambs with grain or completing the fattening with a stall finishing period, in which case the effects on carcass and meat quality will depend on level of supplement feed or length of stall finishing. Another possibility might involve increasing consumer awareness of the characteristics of pasture-fed lamb meat, especially flavour (Sheath et al., 2001).

Organic vs conventional pasture-fed lamb

Organic farming has positive effects on meat nutritional (FA profile) and image quality attributes but may present higher risk of off-flavours and sub-firm fat cover (organoleptic and commercial quality attributes) (Prache et al., 2011). These risks are tied to certain legume forages, chiefly white clover, that are often more abundant in organic grasslands. Research is investigating farming practices that could reduce the incidence of defective quality attributes while exploiting the potential benefit of white clover at pasture (for example, using condensed tannin-rich plants, Rivaroli et al. (2019)).

Conclusions

Sheep meat produced in Europe comes from a wide variety of farming systems and types of animals. There are strong country-specific patterns tied to the importance of dairy and grassland-based systems. Quality is multidimensional, with potential antagonisms between different dimensions and people involved in the food chain, which necessitates to search for trade-offs, as illustrated through selected examples. As quality builds and can also deteriorate along the continuum from the conception of the lamb to the consumer, there is a need for an integrated approach encompassing animal characteristics, farming and consumer practices. Progress may come from approaches such as the Meat Standards Australia system first developed for beef but now being adapted for sheepmeat, as it aims to articulate key variables into a predictive model of eating quality. This system does not yet encompass other dimensions of quality, but rapid characterisation methods (like near-infrared reflectance spectroscopy) already in the development pipeline hold substantial real-world potential to enlarge these dimensions.

Flavour is a key criterion for sheepmeat quality, yet the literature highlights huge variation in flavour liking and sensitivity between groups of consumers, between sensory panellists, and between trained and untrained sensory panels. Research into the compounds involved in sheepmeat flavour and its variability is rapidly evolving.

Orientating farming systems towards more agroecology-based principles, which means using more on pasture grazing and less inputs, can bring advantages in terms of the nutritional and image quality attributes of sheepmeat, but it also carries risks in terms of greater variability in product quality, off-flavours, feed deficits at certain key periods (gestation and the weeks preslaughter) and uneven supply. The main thrust of genetic selection, logically driven by commercial quality attributes which are the basis of payment to farmers, has been for increased lean meat yield and muscularity in high-valued cuts and against fat, at a risk of compromising on organoleptic quality attributes and making it more difficult to finish lambs on grass. Furthermore, we know there is significant interindividual variability in sheepmeat flavour but still no data on the heritability of this trait and no studies reporting sire selection for flavour heritability.

Consumers have a range of different needs, perceptions and preferences, but they are converging in a movement towards fairer, more ethical and environmental values, with alternative food systems (organic farming, community-supported agriculture, local food markets) now co-existing alongside the dominant agro-

Table 2
Positive and negative effects on lamb carcass and meat quality attributes associated with pasture-feeding (vs stall-feeding with a concentrate-based diet).

Quality attributes	Positive effects	Negative effects
Commercial	Increased firmness and lightness of fat cover	Increased risk of insufficient carcass fatness Higher variability Seasonal output
Organoleptic		Darker meat Higher risk of intense flavour and of off-flavours[1] Higher variability
Nutritional	Meat fatty acid composition[2]	Higher variability[3]
Technological	Higher meat oxidative stability[4]	
Image	Naturalness Outdoor animals Lower environmental impact (carbon sequestration, pasture biodiversity, less use of inputs)	

[1] Depending on consumer preference.
[2] Higher content of n-3 fatty acids, lower content of palmitic acid, and lower n-6 PUFA/n-3 PUFA ratio.
[3] Depending on the season, the grass quality/availability/degree of maturity.
[4] Antioxidants naturally present in grass.

industry systems. Labels and branding of food quality can offer consumers the reassurances they need and add value by differentiating products farmed through more agroecologically conscious systems.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository.

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Declaration of interest

None.

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