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Review: Improving the nutritional, sensory and market value of meat products from sheep and cattle

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ABSTRACT

This paper focuses on improving the sensory, health attributes and meat yield of beef and lamb meats. Value for meat is defined as the weight of meat × price/kg received with price linked to eating quality. To maximise value across the supply chain, accurate carcass grading systems for eating quality and yield are paramount. Grading data can then be used to target consumers' needs at given price points and then to tailor appropriate production and genetic directions. Both the grading methodologies and key phenotypes are complex and still under intensive research with international collaboration to maximise opportunities. In addition, there is value in promoting the health aspects of red meats served as whole trimmed meats. Typically, the total fat content is relatively low (less than 5%) and for forage systems, they deliver a very significant content of long-chain *n*-3 fatty acids. Further research is needed to clarify the healthiness or otherwise of ground beef served as burgers given the fat content is typically 20% or more. It is important to continue to improve the feedback to producers regarding the quantity and quality of the products they produce to target new value opportunities in a transparent and quantitative manner.

Implications

Modern animal products must meet consumer expectations across a broad front so as to extract value at given price points. Value is defined as a combination of quality and quantity. The red meat industry needs accurate and transparent grading and/or measurement systems connected to animal identification so as to tailor a diversity of products based on various combinations of yield and quality depending on the price points of the various products produced. Given clear feedback signals from processors/retailers, beef and lamb farmers will rapidly optimise their systems to maximise value.

Introduction

The value of whole meat products is a complex mix of consumer expectations which determine both the willingness to pay and the final decision to purchase these important food groups in the human diet. Modern products must place the consumer first from the point of production on farm and then through the supply chain out to retail. As previously outlined (Pethick et al., 2011), there are a number of fundamental consumer-focused attributes for the future value proposition of red meat products:

- they must have a high organoleptic appeal, i.e. for meat be juicy, tender and good in flavour to result in an acceptable level of overall liking (eating and sensory quality),
- products should be health enhancing such that they are good sources of high-quality protein and nutrients (fatty acid species, minerals and vitamins) that are consistent with a healthy diet (human health attributes),
- the production systems underpinning the products must be perceived as ethically and environmentally sustainable.
- the products are safe and there is integrity within supply chains to justify claims relating to quality and health-promoting features (credence attributes of production).
- production systems throughout the supply chain are efficient from a cost of production perspective such that consumers perceive the product as 'good value for money'. That is quality and price are perceived to match (efficiency).

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These products are typically sold under company brand names at wholesale or retail. There are many other social factors affecting value discussed in Hocquette et al. (2014) and one example is food provenance or origin, which embraces some of the points above but in addition, the place of production, the cultural aspects of how the food is produced and finally an emotional connection to the intended consumer. These factors will not be included in this review. This paper will focus on improving the sensory and human health attributes of lamb and beef in addition to aspects of efficiency such as lean meat yield derived from carcasses. It is argued that accurate carcass grading for both eating quality and lean meat yield is crucial to allow value-based trading and meaningful feedback to all sectors of the industry on which decisions for improvement can be made. Improving human health attributes by genetics and nutritional regimes is also discussed.

Beef and sheep meat quality and yield

For a given meat brand, the value of the carcass meat components can be described as:

$$\text{Value} = \text{meat sold (kg)} \times \text{price/kg}$$

The weight of meat sold in this paper will be defined as lean meat yield or the related term saleable meat yield and represents a function of carcass weight and composition (meat, fat and bone). Saleable meat yield can include some fat either covering primals or as trim destined for grinding and the production of burgers or ground meat. Some bone in product is also sold. However, the more valuable cuts/muscles of the carcass will end up being sold to consumers or food service as highly trimmed lean meat for home preparation into meals. The sustainable price received for the different carcass meat components approximates the willingness to pay which is largely be driven by the eating quality of those cuts particularly within any one supply chain or overarching brand. Willingness to pay data for different eating quality levels in lamb (Tighe et al., 2018) and beef (Bonny et al., 2017) supports the strong link between eating quality and price. Estimates of the weighting given to lean meat yield versus eating quality will vary across different supply chains. For example, if the production of ground beef is the priority, then lean meat yield will be clearly the most important driver of value given one of the key quality traits, tenderness of the product, is now guaranteed by the grinding process. However, where eating quality is more important to the brand, then the value proposition is a mix of lean meat yield and eating quality of the cuts/muscles. Using data on saleable meat yield (kg) and price received for cuts in a supply chain using the Meat Standards Australia (**MSA**) system selling product based on quality grades (good every day, better than every day and premium), the balance of value was close to 50% for yield and 50% for eating quality (Bonny et al., 2018).

To simultaneously improve or optimise the lean meat yield from a carcass and sensory quality of that meat requires systems and technologies to predict both, which means using sophisticated carcass grading, tracking of data to carcasses and live animals. In this way, on-farm production systems and genetic improvement programmes can obtain reliable data to allow continuous improvement of 'value'.

Carcass grading for beef eating quality

A limited number of countries have carcass grading systems to underpin eating quality (Ellies-Oury et al., 2020) with most being relatively simple in that they focus on measures related to carcass characteristics (conformation and fatness as in Europe), animal age (dentition, ossification) and marbling or intramuscular fat content of the loin muscle (USA, Japan, Korea). These systems are useful and may, as in the USA (USDA, 1996; Garmyn et al., 2011) or not, as in Europe (Bonny et al., 2016) be related to palatability. However, they are (i) dated or (ii) more tailored to extended grain finishing systems compared with the more modern MSA grading scheme. The MSA scheme has been well described (Watson et al., 2008) and its applicability for predicting beef consumer outcomes in European and other countries has been confirmed (Hocquette et al., 2020). A crucial part of the MSA system is the extensive use of untrained consumers used in large scale sensory testing of beef to develop a combined eating quality score based on tenderness, juiciness, liking of flavour and overall liking. Production and carcass grading factors that were statistically related to the combined eating quality score were combined to form eating quality prediction algorithms. Furthermore, the combined eating quality score (0–100) can then be segmented into four eating quality grades, 2* unsatisfactory, 3* good every day, 4* better than every day and 5* premium. In this way, beef can be graded to value points suited to consumer expectations. The willingness of consumers to pay for these grades supports these four different points of value such that if 3* beef or lamb is set a monetary value of one unit of currency, then 2*, 3* 4* and 5* eating quality graded products are valued at 0.5, 1, 1.5 and 2, respectively, across both beef and lamb and several countries (Bonny et al., 2017; Tighe et al., 2018).

The MSA system can predict the eating quality score and/or the star rating (and so value) of cuts/muscles from carcass grading inputs (by human graders) which include carcass weight, carcass suspension method, rib fat depth, marble score, ultimate pH < 5.7, ossification, hump height (estimate of *Bos indicus* content), sex and steroidal hormonal growth promotant administration. This is combined with cut/muscle × cooking method and the aging of meat *postmortem* and retail case ready display method (negative effects of high oxygen modified atmosphere packaging). Additional factors include the need for registered abattoirs with audited chilling and pH decline regimes. Continual validation and model development over the 25-year history of MSA have assured both updating and the inclusion of new predictive factors as they arise or different weightings of eating quality scores with a higher contribution of flavour liking in recent years (Liu et al., 2020). Livestock producers also need to be registered with the system and understand various pathway rules such as limitations to mixing of unfamiliar cattle and time off feed after dispatch from the property of origin.

The sustainable legacy from this grading system is 2-fold in that (i) the consumer receives the beef quality that they are prepared to pay for and (ii) numerical grading data and predicted meat quality scores measured at the point of slaughter/carcass fabrication are available for the supply chain to utilise and so maximise value. Usage occurs via brand owners placing minimum numerical thresholds on the eating quality scores for cuts. In some cases, these thresholds might be simple such that cuts for a particular brand will be at least 3 star or above. Other brands will be more complex and place particular cuts in quality percentiles even within a quality grade. That is 'Brand AAA' might be cuts that reach the top 20% of the scores for that cut based on national data bases. In all cases, the MSA underpinned brands are sold at a higher price compared to non-MSA product. Moreover, beef producers are paid more per kg of carcass for MSA compliant animals and even more for higher grading carcasses depending on the brand. To this extent, the value created by carcass grading is not completely dependent on supply and demand.

Carcass grading for lamb eating quality

Currently, the MSA lamb and sheepmeats system is a best practice pathway approach with rules and guidelines for producers, abattoirs and retailers including parameters such as sheep age category, carcass fatness, low stress handling, chiller pH/temperature management and aging with some cut × cook recommendations. More recently, statistical modelling utilising sensory data from 8 850 consumers testing 10 cut × cook combinations derived from over 1 500 lambs has shown the importance of lean meat yield and intramuscular fat as additional predictors of eating quality. Lean meat yield is a negative predictor while intramuscular fat, a positive predictor (Pannier et al., 2018) and so reliable estimates for these as carcass grading parameters are now a high industry priority. Measuring intramuscular fat at line speed in whole lamb carcasses on the kill floor is the most preferable operation from an abattoir perspective, although camera systems assessing a cut surface in chilled carcasses/cuts might also be possible to incorporate (Gardner et al., 2021). A combination of carcass grading data for lean meat yield and intramuscular fat, carcass weight, meat aging time and pH/temperature decline postslaughter will form the predictors for a lamb cut × cook model similar to MSA beef system.

Grading for lean meat yield in lamb and beef

Carcass grading for lean meat yield is more common although sophistication and accuracy are highly variable. Camera based whole body grading of beef is compulsory in Europe to estimate the EUROP score (Anonymous, 1982) which is related to lean meat yield (Allen and Finnerty, 2001) with newer systems under development likely to provide even more accuracy for both yield and marbling assessment. Other systems use a variable combination of carcass weight, subcutaneous fat depth or kidney/pelvic abundance and eye muscle area of the loin muscle. However, the accuracy is variable being influenced by genotype and certainly, the fat depth × carcass weight predictions used in Australia are variably related to Computer Tomography determined lean meat yield which is often used as the ‘Gold Standard’ (Williams et al., 2017a; 2017b). We suggest more focus should be placed on using technologies ‘online’ within abattoirs to measure carcass composition in addition to carcass weight so the weight of saleable meat given its contribution to the value of the carcass. New research has shown that dual energy X-ray absorptiometry systems show great promise for measuring carcass composition at abattoir line speed (Connaughton et al., 2020).

Implications of sophisticated carcass grading to improve value

Assessment of both lean meat yield and eating quality will allow value-based trading across the value chain giving incentive to improve the true worth that can be extracted from carcasses (Fig. 1).

Elite eating quality-based brands

The abattoir and associated retailers can act to sort cuts/muscles from carcasses (typically as carcass boning runs) into ‘like’ eating quality grades or eating quality scores in higher quantile brackets and so develop tiered or layered brands underpinned by eating quality. The tiered brands, which includes systems underpinned by both grass and grain finishing, extract more financial reward than simply selling to an average quality and finally result in the beef and lamb producers being rewarded for carcasses being graded in higher eating quality brackets. MSA graded beef carcasses currently receive more money per kg than ungraded carcasses (Meat and Livestock Australia, 2020) even with eating quality thresholds set at 3*. However, several abattoir supply chains and retailers give further financial reward to beef producers for carcasses delivering higher quality cuts. Importantly, carcass grading to predict and allow sorting of cuts by quality grade or eating quality scores in the higher quantile brackets (within grades) is more efficient in extracting value than using threshold or pathway methods commonly used by supply chains. For example, having global animal/carcass thresholds for ultimate pH, age, fat score, and meat ageing to underpin eating quality of the striploin can remove poor eating quality samples but at the same time, some 40% of acceptable striploins are discarded (Ellies-Oury et al., 2020).

Brands with emphasis on lean meat yield

Combined feedback on yield and quality might also be utilised to justify the use of hormonal growth promotants (in those countries where they are legal) or heavily muscled and lean genotypes (entire males) of cattle and sheep. In the case of growth promoting steroidogenic and beta agonist compounds, they deliver improved efficiency on farm in the form of faster growth rates with the resulting carcasses delivering more muscle and less fat (higher lean meat yield). However, there is a negative effect in that eating quality of cuts from hormone treated cattle have lower eating quality scores (Dunshea et al., 2005). None the less clear information on value based on yield × eating quality will often justify use for brand owners where legally possible – that is when lean meat yield and on-farm efficiency out weight the extra value that can be extracted from improved eating quality.

Maximising value from older beef animals

In France, 47% of beef is produced from cows (48% from dairy cows and 52% from beef cows) with French people eating more beef from cows (61% of total consumption) than they produce (47%). This specific demand requires the production high quality cuts from well-finished cows with adequate characteristics. One explanation for the highly acceptable eating quality of some beef cuts from cows is likely to be a high level of marbling compared to younger animals. Furthermore, a recent experiment conducted with Limousine cows confirmed that tender-stretching and longer ageing time improve significantly tenderness, flavour linking, juiciness, and overall liking assessed by untrained consumers. Consequently, a threshold for marbling score, a minimum ageing time and tenderstretch were included in the specifications of the private brand ‘Or Rouge, Limousine high quality beef’ which has recently been launched by the company C.V. Plainemaison (Ellies-Oury et al., 2020). This new brand is also based on extrinsic quality traits such as better animal welfare and a low environmental footprint since the Limousine breed is mainly reared in a rural region where grass-feeding systems are common. This initiative is innovative since marbling, ageing time and the carcass hanging method were not taken into account so far in France.

Data to underpin balanced genetic selection

Genetic selection plays a powerful longer term role that can influence the live and carcass performance of sheep and cattle. While many countries have systems for commercial genetic evaluation of sheep and beef cattle with all having a focus on breeding values associated with lean meat yield (growth, fat and muscling characteristics), fewer have incorporated eating quality characteristics (marbling or intramuscular fat) to develop balanced selection indexes. Consequently, selection for lean meat yield from the carcass has been a dominant phenotype and especially so for meat sheep production. Unfortunately, selection in favour of muscle growth is associated with a decrease in intramuscular fat content and in muscle oxidative metabolism in both lamb (Kelman et al., 2014) and beef (Hocquette et al., 2012) and hence, is likely to decrease eating quality of meat. The Australian lamb industry has been the first to invest in the development of commercial breeding values for eating quality in sheep, namely intramuscular fat and shear force underpinned by genomic selection and a reference genetic resource flock (Van der Werf et al., 2010). Indeed, the industry was so concerned about the unfavourable genetic correla-

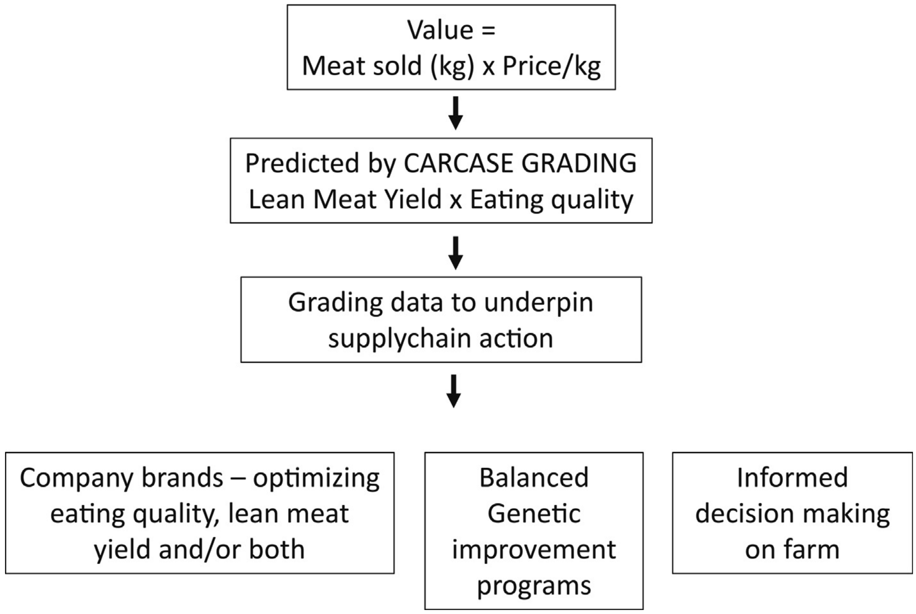

Fig. 1. Implications of carcass grading connected to the value of lamb or beef meat sold.

tion between lean meat yield and intramuscular fat (−0.55) and shear force (+0.4) they have developed new balanced indexes (Swan et al., 2015) and removed previously a long-standing index based solely on lean meat yield (Sheep Genetics, 2020). Reference herds or flocks needed for genomic selection are costly and so routine high quality carcass grading data connected to live animal identification in abattoirs for lean meat yield and eating quality attributes (marbling or intramuscular fat) will allow for balanced genetic progress at reduced cost on large numbers of slaughter animals.

Feedback to livestock producers for decision-making

Clearly, the grading data can also be used by beef and lamb producers to target the value proposition between lean meat yield and eating quality best suited to their farming systems. Decisions include manipulating genotype via bull/ram selection and phenotype by nutritional management. For example, if marbling or intramuscular fat thresholds are a key part of a beef or lamb brand, then producers have several mechanisms to improve this grading aspect including genetics, carcase weight/fatness, higher energy diets, maturity pattern, animal age (Pethick et al., 2004). More generally, the use of a transparent new grading system, which includes eating quality, such as the MSA, has underpinned in Australia a new and innovative supply chain with increased added value. It allows producers to derive benefit from the financial gain of incremental improvements in quality knowing the precise economic gains associated with traits such as marbling or relevant phenotypic traits associated with eating quality (Bonny et al., 2018).

International collaboration to initiate and improve carcass grading

Based on its scientific and economic success within Australia, the MSA grading scheme was studied successfully in New Zealand, South Korea, Japan, the US, South Africa, UK, Ireland, Poland and France. The research teams who have collaborated closely across countries observed that, to maximise research outputs and concrete benefit for the meat industry, it is necessary to work with standardised and pooled data according to the "big data" approach in expansion. This is the objective of the International Meat Research 3G Foundation, which considers that it is crucial to accumulate data from various experiments and commercial products no matter the country and the livestock system with, of course, information about them. Thus, a common database has been set up utilising consistent description of beef, carcasses and animals to enable scientific research to be conducted over multiple disparate base studies. A prerequisite for this strategy is the use of common protocols, and sensory test protocols, including traits not used in all countries such as marbling and ossification. This approach is being developed under the auspices of the UNECE Specialized Section on Standardization of Meat following the first publication of UNECE Bovine Language (Hocquette et al., 2020).

The need for new eating quality phenotypes

Future research should develop new grading phenotypes. When using the MSA model, many factors are fixed for any single supply chain. For example, consider a supply chain where all carcasses will be hung in one format (say tenderstretch), *Bos indicus* content is always zero, there is no use of hormonal growth promotants and all primals selected for the brand are aged for at least 20 days. This leaves two main drivers of eating quality namely ossification score and marbling thus narrowing the scope for continuous improvement. Further research is thus needed with new objectives: measuring the remaining drivers of eating quality with improved accuracy for a better management of eating quality, and discovering other quality traits that might have commercial application to improve eating quality.

For the first point, the current strategy is to replace the existing human-based measurements with technologies to objectively measure the same traits, based on the principle that the technology must perform as well as, or better than, the existing human grader in their precision, accuracy, and repeatability for the trait of interest. The new methods should be very cheap, automated and fast with the potential to generate a large amount of data with no bias (Hocquette et al., 2020). These methods have the potential to better predict directly the trait of interest (such as tenderness) or a trait much more difficult to measure but related to eating quality (such as marbling) or any muscle component (such as characteristics of muscle fibres or connective tissue). Importantly, industry systems are needed to develop new language as required such as chemical intramuscular fat rather than visual marbling. These industry systems (such as the USA Department of Agriculture; AUSMEAT) will also be responsible for developing metrics to underpin the accuracies required by new carcass grading technologies.

Second, in some cases, any new technology has the potential to introduce new traits into existing eating quality prediction systems. For instance, the advent of genomics, proteomics, and metabolomics has favoured the development of new predictive tools from technological breakthroughs (Berri et al., 2019). Indeed, gene markers and genomics offer great potential for improving lamb and beef eating quality. For example, Robinson et al., (2012) showed that gene markers associated with the calpain-system unfavourably effect the eating quality of three beef cuts from *Bos indicus* cattle. The unfavourable alleles have a high frequency in *Bos indicus* cattle and genetic selection against these alleles would dramatically improve the eating quality and potentially remove some of the negative *Bos indicus* effect from the MSA model. Similarly, proteomic or other omic analyses allow the identification of a list of proteins and biomarkers considered as potential biomarkers of beef tenderness. However, their relevance depends on the reference method (how tenderness is measured) and on origin of cattle and of consumers as well as on the cut. Thus, commercial implementation will require first validation on large pools of data and then a rapid test that could be used online in the abattoir on carcasses or in live animals before slaughtering (Berri et al., 2019; Hocquette et al., 2020). Other new technologies include methods based on devices capturing imagery through insertable probes or using scanning technologies such as nuclear magnetic resonance, spectroscopy or X-rays. These methods have the potential to predict the trait of interest using for instance specific features of spectra (Gardner et al., 2021).

Reconsidering the relative contributions to sensory outcomes of existing eating quality traits

Flavour is one phenotype that does receive considerable discussion beyond its overall contribution to sensory outcome and has potential to be targeted by brand owners to increase value. Recent studies have shown that at least in beef, the relative weight of flavour has increased during the last past years since it is today higher than that of tenderness (Liu et al., 2020). The science of lamb and beef flavour is complex and reviewed elsewhere (Watkins et al., 2013). The key question is: can the general consumer discern differences in the flavour of cuts from beef or lamb derived from diverse production systems such as young versus older animals or pasture versus grain finishing systems? Sensory panels using participants trained to rate a large range of flavour notes can detect some differences in the cuts derived from lambs (reviewed by Watkins et al., 2013) or beef (Musa et al., 2020) raised on pasture versus grain-based diets. However, when untrained consumers are used in general, there are no consistent differences in flavour and overall liking, especially when corrected for animal age and intramuscular fat levels. A recent study by Gkarane et al., (2019) investigated the effect of diet composition on the flavour notes of lamb using trained panellists and concluded the (i) differences were small and (ii) that lamb producers could use alternative feed types without affecting the sensory quality of lamb negatively, but (iii) there was potential to discriminate lamb meat on the basis of its dietary background using the chemical volatile signature. In conclusion, the value proposition of the flavour phenotypes is still unclear beyond current claims made by brands that the beef or lamb is raised on pasture or grain for example. However, new technologies such as the rapid evaporative ionisation mass spectrometry 'iknife' system might allow chemical signatures for both positive and negative flavour attributes to be measured on line in abattoirs and so underpin brands accordingly (Ross et al., 2021).

Lamb and beef human health

Animal sourced foods in general, but beef and lamb in particular, can supply a range of essential nutrients in the human diet. While many nutrients can be obtained in foods from other food groups, a balanced diet from all five food groups better ensures adequacy of all nutrients. Some nutrients found in animal sourced foods are limited in other foods or are less bioavailable or virtually absent (eg. Vitamin B12). A detailed review has been published by Williams (2007) who identifies lean red meats as:

- An excellent source of high biological value protein;
- B vitamins (vitamin B12, niacin, pyridoxine, riboflavin, pantothenic acid);
- vitamin B6 (Pyridoxine);
- iron, zinc, selenium, phosphorus;
- a source of long-chain omega-3 polyunsaturated fatty acids (PUFAs).

Given the broad range of nutrients in all fresh meats, the focus in this section will be on those characteristics more unique to lamb and beef, namely maintaining the aerobic biochemistry or redness of the meat products, the potential to deliver long-chain *n*-3 fatty acids and the total fat content (intramuscular fat).

Maintaining aerobic biochemistry of beef and lamb

Lamb and beef are significant sources of Fe and Zn for the human diet and these traits are another important value proposition differentiating them from other main stream meats. In a large study (>5,500 lambs) across eight different farming locations in Southern Australia encompassing the major sheep producing areas, the average concentration of Fe and Zn in the *m. longissimus dorsi* of Australian lamb was found to be 2.0 and 2.4 mg/100 g fresh meat, respectively (Pannier et al., 2014b; Mortimer et al., 2014). Based on a serve of 135 g of fresh lean lamb, the Fe levels are sufficient to make a claim of 'good source' for all men and women over 50 years and a 'source' for younger women. Similarly, the concentrations of Zn are a 'good source for all women and a 'source' for men (Pannier et al., 2014b). The concentration of Fe and Zn is 1.6 and 4.1 mg/100 g fresh *m. longissimus dorsi* according to the USDA (2010) and this is supported by Garmyn et al. (2011). It is concluded that the content of Fe and Zn in lamb and beef should not reduce from a human nutrition point of view.

So what factors were associated with changes in Fe and Zn? Animal age was the dominant production factor with increasing levels as animals became older. However, there were important genetic interactions which clearly showed that genetic selection for lean meat yield (increased muscling or reduced fatness) reduced especially Fe levels (Pannier et al., 2014b; Knight et al., 2020; Hocquette et al., 2012) and was associated with reduced measures of aerobicity such as myoglobin and isocitrate dehydrogenase (Kelman et al., 2014). Both minerals have significant heritability and for Fe, there is a clear genetic link to aerobic indicators although Zn levels in lamb meat are not so heavily influenced by aerobicity (Mortimer et al., 2014). Ortiques-Marty et al. (2005) have also shown in lamb and beef that Vitamin B12 occurs at higher levels in more aerobic muscle. It is recommended that genetic selection programmes for lamb and beef at least monitor the muscle aerobicity either directly (Fe, myoglobin) or indirectly (via genetically associated objective measures of meat colour).

Total fat content of trimmed lamb and beef meats

While consumers maintain a desire for flavoursome, juicy and tender meat, they are increasingly seeking lower fat/healthier food options, two important consumer drivers which are linked through the amount of IMF. Intramuscular fat has an important influence on meat palatability due to its specific contribution to juiciness, flavour and tenderness (Pannier et al., 2014a; Thompson, 2004). Carcass grading to predict eating quality using the MSA system clearly shows that modest levels of IMF or marbling are needed to underpin higher levels of eating quality in lamb and beef (Table 1). Indeed, in relatively young animals (<1 year for lamb, <18 mo for beef), 3% IMF can underpin acceptable eating quality in several higher value cuts and at 5% or higher IMF, the frequency of 4 and 5 star grading outcomes increases (Table 1). Likewise, a threshold of 3% IMF (based on sum of fatty acid species determined by gas chromatography) to deliver acceptable eating quality of the lamb loin was supported by Lambe et al. (2017) using trained sensory panels. Further work on lamb has estimated that a threshold of approximately 5% IMF is required to achieve a high level of consumer satisfaction (4 star or above) for the palatability of grilled lamb loin cuts (Hopkins et al., 2006; Pannier et al., 2014a). Recent estimates of IMF in Australian lamb have an average value of 4.3 with 90% of lambs between 3 and 7% (Pannier et al., 2014a) with the vast majority of Australian beef being similar based on the mean MSA grading scores for marbling (Meat and Livestock Australia, 2020). Importantly, there is a need to cross-validate the estimates of chemical IMF since different methodologies will deliver different results.

To claim a meat cut as ‘low fat’, the fat content should be equal to or less than 3% (measured via soxhlet calibrated methodology, Food Standards Australia & New Zealand, 2017), hence, it is unlikely that lamb and beef meat will be promoted as ‘low fat’ due to this consumer desire for palatability. However, lamb and beef meat certainly has the potential to be promoted as containing a healthy balance of fats depending on the diet and species. However, according to Standard 1.2.7 – Nutrition, Health and Related Claims (Food Standards Australia New Zealand, 2017), any food that contains less than 1.5 g of saturated fat per 100 g of solid food can be claimed as ‘low in saturated fat’ and Australian lamb on average has levels below this threshold (Ponnampalam et al., 2014) with product from other countries likely to be even lower.

Ironically, some of the most expensive beef brands worldwide target a highly marbled product (>10% fat and often >20%) with a combination of cattle genetically selected for marbling (eg Japanese Black, Hanwoo breeds) and/or long-term grain feeding. These systems target elite high-priced markets and are not designed for main stream everyday use by consumers and currently do not represent a human nutrition issue given the low rates of production and consumption. Indeed, they are important alternative production systems that add to the diversity and value of beef markets.

Ground beef products

Minced or ground beef is a major product line purchased by consumers in many countries and represents a significant part of the value generated from the beef carcass. The value proposition for ground beef occurs since it is generated from lower value primals that have inherently lower eating quality as whole meat, including those from leaner cows and bulls which is then blended with meat and fat carcass trim (often from grain feed beef) to a predetermined lean percentage. In 2015, figures for the USA show 64% of beef consumption at food service and around 40% at retail is sold ground with 70% of the product having a total fat content of 16% or greater (Speer et al., 2015). This high fat product, rich in saturated fats, is potentially problematic from a human health perspective and is a key reason for the negative view of beef by many dieticians and health professionals. Clearly, this represents a potential threat to the generation of value for the beef industry.

Smith et al. (2020) have challenged this view and argue that a standard beef burger (approximately 20% fat) can be healthy based on evidence obtained in limited human intervention trials using ‘high’ oleic acid beef burgers. The oleic acid content of beef fat can be increased by both genetic selection (certain beef breeds) and feeding systems (especially high energy corn-based diets). In theory, this approach might result in higher value beef burgers underpinned by health claims. Indeed, a related but different claim is also made in relation to ground beef from grass-fed cattle. However, these propositions need further in depth research in collaboration with human health professionals before evidence-based claims are possible.

Lamb and beef as a source of n-3 long-chain fatty acids

The amount of fat and fatty acid intake consumed by humans impacts health and well-being. This has been an area of extensive research over the last 20 years, contributing to national public health nutritional recommendations. For ruminant products, much interest relates to the high content of saturated fatty acids, low content of *n*-3 polyunsaturated fatty acids (PUFAs) and variable content of trans-fatty acids. Reviews by Bessa et al. (2015), Scollan et al. (2017) and Vahmani et al. (2020) provide comprehensive reports of factors influencing and biological constraints to improving the nutritional quality or ruminant meat (and milk) lipids. Here, we describe the important contribution ruminant meat potentially makes in providing useful amounts of *n*-3 PUFA to the human diet, namely α-linolenic acid (18:3*n*-3), eicosapen-

Table 1
The effect of marbling and intramuscular fat on Meat Standards Australia predicted consumer star rating (and score) of grilled cuts from beef and lamb.

		Predicted consumer star rating (and score)				
		Beef[a]			Lamb[b]	
IMF[c] (%)	Marble score[d]	*m. longissimus thoracis*	*m. longissimus dorsi*	*m. gluteus medius*	*m. longissimus dorsi*	*m. semimembranosis*
3	280	4 (65)	3 (59)	3 (53)	3 (61)	3 (49)
5	355	4 (67)	3 (61)	3 (54)	4 (67)	3 (52)
9	540	4 (72)	4 (67)	3 (56)	5 (77)	3 (56)

Abbreviations: IMF = intramuscular fat.
[a] Meat Standards Australia beef model prediction, SP2007 edition – *Bos tauris*, steer, 260 kg Hot carcass weight, ossification 140, hang achilles tendon, no hormonal growth promotants, 5 days ageing, temperature at pH6 approximately 20 °C.
[b] Prototype MSA lamb model prediction, 2021 edition – Terminal sire, 24 kg hot carcass weight, lean meat yield 57% (equivalent to Greville [GR] tissue depth of 15 mm measured 110 cm from the midline to the lateral surface of the 12th rib), 5 days ageing, temperature at pH6 approximately 20 °C.
[c] Determined via Soxhlet calibrated Near Infrared spectroscopy (Pannier et al., 2014a) expressed as % on fresh weight basis.
[d] Meat Standards Australia beef marble score.

taenoic acid (EPA; 20:5*n*-3), docosapentaenoic (DPA: 22:6*n*-3) and docosahexaenoic acid (DHA; 22:6*n*-3).

It is widely acknowledged that *n*-3 PUFA exhibits effects beneficial to human health and well-being, including reduced incidence of heart attacks, arrhythmias, strokes, depression and cognitive decline (Stark et al., 2016; Alexander et al., 2017; Punia et al., 2019; Stanton et al., 2020). Hence, national and international public health guidelines recognise oily fish as a rich source of long-chain *n*-3 PUFA and thus recommend the consumption of at least one portion of oily fish per week (>250 mg of EPA and DHA; European Commission (2010)). However, the availability and consumption of oily fish are limited in many countries and there is much concern around the sustainability of fish supplies and the reduction in *n*-3 PUFA content in oily fish, particularly concerning farmed fish stocks (Stanton et al., 2020). This has accelerated the need to enrich *n*-3 PUFA in foods and in particular those which are frequently consumed by society (Stanton et al., 2020). Enser et al. (1996) confirmed that red meat contains significant amounts of beneficial *n*-3 PUFA, particularly, α-linolenic acid but also the long-chain PUFA, EPA, DPA and DHA.

In ruminant meat, the main approach employed to increase *n*-3 PUFA is based on modifying the animal diet by enhancing the intake of PUFA provided as (1) fresh and ensiled forages (i.e. pasture), (2) *n*-3 rich oils and oilseeds (i.e. linseed), fish oil and marine algae. Despite extensive lipolysis and biohydrogenation of lipid in the rumen by the rumen microbiome, these dietary interventions contribute important beneficial changes in lipid composition. The effect of pasture feeding and the inclusion of microalgae in the diet are particularly noteworthy as nutritional approaches to enrich *n*-3 PUFA.

Pasture is often the basal nutrition for ruminants and although low in lipid, the chloroplasts are dense in 18:3*n*-3 which can represent up to 75% of the total lipid fraction. Lipids in grasses and forages are affected by species, growth stage, plant maturity, and senescence (Morgan et al., 2020). Temperature, light exposure and seasonality also affect the fatty acid content of grasses, with the highest fatty acid concentrations in summer when days are longer, and temperatures are higher (Elgersma et al., 2003; Yalcin et al., 2011).

The intramuscular content and fatty acid composition of beef and lamb differ between animals finished on grass or fed concentrates (Nuernberg et al., 2005; Warren et al., 2008). Grass-finishing results in higher amounts of 18:3*n*-3 but also 20:5*n*-3, 22:5*n*-3 and 22:6*n*-3 content is increased due to the elongation and desaturation of 18:3*n*-3 in body tissues. Feeding concentrates in the finishing period of animals reared on pasture causes depletion of 18:3*n*-3 and higher accretion of 18:2*n*-6 (Ponnampalam et al., 2006). Forages can be used to lower total and saturated fat content and increase the *n*-3 PUFA content relative to cereal-based diets (Scollan et al., 2017).

Pasture-based feeding beef and lamb increased the concentrations of 18:3*n*-3 to ~50 mg/100 g, while levels of EPA, DPA and DHA achieved 43, 34 and 19 mg/100 g in lamb (Nuernberg et al., 2005) and 25, 37 and 4.2 mg/100 g in beef (Ponnampalam et al., 2006). This equates to ~98 and 154 mg/100 g for total *n*-3 PUFA and ~29 and 62 mg/100 g total EPA + DHA for beef and lamb, respectively.

Microalgae rich in 20:5*n*-3 and 22:6*n*-3 have resulted in increased concentrations of these *n*-3 PUFAs in lamb (Meale et al., 2014; Hopkins et al., 2014). Meale et al. (2014) reported ~32, 61,114, 232 and 146 mg/100 g muscle for EPA, DPA, DHA, total *n*-3 PUFA and EPA + DHA, respectively. Hopkins et al., (2014) reported 48, 37, 92, 216 and 140 mg/100 g muscle for EPA, DPA and DHA, total *n*-3 PUFA and EPA + DHA, respectively. These higher concentrations of EPA and DHA may relate to increased resistance to biohydrogenation in the rumen. Alves et al., (2018) demonstrated that some microalgae species possess complex cell walls which renders them more resistant to ruminal microorganisms and hence affording increased delivery of the *n*-3 PUFA into the small intestine. Further research is required to assess the impact of microalgae, particularly in relation to duration, level and algae species on fatty acid profiles of meat (Alves et al., 2018).

n-3 PUFA and labelling standards

National and international guidelines provide recommendations on reference nutrient intakes (RNIs) and recommended daily intakes for adults and the European Food Safety Authority (European Commission, 2010) stated RNI and intakes for adults of 250 mg EPA plus DHA/d and 2 g 18:3*n*-3/day. Foods should supply >15% of the RNI per 100 g and 100 kcal to be labelled as a 'source of', and >30% of the RNI to be labelled as 'high in'. As described by Scollan et al. (2017), meat or meat products must contain ≥40 mg per 100 g and per 100 kcal of EPA plus DHA or ≥0.3 g per 100 g and per 100 kcal 18:3*n*-3 to be labelled as a 'source of' *n*-3 PUFA; or ≥ 80 mg EPA plus DHA per 100 g and 100 kcal or ≥0.6 g per 100 g and per 100 kcal 18:3*n*-3 to be labelled as 'high in' *n*-3 PUFA.

For beef and lamb, no published studies meet the required ≥0.3 g of α-linolenic acid to be classed as a 'source of' *n*-3 PUFA. However, typically lamb and beef derived from forage-based production systems would be classified as 'a source' of EPA plus DHA. The microalgae supplementation of lamb in the studies by Meale et al. (2014) and Hopkins et al., (2014) achieved concentrations of EPA + DHA which were sufficient to claim 'high in' *n*-3 PUFA. While DPA is not presently considered in guideline RNI recommendations, studies by Guo et al. (2020) and Miller et al. (2013) suggest that DPA might act as a reservoir of *n*-3 long-chain PUFA incorporated into blood lipid fractions, metabolised into DHA, and retro-converted back to EPA in small quantities. DPA levels in beef and lamb are typically similar or higher than EPA. Hence, it is important to consider the importance of DPA in *n*-3 PUFA metabolism given that lamb and beef derived from forage-fed systems would typically be close to a 'high in' source of total long-chain *n*-3 PUFA if DPA is included.

Clearly, the *n*-3 PUFA in beef and lamb make an important contribution to total *n*-3 PUFA in humans. Currently, a number of beef and lamb brands are sold under strict forage-fed code of practice that prevents the feeding of any cereal grains (eg. the PCAS system in Australia; PCAS, 2021) and these receive a price premium over similar products with no such claims. The price premium paid by consumers for such forage-fed products is multifactorial and perhaps the premium could be even higher if the *n*-3 PUFA health benefits were more clearly defined. Clearly, further studies are needed so as the value proposition for the industry can be clearly stated. Firstly, there is a need to extend studies in a carefully controlled design to investigate the effects of lamb and beef from both traditional (forage and grain) and enriching *n*-3 PUFA diets through to human intervention studies. An initial study by McAfee et al. (2011) demonstrated the positive impact of consuming grass-fed beef and lamb has on blood plasma and platelet *n*-3 PUFA concentration, in a 4-week randomised dietary intervention. More recently, Stanton et al. (2020) demonstrated that eating chicken meat and eggs enriched with *n*-3 PUFA increased omega-3 index in red blood cells and reduced diastolic blood pressure. Such studies usefully illustrate how consumption of commonly eaten omega-3-PUFA enriched foods can deliver long-term population health benefits, despite research connecting the two disciplines being limited. Secondly, sensory studies, overlaid with variable aging, packaging and antioxidant systems, need to be undertaken especially for ruminant meats that are heavily enriched with high levels of *n*-3 PUFA. High levels of *n*-3 PUFA in meat may lead to flavour taints and oxidative damage.

Conclusion

In this paper, we argue a crucial step to facilitate improving value of lamb and beef meat products is dependent upon transparent carcass grading to determine both the yield and sensory quality of the meat produced. Carcass grading for sensory quality allows meat to be sorted into different quality grades and priced accordingly such that consumers can have the eating experience they are willing to pay for. Grading also allows for clearer decision-making by livestock producers regarding the emphasis to be placed on yield of meat quality. The decisions may be in favour of yield, quality or more typically a balance of both depending on the end product(s) produced. The intrinsic health attributes of lamb and beef are beyond dispute. It is argued that production systems and genetic improvement programmes monitor Fe and Zn levels in lamb and beef, making sure they do not decrease given red meat is a vital source of these nutrients for humans. While the level of intramuscular fat is an important determinate of sensory quality, it is clear that high quality grilling cuts from lamb and beef can be derived from meat with levels of fat from 3 to 10% implying only a modest contribution to fat in the total human diet. Finally, fatty acid composition, in particular, the long-chain *n*-3 PUFA, is an important human health attribute of lamb and beef for meat derived from pasture-based systems. Further human intervention studies are needed to further clarify the beneficial role of the *n*-3 PUFAs and indeed total fat content of lamb and beef.

Ethics approval

Not applicable.

Data and model availability statement

The statistical model underpinning the Meat Standards Australia models (beef and lamb) is confidential and is owned by Meat and Livestock Australia.

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Dave Pethick produced the early conceptualization and then all authors equally contributed to writing, reviewing and editing.

Declaration of Interest

D.W. Pethick and F.D. Dunshea are members of the Meat Standards Australia Pathways committee. J.-F. Hocquette is the president of the French Society of Animal Sciences.

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Transparency Declaration

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