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Pannier, L., Gardner, G.E., O'Reilly, R.A. and Pethick, D.W. (2018) Factors affecting lamb eating quality and the potential for their integration into an MSA sheepmeat grading model. Meat Science

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Accepted Manuscript

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PII: S0309-1740(18)30191-8
DOI: doi:[10.1016/j.meatsci.2018.06.035](https://doi.org/10.1016/j.meatsci.2018.06.035)
Reference: MESC 7608
To appear in: *Meat Science*
Received date: 22 February 2018
Revised date: 24 June 2018
Accepted date: 26 June 2018

Please cite this article as: L. Pannier, G.E. Gardner, R.A. O'Reilly, D.W. Pethick , Factors affecting lamb eating quality and the potential for their integration into an MSA sheepmeat grading model. *Mesc* (2018), doi:[10.1016/j.meatsci.2018.06.035](https://doi.org/10.1016/j.meatsci.2018.06.035)

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Factors affecting lamb eating quality and the potential for their integration into an MSA sheepmeat grading model

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Abstract

Major efforts in the sheep industry to control eating quality have resulted in reduced product variability. Yet inconsistent eating quality for consumers remains, due to a degree of inaccurate representation of cut quality. Eating quality defined through a complex interplay of different factors can be predicted for individual cuts, and Meat Standards Australia (MSA) grading schemes have been developed to achieve these defined quality outcomes. This review outlines the justifications to refine the current sheepmeat MSA pathways system to transition into a cuts-based prediction model and details some of the factors affecting sheepmeat eating quality as key factors under consideration into the new model. The development of the new sheepmeat MSA prediction model will allow for more efficient carcass sorting to underpin a value based payment system throughout the supply chain. However it requires the inclusion of individual carcass yield and eating quality measurements (i.e. IMF). Furthermore, the adoption challenges internationally of an MSA like model are discussed.

Keywords: Eating quality; Consumers; Meat Standards Australia; International

1. Introduction

With the global population on the rise, currently estimated at 7.5 billion (The World Bank, 2017), sustainable food security systems have been a major topic of interest. This, in line with specific market and consumer demands creates a challenge for the agricultural sector as a whole, and has put pressure on the red meat industry to maintain productivity gains and stay competitive against other protein sources. The Australian sheep and beef sectors are highly export driven with 57% and 68% of total lamb (worth AUD\$1.9 billion) and beef (worth AUD\$7.1 billion) production being exported worldwide in 2016-17 (Meat and Livestock Australia, 2017a, 2017b). Thus given its value and volume, it is inevitable that international market requirements and consumer expectations will need to be met to maintain product confidence and to ensure continued demand.

Reasons for global decline in red meat consumption are multifactorial, and vary between countries and different consumer groups. The increase worldwide in obesity and associated diseases has no doubt resulted in dietary changes and new food trends (Binnie, Barlow, Johnson, & Harrison, 2014). Consumers are seeking healthier food options, aiming to eat more natural, fresh and unprocessed foods (Food Chats, 2016). In some cases, these changes in food consumption patterns have also been influenced by perhaps different restrictive dietary advice to reduce red meat consumption despite red meat intake levels being within dietary recommendations (Binnie et al., 2014). Furthermore, the environmental impact of food production has no doubt stimulated different consumer choices (Westhoek et al., 2014; Westhoek et al., 2011). Additionally, the price per kg for beef and lamb is much higher than other protein sources thus affecting demand and placing pressure on industry to deliver not just consumer value but also consistent and predictable quality to maintain consumer trust. Collectively, these factors along with inconsistency in eating quality, are regarded as major issues contributing to the global beef and sheepmeat consumption decline (Henchion, McCarthy, Resconi, & Troy, 2014; Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Russell, McAlister, Ross, & Pethick, 2005). Irrespective of these consumption levels, it is well established that consumers demand good nutritional attributes, high animal welfare standards, value for money and consistent eating quality (Henchion et al., 2014; Pethick, Ball, Banks, & Hocquette, 2011; Pethick, Banks, Hales, & Ross, 2006). Hence consumer focused research is highly important to underpin future demand for red meat, particularly for beef, and sheepmeat.

Eating quality in terms of sensory perception is one of the key factors influencing red meat demand, determining and reinforcing the consumer's food choice and repeat purchase behaviour (Grunert, Bredahl, & Brunsø, 2004; Henchion et al., 2014; Pethick et al., 2006).

Providing acceptable eating quality is essential to underpin consumer demand and willingness to pay, which are key profitability drivers of the industry moving forward (Pethick et al., 2006). However, because eating quality is not apparent to the consumer at time of purchase, predicting eating quality before consumption is essential. Furthermore, reduced variation through improved product description according to eating quality would maintain and strengthen consumer confidence. This has been successfully demonstrated by the Meat Standards Australia (MSA) prediction model (Polkinghorne, Thompson, Watson, Gee, & Porter, 2008) particularly for beef which is aimed at delivering an eating quality guarantee to consumers at a cooked portion level. Additionally, the sheepmeat MSA pathways model aims to improve the overall eating quality of sheepmeat.

Therefore, to maintain a strong global demand for beef and lamb, the product must be tailored to meet consumer demands of good value for money, nutrition, sustainably and ethically sourced, yet maintain consistent eating quality. This review aims to provide an overview of the factors affecting consumer eating quality of lamb ranging from paddock to plate, and the need for a new sheepmeat MSA grading system. Although focussed on sheepmeat, this paper illustrates some concepts in beef where research is more extensive as a point of comparison. In particular, the review highlights the evolving development of the sheepmeat MSA system in comparison with the well-developed and published beef MSA model. Furthermore, the paper explores the possibilities to apply the MSA system internationally.

2. Factors affecting eating quality

Tenderness, juiciness, liking of flavour and overall liking are all important quality determinants of sensory perception of meat. Several studies in both lamb and beef have described the influence of genetic and production factors on sensory attributes. The complex interplay between these production, genotypic and environmental factors contribute to the phenotypic variation in meat eating quality. Many of the findings from these studies have been incorporated into the beef MSA system to predict eating quality for individual cuts under different cooking methods. In future, a similar approach is intended for sheepmeat, with the key factors under consideration discussed below.

2.1. Genotype

There are numerous studies presenting conflicting evidence regarding the impact of genotype on sensory scores. However it should be noted that many studies used small datasets contributing to inconsistency in results and therefore should be interpreted with care. In addition, differences between the studies, such as trained or untrained consumer panels and a combination of production factors, make comparison difficult. For example, Safari, Fogarty, Ferrier, Hopkins and Gilmour found no sensory differences between progeny from three sire type groups (Maternal, Merino, and Terminal genotypes) although the study used trained panelists and cryptorchid lambs. Similarly, several other studies found no or small significant differences in eating quality between genotypes (Arsenos et al., 2002; Ellis, Webster, Merrell, & Brown, 2010; Esenbuga, Yanar, & Dayioglu, 2001). An earlier study in New Zealand, indicated more distinct flavour intensities (referred to as “foreign flavours”) and higher sensory tenderness in meat from Merino lambs compared to meat from crossbred lambs (Young, Reid, & Scales, 1993), however there was no difference in juiciness, flavour and overall acceptability of the *longissimus* muscle. Meat from UK Scottish Blackface lambs versus meat from Texel lambs had higher tenderness, stronger flavour and higher overall liking scores (Navajas et al., 2008). Furthermore, certain high muscling genotypes such as the Callipyge and Carwell mutations have shown to impact on meat quality through reductions in tenderness and IMF content (Duckett, Snowder, & Cockett, 2000; Jopson et al., 2001; Koohmaraie, Shackelford, Wheeler, Lonergan, & Doumit, 1995). Though it has been suggested that meat from sheep carrying the *Callipyge* mutation, can have improved eating quality, particular for the loin and leg muscle, when post-mortem tenderisation treatments such as electrical stimulation, prolonged ageing and freezing prior to ageing are used (Carpenter & Solomon, 1995; Duckett, Klein, Dodson, & Snowder, 1998).

Untrained consumer data within Australia showed genotypic differences in Merino lambs with lower sensory scores (juiciness, flavour liking, and overall liking) than Border Leicester \times Merino lambs, and Terminal first cross lambs (Hopkins, Walker, Thompson, & Pethick, 2005b). Yet in contrast, a much larger study ($n = 1434$) by Pannier et al. (2014a) found Merino sired progeny to have higher sensory scores than Terminal sired lambs (Poll Dorset, Suffolk, Texel, White Suffolk mated with Merino or Border Leicester–Merino ewes). This was irrespective of the difference in intramuscular fat % (IMF) between sire types (Pannier et al., 2014a; Pannier et al., 2014b), and possibly reflected the higher selection pressure for leaner animals within the Terminal sire line resulting in unfavorable sensory effects (lowest scores) compared to Merino and Maternal sired lambs. In addition, individual sire ($n = 175$) variation across the three sire types (Merino, Maternal, Terminal) accounted for 10 eating quality score

differences (in tenderness and overall liking) for both the *longissimus lumborum* and *semimembranosus* muscle (Pannier, unpublished results), indicating a strong influence of sire genetics on eating quality in this large dataset. Genotypic differences are unlikely to be driven by just breed, as typically variation of traits within a breed is quite large, therefore studies that conduct sensory analysis on large numbers of progeny from many sires within and across breeds are needed to determine the genetic parameters for eating quality (Mortimer et al., 2015).

2.2. Gender

In lamb, studies across several countries have shown gender to have a small and weak influence on sensory attributes, sensory scores are generally higher for meat from female animals compared to males (Arsenos et al., 2002; Navajas et al., 2008; Pannier et al., 2014a). Pannier et al. (2014a) showed female lambs to have 1.8, 1.6, 0.9, 0.9 and 1.5 higher sensory scores for tenderness, juiciness, flavour, odour and overall liking, respectively in the *longissimus lumborum* muscle when compared to wether lambs. Often these sensory differences are thought to be due to IMF differences between females and males (females having more IMF) (Craigie et al., 2012; Pannier et al., 2014b) however this was not the case in the latter study (Pannier et al., 2014a). Similarly Navajas et al. (2008) reported a small difference between ewe and rams lambs for the *longissimus lumborum*, with ewe lambs having higher flavour and overall liking scores, although IMF was not tested. There are also a number of studies which have shown no gender difference in terms of impact on sensory attributes (Teixeira, Batista, Delfa, & Cadavez, 2005; Tejeda, Peña, & Andrés, 2008). However the datasets used were significantly smaller (e.g. $n = 48$ Tejeda et al. (2008); $n = 72$ Teixeira et al. (2005) compared to Pannier et al. (2014a) ($n = 1434$) and were unlikely to be able to prove any difference because of the low power of the study due to the low animal numbers. In addition, uncastrated lambs were used, likely contributing to the discrepancy in the results. Largely these results are in agreement with the view that differences between the genders in eating quality traits are less important (Dransfield, Nute, Hogg, & Walters, 1990) compared to other factors affecting eating quality (e.g. IMF) as discussed in this review. This implies that production systems producing ewe, uncastrated, and wether lambs will provide very similar products on the market in terms of eating quality.

2.3. Animal age

Eating quality is also influenced by animal age. In Australia, sheep age classification is based on teeth eruption with lambs being classified as having no erupted permanent incisor

teeth and yearlings (or hoggets) having one but no more than two erupted incisors (AUS-MEAT specifications) (Anonymous, 2005). Based on this, lambs are typically slaughtered from 4 to 12 months of age and yearlings typically between 12 to 24 months. Studies in Australia have generally shown older animals to have lower sensory scores compared to younger lambs (Hopkins, Hegarty, Walker, & Pethick, 2006; Pethick, Hopkins, D'Souza, Thompson, & Walker, 2005c). Grilled *longissimus lumborum* muscle samples from older sheep across a large age range (ranging from 5 to 68.5 months of age) were less acceptable for consumers for tenderness, juiciness, liking of flavour and overall liking (Hopkins et al., 2006). Across a much smaller age range, yearlings aged 16-20 months had generally lower eating quality scores compared to lambs aged 9-12 months for grilled *longissimus lumborum* samples (Hopkins et al., 2005b). In both studies animal age had the largest effect on sensory tenderness compared to other design factors. This consumer data is supported by Warner-Bratzler shear force tenderness which increased in older animals (Bouton, Harris, Ratcliff, & Roberts, 1978; Hopkins, Stanley, Martin, Toohey, & Gilmour, 2007) with the biological mechanism believed to be due to less soluble forms of collagen in older animals (Young & Braggins, 1993) attributed to increased cross-linking between collagen molecules (Bailey, 1985; Light, Champion, Voyle, & Bailey, 1985). The data of Pethick et al. (2005c) demonstrated an overall age effect beyond 20 months of age though the authors found no significant sensory differences for grilled *longissimus lumborum* samples between lambs and yearlings of 8.5 versus 20 months of age, and 12 versus 22 months of age. Therefore the study highlighted the acceptable eating quality of the yearling sheep for this muscle, and this was recently confirmed by the study of Pannier, Gardner, and Pethick (unpublished results) who found relatively little to no difference in sensory eating quality attributes between yearling (average 23 months) and lamb (average 12 months) age groups for the *longissimus lumborum* muscle.

This effect of animal age varied between muscles, as yearling versus lamb *semimembranosus* muscle was significantly different in the study of Pannier et al. (unpublished results), as was the *biceps femoris* and *semimembranosus* muscle in the study of Pethick et al. (2005c). The muscle differences can to some extent be explained by their differing collagen concentrations and protein cross-linking with the *semimembranosus* muscle having more collagen (Hopkins, Allingham, Colgrave, & van de Ven, 2013) and increased desmin cross-linking (Frank et al., 2017b) compared to the *longissimus lumborum* muscle. Furthermore, these studies also demonstrate that animal age is less influential in sensory differences for higher quality muscles when compared to other factors that have a greater impact, or are more direct drivers of eating quality such as IMF, muscle type, genotype, form of packaging, selection for

lean meat yield, and other production factors (Frank et al., 2017b; Pannier et al., 2014a; Tejada et al., 2008).

Another aspect of animal age is its effect on sheepmeat flavour which generally intensifies when animals get older (Channon, Thatcher, & Leury, 1997). This is thought to be due to increased branch chain fatty acids (Young, Berdague, Viallon, Rousset-Akrim, & Theriez, 1997), and has been identified in older sheep (mutton) compared to younger animals (Watkins et al., 2010). However this effect probably only comes to light when sheep are over one year old as no significant relationship between liking of flavour scores and branch chain fatty acids was found in lambs in their first year (Watkins et al., 2014). Moreover, minimal to no effect of increasing age on flavour scores was observed in grilled muscles, particularly the *longissimus lumborum*, denuded of subcutaneous and intermuscular fat minimizing the age effect (Pannier et al., unpublished results; Pethick et al., 2005c). Further supporting the notion that age is less influential on eating quality in comparison to other factors.

2.4. Intramuscular fat

Meat eating quality is also determined through the use of instrumental meat quality measurements. IMF percentage, determined via chemical extraction, has an important influence on eating quality. Generally, as IMF content increases, eating quality improves. In lamb, it has been shown to increase overall liking scores (Hopkins et al., 2006), and more recently, a larger scale study (n = 1434) using MSA sensory protocols, showed IMF to be a very strong positive driver of consumer sensory scores, demonstrating the largest magnitude of effect for juiciness, flavour and overall liking (Fig. 1) ($P < 0.001$) (Pannier et al., 2014b). The latter study showed increasing levels of loin IMF, from 2.5% to 7% IMF, increased sensory scores (on a 0–100 scale) for tenderness (5.9), juiciness (10.7), liking of flavour (9.1), liking of odour (2.7) and overall liking (10). The results clearly indicate that even though IMF is just one of several factors determining final eating quality (Pethick, Barendse, Hocquette, Thompson, & Wang, 2007), it is a very important factor in lamb. Based on this within cut (i.e. loin) variation of IMF and the change in eating quality scores it demonstrates, it could be sufficient to change the consumer quality grade within the MSA system. For example increasing from a ‘good every day’ quality grade to a ‘better than everyday’, or ‘better than every day’ to ‘premium’ quality grade.

(Insert Fig.1 here)

Data from the Information Nucleus Flock (INF) program of the Australian Cooperative Research Centre (CRC) for Sheep Industry Innovation identified the average *longissimus lumborum* IMF level to be $4.23 \pm 0.01\%$ (\pm SE) of 5867 lambs (Pannier et al., 2014b). Previously, it has been suggested that a level of 5% IMF for this cut (from sheep ranging from 5 to 68.5 months in age) is required to achieve a ‘better than every day’ sensory score for overall liking (Hopkins et al., 2006). Equal to or less than 3% IMF is recommended for a ‘low fat’ claim (Food Standards Australia & New Zealand, 2003), however a value of 4-5% IMF for lamb should be maintained (Pethick et al., 2006) based on reduced sensory scores when IMF declines (Pannier et al., 2014a) and the negative impact of lean meat yield selection on both IMF and eating quality (Pannier et al., 2014a; Pannier et al., 2014b). Therefore, ensuring that lamb IMF does not decrease is important, particularly in a country like Australia where selecting for lean meat yield has been a high priority. This has resulted in the development of a breeding value for IMF currently being used commercially under the Sheep Genetics program in Australia, the first of its type for sheep.

There have been several speculations on the contribution of IMF on sensory attributes, in particular its impact on juiciness, flavour and tenderness (Hocquette et al., 2010; Oddy, Harper, Greenwood, & McDonagh, 2001; Thompson, 2004). Whilst it is agreed that flavour compounds and volatiles, obtained through thermally induced reactions, play a role in determining flavour (Frank et al., 2016; Shahidi, 2002), the effect of IMF on the generation of flavour is not well defined. Recently, it was demonstrated that at lower IMF levels in beef (5.2 – 10.2%) there was no difference in lipid derived flavor volatiles (Frank, Kaczmarek, Paterson, Piyasiri, & Warner, 2017a). In contrast at IMF levels greater than 10%, volatile concentration increased significantly (Frank et al., 2017a). Tenderness, on the other hand, is thought to be affected by IMF through alteration of the meat structure rather than through influencing the meat ageing process (Warner, Greenwood, Pethick, & Ferguson, 2010a). This has been shown by the same predicted IMF effect on shear force after aging for either 1 or 5 days (Warner et al., 2010b). In heavily marbled cattle, muscles with IMF levels over 8%, showed separation of the muscle perimysium and dilution into thinner collagen fibrils (Nishimura, Hattori, & Takahashi, 1999). Hence it was suggested that IMF disorganises the structure of intramuscular connective tissue thus making it more tender (Hocquette et al., 2010). When IMF levels are low, less than 8%, which is the case for lamb, its’ impact is possibly driven through enhanced flavour and juiciness. Whereas at higher levels, IMF would have changed the muscle structure, and sensory effects would be driven more through muscle toughness (Warner et al., 2010a). This might explain the different magnitudes of the IMF effect for juiciness, flavour, and

tenderness seen in the study of Pannier et al. (2014a) (Fig. 1) in which the IMF effect on tenderness was almost half compared to the IMF effect on juiciness and flavour. However, it should be noted that consumer responses are highly correlated with each other due to the consumer 'halo' effect (Font et al., 2009; Pannier et al., 2014a; Thompson et al., 2005a). This is observed in studies using untrained consumers who have a lower ability to distinguish between the different sensory attributes. Hence any effect seen on eating quality needs to take this into account, and would therefore have contributed to the IMF impacts seen on all sensory traits in lamb given these levels were below 8% (Pannier et al., 2014a).

2.5. Carcass muscling and fatness

Sensory scores in lamb have been shown to increase with higher carcass fatness and lower muscling (Pannier et al., 2014a). Computer tomography has been used to determine the percentage of muscle and fat in the carcasses of genetically diverse lambs (Anderson, Williams, Pannier, Pethick, & Gardner, 2015). The latter data also demonstrated a strong association between muscle weights of the shortloin (*longissimus lumborum*; $R^2 = 0.72$) and topside (*semimembranosus* including cap and abductor; $R^2 = 0.71$) with muscling, and shortloin fat weight (calculated as the fat from a denuded shortloin; $R^2 = 0.65$) with carcass fatness, when corrected to the same hot carcass weight (Anderson, unpublished results). As such, these measurements are good indicators of whole carcass muscling and adiposity.

The muscling components demonstrated a negative relationship with consumer sensory scores when adjusted to the same hot carcass weight (Pannier et al., 2014a). In part this may be explained by the suppressing effect of increased muscling on IMF (Pannier et al., 2014b). However, Pannier et al (2014b) demonstrated that the change in IMF across the extremes of the muscling phenotypic range was equivalent to only 1.4% IMF, which would account for only half of the 7 unit eating quality score (overall liking) impact of increased muscularity (Pannier et al., 2014b). Further to this when the analysis of EQ scores was corrected for IMF, the impact of shortloin muscle weight and topside weight were still significant. Work in lamb has demonstrated that certain high muscle genotypes, such as the Callipyge mutation can decrease tenderness due to depressed proteolysis post-mortem (Koochmaraie et al., 1995), potentially explaining the mechanism involved in this case, although this warrants further research.

For the carcass fatness components, at a constant hot carcass weight, the sensory scores of both the *longissimus lumborum* and *semimembranosus* muscles showed a small increase (2.3 eating quality scores for overall liking) as shortloin fat weight increased (Pannier et al., 2014a). This is probably reflected through the positive association of carcass fatness (i.e shortloin fat

weight) with IMF (Pannier et al., 2014b). This analysis was further explored for this paper, with IMF being included into the shortloin fat weight model. Shortloin fat weight remained significant, however the magnitude of the effect of shortloin fat weight on sensory scores reduced from 2.3 to 0.7 scores for overall liking between 60 to 450 g shortloin fat weight. This indicates that the positive association of carcass fatness and eating quality is strongly driven through IMF.

In addition to the phenotypic association between muscling and carcass fatness with sensory scores, selection for lean meat yield through breeding values for increased eye muscle depth (PEMD) and decreased fat depth (PFAT) have shown a negative impact on sensory scores (Hopkins, Hegarty, & Farrell, 2005a; Pannier et al., 2014a). This was in contrast to the study of Navajas et al (2008) who found similar eating quality scores of progeny from low (Scottish Blackface) and high (Texel) muscling sires. However the authors speculated that the muscularity difference between the progeny from the high and low muscling sires was perhaps not big enough to be detected through taste panels (Navajas et al., 2008). The latter study did not explore the effect of factors such as IMF, however the impact of PEMD and PFAT on eating quality was not just driven through a reflection of the negative association between IMF and these breeding values (decreased PFAT and increased PEMD) (Hegarty, Warner, & Pethick, 2006; Pannier et al., 2014a; Pannier et al., 2014b).

2.6. Other production factors

The feeding of livestock is also a factor impacting on eating quality. An animal's nutrition prior to slaughter impacts on varying flavour compounds that in turn affect sensory components, and this has been reviewed by Watkins, Frank, Singh, Young, & Warner (2013). Also, differing IMF levels can be achieved through nutrition, with IMF shown to be lower in pasture fed animals (Díaz et al., 2002; Pannier et al., 2017). Several studies have shown the effects of different feeding systems on sensory traits, particularly when concentrate versus pasture fed systems were applied. Higher consumer acceptability of concentrate fed lambs compared to pasture fed lambs has been demonstrated for several European consumer groups (Font et al., 2009). Similarly, meat from concentrate fed lambs had improved sensory attributes compared to meat from grass fed lambs however these studies were conducted with experienced panelists (Priolo, Micol, Agabriel, Prache, & Dransfield, 2002; Resconi, Campo, Furnols, Montossi, & Sanudo, 2009). On the other hand in a recent study, Australian consumers had only a small preference towards grain-fed lamb meat compared to meat from grass fed lambs for tenderness, juiciness and overall liking (Pannier et al., 2017). Though in the latter study this

was only observed in wether lambs and was mostly explained by differences in IMF between grain (5.6% IMF) and pasture (4.4% IMF) fed groups. In addition, an earlier study showed that Australian consumers could not discriminate sensory characteristics between lambs finished on pasture and grain (Pethick et al., 2005b). Whilst there seems to be a preference towards meat derived from concentrate fed animals, cultural aspects and therefore different consumption habits (habituated to the frequency of consuming sheepmeat) may also influence sensory preferences.

3. Meat Standards Australia

In an effort to predict the eating quality of the end product for consumers, the MSA program was developed in 1998 for beef (Polkinghorne et al., 2008) and 2005 for sheepmeat. Currently it is well developed for beef and still evolving for sheepmeat. MSA has adopted large scale consumer panels to underpin the beef grading systems, and the sheepmeat pathways system, and strives to reflect value to the consumers in regards to the final eating quality experience of a cooked meal portion. This focus on consumer responses and individual cut grading are unique aspects to the MSA system, which implements a Total Quality Management approach that includes information of all the factors across production, pre-slaughter, processing, and value adding sectors, which contribute to the final eating quality of the product (Polkinghorne et al., 2008; Polkinghorne & Thompson, 2010).

3.1. Beef

For beef, the MSA system is an individual cut by different cooking method grading system that can independently predict the eating quality of 39 cuts for 6 different cooking methods (Polkinghorne & Thompson, 2010). In Australia across 2016–17, over 2.7 million cattle were graded through the MSA program (Meat and Livestock Australia, 2017c) adding to the total of over 19 million beef MSA graded carcasses to date through MSA accredited beef processing plants. The current prediction model utilises data from over 100,000 consumers and 70,000 beef cuts (Meat and Livestock Australia, 2017c).

As part of the consumer panel testing, consumers score meat samples for four sensory attributes (tenderness, juiciness, flavour liking and overall acceptability) and rate each sample to a quality grade of unsatisfactory (no grade), good everyday (3 star), better than everyday (4 star), or premium quality (5 star) (Watson, Gee, Polkinghorne, & Porter, 2008a). Based on this consumer data and the input variables from the production, processing and retail sectors, an

eating quality prediction MQ4 score is calculated to define a single score describing the whole consumer eating experience for a particular cut (Watson, Polkinghorne, & Thompson, 2008b). The prediction factors incorporated into the beef model, and the beef MSA model as a whole have been described in detail, hence readers are referred to other scientific papers and reviews (Polkinghorne et al., 2008; Polkinghorne & Thompson, 2010; Thompson, 2002; Thompson et al., 2008a; Watson et al., 2008b). In addition, the economic benefits of supplying better beef quality based on the MSA grading have been addressed elsewhere (Griffith & Thompson, 2012; Polkinghorne & Thompson, 2010).

An important feature of the MSA system is the flexibility it holds to enable continuous improvement to constantly reflect the current consumer tastes and production methods. This ensures that the quality grading remains relevant and accurate for consumers when consumer preferences change. With continued consumer testing, over time the ability to deliver a guaranteed eating quality result has progressed and become more accurate with the ability to include more cattle types, cuts, processing inputs and cooking methods (Pethick et al., 2018).

3.2. Sheepmeat

In contrast to the beef MSA model, the sheepmeat MSA program is currently a “pathways-system” structured around a set of requirements for best practice both pre- and post-slaughter. There are no objective carcass measurements to characterise eating quality, with only carcass weight and a measure of carcass fatness (palpated manual GR tissue depth) used to exclude carcasses that are too light or too lean. As such, once these minimum requirements have been met, there is nothing to further discriminate between carcasses. Therefore, the sheep industry has called for the development of a new cuts-based MSA system that can predict the eating quality of each cut by different cooking method, enabling differentiation between carcasses and the cuts within them. In this section we describe the current sheepmeat MSA model, its limitations, and the reasons underlying the approach for the new sheepmeat MSA prediction system.

Within the current sheepmeat MSA model, all sectors involved (producers, processors and retail) need to comply with guidelines for best practices of feeding, handling and curfew management, slaughter protocols (pH decline), product ageing and retail presentation of lamb cuts (Pethick, D’Souza, Anderson, & Muir, 2005a; Young, Hopkins, & Pethick, 2005). The scientific outcomes and components underlying the current sheepmeat MSA model have been published elsewhere across several scientific publications (Pethick et al., 2005a; Pleasants,

Thompson, & Pethick, 2005; Thompson et al., 2005a; Thompson et al., 2005b). Briefly, animals are raised by MSA registered producers who are trained to comply with the producer guidelines. The sheep cannot change properties or under-go selected management procedures such as shearing and drenching for at least two weeks prior to slaughter. There are no breed restrictions, however the recommended growth rate three weeks prior to slaughter for Merinos (150 gm/day) is higher than for cross breed lambs (100 gm/day) to offset the propensity of Merino's having increased rates of high ultimate pH or dark cutting meat (Gardner, Kennedy, Milton, & Pethick, 1999). Furthermore, the sheep age classification is based on dentition, with animals classified as lamb having no erupted permanent incisor teeth. The carcass measurements of hot carcass weight must be greater than 18 kg and the GR tissue depth must be minimum 5 mm. The product aging recommendations (short: 5-10 days; long: >10 days) vary according to the pH decline and temperature post-slaughter, with short-aged products requiring electrical stimulation to ensure temperature at pH6 is greater than 18°C. At retail, recommendations for cuts by different cooking methods are available with most cuts being acceptable for grilling or roasting, except the *semimembranosus* muscle which is eligible for a stir-fry (Meat and Livestock Australia, 2012). Since the implementation and adoption of these current practices in 2006, the variation in lamb tenderness has significantly reduced (measured objectively by Warner-Bratzler shear force) through controlling the factors influencing eating quality (Pethick et al., 2006). For example, the aging of sheepmeat for a minimum of five days and the use of electrical stimulation to comply with the pH x temperature window significantly improved tenderness (Pethick et al., 2006; Thompson et al., 2005b), subsequently impacting on sensory quality as discussed earlier. In 2016–17, 5.7 million sheep were processed through the current sheepmeat MSA pathways and standards program, which is expected to rise in the coming years (Meat and Livestock Australia, 2017c).

Limitations do exist under the current sheepmeat pathways system. Firstly, the current system does not predict final quality grades for any individual cut by different cooking method. To date there are simple cut by cook recommendations based on the classification that if all carcasses within the flock comply with the MSA requirements they are accepted and graded as good everyday (3 star). However, there is no ability to differentiate beyond a good everyday (3 star) quality grade to a better than every day (4 star) and premium (5 star) quality grade as done within the beef system. Moreover these MSA quality grades have been identified as the most significant variable affecting a lamb consumer's willingness to pay decision. Based on consumer responses using MSA sensory protocols, it has been shown that Australian consumers are willing to pay double for a product graded good everyday (3 star) quality compared to

ungraded (unsatisfactory) products (Pethick et al., 2015; Tighe et al., 2017). Additionally, consumers are prepared to pay 1.43 and 1.90 times more for better than everyday (4 star) and premium quality (5 star) lamb meat, relative to a good everyday (3 star) quality grade (Tighe et al., 2017).

Secondly, research has shown that variation in eating quality still exists for the *longissimus lumborum* and *semimembranosus* muscle (Pannier et al., 2014a), even with the best practice MSA protocols currently employed across the value chain. This is partly due to variation in easily measured carcass traits such as carcass weight and carcass fatness. However, there also appears to be other genotypic factors that these carcass measures don't describe likely associated with the negative impact of selecting for lean meat yield on consumer acceptance of lamb meat (Pannier et al., 2014a). Furthermore, there are effects at retail that are known to impact eating quality. Alternative packaging systems based on displaying cuts under high oxygen modified atmosphere to promote a cherry red colour, have been shown to reduce the eating quality score for lamb (Frank et al., 2017b). Therefore, it will be crucial to incorporate predictors such as sire type, carcass weight and direct measurements of lean meat yield and IMF into the proposed new sheepmeat MSA model, as well as an input for retail packaging type.

To capture these descriptive inputs, a range of new measurements are required within the sheepmeat industry. In particular a measure of lean meat yield and IMF are essential. For this reason the Australian sheep industry and researchers have been developing and implementing online objective measurements for these traits. This includes technologies such as dual energy X-ray absorptiometry (DEXA) to determine lean meat yield (Gardner, Glendenning, Brumby, Starling, & Williams, 2015), and hyperspectral imaging and Near Infra-red probes to measure IMF (Craigie et al., 2014; Pethick et al., 2018).

These new objective carcass measurements will enable the deployment of a more sophisticated eating quality model. This proposed new sheepmeat MSA model is shown in Fig. 2 and has been previously described by Pethick et al (2018). It is designed to incorporate all of the key factors that impact sheepmeat eating quality from farm to retail, and when these new measurements are linked to individual carcass tracking systems this will allow carcasses to be traded based on the value of their cuts reflected by their weight and eating quality. The existing sheepmeat MSA system could then expand to an individual cut by different cooking method grading system, in which each cut can be graded as unsatisfactory (no grade), good everyday (3 star), better than everyday (4 star), or premium quality (5 star) with corresponding price points. For the processor this offers the opportunity for more efficient carcass sorting to meet

market specification, market volumes and consumer requirements. In addition it enables value based carcass feedback systems and subsequent pricing mechanisms for producers. This will also provide transparent market signals for lean meat yield and eating quality, promoting a balance selection for these two antagonistic traits.

(Insert Fig.2 here)

4. Does the MSA system describe international consumers?

4.1. Validation of the MSA system internationally – Beef

To date, several different countries or international regions have undertaken consumer panels following the MSA sensory protocols. These include for beef; France (Legrand, Hocquette, Polkinghorne, & Pethick, 2012), Ireland (Allen, 2015), Japan (Polkinghorne, Nishimura, Neath, & Watson, 2014), Korea (Thompson et al., 2008b), New Zealand (Crownover et al., 2017), Northern Ireland (Bonny et al., 2017a; Bonny et al., 2017b), Poland (Bonny et al., 2016), South Africa (Thompson et al., 2010) and United States of America (Smith, Tatum, & Belk, 2008). These individual studies have previously been reviewed by Hocquette et al. (2014). The results have consistently demonstrated the ability of the MSA system to predict beef eating quality based on consumer responses regardless of country of origin. However there were some minor differences when predicting the final quality grade. These differences between consumer groups are derived from different eating quality attribute weightings and final quality grade boundaries, and have been reviewed by Bonny et al. (2018). Overall, consumers reliably provide similar responses when it comes to beef eating quality when assessed for their preferences using MSA testing.

In addition to the Australian consumer studies, cross cultural comparisons of willingness to pay data have yielded remarkably results across countries. Consumers were consistently willing to pay a premium for higher quality products (Pethick et al., 2018; Polkinghorne & Thompson, 2010). A comparison of 22920 consumers from France, Ireland, Japan, New Zealand, Poland, South Africa, and the USA, demonstrated a willingness to pay double the price for a premium product (5 star) compared to a good every day (3 star) product. Similarly, participants were prepared to pay half for an unacceptable quality product compared to a good every day product. Small deviations to this were observed with Irish and Polish consumers being more sensitive to premium product pricing, and Japanese consumers placing a higher price on premium products (Pethick 2018). These MSA quality grades were identified as the most significant variable affecting consumer willingness to pay data (Bonny et al., 2017a)

indicating that appropriate quality-grade based labelling should be successful in securing a premium for higher quality meats regardless of the country of implementation.

4.2. Validation of the MSA system internationally – sheepmeat

Utilising the MSA system to assess international consumer preferences for sheepmeat has only just begun. China, the USA and New Zealand (Pethick et al., 2018) have undergone trials for sheepmeat (O'Reilly, Pannier, Gardner, & Pethick, 2016; Pethick et al., 2018). Cross cultural consumer testing involving a total of 2160 American, Australian and Chinese participants, eating and scoring grilled *longissimus lumborum* and *semimembranosus* muscles demonstrated similar eating quality preferences for Australian lamb and yearling products (O'Reilly et al., 2016). The eating quality attributes of juiciness and overall liking were consistent for the American, Australian, and Chinese consumer groups. An exception was for tenderness, with Chinese consumers being less generous and scoring tenderness up to 5 scores lower than American consumers (O'Reilly et al., 2016). These differences could be attributed to inherent cultural preferences for tenderness, as even within China, consumers from particular provinces are known to place different values on the “chewiness” of their meat. Also the novelty of eating “western” style cooked meat for Chinese consumers compared to their traditional Chinese methods (e.g. stirfry, hot-pot) will likely have impacted on the results. Nevertheless, initial findings indicate the MSA system may be suitable to predict Australian sheepmeat eating quality for American and Chinese consumers.

Further to this, American, Australian, and Chinese consumers all responded positively to increases in IMF for all eating quality attributes (O'Reilly et al., 2017). Across all countries, eating quality scores (0-100 scores) increased for tenderness (7.9), juiciness (5.8), flavour (7.2) and overall liking (6.7) respectively between a 2.5%-9% IMF range. However the magnitude of these responses differed between countries and Australian consumers expressed the strongest response to increasing IMF%, which was significantly greater than that of American or Chinese consumers (Fig. 3) (O'Reilly et al., 2017). Whilst there are country differences in the response to IMF, results further illustrate IMF as a strong predictor of sheepmeat eating quality not only for Australian (Pannier et al., 2014b) but also for consumers in these different countries.

(Insert Fig.3 here)

Similarly, a study comparing 3240 American and New Zealand consumers revealed that a grading system to predict sensory scores utilising MSA sensory protocols could accurately

predict the eating experience of multiple grilled cuts for both consumer groups (Pethick et al., 2018). Given the successful application of MSA sensory protocols in these initial international sheepmeat studies, and its well-evidenced application within the beef sector across the globe, an international MSA like system is viable to better reflect consumer preferences in different countries.

5. Barriers to the adoption and application of an MSA type system internationally

Given the success of the MSA system in describing consumers from other countries, this presents an opportunity for these countries to deploy an MSA like system describing eating quality. This would enable markets to trade on eating quality, promoting uniform quality descriptions to facilitate increased global trade and brand promotion. The associated benefits such as consumer demand for quality products, economic gain and supply chain values of the MSA system have been described elsewhere (Griffith & Thompson, 2012; Polkinghorne et al., 2008; Polkinghorne & Thompson, 2010).

None-the-less there are barriers to the adoption of systems like MSA. This includes the new measurements required to deploy the system into commercial supply chains, the change in existing market structures and brands, the industry and consumer acceptability and awareness of a new quality grade system, and the data storage and management systems needed to deploy a program like MSA. In addition, a model rolled out internationally would need to maintain consistent prediction inputs and produce consistent consumer discrimination thresholds across countries.

For sheepmeat, the new individual carcass measurements discussed earlier would need to be deployed within abattoirs, and would have to be cost-effective to overcome the smaller return per head from sheep carcasses compared to beef carcasses. Furthermore, the MSA type system may require adaption to that country's particular production and processing factors for it to be successfully implemented. For example, there are popular cooking methods unique to particular countries (e.g. hot-pot in China), different animal age and sheepmeat definitions (e.g. yearling, mutton, hogget), different genotypes (e.g. muscular breeds Texel) and different animal classifications (e.g. ram versus wether). In addition the different production systems used (e.g. extended grain feeding or indoor systems) will also need to be taken into account. These factors can be used as predictors within the model, but will need to be extensively tested using a country's local products before being deployed into a model.

Another consideration for the successful implementation of an MSA type system are the industry systems and consumer marketing strategies that would need adaption. Given that

MSA is not a brand, but simply a quality assurance system designed to support company brands, an alteration to the existing market structures and brands would need to be considered. In addition, grader training schemes, auditing structures and product traceability systems would need to be developed. Lastly, education activities would need to extend along the entire supply-chain; for producers to enable them to understand the new carcass feedback information, and rewards available for their participation in an MSA scheme; for processors to understand the measurements and auditing required; and for consumers to understand the eating quality assured brands. Underpinning these brands with an eating quality assurance would increase consumer trust and thus build demand.

The last consideration for successfully implementing an MSA type system internationally is the extensive volume of consumer testing required to determine consumer preferences across various countries. This should utilise both local and international products so necessary adjustments to the MSA like model can be made. However, collecting this consumer data is a time consuming and expensive exercise, and profound cooperation and collaboration between industry and research groups is needed to undertake a huge task like this. This collaboration will also rely on a system to consistently provide prediction inputs and work out consumer discrimination thresholds across countries. It is important to generate large volumes of data to overcome the consumer ‘halo’ effect (Pannier et al., 2014a; Thompson et al., 2005a) evident when developing a system based on untrained consumer eating scores. The ‘halo’ effect occurs when the consumer’s scoring of one sensory attribute influences the scoring of one or all of the other sensory attributes. For example, consumers may score all sensory attributes high (or all low) because they find it difficult to differentiate between the traits. This ‘halo’ effect is unavoidable with untrained consumers who are ultimately the product buyers, but can be reduced when the amount of sensory attributes are kept to a minimum.

Given the success of the beef MSA system within Australia, the majority of international research has focused on its’ application within the beef sector. Investigation and discussion into approaches to more accurately predict beef eating quality of international consumer groups, and potentially develop an international eating quality prediction model for beef has started. Since late 2017, a global eating quality DATAbank, was established under the name “International Meat Research 3G Foundation” and has been described in Pethick et al. (2018). This DATAbank was created as a means of pooling together all individual beef MSA tested eating quality data collections across various countries that have utilised the MSA consumer testing protocols, to allow merging, sharing and data standardisation amongst the scientific community. The DATAbank will allow for increased consumer data, and additional

MSA grading inputs of differing production (e.g. varying breed type) and processing (e.g. aging, packaging methods) systems, and cooking methods (e.g. hot-pot, degree of doneness). These can be used in a possible collaborative eating quality prediction model to develop a clear and simple predicted end meal result for consumers. This will allow transparency of data for global trading to be taken to the next level. For sheepmeat, perhaps a similar approach could be taken in the distant future.

6. Summary and conclusions

Eating quality is defined through a complex interplay of genetic, processing and environmental factors. However, by developing models that capture inputs for these factors, as done through systems like MSA, reductions in eating quality variation can be achieved. The MSA system centers itself on estimating the final product eating quality response of untrained ordinary consumers who ultimately purchase the meat. The evidence shows clearly that the beef MSA model is a reliable tool for predicting the eating quality for not only domestic consumers but also international consumer groups across various countries, and it could represent an opportunity for these countries to deploy an MSA like system describing eating quality.

The current sheepmeat MSA pathways system within Australia will need to be advanced to predict consumer satisfaction for individual cut by different cooking methods as a means of increasing the representation of cut quality for consumers. There is clear potential to develop a new sheepmeat MSA prediction system through the inclusion of factors affecting eating quality as described in this review. However it can only be fully deployed when individual carcass measurements for lean meat yield and eating quality are developed. When successfully implemented, the sheepmeat MSA prediction system will allow more efficient carcass sorting to underpin a value based payment system throughout the supply chain, and will make the sheepmeat industry more responsive to various market demands. Hence, in Australia this is currently an area of intense focus and research to develop a new cuts based sheepmeat MSA model, and to develop, calibrate and validate on line technologies for grading lean meat yield and IMF in lamb carcasses.

Acknowledgements

The contributions of authors' colleagues in the conduct of research described in this review are most gratefully acknowledged. The authors would like to thank Rod Polkinghorne for his guidance and mentoring, the contribution of staff employed by CSIRO and Murdoch University and all collaborating partners who participated in the international Meat Standards Australia

studies. Furthermore the authors acknowledge the contributions of support provided through the Cooperative Research Centre for Sheep Industry Innovation, Cooperative Research Centre for Sheep, Meat & Livestock Australia, NSW Department of Primary Industries, University of New England, Department of Primary Industries Victoria, South Australian Research & Development Institute and the Department of Primary Industry & Regional Development (Sheep Industry Business Innovation) WA. The Meat program also benefits from the contribution of staff employed by CSIRO and Murdoch University.

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Highlights

- Interactions between many complex factors determine the final eating quality outcome
- Despite efforts to control sheepmeat palatability, variability remains high
- There is potential to develop a cuts-based sheepmeat MSA prediction model
- Inclusion of yield and intramuscular fat measures into a new sheepmeat model are key
- Consumer focused research is fundamental to underpin future demand of red meat

ACCEPTED MANUSCRIPT

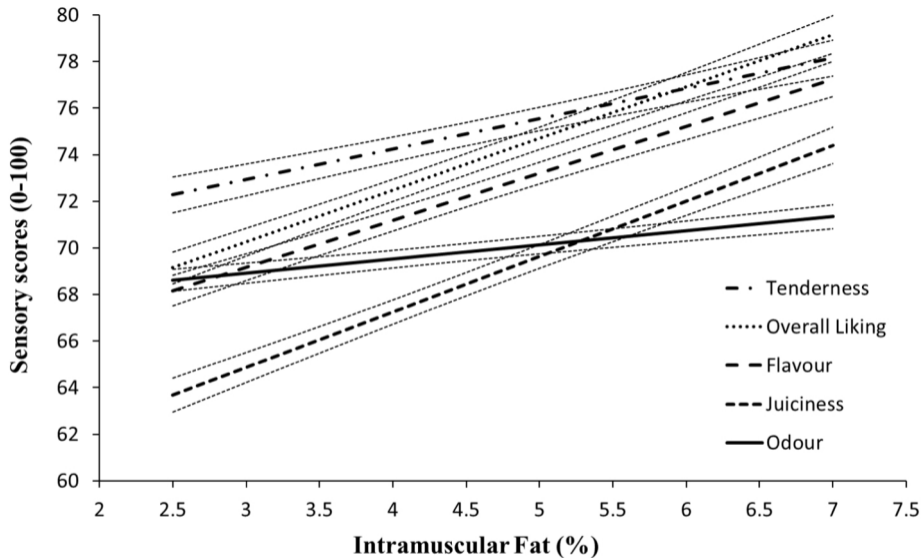


Figure 1

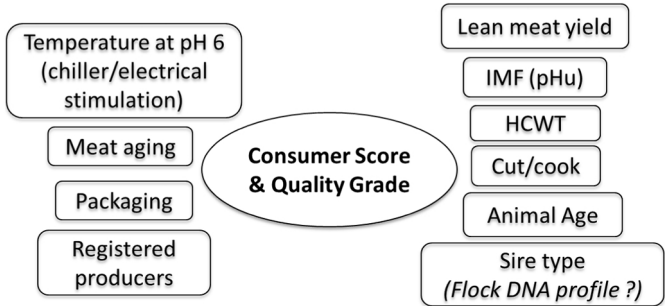


Figure 2

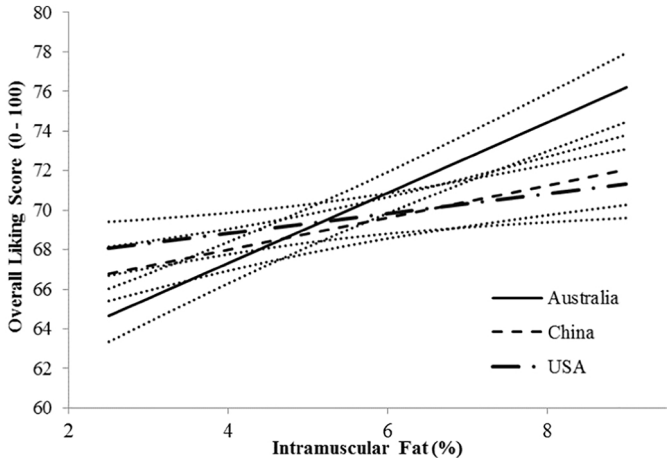


Figure 3