THESIS

Understanding the Eating Quality Perceptions of International Consumers to Australian Sheepmeat

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Bachelor of Animal and Veterinary Bioscience (Hons I)

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Declaration

I, Rachel O'Reilly verify that in submitting this thesis; the thesis is my own account of the research conducted by me, except where other sources are fully acknowledged in the appropriate format, the extent to which the work of others has been used is documented by a percent allocation of work and signed by myself and my Principal Supervisor, the thesis contains as its main content work which has not been previously submitted for a degree at any university, the University supplied plagiarism software has been used to ensure the work is of the appropriate standard to send for examination, any editing and proof-reading by professional editors comply with the standards set out on the Graduate Research School website, and that all necessary ethics and safety approvals were obtained, including their relevant approval or permit numbers, as appropriate.

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Abstract

Consistent eating quality of sheepmeat is crucial to satisfy consumers, ensuring that they repurchase product. Therefore, this thesis explored the key factors that affect consumer perceptions of eating quality, namely American, Australian and Chinese consumers tasting Australian sheepmeat. These international consumer groups were selected based on their divergent relationships with lamb and sheepmeat products, and relevance to the Australian sheepmeat industry. To test consumer responses, the Meat Standards Australia (MSA) sensory protocols were utilised as they provide an internationally accepted methodology to assess untrained consumer perceptions of sheepmeat and beef products. Further, the existing MSA prediction models already adopted by the Australian industry provide a mechanism for the seamless integration of findings from this work.

The first experiment compared the sensory responses of 2,160 untrained American, Australian and Chinese consumers to grilled *longissimus lumborum* and *semimembranosus* muscles from Australian lambs (n=164) and yearlings (n=168). Linear mixed effects models demonstrated no difference between the three countries for juiciness and overall liking scores, while for tenderness, liking of flavour and odour, American consumers scored highest, followed by Australian and Chinese consumers. Across these consumer groups, similar factors were shown to influence eating quality, yet varied in the magnitude of their effect. All consumer groups preferred the *longissimus lumborum*, lambs compared to yearlings, and Merino sired and female lambs. Analysis of consumer demographic factors and sheepmeat consumption habits on eating quality scores, demonstrated consumer age, gender, number of adults in a household and income affected sensory scores, however no consistent trend was observed across the different countries. Frequency of lamb consumption had an impact on sensory scores of the three consumer groups. Linear discriminate analyses were used to determine quality thresholds, and accuracy of predicted quality grades compared to actual consumer assigned grades. Chinese consumers demonstrated the most generous consignment of samples to higher quality grades, while American and Australian consumers were similarly more critical. The optimised discriminate function was also most accurate for Chinese consumer assignment to quality grades compared to Australian and American predictions. The last component of this work aimed to develop and test a new MSA cooking method, traditional Chinese hotpot. This experiment involved testing sensory responses of 720 untrained Chinese consumers to Australian lamb (n=108) and yearling (n=109) shoulder and leg cuts to assess the impact of cut-type and animal factors on eating quality using this cooking method. Shoulder cuts were more palatable than leg cuts, lambs were preferred to yearlings, and increasing intramuscular fat had a positive influence on sensory scores. Conversely, increasing muscularity negatively influenced eating quality scores. Results suggest shoulder and leg cuts cooked using hotpot could provide a better eating experience compared to some previously tested sheepmeat cooking methods. In addition, the influence of muscularity and intramuscular fat emphasise the importance of balanced selection for quality and yield traits to ensure consumer satisfaction is maintained.

Overall, results demonstrated that consumer sensory perceptions of sheepmeat are highly consistent across countries, irrespective of cultural differences, with minimal variation in eating quality scores between the three countries and a consistent response to animal and production factors. However, the discriminate analysis demonstrated some perceptions of quality varied between the three countries, suggesting further investigation through the scope of the new sheepmeat MSA model may be beneficial to determine whether adjustments should be made to prediction models for product destined for these markets.

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Abbreviations

ASBV	Australian Sheep Breeding Value
ATP	Adenosine Triphosphate
DDF	Denominator Degrees of Freedom
DEXA	Dual x-ray absorptiometry
HCW	Hot Carcase Weight
IMF	Intramuscular Fat
INF	Information Nucleus Flock
LL	*longissimus lumborum* muscle
LLFAT	*longissimus lumborum* (loin) fat weight
LLWT	*longissimus lumborum* (loin) weight
LMY	Lean Meat Yield percentage
MLA	Meat and Livestock Australia
MQ4	Meat Quality 4
MSA	Meat Standards Australia
N	Newtons
NDF	Numerator Degrees of Freedom
NIR	Near-infrared
pH	-log hydrogen ion concentration
pHu	Ultimate pH
SE	Standard Error
SF5	Shear Force at 5 days aged
SM	*semimembranosus* muscle
WBSF	Warner-Bratzler Shear force

Statement of Thesis Structure

This thesis has been designed to present the data collected during the degree of Doctor of Philosophy as a coherent piece of work incorporating a series of stand-alone manuscripts. Each manuscript was written according to the authorship guidelines of the journal that the manuscript has been accepted for publication, submitted for review, or will be submitted in the future. Statements of author attribution are included. All chapters are presented in a similar format with continuous referencing and table and figure numbering to maintain the continuity of the document.

The content in this thesis was developed by the Candidate with advice from their supervisory panel.
The following individuals contributed to the thesis.

Contributor	Contribution (%)	Concept Development	Data Collection	Data Analyses	Drafting of Chapters
Rachel A. O'Reilly	85	X	X	X	X
Liselotte Pannier	5	X	X	X	X
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Contribution indicates the total involvement the Candidate has had in the creation of the thesis. Placing an 'X' in the remaining boxes indicates what aspect(s) of the thesis each individual engaged in.

By signing this document, the Candidate and Principal Supervisor acknowledge that the above information is accurate and has been agreed to by all other contributors.

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Statement of Contributions to Thesis by Publication

Chapter 3 presents the results of research published in the following journal article:

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L. Pannier, G.E. Gardner (acting as principle supervisor in 2015), and D.W. Pethick who were in charge of conceptualisation and methodology of the project in conjunction with R.O'Reilly. Project investigation, sample collection and resource management was carried out by R.A. O'Reilly with assistance from L. Pannier plus H. Luo, and Q. Meng of China Agricultural University, and A.J. Garmyn, and M.F. Miller of Texas Tech. Validation of data was carried out by R.A. O'Reilly and statistical analysis was performed by R.A. O'Reilly under the supervision of L. Pannier and G.E. Gardner. The original draft preparation and writing was performed by R.A. O'Reilly. The co-authors that provided feedback during the reviewing stage were L. Pannier, G.E. Gardner, D.W. Pethick, A.J. Garmyn, M.F. Miller, H. Luo. All editorial changes were coordinated by R.A. O'Reilly, who also implemented the editorial changes to the manuscript as recommended by journal reviewers. Project funding and acquisition was by L. Pannier, G.E. Gardner, D.W. Pethick.

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Chapter One

1

Introduction

Eating quality is a known driver of consumer demand, and expectations of quality are closely linked to willingness to pay for delivery of that promised quality (Grunert et al., 2004; Tighe et al., 2018). Thus, a consumer-based approach to guarantee eating quality was adopted in Australia in the 1990's for beef, and 2000's for sheepmeat, in the form of the Meat Standards Australia (MSA) system (Thompson et al., 2005a; Watson et al., 2008b). Through extensive untrained consumer testing, critical control points for eating quality across the supply chain were identified which impact on eating quality and robust predictive models for eating quality were determined. The sheepmeat MSA model started as a pathways system for quality assurance, whereby producers and processors met minimum requirements for eligibility, but has recently evolved into a cut by cooking method eating quality prediction model with additional inputs for intramuscular fat (IMF), lean meat yield (LMY) and hot carcase weight (HCW) (MLA, 2022). Untrained taste panels are used to underpin models given they provide a more accurate representation of the population sampled, and while they introduce more variability than trained taste panellists this drawback can be overcome by recruiting large numbers of participants (Watson et al., 2008a). Consumer eating quality preferences under MSA are measured through the sensory traits of tenderness, juiciness, liking of flavour and overall liking. These four sensory traits contribute to a composite meat quality score which when applied with quality thresholds, allocates product into quality grades.

The variable production pathways in the Australian sheepmeat industry introduce many challenges to produce consistent eating quality, thus many factors have been researched for potential incorporation into the MSA system (Pannier et al., 2014b; Pethick et al., 2005; Pethick et al., 2006b; Thompson et al., 2005a; Thompson et al., 2005c). Recommending optimal cooking methods for particular cuts is a crucial component of the MSA system (MLA, 2012), given different muscles within the same carcase can have a diverse range in eating quality due to compositional factors specific to the muscle type and the cooking treatment applied (Koohmaraie et al., 2002). Thompson et al. (2005a) and Pethick et al. (2006b) demonstrated the palatability of a range of lamb cuts when grilled and roasted, with Australian consumer preference for the *longissimus lumborum* (loin/LL) and then in descending order, the *serratus ventralis* (chuck) › *gluteus medius* (rump) › *biceps femoris* (outside) › and *semimembranosus* (topside/SM) muscles when grilled. Animal age at slaughter has also been shown to influence quality, with the greatest differences observed between lamb and mutton categories (Hopkins et al., 2006; Pethick et al., 2005). This is attributed to structural changes in intramuscular connective tissue, and build-up of stronger flavour profiles in fat deposits with age (Hopkins et al., 2007; Watkins et al., 2013). Notably, reported differences between lamb and yearling age groups are inconsistent across sensory traits and muscle types (Pannier et al., 2018b; Pethick et al., 2005). These factors along with many others include but are not limited to, intramuscular fat levels, muscularity, sire type, animal sex, and slaughter group can affect eating quality. In addition, consumer demographic factors and meat consumption preferences have been shown to influence eating quality scores to a variable degree across numerous countries tested, including consumer age, income level, gender, and occupation. Moreover, a consumer's higher appreciation of red meat in the diet and preferred cooking doneness can also impact on sensory scores (Bonny et al., 2017; Huffman et al., 1996; Hwang et al., 2008; Thompson et al., 2005d).

Therefore, it is important to understand how consumer perceptions of eating quality may differ to Australian consumers, given they inform predictive models used in the MSA system. Australia is the worlds' largest sheepmeat exporter, valued at 3.7 billion in 2020 (MLA, 2021d), thus a guarantee of quality is essential to maintain consumer trust and manage expectations not only domestically but globally. Two such diverse international groups are American and Chinese consumers. American consumers share a similar suite of cooking styles to Australian consumers but have extremely low sheepmeat consumption rates (0.4 kg per annum) and some negative perceptions of imported sheepmeat compared to domestically produced product (Hoffman et al., 2016; Phelps et al., 2018b). On the other hand, Chinese consumers have quite positive perceptions of Australian sheepmeat, higher consumption rates (3.9 kg per annum) but different sheepmeat usage with most frequent cooking styles being hotpot, stewing, and roasting (Mao et al., 2016; MLA, 2021b).

The first experiment in this thesis aimed to evaluate the sensory scores of untrained American, Australian and Chinese consumers to Australian grilled lamb and yearling *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles. The second experiment aimed to develop a MSA sheepmeat hotpot testing protocol to examine Chinese consumer sensory responses to Australian lamb and yearling shoulder and leg cuts using this traditional cooking style. The objectives of these experiments were to identify whether there were significant differences between the three groups of consumers in relation to known influencers of eating quality: animal, production, and processing factors, meat consumption preferences, and consumer demographic attributes. In addition, perceptions of quality grades within the three consumer groups were examined and the reliability of using an MSA type model to predict these quality outcomes. The benefits of this thesis include greater insights into American and Chinese sensory perceptions of Australian lamb and yearling products, and sensory data that could advise adjustments of the sheepmeat MSA cut by cook model if catering for specific product destinations, thus providing value adding opportunities for industry.

Chapter Two

2

Literature Review, Aims and Hypotheses

This literature review will describe factors associated with eating quality of sheepmeat products as this is the particular area of investigation of this work. It will explain why eating quality is important, the factors that may impact on eating quality, how Australia improved its sheepmeat quality standards, and why the focus was to investigate the eating quality of Australian lamb and sheepmeat products in America and China.

2.1 Eating quality

Eating quality is one of the most important drivers of consumer demand for sheepmeat, as the quality experienced will shape future expectations and intent to repurchase (Grunert et al., 2004; Henchion et al., 2014). Expectations of eating quality are closely linked to the consumer willingness to pay for sheep and beef meat products, demonstrated in both domestic and international consumers (Bonny et al., 2017; Lyford et al., 2010; Tighe et al., 2018). Irrespective of product destination, consumers expect a consistent eating experience with every purchase (Yann et al., 1994), and the very nature of livestock production introduces many variables that made it difficult to ensure a quality product was always reaching the consumers' plate (Bennett, 1997; Safari et al., 2002; Yann et al., 1994).

2.2 Factors influencing eating quality

2.2.1 Production factors

2.2.1.1 Nutrition and finishing diet

The quality of nutrition provided can have a significant impact on sheepmeat eating quality through several processes. Quality feed allows an animal to optimise muscle volume and intramuscular fat (IMF) deposits, which can impact on tenderness, juiciness and flavour (Hopkins et al., 2005; Pannier et al., 2014b). Animals receiving good nutrition continue to actively grow, which is particularly important in the weeks leading up to slaughter. When an animal is actively growing, collagen the primary component of connective tissue is continually being turned over, delaying the process of connective tissue hardening (Warner et al., 2010). This hardening of connective tissue is considered to be one of the factors contributing to the toughness of meat especially in older animals. Good finishing also ensures adequate glycogen deposits in muscles at the time of slaughter, with low levels of glycogen causing high pH meat which can result in an undesirable dark meat colour, cooking inconsistency, reduced shelf life, and decreased tenderness (Pethick et al., 1995). Further to this, if an animal is deficit in feed, muscle fibres and IMF will be mobilised for energy, leaving a larger proportion of connective tissue fibres and a corresponding increase in the toughness of meat.

There is no clear consensus on the effect of different finishing diet on eating quality, particularly flavour (Watkins et al., 2013). Trained panellists can discern some flavour differences in pasture versus grain-fed lambs (Gkarane et al., 2019), while untrained consumer responses are highly variable, with no consistent effect on flavour and overall liking (Watkins et al., 2013). For example French and Spanish consumers respond more favourably as a whole, to sheep fed a concentrate diet, while German and British consumers favour animals fed a mixed ration of pasture and concentrate compared to lambs fed only pasture (Font i Furnols et al., 2009). Notably, several studies demonstrated the influence of finishing diet on eating quality could be explained by correcting for IMF and animal age (Pannier et al., 2017; Pethick et al., 2021). However, without agreeance on the impact of diverse diets on eating quality, the opportunity to value add remains in diet claims underpinning brands. Consumer acceptability increases when a product aligns with their value system, for example beef acceptability was higher when product was labelled as grass-fed compare to grain for Chilean consumers irrespective of whether the product was in fact grass or grain-fed (Morales et al., 2013).

2.2.1.2 Age and maturity at slaughter

Meat eating quality declines as sheep increases in age, with discernible differences found between age class categories of lamb, yearling, and mutton (Hopkins et al., 2006; Pannier et al., 2018b; Pethick et al., 2005; Thompson et al., 2005c). AUS-MEAT defines lamb as an ovine animal that is under 12 months of age or does not have any permanent incisor teeth in wear (prior to July 2019 lamb was defined as an ovine with no permanent erupted incisors) (AUS-MEAT, 2022). Yearling or hoggets come under the alternatively MSA categorisation of sheepmeat and are female or castrated males with no more than 2 teeth in wear (usually 10 to 18 months old). Ewes and wethers are female and castrated males, with 2 to 8 teeth in wear. If using basic classifications anything older than lamb would be classified as mutton (AUS-MEAT, 2022)

Changes in eating quality with age are attributed to several physiological aspects of animal maturity. Reduction in tenderness, as measured through untrained consumer scores and shear force values (Hopkins et al., 2007; Pannier et al., 2018b), is attributed to the development of more cross-links between collagen fibres, contributing to ‘tougher’ connective tissue surrounding muscles fibres. This ‘tougher’ connective tissue in older animals does not respond easily to cooking (especially the faster cooking techniques like grill), resulting in increased shear force values and a corresponding decrease in sensory tenderness (Pannier et al., 2018b; Pethick et al., 2005). However, development of IMF with maturity has also been demonstrated in several studies (Pannier et al., 2014c), and a corresponding increase in eating quality with IMF levels is widely reported (Hopkins et al., 2006; Pannier et al., 2014b; Thompson, 2001). While IMF levels can have a positive influence on eating quality, with age a build-up of undesirable flavours can occur in fat deposits (Watkins et al., 2013). This aligns with findings by Thompson (2001) showing that at the same IMF level and shear force value, older animals had less desirable flavour scores. With age also comes a darkening of meat colour, which has a negative effect on acceptance of meat at retail (Hopkins et al., 2007). Consumers associate a darker meat product with a shorter shelf life and lower quality hence are less likely to purchase. Generally the greatest differences in eating quality are observed between lamb and mutton categories, with a variable impact found for different cuts and sensory traits for lamb and yearling age classes (Pannier et al., 2018b; Pethick et al., 2005).

2.2.1.3 Stress control

Compromised eating quality due to stress is most likely to occur in the two weeks prior to slaughter given the high level of activity in the lead up to this event (Ferguson & Warner, 2008; Pethick et al., 1995). Stress causes the release of adrenaline, which initiates a series of biochemical events increasing the metabolism of muscle glycogen to lactic acid. Hence glycogen is rapidly depleted in the live animal, and it is these glycogen stores that are required to reduce muscle pH of the animal post slaughter. Muscle glycogen is converted to lactic acid in the muscle post slaughter which results in a reduction in pH, decreasing the risk of unacceptably dark meat, increased toughness, reduced shelf life, and an inconsistent cooking experience for the consumer (Díaz et al., 2014; Gardner et al., 1999; Pethick et al., 1995). Stressors can take many forms and often have a combined impact from mustering to the point of slaughter. Stressors include shearing, the use of dogs during mustering, excessive transport times, inclement weather during transport, mixing and separating sheep, time off feed prior to slaughter, dehydration, unfamiliar environments and extended time in lairage (Daly et al., 2006; Ferguson & Warner, 2008).

2.2.2 Slaughter and processing conditions

2.2.2.1 Electrical stimulation, chilling and aging period

Electrical stimulation can have a significant impact on tenderness and sensory characteristics (Hanrahan et al., 1998; Shaw et al., 2005); it improves eating quality by providing control over when a carcass enters rigor mortis; this state occurs post mortem, when actomyosin bridges within muscles become locked due to a depletion of adenosine triphosphate (ATP), or at which the pH meat decreases to 6.00. Using an electrical current stimulates conversion of glycogen to lactic acid accelerating the fall of pH and ensuring muscles enter rigor at higher temperatures (Hwang et al., 2003).

The temperature at which a carcase enters rigor mortis can have a significant impact on the degree of shortening of muscles (Locker & Hagyard, 1963), and consequently the toughness of meat (Marsh & Carse, 1974). Biochemical reactions within muscles post-mortem are highly dependent on temperature. If a carcass is cooled too rapidly, and ATP is still present, cold shortening can occur. Cold temperatures slow the conversion of glycogen to lactic acid, delaying the onset of rigor, and combined with the irreversible release of Ca^{++} through the endoplasmic reticulum at cold temperatures the muscle will be driven to maximum contraction. This leads to permanent toughness, and cuts require longer aging periods. Conversely if a carcass is cooled too slowly the high temperatures will speed up biochemical reactions and muscles will enter rigor (pH 6) at higher temperatures, and above 35^{o}C muscles will tend to heat shorten. During heat shortening some contraction occurs but negative effects are primarily attributed to the protein denaturation that occurs reducing the water holding capacity of the muscle cells, which increases the sensation of dryness when eaten. In addition, the denaturation of proteolytic enzymes reduce the aging potential of the meat and has a large impact on subsequent tenderness (Devine et al., 2002a; Hwang & Thompson, 2001). The ideal temperature range for muscles to enter rigor is between 35°C and 8°C when carcasses cool, however optimal ranges have been suggested from 18 to 10°C (Devine et al., 2002b) and at 21°C (Thompson et al., 2005c). Above 35°C, muscles can heat shorten resulting in pale, tough, and exudative meat, with inhibition of tenderisation, and below 8°C, cold shortening may occur (Devine et al., 2002a). Position of carcasses within the chiller, location of individual muscles on a carcase, and degree of leanness can all affect the rate of temperature change within specific muscles; this is of particular importance in commercial processing plants where chiller temperatures are often pre-set to enable ease of management and high through-put.

Aging period has an impact on all sensory traits, with an optimal aging period identified at 5 days when eating quality was compared at 2, 5 and 14 days aged (Thompson et al., 2005c). The greatest eating quality improvements were observed between days 2 and 5, and in the *longissimus lumborum* (loin) muscle, and notably the *biceps femoris* (outside) demonstrated some reduction in eating quality between days 5 and 14, indicating some undesirable flavour notes may appear with extended aging. Therefore despite the benefits of electrical stimulation, it is not a necessity if a carcass is aged for 10 days prior to consumption and the carcass enters rigour between 8-18°C (Devine et al., 2002b) as aging period develops similar tenderness outcomes with enough time (Shorthose et al., 1986). Careful monitoring of muscle pH and temperature of carcasses is required to manage rigor and maintain good eating quality.

2.2.2.2 Hanging method

Carcasses may be hung by the Achilles tendon or using the tenderstretch method to reduce the extent of shortening of various muscles as they enter rigor. While there is chemical energy still available in muscles in the form of ATP, crossbridge cycling of actin and myosin filaments can still occur, causing continued muscle contraction. The degree to which a muscle is contracted when it goes into rigor can have a significant impact on toughness (Marsh & Carse, 1974). Hanging sheep carcasses by gambrel inserted behind the Achilles tendon results in a curved spine and minimum tension on hindquarter muscles. Some toughening may occur in these hind quarter muscles during rigor using this hanging method, therefore electrical stimulation, management of temperature during rigor mortis, and aging of meat is required for acceptable meat for retail sale (Young et al., 2005).

Tenderstretch hanging involves carcass suspension by the pelvic or aitchbone so that the leg of the carcass hangs at a 90° angle. This prevents muscle shortening particularly in the hindquarter where muscles are held in a stretched position during the onset of rigor (Bouton et al., 1973a). The majority of leg muscles, and the LL have improved eating quality using the tenderstretch hanging method, the forequarter cuts remain unaffected. The only cut to see a negative impact of tenderstretching compared to the Achilles hung method is the tenderloin muscle (Bouton et al., 1973b). Benefits of the tenderstretch hung carcass include improvement in a large proportion of cuts without the need of electrical stimulation, more even distribution of muscles around the leg bone, a higher degree of uniformity in eating quality of cuts in older animals, and more rapid aging of meat in tenderstretch carcasses compared to Achilles hung equivalents (Thompson et al., 2005b; Young et al., 2005). Note, the tenderstretch method is rarely used in sheep abattoirs.

2.2.2.3 Cut by cooking method

Different muscles within the same carcase can have vastly different palatability outcomes based on intrinsic compositional factors distinct to that muscle type, and the subsequent cooking effects. Variation in tenderness of aged meat was explained through sarcomere length, proteolysis of myofibrillar proteins, and intramuscular connective tissue content, with principle drivers dependant on the muscle type (Koohmaraie et al., 2002). In the loin, proteolysis was the major contributor, sarcomere length in the *psoas major* (tenderloin), and connective tissue content the primary driver for muscles akin to *semimembranosus* (topside) and outside (Koohmaraie et al., 2002). In cooked meat, it is well established that connective tissue has a strong influence on tenderness, and the distribution, composition and volume can change depending on the muscle location and with increasing animal age (Koohmaraie et al., 2002; Purslow, 2005). The major component of intramuscular connective tissue is collagen and collagen fibres undergo shrinkage when heated within a temperature range of 20 to 50°C increasing the toughness of meat, however above this range collagen can break down and be converted to gelatin (Tornberg, 2005), thus challenges to tenderness can be overcome by using appropriate cooking methods for each muscle. Cooking various cuts using recommended cooking methods, can optimise the eating experience, for example in untrained Australian consumers scoring grilled lamb, sensory scores were greatest for the loin and then in descending order, the *serratus ventralis* (chuck) › *gluteus medius* (rump) › outside › and topside (Thompson et al., 2005a). Further to this, the same muscles all scored slightly higher when grilled compared to roasted (Thompson et al., 2005a). In agreement, Pannier et al. (2014b) and Pethick et al. (2006b) demonstrated variation in sensory scores in a range of different commercial cuts cooked using grill and roasting methods, hence it is important to address the right cut by cooking method when describing eating quality of various cuts.

2.3 Objective measurement of eating quality

There are several objective measurements that can be used to reflect eating quality in lieu of trained or untrained taste panels. Shear force, IMF percentage and lean meat yield (LMY) have a known association with eating quality (Connaughton et al., 2020; Pannier et al., 2014b; Perry et al., 2001a), thus provide an alternative measure of quality rather than consumer testing. The latter two have recently evolved as more practical industry tools with the development of technology to sample these traits at processing line speed (Connaughton et al., 2020; Gardner et al., 2021). Note, the Sheep Cooperative Research Centre established an Information Nucleus Flock (INF) in 2007 (then extended to Meat and Livestock Australia genetic resource flock), and with approximately 2000 slaughter lambs per year, it allowed the measurement of a broad range of phenotypic traits and development of many new Australian Sheep Breeding Values (ASBV's) to manage quality (Fogarty et al., 2007; Perry et al., 2001a; Sheep Genetics, 2018).

2.3.1 Shear force

Shear force is traditionally an objective measure of tenderness, but has also demonstrated an association with overall liking, liking of flavour and juiciness, attributed to high correlations between the sensory traits when scored by untrained consumers (Hopkins et al., 2006; Pannier et al., 2014b). Warner-Bratzler Shear Force (WBSF) is a measure of peak shear force in Newtons (N), and testing protocols require 65g of loin muscle aged 5 days and frozen prior to testing. Samples are cooked from frozen, cooled, and divided into six 1cm^2 test strips and sheared using a Lloyd texture analyser fitted with a vee-shaped cutting blade, perpendicular to the muscle fibre direction (Hopkins et al., 2010; Perry et al., 2001a). Extensive shear force data collection allowed development of an ASBV for shear force so producers could select for positive tenderness outcomes (Sheep Genetics, 2018). Several studies have shown as sheepmeat shear force values increase, untrained consumer scores for tenderness, juiciness, liking of flavour and overall liking decrease (Hopkins et al., 2006; Pannier et al., 2014b). Across an increasing shear force range of 12 to 49 N in the loin, eating quality scores decreased from 7.4 to 11.6 units, while in the topside across a range of 22 to 65 N sensory scores decreased by 9.8 to 17.4 units across the sensory attributes (Pannier et al., 2014b). In addition, to avoid product failure rates of greater than 10%, it was proposed muscles should have shear force values of 27 N or less (Hopkins et al., 2006). And while a clear relationship is evident, eating quality is a complex trait, therefore shear force should be used in conjunction with other objective measurements for effective outcomes.

2.3.2 Intramuscular fat

IMF percentage is a strong positive driver of eating quality in both sheep and beef meat (Frank et al., 2016b; Hocquette et al., 2010a; Pannier et al., 2014b; Thompson, 2004). There are several mechanisms through which IMF is thought to impact on palatability. Species specific flavours can be found in flavour compounds and volatiles found in lipids, which can strengthen with greater volumes of fat present (Frank et al., 2016a; Realini et al., 2021b). Whereas the perception of greater juiciness has been attributed to the lubricative effect of greater IMF% levels prompting additional salivation (Frank et al., 2016b; Savell & Cross, 1988). The influence on tenderness is considered less direct and to be a result of increasing IMF% deposits diluting myofibres and disorganising connective tissue, more relevant at higher IMF levels (Nishimura, 2010; Thompson, 2004). In lamb, IMF is shown to be a strong driver of tenderness, juiciness, flavour and overall liking (Hopkins et al., 2006; Pannier et al., 2014b), and across an IMF range of 2.5% to 7%, eating quality scores have been shown to increase by up to 10.7 units in Australian consumers. Data from 5867 lambs of the INF flock indicated average IMF levels to be at 4.23% (Pannier et al., 2014b), and it is proposed a minimum level of 4 to 5% is required to maintain consumer acceptability for Australian consumers (Pethick et al., 2006a). For New Zealand consumers acceptability thresholds have been proposed at a minimum 3% IMF, demonstrating acceptability can vary depending on the population tested (Realini et al., 2021a). In addition, two clear types of consumers were identified, those who prefer high levels of IMF in their lamb with a linear response to increasing IMF%, and those who enjoy at optimal amount of IMF, where no benefit in eating quality is achieved with greater levels of IMF (Realini et al., 2021a). Given the well-established positive impact of IMF on palatability, an ASBV IMF trait was developed and is now in use commercially to manage IMF in Australian flocks (Sheep Genetics, 2018). The IMF trait is recommended for use alongside selection for LMY, as final eating quality has been determined as a combination of both traits (Swan et al., 2015), with higher yielding carcasses demonstrating lower overall adiposity and subsequent reductions in IMF (Anderson et al., 2015a; Pannier et al., 2014b; Pannier et al., 2014c).

2.3.3 Lean meat yield

Australian lambs have become more muscular, leaner and generally larger (Gardner et al., 2010), through the introduction of more Terminal sires to the national flock as the Australian sheep industry focused heavily on selection for LMY. This was a reasonable objective given price grids were based on hot carcase weight (HCW) and GR fat depth to determine saleable meat. However, consumer testing showed gains in yield were to the detriment of palatability, as animals with higher muscling and lower carcase fat levels consistently demonstrated decreased eating quality scores (Pannier et al., 2014b). Associations between eating quality and phenotypic traits were measured through loin muscle and loin fat cap weights adjusted for HCW, given a strong relationship to muscularity ($R^2 = 0.71$), and carcase adiposity ($R^2 = 0.65$) as revealed through computed tomography (CT) (Pannier et al., 2018a). Aligning with these phenotypic observations, a negative relationship between eating quality and yield ASBV's of increased eye muscle depth (PEMD) and decreased fat depth (PFAT) has also been shown (Hopkins et al., 2005; Pannier et al., 2014b). Terminal sire breeds are heavily selected for yield traits (muscularity), compared to Merino and Maternal sire types where the emphasis is on wool and reproductive capabilities. In the study of Pannier et al. (2014b), Merinos had consistently higher eating quality compared to Maternal and Terminal sire types for the loin and topside muscles. With the installation of new technology to measure LMY% at chain speed, i.e. dual-energy X-ray absorptiometry (DEXA) (Connaughton et al., 2020), physical measures of yield will no longer be required. And alongside IMF, an ASBV for LMY has been developed for producers to manage genetics for yield gains whilst still maintaining positive eating quality outcomes.

2.4 Meat Standards Australia system

2.4.1 Development of the sheep Meat Standards Australia system

As highlighted, eating quality is affected by a range of factors across the supply chain and lamb quality in the retail sector used to reflect this. Inconsistency in red meat quality at retail was well reported in the nineties (Safari et al., 2002; Yann et al., 1994), versatility of lamb was considered low, and over a third of consumers lacked product confidence due to variation in quality (Hanrahan et al., 1998; Yann et al., 1994). When the eating quality of mid-loins in retail shops and supermarkets was assessed Australia-wide in 1997, 20% of loins were classified as unacceptably tough, with objective measures of shear force exceeding acceptable thresholds. Further to this, 10% of loins had a pH above the critical value of 5.8 (Safari et al., 2002).

In response to these findings, in 2005 the red meat industry developed the Meat Standards Australia (MSA) sheepmeat pathways system, using consumer based testing to identify the critical control points that play an integral role in eating quality and define best practice procedures to improve quality (Thompson et al., 2005a; Thompson et al., 2005c). This approach was based on the successful implementation of the beef MSA system, which had proven to be a robust means of predicting the eating quality of individual beef cuts prepared according to recommended cooking methods (Polkinghorne, 2006; Watson et al., 2008b). The beef MSA system had the advantage of a pre-existing chiller assessment framework that assessed each carcase individually and allowed for some measures of quality to be integrated into the new MSA model alongside newly identified critical control points. Whilst in sheep, mob-based management practices and processing implications of smaller sheep carcasses (compared to beef) meant far less inputs could be accommodated in the sheepmeat pathways system. In order to buy and sell MSA sheep and lambs, industry participants must follow the MSA recommendations to address critical control points to meet minimum requirements. These requirements cover the entire supply chain from paddock to plate and are listed below.

Pre-slaughter factors:

- Genetics
- Animal age
- Growth path (feed type and finishing)
- Selling method
- Pre-slaughter stress (welfare, handling, time off shears, lairage conditions)

Post-slaughter:

- Ultimate pH (pHu) management (temperature control and electrical stimulation)
- Hang method
- Aging period of meat
- Muscle/ primal
- Value adding
- Cooking method

Using grilled muscle samples was proven to be the best method of detecting treatment effects on eating quality initially (also logistically practical) and has provided a strong basis for identifying where management of critical control points is required for consistent quality (Thompson et al., 2005a). Further cooking methods were utilised over time to broaden the scope of the prediction model (Watson et al., 2008a)

In 2020-2021, over 3.4 million sheep followed the MSA pathways scheme (Figure 2.1) equating to 14% of the total national lamb slaughter. Further to this, 99% of the lambs that presented for MSA met the program's minimum requirements. Price differentials for MSA lamb compared to equivalent non-MSA products was $0.88/kg at retail and $2.13/g at wholesale in 2020-2021 (MLA, 2021a), demonstrating products underpinned by MSA provide assurance of quality to wholesale, retail and food service sectors which in turn has positive effects on trade. At the consumer level, MSA labels inform of correct cooking methods for specific cuts and assure a consistent eating experience with every purchase.

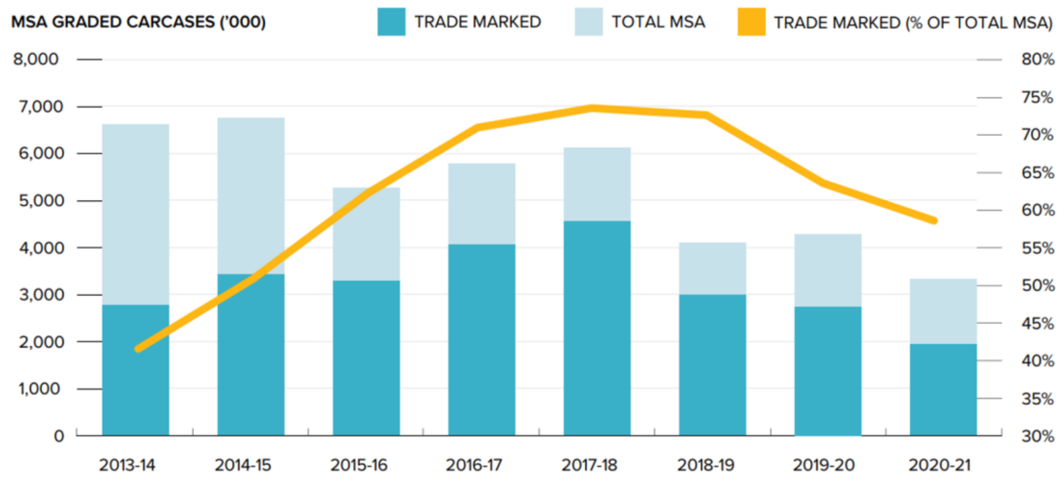

Figure 2.1
Total numbers of Australian lamb meeting MSA minimum requirements in 2020-2021, and the proportion of those lambs channeled into MSA trademarked brands (source: MSA Annual Outcome Report 2020-2021).

2.4.2 Consumer based evaluation principles

The sheepmeat eating quality standards are based on over 90,000 untrained consumer taste tests to date, with MSA testing protocols describing eating quality using the traits of tenderness, juiciness, liking of flavour and overall liking. Untrained consumers are asked to score samples on a scale line of 0 to 100, with tenderness and juiciness scale lines anchored with ‘not’ and ‘very’ preceding the trait, and ‘dislike extremely’ and ‘like extremely’ preceding liking of flavour and overall liking. In addition to palatability attributes, consumers are also asked to rate each sample on quality, either unsatisfactory (2 star or fail), good everyday (3 star), better than everyday (4 star), or premium (5 star) quality (Pleasants et al., 2005; Thompson et al., 2005a). A single composite MQ4 score is constructed based on the weighted values of the four sensory traits derived using discriminate analyses. Boundaries between the discriminate functions provide quality thresholds for good everyday, better than everyday and premium level product segregation (Watson et al., 2008a). Through extensive consumer testing, MSA has built a cut by cooking grid of recommended cooking techniques by retail product and animal age class demonstrated in Figure 2.2. (MLA, 2012). This information assists with product labelling at retail, as consumer education is the key to a positive eating experience when cooking in the home.

CUT	HAM*	GRILL	ROAST	STIR FRY	C/ ROLE
Leg Chump / On	4800		●●		
Leg 'Easy Carve'	4821		●●		
Leg Chump / Off	4820		●●		
Chump	4790		●●		
Chop		●●●			
Hindshank	5031				●●
Leg Chump / On (Boneless)	5080		●●		
Rolled / Tied			●●		
Topside	5073			●●	
Silverside	5071			●●●	
Thick Flank (Round)	5076	●●	●●	●●	
Chump (Rump)	5130	●●	●●	●●	●●
Topside Den	5077			●●	
Outside (Den)	5075			●●●	
Knuckle (Round)	5072	●●	●●	●●●	
Rump (Den)	5074	●●●	●●●	●●	●●
Loin	4880		●●●		
Shortloin	4880		●●●		
Rolled			●●●		
Noisettes		●●●	●●●		
Chop		●●●			
Eye of Shortloin	5150	●●●		●●●	
Rack	4932		●●●		
Rack Cap / On (Frenched)	4756		●●●		
Cutlet		●●●			

CUT	HAM*	GRILL	ROAST	STIR FRY	C/ ROLE
Rack Cap / Off (Frenched)	4764		●●●		
Cutlet		●●●			
Backstrap	5109	●●●		●●●	
Eye of Rack	5153	●●●		●●●	
Forequarter	4972		●●		
Square Cut Shoulder	4990		●●		
Chop		●●			
Shoulder Rack (Frenched)	4739		●●		
Cutlet		●●			
Foreshank	5030				●
Oyster Cut Shoulder	4980		●●		
Shoulder (Easy Carve)	4994		●●		
Forequarter (Boneless)	5047		●●		
Shoulder Rolled / Netted	5050		●●		
Neck Fillet Roast	5059		●●		
Eye of Shoulder	5151		●●		
Tenderloin	5080	●●●			
Butt Tenderloin	5081	●●●			
Tenderloin / Butt Off	5082	●●●			
Breast & Flap	5010	No recommended cooking methods			
Neck	5020				
Spare Ribs	5015				

*HAM: Handbook of Australian Meat, 7th edition.

LAMB (L) ●
HOGGET (H) ●
MUTTON (M) ●

Figure 2.2
Demonstration of the eligible sheepmeat cuts, and recommended cooking methods for lamb, hogget (yearling) and mutton once MSA program requirements are met (source: MSA Sheepmeat Guide).

2.4.3 Untrained consumer assessment of eating quality

Untrained consumers are used in sheepmeat and beef MSA testing instead of trained panellists as they provide estimates of the true population mean, are generally considered unbiased, and allow assessment of products by the target market (Polkinghorne, 2006; Thompson et al., 2005a; Watson et al., 2008a). Using untrained consumers to underpin the MSA system provides industry with confidence that predictions accurately reflect current customer perceptions of quality. The variability introduced by using untrained consumers is overcome by testing large numbers of participants to generate models, in addition to each sample being scored by multiple consumers. Thompson et al. (2005d) demonstrated ten consumer responses per cut was enough to reliably differentiate between muscle types.

The alternative to untrained consumers is using trained panellists, experienced in scoring specific eating quality attributes independent of each other, this results in less variation but some bias in results (Watson et al., 2008a). In contrast, untrained consumer scores are highly correlated with one another resulting in the 'halo' effect (carry-over effect) (Kunert, 1998; Thompson et al., 2005d), however trained panellists are unlikely to reflect consumer preferences hence are a less reliable option to underpin predictions of consumer satisfaction (Perry et al., 2001b). In addition, utilising untrained consumers in taste panels allows for continuous updates to the MSA prediction models as consumer preferences change over time (Polkinghorne et al., 2008; Watson et al., 2008a).

2.4.4 Demographic and meat consumption preferences

Collection of demographic data and meat consumption preferences is part of the MSA testing protocols (Thompson et al., 2005d; Watson et al., 2008b). When assessing the impact of Australian consumer demographics and meat preferences on sensory scores, effects were all relatively low in magnitude and not consistently observed across the eating quality traits, hence perfect balancing for these factors was not deemed essential (Thompson et al., 2005d). Age, and gender had a small effect on juiciness scores, and consumers who identified meat as an important part of their diet gave overall higher scores for all sensory traits. Greater sensory scores were also observed by consumers who preferred their meat done to a higher degree of doneness (Thompson et al., 2005d). Nevertheless, collection of demographic information is still included in tasting session protocols, and is considered important when assessing international consumers, with varied cultures, religions, and meat consumption practices compared to the majority of Australians.

2.4.5 Recent developments in sheep the Meat Standards Australia system

A new MSA sheepmeat cut by cooking method model has recently been announced based on ten years of consumer testing and analyses of the factors exerting the greatest influence on eating quality for sheepmeat (MLA, 2022; Pannier et al., 2018a; Thompson et al., 2005a). Along with the standard requirements that consigned animals need to meet under the existing pathways scheme, the model requires inputs of IMF, LMY and HCW to predict several cut by cooking method outcomes. With the recent accreditation of accurate measurement technologies (Gardner et al., 2021), IMF and LMY% can now be captured at line speed and allow for real-time input into prediction models and rapid product segregation. The MSA model now provides eating quality predictions for grilled cuts (knuckle, loin, outside, rump, and topside) and roast cuts (knuckle, leg, rack and shoulder) with plans to expand cooking methods to include stir-fry, slow cook and low-n-slow barbeque. In addition, commercialisation activities are currently underway to benchmark Australian flocks, identify branding and product segregation opportunities, determine MSA integration requirements for processors, and feedback systems for the producers (MLA, 2022).

2.5 Sheepmeat industry and consumer preferences

2.5.1 Australia

Sheepmeat consumption rates in Australia are around 6.5 kg per person annually, and despite steady declines in red meat consumption in the last decade, still remain amongst the highest in the world (MLA, 2021d). The national flock stands at 63.5 million head, with around 19.8 million lambs and 6 million sheep slaughtered annually. Australia accounts for 6% of global lamb and sheepmeat production, and is the worlds' largest sheepmeat exporter, with the value of Australian sheepmeat exports at A$3.7 billion in 2020 (MLA, 2021d). Quality assurance is key to consumer satisfaction, thus the MSA sheepmeat systems (pathways approach and new cut by cooking method model) are available for industry to manage consumer expectations (MLA, 2021a). However, these models have been developed using Australian sheepmeat consumers (Thompson et al., 2005c), thus whether they adequately reflect the international consumer eating experience is unknown. Given the value of exported sheepmeat products to Australian industry, it is essential to understand whether adjustments to models should be made to typify consumers with diverse sheepmeat perceptions and exposure experiences.

2.5.2 United States of America

2.5.2.1 Industry structure

America has seen a steady decline in sheepmeat and wool production in the last century, with the national flock at its peak of 51 million to around 5 million head (USDA, 2020). Compared to 33.9 million head of beef processed, only 2.26 million head of sheep are slaughtered annually (USDA, 2022). Imports have offset these domestic declines in production, and the development of Australia's second most valuable export market for frozen and chilled premium lamb products has ensued. Australia currently occupies around 80% of the imported lamb market share, with the other major supplier New Zealand (MLA, 2021c). Imports from Australia have increased 127% in the last decade and now equate to over 80,500 tonnes of sheepmeat per year at a value of A$913 million. Thirty percent of lamb carcasses are exported whole, and the other major products include short-loins, racks, shoulders, and legs (MLA, 2021c). Compared to Australian production systems where animals are finished on grass and grain, American lamb available at retail is primarily finished on grain (Phelps et al., 2018b).

2.5.2.2 Carcase grading system in America

The official United States Department of Agriculture (USDA) grading system for lamb and mutton has been in existence for over 80 years (USDA, 1992). In contrast to the MSA consumer based system of grading, each entire carcase is assigned a grade based on quality and yield measures as a means of grouping carcasses of the same visual quality for trade purposes. Carcasses are graded by licenced USDA graders who receive extensive training, thus a high degree of consistency is maintained across industry (Strong, 2004). Quality is graded into one of five categories: Prime, Choice, Good, Utility, and Cull and these quality grades serve to predict the eating quality of the carcass. There are three carcass classes; lamb, yearling mutton, and mutton with the first two having a maximum quality grade range of Prime down to Utility, while mutton carcasses may only obtain a maximum quality grade of Choice down to Cull (Figure 2.3). Quality grades are obtained using a combination of maturity, lean quality and carcass conformation measures (USDA, 1992). Maturity is determined using the lean texture and colour, degree of rib flattening, and break joints on shanks. Lean quality is graded using a combination of texture, marbling, and firmness, measured indirectly through fat streaking on the inside flank muscles. Figure 2.3 shows the relationship between maturity, fat flank streaking and USDA quality categories. Conformation is evaluated on the whole carcass however particular focus is given to higher value cuts, with superior conformation carcasses having a greater lean to bone ratio (USDA, 1992).

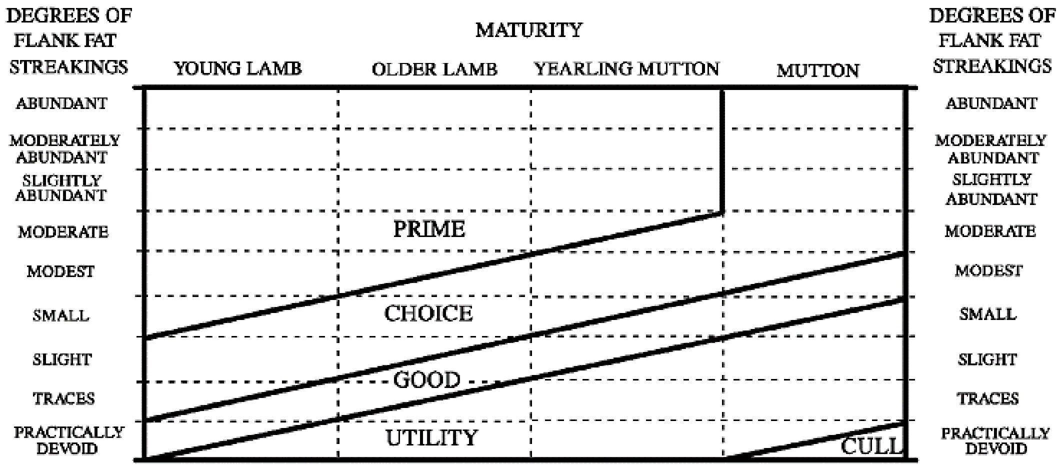

Figure 2.3
Relationship between sheep maturity, fat flank streaking and USDA grading category (source: USDA, 1992).

Yield reflects the total proportion of retail cuts that can be obtained from a carcass, using the grades of one to five, with one being the most desirable. Yield scores represent the percentage cutability, which is a measure of the percentage of total retail cut weight in comparison to hot carcass weight. Yield scoring is adjusted for fat thickness, measured between the 12th and 13th rib over both rib eyes at the midpoint (USDA, 1992).

The USDA grading system is vastly different to the MSA system in that every cut within the same carcass will have the same grading, even though cuts within the same animal can exhibit vastly different eating qualities (Pannier et al., 2014a; Thompson et al., 2005a). This system relies heavily on the consumer having a good understanding on how the same grade may be represented across different cuts within the same animal. Therefore, it is important to determine how American consumers respond to Australian lamb and yearling products when tested using MSA protocols. If the system proves accurate for American consumers, Australian exporters will be able to provide a guaranteed eating experience with every purchase, which improves marketability of Australian sheep products and rewards producers. If not, industry will benefit from identifying adjustments that need to be made for application of MSA products in this market.

2.5.2.3 Meat consumption patterns and consumer preferences

In America per capita consumption rates for lamb and mutton are very low in comparison to other proteins (Byrne et al., 1993; MLA, 2021c). On average the individual American will consume less than 0.4 kg of lamb per year (Phelps et al., 2018b), with over one third of Americans indicating they have never tried lamb. Interestingly a major reason for not eating lamb is uncertainty of cooking techniques, unfamiliarity, and concerns over taste, therefore for first-time lamb eaters their initial eating experience is usually outside the home (MLA, 2021c).

Regions of higher lamb consumption in comparison to entire country estimates include the north-eastern states and California, Texas, Idaho, and the south-east, in particular Florida (MLA, 2021c). In addition there have been several lamb consumer groups identified: wealthier consumers whom are generally located in the north-east and west coast of the US, ethnic sectors of the community including both Hispanic and Muslim consumer groups, and adventurous consumers who enjoy trying "new" ethnic flavours and have a focus on sustainably produced products (MLA, 2021c). Wealthier consumers tend to use more traditional British cooking methods of roasting legs and shoulders, and grilling chops. While the growing Hispanic community use a barbacoa cooking style, complimentary to sheepmeat. Muslim consumers maintain strong cultural connections with sheepmeat for traditional cooking techniques and often utilise products for slow cooking with a variety of spices. Adventurous consumers are just that, keen for new flavours and cuisine, and have been associated with ethically sustainable options, with the millennial generation considered part of this group (MLA, 2021c). As regional and ethnic differences have been identified for sheepmeat consumption, it is important that the impact of socio-economic factors on eating quality of Australian sheepmeat products is thoroughly investigated.

2.5.3 China

2.5.3.1 Industry structure

China is Australia's largest sheepmeat export market in terms of volume and value, with export figures at 147,700 tonnes in 2021, and value of $1.5 billion annually to industry (MLA, 2021b). While Australia and New Zealand dominate the Chinese import supply, around 92% of the domestic sheepmeat consumed is produced in China with a national flock of around 316 million head. Inner Mongolia with its vast grasslands is a primary production region for sheepmeat in China alongside more densely farmed provinces of Xinjang, and Shandong (Mao et al., 2016), with the industry structured around large numbers of small opportunistic producers (MLA, 2021b). Currently there are no official quality management systems in place for sheepmeat production and processing in China.

2.5.3.2 Meat consumption patterns and consumer priorities

In China slow but steady growth in sheepmeat consumption rates have been observed over the last decade with per capita sheepmeat consumption estimated at 3.9 kg for 2021 (MLA, 2021b). Popular imported cuts include the breast and flaps, neck, whole carcase, and manufacturing products which are further processed. A large proportion of imported product is processed into thin-slice rolls used for hot pot cooking (MLA, 2021b). In the foodservice sector, hotpot has been identified as a significant driver of greater consumption rates observed for sheepmeat alongside stewing and roasting (Mao et al., 2016; Zhang et al., 2014). Traditionally, the north-west of China was a region of higher consumption, given the large Muslim population in this area with strong preferences for sheepmeat (Mao et al., 2016). However, popularity of sheepmeat has grown in coastal cities where more affluent consumers seek variety in their protein sources (MLA, 2021b). The growing middle class of the Chinese population are the primary driver for red meat demand, and with increasing affluence comes a corresponding increase in consumption of animals products (Gould & Villarreal, 2006; Nam et al., 2010). Several trends that impact on the purchasing decisions of the Chinese middle class have been identified. The first being a demand for premium products and a better eating experience (MLA, 2021b). The second a priority of food safety, consumers have little confidence in local products due to frequent health scares and contamination of food products (Zhou et al., 2012); hence there is a strong demand for imported food that is considered safe (Liu et al., 2009), and a move from away from traditional farmers markets and local retail meats where bacterial contamination is common (Gong et al., 2011; Zhou et al., 2012). Lastly, an increasing interest in health and well-being in respect to the nutritional benefits of lamb meat rather than the more commonly consumed pork meat (Kantono et al., 2021; MLA, 2021b). As such, affluent urban consumers consider it worth paying more for Australian lamb compared to domestic product for these aforementioned reasons (MLA, 2021b).

2.5.3.3 Future demand

With China having one of the world's fastest growing economies, and population growth, a corresponding increase in the demand for sheepmeat products is anticipated (Kantono et al., 2021; Liu et al., 2009). Improved market access for Australian sheepmeat exporters is also expected with the removal of all import tariffs on sheep and goatmeat by 2023 under the China-Australia Free Trade Agreement (currently range from 1.3 to 5.1%) (MLA, 2021b). Therefore, understanding the quality perceptions of this consumer group is imperative to ensure Australian industry can continue to meet product demand as well as quality expectations for lamb and sheepmeat products.

2.6 International consumer comparisons

2.6.1 Cross-cultural comparison

Comparison of international consumer groups through the scope of MSA tasting protocols are extensive in beef, with countries including France (Hocquette et al., 2010b; Liu et al., 2020), Irish Republic (Allen, 2015), Japan (Polkinghorne et al., 2011), New Zealand (Crownover et al., 2017), Northern Ireland (Bonny et al., 2016; McCarthy et al., 2017), Poland (Pogorzelski et al., 2020), Korea (Thompson et al., 2008), South Africa (Thompson et al., 2010), and the USA (Smith et al., 2008), testing a variety of domestic and Australian beef products using a range of cooking methods (Bonny et al., 2018). This is perhaps unsurprising given the MSA program is well established in Australia and there is global interest in adoption of a similar system (Pethick et al., 2018). In contrast there is a paucity of international sheepmeat consumer testing utilising MSA methods, and more specifically no direct comparisons of American, Chinese and Australian sensory responses to Australian lamb and sheepmeat. While consumption rates are low (MLA, 2021c), American consumers have demonstrated they can readily identify cut differences (Phelps et al., 2018b), flavour variation with animal age (Jaborek et al., 2017), respond positively to increasing IMF levels (Phelps et al., 2018a), and notably prefer American lamb to Australian and New Zealand product (Phelps et al., 2018b). In a study by Phelps et al. (2018b) grilled loin chops were scored higher than legs for all sensory attributes, similarly Maddock et al. (2004) showed consumers preferred loin and rib chops compared to blade or leg cuts when in-home testing a range of cuts. Animal age also appeared to influence American consumer perceptions particularly of flavour, with higher flavour intensity scores reported in yearling grilled loin samples compared to lamb (Jaborek et al., 2017). Lamb flavour was the most common response to the definition of eating satisfaction in open ended surveys of American consumers (Hoffman et al., 2016), more positive descriptors of flavour were attributed to domestic lamb product above imported products, with milder more approachable flavour for locally sourced compared to gamey, different, and stronger flavour for imported products (Hoffman, 2015). Further to this, Phelps et al. (2018b) reported greater tenderness, juiciness, liking of flavour and overall liking scores for domestically sourced lamb loin and leg, compared to Australian and New Zealand products. However it is important to note, no background animal, rearing, or processing information was provided on imported samples, therefore negative sensory scores could be explained through factors other than country of origin. In contrast to American consumers, Chinese perceptions of Australian sheepmeat are generally positive as measured through surveys and market analysis (Kantono et al., 2021; MLA, 2021b). There are limited studies on sensory preferences conducted within China. Xu et al. (2017) demonstrated a Chinese preference for loin samples versus topside using roast and hotpot cooking methods, however only 12 panelists were recruited and a total of 5 carcasses tested. Comparisons of Australian based Chinese immigrants versus Australians of non-Chinese background found no differences in sensory responses to Australian lamb loins, and a consistent positive response to higher IMF levels for both groups (Frank et al., 2016c). However, it is difficult to assume these results would be consistent with Chinese nationals who would be less accustomed to a Western style cooking method such as grill.

2.6.2 Influence of demographics

Demographic and meat consumption preferences of consumers are collected as part of MSA testing protocols in sheep and beef testing. Across the literature, the influence of these factors on sensory responses have been inconsistent, often low in magnitude and variable across the different countries tested (Bonny et al., 2017; Huffman et al., 1996; Hwang et al., 2008; Thompson et al., 2005d). While inconsistent, the main demographic factors to influence eating quality include consumer age, gender, occupation, income level, and household size. Older Australian consumers demonstrate higher sensory scores than younger consumers (Hastie et al., 2020; Thompson et al., 2005d), but no clear trend exists for American consumers (Huffman et al., 1996). In contrast, increasing consumer age influenced eating quality scores negatively for tenderness in France and Poland, and juiciness in Ireland, Northern Ireland and Poland (Bonny et al., 2017). As with consumer age, a variable gender effect on eating quality has been observed with males scoring lamb and beef higher in Ireland, Northern Ireland, and Poland (Bonny et al., 2017; Kubberød et al., 2002), while Australian females score grilled lamb higher than males (Thompson et al., 2005d), and no gender effect for American, Australian and Korean consumers scoring grilled and Korean barbeque beef was observed (Huffman et al., 1996; Hwang et al., 2008). Income and a greater number of adults in the household also demonstrated a small influence in some studies. Red meat consumption habits and preferences have a variable effect amongst international consumer groups. A higher appreciation of red meat in the diet has been shown to positively impact on lamb and beef sensory scores for Australian, French, Northern Irish and Polish consumers, however not for Irish or Korean consumers (Bonny et al., 2017; Hwang et al., 2008; Thompson et al., 2005d). Similarly, a higher degree of cooking doneness positively influenced sensory scores compared to consumers who prefer medium doneness for Australian, Northern Irish and Irish consumers, with no effect for French or Korean consumers, and Polish consumers demonstrating the opposite effect (Thompson et al., 2005d, Bonny et al., 2017, Hwang et al., 2008). Previous studies largely imply demographic factors pose a relatively unimportant source of bias on sensory scores for sensory evaluations of beef and sheepmeat using untrained consumers, (Bonny et al., 2017; Huffman et al., 1996; Hwang et al., 2008; Kubberød et al., 2002; Thompson et al., 2005d). However American and Chinese consumer responses to Australian grilled sheepmeat have not been measured, therefore this data should be examined in case small modifications to prediction models are required to better meet expectations of quality.

2.6.3 Accuracy of MSA model to predict the consumer eating experience

The application of an MSA beef grading system has been tested in several countries, utilising a range of cooking methods, and has met with a reasonable degree of success (Bonny et al., 2016; Legrand et al., 2013; Pogorzelski et al., 2020; Polkinghorne et al., 2011; Thompson et al., 2008). In France, using beef grill protocols on six muscles from French and Australian cattle, the MSA system was able to predict the French consumers' final quality scores of unsatisfactory, good everyday, better than everyday, and premium quality with 70% accuracy. Results suggested a MSA beef grading system could be managed in France, with a degree of similarity between French and Australian consumers observed (Legrand et al., 2013). Likewise in Japan, when several beef cuts and cooking methods (grill, yakiniku, shabu shabu) were graded using MSA methods, the system was able to predict with 64% accuracy the quality grading for Japanese consumers (Polkinghorne et al., 2011). Similarly, accuracies ranging from 55% to 72% have been reported for consumers within Australia, Ireland, Poland, and South Africa using MSA methodologies (Allen, 2015; Pogorzelski et al., 2020; Thompson et al., 2010; Watson et al., 2008a). The MSA sheepmeat grading system can reliably predict the eating experience for the Australian consumer (MLA, 2022), however its application in two of Australia's strongest sheepmeat export markets, America and China has not been examined. The precedence set in beef studies suggest the grading system is likely to prove successful at capturing the eating experience of these international consumer groups.

2.7 Aims and Hypotheses

The research work undertaken in this study has an overarching aim of exploring the eating experience of lamb and sheep meat products using Australian, American and Chinese consumers in a controlled study. Consumers from these three countries typically have different exposure to lamb and sheepmeat and also a diversity of cooking methods. The work will advise on whether industry is able to use the current MSA sheepmeat system to guarantee a consistent eating experience or whether adjustments need to be made for consumers in other countries.

The primary aims of the first experiment are to evaluate the eating quality scores of Australian, American and Chinese consumers to Australian grilled lamb and yearling *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles; to examine whether the influence of animal factors, consumer demographics, and meat consumption preferences vary between the three groups; and to investigate whether consumer sensory perceptions of sheepmeat quality differ and the reliability of a sheepmeat prediction models in assigning eating quality grades for these consumer groups. The principle aim of the second experiment is to develop a MSA sheepmeat hotpot testing protocol and examine Chinese consumer sensory responses to Australian lamb and yearling shoulder and leg cuts. Similar to experiment one, the influence of animal factors will be considered, in addition to important industry parameters of yield and meat quality, muscularity and IMF.

The specific hypotheses of this study are detailed below in chapters 3 to 6.

Chapter 3: *Minor differences in perceived sheepmeat eating quality scores of Australian, Chinese and American consumers*

Objective: Compare Australian, Chinese, and American consumer sensory responses to LL and SM muscles derived from Australian lamb (no erupted permanent incisors) and yearling sheep (2–4 erupted permanent incisors)

Hypotheses tested:

- Untrained American and Chinese consumers would score lamb and yearling meat samples lower than untrained Australian consumers.
- Animal factors such as muscle type, age of animal, sire type, sex, and kill group would influence sensory scores for all consumer groups.

Chapter 4: *Influence of demographic factors on sheepmeat sensory scores of American, Australian and Chinese consumers*

Objective: To identify whether demographic factors and meat consumption preferences would influence the sensory scores of American, Chinese and Australian consumers testing Australian sheepmeat.

Hypotheses tested:

- Demographic factors would have a small and inconsistent effect on eating quality scores across countries.
- Higher appreciators of lamb and sheep meat and those that prefer their meat medium-well done will score samples more favourably.
- Chinese eating quality scores would be less responsive to changes in meat consumption preferences compared to American and Australian counterparts.

Chapter 5: *Defining sheepmeat eating quality thresholds for Chinese, American and Australian consumers*

Objective: Examine whether the sensory scores of untrained Chinese, American and Australian consumers would accurately predict eating quality grades of Australian lamb and yearling LL and SM muscles.

Hypotheses tested:

- The three countries would differ in their allocation of samples to quality grades.
- The importance of the four sensory traits on a single quality score would differ between the three consumer groups.
- Consumer assessed sensory scores obtained through MSA testing protocols would be able to accurately predict quality grades within the consumer groups tested.

Chapter 6: *Chinese consumer assessment of Australian sheepmeat using a traditional hotpot cooking method*

Objective: Develop an MSA sheepmeat hotpot testing protocol to examine the sensory responses of Chinese consumers to Australian lamb and yearling shoulder and leg cuts cooked using a traditional Chinese hotpot cooking technique.

Hypotheses tested:

- Shoulder cuts would score greater than leg cuts, particularly for sensory traits of liking flavour and juiciness.
- Merino and Maternal sired animals and lambs would have higher sensory scores compared to Terminal lambs.
- Increasing carcase adiposity would have a positive influence on sensory scores.
- Increasing carcase muscling would have a negative influence on sensory scores.

Chapter Three

3

Minor Differences in Perceived Sheepmeat Eating Quality Scores of Australian, Chinese and American Consumers

Manuscript details

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Minor differences in perceived sheepmeat eating quality scores of Australian, Chinese and American consumers

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Abstract

Understanding consumer sensory perceptions of sheepmeat is essential for consumer satisfaction post-purchase. Meat Standards Australia (MSA) sensory protocols have been effectively utilised in beef for international consumers however, to date sheepmeat testing is largely limited to Australian consumers. This study measured the sensory responses (liking of odour, tenderness, juiciness, liking of flavour, and overall liking) of 2,160 untrained American, Australian and Chinese consumers to grilled *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles from 164 lambs and 168 yearlings. Across countries there was no difference in juiciness or overall liking sensory scores. American consumers scored tenderness, flavour and odour slightly higher than Australian consumers, and Chinese consumer scores were lowest. Consistently for all countries, sensory scores were greatest in the LL muscle, in lambs compared to yearlings particularly for the LL, and Merino sired and female lambs. These results indicate that cultural background has minimal impact on sensory perceptions of sheepmeat, and provides valuable information for future eating quality prediction models.

3.1 Introduction

Eating quality satisfaction is an important driver for repeat consumer purchasing behaviour (Grunert, Bredahl, & Brunsø, 2004; Henchion, McCarthy, Resconi, & Troy, 2014), therefore it is imperative that a consistent eating experience can be guaranteed with every purchase. Eating quality can be described through the palatability traits of tenderness, juiciness, liking of flavour, and overall liking (Forrest, Aberle, Hedrick, Judge, & Merkel, 1975), and factors such as animal age, muscle type, gender and genotype have been shown to impact on eating quality as reviewed by Pannier, Gardner, O'Reilly and Pethick (2018). These sensory attributes have been used in the Meat Standards Australia (MSA) grading system which is a consumer based eating quality prediction model, which has been commercialised for beef meat (Polkinghorne, Thompson, Watson, Gee, & Porter, 2008), and is currently being developed for sheepmeat (Pannier, Gardner, O'Reilly, et al., 2018). MSA protocols have been trialed extensively with untrained Australian consumers to assess sensory perceptions of Australian sheepmeat products (Hopkins, Hegarty, Walker, & Pethick, 2006; Pannier et al., 2014; Pethick, Hopkins, D'Souza, Thompson, & Walker, 2005), however there is little research into American and Chinese sensory perceptions of Australian sheepmeat products. Both the United States of America (USA) and China are very important market destinations for Australian sheepmeat products, albeit with a very different product mix entering both countries. Measuring the sensory responses of these international consumers to Australian sheepmeat, using well established MSA protocols, would enable accurate prediction of eating quality to assure ongoing consumer satisfaction.

While direct cross-cultural sensory comparisons between Australia, China and the USA have not been conducted, several sensory studies utilising domestic sheepmeat products within each country have occurred. American consumers evaluating domestic sheep cuts, demonstrated a preference for rib and loin chops, scoring them higher for overall liking, tenderness, juiciness, and flavour desirability compared to the blade or leg cuts (Maddock, McKenna, & Savell, 2004). American consumers also identified flavour intensity to be higher in yearlings compared to lamb for grilled *longissimus thoracis et lumborum* samples, with no difference in off-flavour intensity between lambs and yearlings (Jaborek, Zerby, Moeller, & Fluharty, 2017). In open ended surveys, lamb flavour was the most common response to the definition of eating satisfaction for American consumers (Hoffman et al., 2016). Furthermore, perceptions of American lamb include descriptions of milder, good, and more approach-able flavour, compared to somewhat negative descriptions of imported lamb including gamey, different, less flavour-ful, and stronger flavour (Hoffman, 2015). Moreover, comparisons of imported Australian and domestic lamb product has demonstrated a preference for locally sourced lamb on tenderness, flavour liking and overall liking eating quality traits (Phelps et al., 2018), however a complete animal history was absent for imported products.

Investigations of sheepmeat sensory preferences within China are very limited. A study by Xu et al. (2017) compared the eating quality of m. *longissimus lumborum* (LL) and m. *semimembranosus* (SM) using roast and hotpot cooking methods. The authors found that the Chinese panelists demonstrated a preference for the LL compared to the SM for both cooking styles. However, carcass (n = 5) and panelist numbers (n = 12) were very low, emphasising a need for further investigation. Within Australia, a comparison of Chinese immigrants and non-Chinese Australian consumers found no differences in their assessment of sensory attributes of grilled lamb (Frank et al., 2016). However, it is difficult to assume these results mimic preferences of Chinese nationals residing within China, instead they are likely to be far less influenced by the Western cooking style and food habits. Also taking into account, the top three sheepmeat cooking styles within China are stewing, roasting or hotpot (Mao, Hopkins, Zhang, & Luo, 2016). Extending to Northeast Asia, cross-cultural comparisons demonstrated that Australian consumers assign slightly higher sensory scores than Japanese (Polkinghorne, Nishimura, Neath, & Watson, 2014), and Korean (Park et al., 2008) consumers for grilled beef samples.

A cross-cultural study was conducted utilising sheepmeat MSA protocols to compare Australian, Chinese, and American consumer sensory responses to Australian lamb (no erupted permanent incisors) and yearling (2–4 erupted permanent incisors) LL and SM muscles. We hypothesised that untrained American and Chinese consumers would score lamb and yearling meat samples lower than untrained Australian consumers. Additionally, we hypothesised that animal factors such as muscle type, age of animal, sire type, sex, and kill group would influence sensory scores for all consumer groups.

3.2 Materials and methods

3.2.1 Animal and slaughter details

Lambs and yearlings were sourced from the Meat and Livestock Australia genetic resource flock at Kirby, NSW. This is an extension of the Sheep Cooperative Research Centre Information Nucleus Flock and design of the flock has been detailed elsewhere (Fogarty, Banks, Van der Werf, Ball, & Gibson, 2007; Pannier et al., 2014; Van der Werf, Kinghorn, & Banks, 2010). In this study, lambs (females and wethers) were the progeny of Maternal (Border Leicester, and Dohne Merino), Merino (Merino, and Poll Merino), and Terminal (Poll Dorset, Suffolk, Texel, and White Suffolk) sires, whereas yearlings were the progeny of Merino (Merino, and Poll Merino) sires only, and comprised entirely of wethers.

A total of 128 different sires were represented in this study having up to 8 progeny spread across the three countries. The number of sires represented within each sire type across the three countries is presented in Table 3.1. A pair-wise design was employed whereby every animal was represented in 2 out of 3 countries at any one time through allocation of muscles collected. This design ensured a statistically valid cross-country consumer comparison could be made while maintaining a within country muscle comparison.

Animals were processed in two kill groups (September (one) and October (two) 2015) at a commercial abattoir licensed for international export to China and the USA. Kill group one contained 85 lambs and 111 yearlings, and kill group two had a total of 79 lambs, and 57 yearlings. Average age of lambs and yearlings in kill group one was 352 days, and 716 days, and kill group two 385 days, and 748 days, respectively. For kill group two, lambs had no erupted permeant incisors, and yearlings had two (n=6) and four (n=51) tooth animals (teething records were absent for kill group one). Animals were yarded, weighed, and transported to the processing facility the day prior to slaughter; held in lairage overnight with free access to water. Animals were electrically stunned prior to slaughter. Average hot carcass weight across both kill groups was 27.8 ± 4.8 kg for lambs, and 20.9 ± 2.7 kg for yearlings. All carcasses were managed in accordance with resource flock protocols: application of medium voltage electrical stimulation (Pearce et al., 2010), trimmed according to AUS-MEAT specifications (Anonymous, 2005), and chilled for 24 hours at 3-4°C prior to sampling.

Table 3.1
Number of sires represented within each country according to sire type.

Country	Sire type			Total
	Maternal	Merino	Terminal	
Australia	10	68	34	112
China	10	65	40	115
USA	10	66	39	115

3.2.2 Carcass information and muscle collection

At 24 hours post mortem, left and right LL muscles were collected from the saddle region of each carcass (AUS-MEAT 4880) (Anonymous, 2005). Each carcass was split at the 10th/11th thoracic rib (instead of standard $12^{th}/13^{th}$) to collect the full LL and the caudal end of *longissimus thoracis* to ensure adequate sample size for both the consumer sensory testing and objective meat quality measurements. The epimysium was removed from entire loins prior to vacuum packaging.

Left and right topsides were collected from each carcass, with the cap (*gracilis*) and removed leaving only the SM prior to entire vacuum packaging (AUS-MEAT 5077) (Anonymous, 2005). Both knuckle subprimals (AUS-MEAT 5072) (Anonymous, 2005) were also collected to serve as starter samples for each consumer. Vacuum packed LL, SM and knuckle subprimals were aged at 2-3°C for ten days prior to frozen export to China, the USA, and domestic transport within Australia. A total of 648 LL, 648 SM and 216 knuckles were collected from 332 animals (a few animals (n = 8) did not have all muscles available).

3.2.3 Sensory sample preparation and consumer testing

Sensory sessions were conducted in Australia, China, and the USA to include a total of 2,160 untrained consumers across 36 sensory sessions; 12 in each country. The sensory sessions were conducted in the outer Melbourne suburbs of Victoria (Australia), at China Agricultural University, Beijing (China) and across ten states in the USA. Consumers were recruited with the aim of representing a cross-section of society with a variety of demographic backgrounds, and ranged in age from 18 to 70. Australian consumers were recruited through a market research company, whereas Chinese and

American consumers were recruited through China Agricultural University and Texas Tech University, respectively. While recruited participants did not represent the full spectrum of lamb consumers within each country, for reporting purposes they are referred in general terms of American, Australian and Chinese consumers.

In each country, 24 hours prior to each sensory session, 42 muscle cuts (18 LL, 18 SM and 6 knuckles) were thawed at 2-5°C. *Adductor femoris muscles were removed* and SM muscles were sliced into 5 steaks of 15mm thickness, and allocated to the appropriate cooking order according to a 6 × 6 Latin square design allocation as described in Thompson et al. (2005). Employing this design provided balance for frequency, order and carryover effects.

The MSA sensory testing protocols used in this study have previously been detailed by Thompson et al. (2005) and Watson et al. (2008). Minor updates to sensory protocols were included in this study, with methods consistent for each country. In brief, steaks from each muscle were grilled on a Silex griller (S-Tronic Single Grill S161GR, Germany) with top and bottom grill plates set to 180°C and 195°C respectively, for a period of 2 minutes and 15 seconds to obtain an internal temperature of 65°C. Steaks were then rested for 1 minute 30 seconds before being halved and served to consumers, resulting in 10 experimental samples for each muscle. Each sample was graded by untrained consumers on a scale of 0-100 for liking of odour, tenderness, juiciness, liking of flavour, and overall liking. Each consumer commenced grading by observing odour before continuing with tasting session. Scale lines were anchored with 'not' and 'very' preceding the eating quality trait for tenderness and juiciness, and 'dislike extremely' and 'like extremely' for liking of flavour, overall liking and liking of odour. Consumers were seated in individual booths and served 7 samples monadically on paper plates, starting with a sample of medium quality (knuckle sample), followed by the 6 experimental samples (3 LL, and 3 SM). Within each consumer session, 60 untrained consumers graded 36 muscles (LL, SM), resulting in 360 consumer responses per session and 4,320 sensory responses per country. The sensory score sheets were identical within each country, apart from Chinese surveys being translated into Mandarin.

3.2.4 Statistical Analysis

Tenderness, juiciness, liking of flavour, overall liking and liking of odour scores were analysed using linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). The 10 consumer responses for each muscle were used in the analysis to account for consumer variation. The base model for each sensory trait included fixed effects for country (Australia, China, USA), muscle (LL, SM), sex within age class (female lamb, wether lamb, and wether yearling), sire type within age class (Maternal lamb, Merino lamb, Terminal lamb, and Merino yearling), and kill group. The Satterthwaite function was included in all models to approximate the degrees of freedom. Random terms included animal identification within sire identification, and consumer identification within consumer session and country. All non-significant terms ($P > 0.05$) were removed in a stepwise manner. Partial correlation coefficients were also calculated between sensory traits within each muscle for each country using multivariate analysis of variance in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). Significant class variables of base models were included in the analysis. The same process was applied to calculate partial correlation coefficients between LL and SM muscles, calculated within each country and for each sensory trait.

3.3 Results

Table 3.2 summarises the number of lambs and yearlings included in the base model analyses within each category. Of the 332 animals with eating quality data, 321 were included in the analysis as they had all production data available. Table 3.3 presents the outcomes of the base models for tenderness, juiciness, liking of flavour, overall liking and liking of odour. The variance accounted for by each base model was 37%, 36%, 38%, 41%, and 46% for tenderness, juiciness, liking of flavour, overall liking and odour. Predicted mean eating quality scores for the effects of country, muscle type and animal age class are presented in Table 3.4.

3.3.1 The effect of country on sensory scores

Across both muscles there were differences between countries in consumer sensory scores ($P < 0.05$; Table 3.3) for tenderness, liking of flavour and liking of odour, with these differences consistent within both lamb and yearling age classes. For tenderness, consumer scores differed for each country and were greatest among American consumers, which when averaged across the age class and muscle groups were higher by 2.5 units compared to Australian consumers, and 5.3 scores higher compared to Chinese consumers (Table 3.4). A similar trend was evident for liking of flavour, although in this case only in the SM muscle, where American consumers scored flavour higher by 2.9 and 3.9 units compared to Australian and Chinese consumers (Table 3.4). For liking of odour, the same trend was evident with American consumers scoring odour 3.2 and 3.9 units higher compared to Australian consumers, and Chinese consumers (Table 3.4). However, in this case Chinese consumers scored liking of odour about 1.7 units less than Australian consumers in the SM, with no difference found in LL (Table 3.4). There were no differences detected between countries for consumer sensory scores for juiciness or overall liking.

Table 3.2
Number of lambs and yearlings analysed in the base model (n = 321) according to country, sex, sire type, birth type, and kill group.

	Animals	
Effects	**Lambs**	**Yearlings**
Country*		
Australia	105	104
China	112	106
USA	107	101
Sire type		
Maternal	25	
Merino	57	157
Terminal	82	
Sex		
Female	83	
Wether	81	157
Kill group		
One	85	106
Two	79	51

* Animals are represented across two of three countries at all times.

Country differences were also evident across sire types with American consumers generally scoring all sire types higher in tenderness than Australian and Chinese consumers ($P < 0.01$; Table 3.3). Comparisons of sire type could only be made within the lamb group in this study as yearlings were entirely Merino. Within the Merino LL samples, American consumer tenderness scores were 4.9 and 7.3 units higher than Australian and Chinese consumer groups (77.9 ± 1.5, 73 ± 1.6, 70.6 ±1.5 respectively; $P < 0.01$), with no difference found between countries for the Merino SM (56.4 ± 1.1; $P > 0.05$). There was no difference in the tenderness of Terminal LL samples between countries (70.6 ± 1.0; $P > 0.05$), while in the Terminal SM samples American and Australian consumers scored 8.5 and 7.5 tenderness units higher compared to Chinese consumers (54.6 ± 1.3, 53.6 ± 1.3, 46.1 ±1.3; $P < 0.01$). All countries scored similarly for overall liking of the LL and SM muscles for Merino (71.4 ± 0.8, 59.2 ± 0.8), and Maternal (70.6 ± 1.2, 58.1 ± 1.2) sired lambs, and the LL of Terminal sired lambs (68.6 ± 0.7). There was an exception in Terminal SM muscles, with American consumers scoring 3 overall liking units higher than Chinese consumers (58.4 ± 1.1 versus 55.4 ± 1.; $P < 0.05$).

3.3.2 Age class effect

Consumers across the three countries reported increased sensory scores of lamb samples compared to yearling samples for tenderness, liking of flavour, and overall liking ($P < 0.01$; Table 3.3 and Table 3.4). On average, lamb samples scored 5.2, 1.9 and 2.7 units higher in tenderness, liking of flavour and overall liking scores compared to yearling samples. This age class difference also varied between muscles for tenderness, juiciness and liking of odour ($P < 0.01$; Table 3.3). For tenderness, lamb LL was 6.9 units higher compared to yearling LL, whereas the lamb SM was only 3.4 units higher than the yearling SM ($P < 0.01$; Table 3.4). The age class difference in juiciness and liking of odour were minor and specific to the LL muscle, with a 1.8 and 1.1 unit increase for lamb over yearling LL samples ($P < 0.01$). In contrast, the SM samples for juiciness and liking of odour did not differ between the age classes. Furthermore, within Merino sired animals represented across both age classes, the lamb samples scored higher than yearling samples for tenderness and overall liking, a trend that was generally consistent across all countries ($P < 0.05$; Table 3.3, individual data not shown).

Table 3.3

F-values for the base linear mixed effects models for degree of tenderness and juiciness, liking of flavour, overall liking and liking of odour scores of m. longissimus lumborum and m. semimembranosus of lambs and yearlings.

Effect	Tenderness		Juiciness		Flavour		Overall liking		Odour	
	NDF, DDF	*F*-value	NDF, DDF	*F*-value	NDF, DDF	*F*-value	NDF, DDF	*F*-value	NDF, DDF	*F*-value
Country	2, 3776	20.34**	2, 3449	1.01	2, 2283	6.07**	2, 3251	0.3	2, 2285	15.91**
Muscle	1, 11000	1435.66**	1, 10000	709.06**	1, 10000	792.7**	1, 10000	931.32**	1, 10000	76.23**
Age class	1, 300	46.93**	1, 286	1.03	1, 290	15.7**	1, 294	22.62**	1, 277	1.23
Sire type (age class)	2, 314	3.89*	2, 304	0.62		n.a.	2, 312	3.54*		n.a.
Sex (age class)	1, 316	4.36*	1, 308	5.62*		n.a.		n.a.		n.a.
Kill group	1, 312	25.71**	1, 302	9.78**	1, 308	45.28**	1, 309	18.3**	1, 308	20.94**
Country*muscle	2, 11000	0.36	2, 10000	0.36	2, 10000	9.32**	2, 10000	3.56*	2, 10000	4.9**
Country*sire type(age class)	6, 9421	0.51	4, 7355	0.37		n.a.	6, 8046	0.82		n.a.
Muscle*age class	1, 11000	18.04**	1, 11000	10.35**	1, 10000	0.95		n.a.	1, 10000	9.19**
Muscle*sire type (age class)	2, 11000	1.03		n.a.		n.a.	3, 11000	0.62		n.a.
Muscle*sex (age class)	1, 11000	4.07*		n.a.		n.a.		n.a.		n.a.
Muscle*birth type	1, 11000	4.78*	1, 11000	0.07		n.a.		n.a.		n.a.
Muscle*kill group	1, 11000	3.54	1, 11000	2.01	1, 11000	0.05		n.a.		n.a.
Age class*kill group	1, 309	0.05	1, 299	6.95**	1, 309	2.26		n.a.		n.a.
Age class*kill group*muscle	1, 11000	5.92*	1, 11000	7.31**	1, 11000	5.22*		n.a.		n.a.
Country*muscle*sire type (age class)	6, 11000	4.13**		n.a		n.a.	6, 11000	2.34*		n.a.

NDF, DDF: numerator and denominator degrees of freedom; n.a.: not applicable as not in final base models after stepwise regression; *: $P< 0.05$: **: $P<0.001$.

Table 3.4

Least square means ± s.e. (on a scale of 0-100) for the effects of country, muscle and age class for degree of tenderness, juiciness, liking of flavour, overall liking and liking of odour.

Muscle	Age class	Country	Tenderness	Juiciness	Flavour	Overall liking	Odour
LL	Lamb	Australia	71.7 ± 1.0^{h}	67.2 ± 0.9^{bc}	69.0 ± 0.8^{g}	70.9 ± 0.9^{g}	67.2 ± 0.7^{cd}
		China	69.2 ± 1.0^{g}	68.7 ± 0.9^{c}	67.9 ± 0.7^{fg}	70.3 ± 0.9^{g}	67.2 ± 0.7^{cd}
		USA	75.3 ± 1.0^{i}	68.7 ± 0.9^{c}	68.3 ± 0.7^{fg}	69.5 ± 0.9^{fg}	70.4 ± 0.7^{f}
SM	Lamb	Australia	54.5 ± 1.0^{cd}	57.1 ± 0.9^{a}	58.4 ± 0.8^{bc}	57.4 ± 0.9b^{cd}	65.1 ± 0.7^{b}
		China	51.4 ± 1.0^{b}	57.2 ± 0.9^{a}	57.5 ± 0.7^{ab}	57.9 ± 0.9^{cd}	63.3 ± 0.6^{a}
		USA	56.8 ± 1.0^{d}	57.9 ± 0.9^{a}	61.2 ± 0.7^{d}	59.1 ± 0.9^{d}	67.6 ± 0.7^{d}
LL	Yearling	Australia	65.7 ± 0.9^{f}	66.0 ± 0.9^{b}	66.8 ± 0.8^{f}	67.0 ± 0.8^{e}	65.6 ± 0.7^{b}
		China	62.2 ± 0.9^{e}	65.3 ± 0.9^{b}	64.6 ± 0.8^{e}	66.2 ± 0.8^{e}	66.2 ± 0.7^{bc}
		USA	67.5 ± 0.9^{fg}	67.8 ± 0.9^{bc}	67.1 ± 0.8^{f}	68.0 ± 0.8^{ef}	69.7 ± 0.7^{ef}
SM	Yearling	Australia	50.8 ± 0.9^{ab}	57.4 ± 0.9^{a}	56.9 ± 0.8^{ab}	55.5 ± 0.8^{ab}	65.2 ± 0.7^{b}
		China	48.5 ± 0.9^{a}	57.9 ± 0.9^{a}	55.7 ± 0.8^{a}	54.9 ± 0.8^{a}	63.7 ± 0.7^{a}
		USA	53.0 ± 0.9^{bc}	58.5 ± 0.9^{a}	59.8 ± 0.8^{cd}	57.0 ± 0.8^{bc}	68.4 ± 0.7^{de}

^{a,b,c,d,e,f,g} Values within columns with different superscripts are different (P<0.05). LL: m. *longissimus lumborum*; SM: m. *semimembranosus*.

For tenderness, Merino lamb LL scored 7.3, 10.4 and 8.4 units higher than Merino yearlings for Australian, American and Chinese consumers. For the SM, Merino lambs scored 4.7, 5.2 and 6.9 tenderness scores higher than Merino yearlings for Australian, American and Chinese consumers. Similarly overall liking had 5.3, 3.0 and 4.7 units greater for lamb than yearling LL by Australian, American and Chinese consumers, whereas lamb SM scored 3.2 and 5.1 more by American and Chinese consumers compared to yearling SM. There were no differences detected for Australian consumers in overall liking of SM muscles of Merino lamb and yearlings (Table 3.3; individual data not shown).

The effect of age class also varied across kill groups and muscles for tenderness, juiciness, and liking of flavour ($P < 0.05$; Table 3.3). Eating quality was higher in lamb LL compared to yearling LL in both kill groups for tenderness, and was specific to kill group two for juiciness and liking of flavour. Within kill group one, a minor improvement in liking of flavour of the SM was observed for lamb compared to yearling (individual kill group data not shown).

3.3.3 Muscle effect

Across all sensory traits the consumer scores of the LL were consistently higher than the SM ($P < 0.01$; Table 3.3), with differences of 16.1, 9.6, 9.0, 11.7, and 2.2 units for tenderness, juiciness, liking of flavour, overall liking and liking of odour (Table 3.4). These differences were generally greater in lambs than in yearlings ($P < 0.01$). For tenderness, LL samples were 17.8 units higher than SM samples for lambs, yet this difference was only 14.4 units higher for yearlings. Similarly, for juiciness the LL was 10.8 units higher than the SM within lamb, yet only 8.5 units higher in yearlings, while for liking of odour the LL samples rated 2.9 units higher than SM samples within lamb and only 1.4 units higher for yearlings.

3.3.4 Impact of animal and production factors on sensory scores

An accurate evaluation of sire type and sex effects on eating quality could only be made within the lamb group in this study as yearlings were strictly wethers; hence, results hereafter are specific to the lamb data.

For sire type, when averaged across countries and muscle type, Merino sired lambs scored higher than Terminal sired lambs by 3.2 and 5.0 tenderness units for the LL (73.8 ± 1.1 versus 70.6 ± 1.0) and SM (56.4 ± 1.1 versus 51.4 ± 1.0), and 2.8 and

2.2 overall liking units for the LL (71.4 ± 0.8 versus 68.6 ± 0.7) and SM (59.2 ± 0.8 versus 57.0 ± 0.7) (*P* < 0.05; Table 3.3).

American consumers scored tenderness and overall liking 5.7 and 3.7 units higher in Merino LL samples (77.9 ± 1.5, 71.1 ± 1.2) compared to Terminal LL samples (72.2 ± 1.3, 67.4 ± 1.1), (*P* < 0.01), while they did not detect sire type differences in the SM for either sensory trait. In contrast, Chinese consumers reported increases of 9.3 and 6.5 tenderness units of Merino and Maternal SM samples compared to Terminal samples (55.4 ± 1.5, 52.6 ± 2.0 compared to 46.1 ± 1.5; *P* < 0.01), while there was no sire type difference found in the LL. Australian consumers reported no sire type difference in tenderness for either the LL or SM muscles, however unique to the LL, Merino lambs scored 3.8 overall liking units higher than Terminal samples (72.3 ± 1.2 versus 68.5 ± 1.1; *P* < 0.01),.

Across all countries female lambs showed a small improvement in juiciness compared to male lambs with an average increase of 1.8 sensory scores (63.7 ± 0.7 versus 61.9 ± 0.6; *P* < 0.05; Table 3.3). For tenderness, this difference was unique to the LL, with female lambs expressing a 3.1 score increase over male lambs (73.6 ± 0.9 versus 70.5 ± 0.9; *P* < 0.01). There was no variation in eating quality between the sexes for liking of flavour, overall liking, or liking of odour (Table 3.3). Kill group had an impact on eating quality for all sensory traits (*P* < 0.01; Table 3.3). Improved eating quality was consistently observed across all countries for kill group two compared to kill group one with average increases of 4.4, 2.0, 3.2, 2.8, and 1.5 units for tenderness, juiciness, liking of flavour, overall liking and liking of odour (*P* < 0.01; Table 3.3; individual kill group data not shown).

3.3.5 Correlations between eating quality traits and muscle types

Partial correlation coefficients between the eating quality attributes within the LL and SM for each country are presented in Table 3.5. Correlations between the eating quality traits were generally high except for liking of odour, and this was consistent across all three countries. Chinese and American correlations between the traits within the SM were very similar, with the lowest correlations between traits observed in Chinese consumer scores of the LL muscle. Between-muscle partial correlation coefficients for the LL and SM muscles are not presented, however they were low for each of the eating quality traits, ranging from 0.05 to 0.08 for Australia, 0.06 to 0.11 for China, and 0.06 to 0.07 for the USA.

Table 3.5

Partial correlation coefficients for eating quality traits for the m. longissimus lumborum (above diagonal) and the m. semimembranosus (below diagonal) within Australia, China and the USA.

	Sensory traits				
	Tenderness	**Juiciness**	**Flavour**	**Overall liking**	**Odour**
			Australian consumers		
Tenderness		0.70	0.67	0.78	0.37
Juiciness	0.66		0.71	0.77	0.37
Flavour	0.68	0.69		0.89	0.46
Overall liking	0.76	0.75	0.91		0.43
Odour	0.36	0.37	0.46	0.47	
			Chinese consumers		
Tenderness		0.60	0.55	0.70	0.30
Juiciness	0.70		0.56	0.65	0.32
Flavour	0.62	0.62		0.86	0.46
Overall liking	0.69	0.66	0.90		0.47
Odour	0.38	0.39	0.53	0.53	
			American consumers		
Tenderness		0.66	0.63	0.71	0.38
Juiciness	0.64		0.65	0.70	0.43
Flavour	0.58	0.58		0.90	0.54
Overall liking	0.69	0.66	0.90		0.54
Odour	0.33	0.33	0.51	0.52	

3.4 Discussion

3.4.1 The impact of country on sensory scores

Contrasting with our hypothesis, the present study showed that there was no detectable difference in overall liking and juiciness scores of lamb and yearling meat for American, Australian and Chinese consumers. This is despite the fact that lamb is not a commonly consumed product in the USA (Meat and Livestock Australia, 2019b) and that significant cultural and culinary differences exist - particularly in China (Mao et al., 2016). Yet contrary to this, differences between the countries were observed for tenderness, liking of flavour, and liking of odour scores.

Aligning with our hypothesis, Chinese tenderness scores were lower than Australian scores for both muscles. These lower tenderness scores for Chinese consumers might be explained through inherent cultural perceptions of tenderness, which can vary by province (Nam, Jo, & Lee, 2010). Hence the preference for "chewier" meat within some provinces would have translated into a negative impact on some consumer scores where tenderness was high. Additionally, many of the Chinese consumers may not have been familiar with the "western" style grilled meat used in this experiment, as the top three traditional cooking methods in China are stewing, hotpot or roasting (Mao et al., 2016). As such, this might have influenced the Chinese consumer responses as the presentation style of the samples is unusual compared to typical Chinese cuisine. Higher eating quality scores might have been observed if the meat samples were cooked according to traditional style cooking methods and prepared using conventional practices whereby sub-cutaneous fat might be retained on meats for cooking. Other influences may include the larger sample sizes, and degree of doneness, cooking meat to medium in this experiment rather than typically "well done" which Chinese consumers are accustomed to in traditional Chinese dishes. Furthermore tenderness and juiciness themselves are not important traits for many styles of Chinese cooking (e.g. hotpot, stir-fry, deep fried foods, and highly sauced proteins) (Waldron et al., 2007), and as such scoring meat on these sensory attributes may have been challenging for this consumer group.

Contrary to our hypothesis, American consumers scored tenderness higher compared to Australian consumers for both the LL and SM. Liking of flavour differed specifically within the SM, with American consumers again scoring liking of flavour higher than Australian and Chinese consumers. Given eating satisfaction, defined as taste/flavour, has been reported as the most important quality attribute for American consumers when purchasing lamb (Hoffman et al., 2016), also evidenced within this study with flavour the most highly correlated to overall liking for American consumers (Table 3.5); this study suggests that Australian sheepmeat, particularly LL muscles can be exported and perceived as highly satisfactory within the US market, a positive result for suppliers of this market. However results of Phelps, Garmyn, Brooks, Martin, et al. (2018), demonstrated an eating quality preference for American

LL and SM lamb samples compared to Australian and NZ equivalents. It should be noted Australian sourced lamb LL scores for tenderness, juiciness, flavour liking and overall liking were lower at 72.7, 65.3, 63.4, and 65.3 compared to Australian lamb scores of 75.3, 68.7, 68.3, and 69.5 in the current study. Given animal background and production practices of imported lamb samples were unknown in the former study, the performance of Australian lamb under similar production or processing conditions to locally sourced product may have yielded different results. Additionally the authors recognise that despite flavour playing an important role in consumer satisfaction, other factors such as animal origin and sheep raising practices are also high priorities for American consumers (Hoffman et al., 2016).

Contradictory to our hypothesis, American consumers graded liking of odour higher than Australian and Chinese consumers within the LL, and differences between all three countries were observed for the SM. Despite anecdotal evidence of an aversion to the smell of cooked sheepmeat for Chinese consumers, negative discrimination of lamb and yearling liking of odour was small within the Chinese consumer group, with a maximum difference of 1.8 eating quality scores below Australian consumers (Table 3.4). However the authors concede, consumers were recruited entirely within Beijing, and different provinces within China can have vastly different culinary preferences (Mao et al., 2016). Hence it is possible that testing across a range of provinces within China would reveal more substantial differences. Given odour is a difficult factor to isolate without the use of sealed serving containers, we suspect moderate correlations with the other four eating quality attributes likely influenced favourable scores recorded for liking of odour for all consumers.

Therefore, while differences exist between the countries for some sensory attributes, the magnitude of these differences are relatively small, suggesting that overall consumers score sensory traits very similarly when assessing the palatability of sheepmeat.

3.4.2 Impact of age class on eating quality

In agreement with our hypothesis age class had an impact on eating quality for all consumer groups and both muscle types. On average across the three countries, lambs scored higher than yearlings for tenderness, juiciness and overall liking however the greatest impact of age class was observed for tenderness, and most discernable in the LL muscle. A direct comparison of lambs and yearlings in this study is difficult, as lambs (female and wethers) were progeny of Merino, Terminal, and Maternal sire types while yearling animals were strictly Merino sired wethers. Nonetheless, a comparison between Merino lambs and yearlings also demonstrated an improvement for lambs in both the LL and SM muscles for tenderness and overall liking. These results are consistent with previous published data that lamb has a superior eating quality to yearlings (Pannier, Gardner, & Pethick, 2018; Pethick et al., 2005), however our results contrast with the findings of the impact of age class on the different muscles. Within this study, the greatest age class improvements were found in the LL muscle of lambs, with average differences in Merino lamb LL and SM compared to yearling being 8.7 and 5.6 units higher for tenderness and 4.3 and 4.2 units higher for overall liking. In contrast, Pannier et al. (2018) demonstrated little to no significant differences in Merino lamb and yearling LL samples within multiple research flocks (n = 391), while lamb SM samples scored 5 to 10 units higher than yearling SM for tenderness, liking of flavour and overall liking. Further to this, Pethick et al. (2005) also reported no significant difference in the eating quality of the LL between lambs and yearlings across all palatability traits and a 5.6 score improvement in tenderness of the SM for lambs. While results in the LL samples differed to previous research, the magnitude of difference between the age class groups for SM samples was quite similar to previous studies. Discrepancies between the current results and previous findings are difficult to explain as animals were similar in age to those used in previous studies (12 *versus* 22 months), and muscle types consistent (Pannier, Gardner, & Pethick, 2018; Pethick et al., 2005). The inconsistent results across studies demonstrates the need for continued testing over time with new consumer groups to ensure the most robust prediction of eating quality can be made, reflecting current flock genetics and nuances in consumer preferences.

3.4.3 Impact of muscle on eating quality

Muscle described the largest amount of variation for all sensory attributes (Table 3.3), with the LL scoring higher than the SM. This was observed for each consumer group and aligns well with previous findings comparing the eating quality of these two muscles in sheep

(Maddock et al., 2004; Pannier et al., 2014; Thompson et al., 2005). The consistency in which these international consumers detect eating quality differences between muscles shows that MSA sensory protocols can be used to assess their preferences in sheepmeat. This has been extensively tested in beef, whereby various international consumer groups provided similar beef eating quality preferences when assessed using MSA testing (Legrand, Hocquette, Polkinghorne, & Pethick, 2013; Polkinghorne et al., 2014; Thompson et al., 2008). These results provide robust evidence for the implementation of a cuts based grading system such as MSA and its potential applicability to international markets (Pannier, Gardner, O'Reilly, et al., 2018).

3.4.4 Correlations between eating quality traits and muscle types

For both the LL and SM muscle tenderness, juiciness, liking of flavour and overall liking were strongly correlated with one another, and this was consistent for all three countries (Table 3.5). The strongest correlations (r > 0.86) were found between flavour liking and overall liking, and this aligns with previous research utilising Australian (Pannier et al., 2014; Thompson et al., 2005), and American consumers (Phelps, Garmyn, Brooks, Mafi, et al., 2018).

American (*r* ranged 0.58 to 0.90), Chinese (*r* ranged 0.55 to 0.90) and Australian (*r* ranged 0.66 to 0.89) consumer correlations were generally similar. This aligns with cross-cultural comparisons in beef including Australian, French, Irish and Polish consumers (Bonny et al., 2016) and are similar in range to correlations found for Japanese consumers (Polkinghorne, Nishimura, Neath, & Watson, 2011). Despite cultural differences between countries, it is clear there is a consistently strong relationship between tenderness, juiciness, liking of flavour, and overall liking. As such individual traits must be interpreted with caution as this demonstrates the well reported “halo” effect whereby untrained consumers are unable to differentiate between the different sensory dimensions (Kunert, 1998; Shorthose & Harris, 1991). Liking of odour was moderately correlated with the other sensory scores, aligning with previous research (Pannier et al., 2014), and this was consistent for both muscle types and across all countries (Table 3.5). This indicates that odour is scored more independently than the other eating quality attributes, and is perhaps unsurprising as while intertwined, the olfactory and gustation systems have their own receptors. Correlations between LL and SM muscles for eating quality were low and generally non-significant for all three countries. This is consistent with previous findings in Australian consumers by Thompson et al. (2005), demonstrating very poor correlations between the SM and five other muscles including the LL, for all eating quality traits. These findings reinforce the need for all muscles to be tested independently when evaluating new cooking methods for accurate eating quality predictions, and potential integration of a cut by different cooking method sheepmeat MSA prediction model (Pannier, Gardner, O'Reilly, et al., 2018).

3.4.5 Impact of animal and production factors on eating quality

3.4.5.1 Sire type effects

In agreement with our hypothesis sire type had a significant impact on eating quality, specifically for tenderness and overall liking ($P < 0.05$; Table 3.3). With yearling animals limited strictly to Merino wethers, a valid comparison of sire types could only be made between Merino, Maternal and Terminal sired lambs. Regardless of cultural background, on average Merino sired lambs scored 4.1 and 2.5 units higher than Terminal sired lambs for tenderness and overall liking. The sire type effect is similar to previous research by Pannier et al. (2014), where Merino's scored 5.2 and 3.9 units higher for tenderness and overall liking compared to Terminal sired lambs, however within our study eating quality differences on average, did not extend to juiciness and liking of flavour and were not observed in Maternal sired progeny compared to other sire types.

The impact of sire type varied across the three countries. American consumers detected sire type differences only within the LL for tenderness and overall liking, while in contrast Chinese participants detected an impact of sire type in the SM samples for tenderness and overall liking. These differences are difficult to explain, however one suggestion may be a familiarisation with muscle types for these particular groups. Frequent consumption of premium quality muscles such as the LL for American consumers may help with discerning minor differences in eating quality. Imported lamb products entering the USA comprise of high quality cuts of meat, and as a primary source of lamb consumption in the USA is through the restaurant sector (Meat and Livestock Australia, 2019b), premium lamb meat would be more common when included in their diet. Furthermore, given traditional Chinese cooking styles generally do not require premium cuts of meat (Waldron et al., 2007), it is feasible that Chinese consumers are more familiar with lower quality pieces of meat and therefore more accustomed to detecting minor intrinsic meat quality factors associated with this specific muscle.

Surprisingly, Australian consumers detected a sire type difference only for overall liking in the LL, with only partial agreement to previous research of Australian consumers by Pannier et al. (2014), demonstrating an eating quality preference for all eating quality traits, in descending order for Merino, Maternal and then Terminal sired lambs. An explanation for this discrepancy could be the lower animal numbers used in this study, particularly Maternal sired lambs, or the use of all ten consumer scores rather than the average of the ten scores. What is clear, is that on average, Merino sired lambs have higher eating quality than Terminal sired lambs regardless of consumers' cultural background. However the impact of sire type varies across consumer cultural groups, eating quality traits and may be specific to certain muscles depending on the consumer group. The sensory preference for Merino animals is consistent with previous research, where selection for increased muscling and leanness in Terminal sired animals has been shown to have a detrimental effect on eating quality (Hopkins, Hegarty, & Farrell, 2005; Pannier et al., 2014).

3.4.5.2 Sex and kill group effects

In agreement with our hypothesis animal sex had an impact on eating quality, however differences were limited to tenderness and juiciness and the magnitude was generally low. Similar to the impact of sire type, a valid comparison of sex could only be made within the lambs of this study. Female samples scored higher for tenderness (LL) and juiciness (LL and SM) with these results consistent across all three countries. These results align with previous research demonstrating an eating quality preference for female sheep (Navajas et al., 2008; Pannier et al., 2014). However in contrast to Pannier et al. (2014) the impact of sex was not inclusive of all eating quality traits. Differences between the current and previous studies could be attributed to inclusion of Merino, Maternal and Terminal sired lambs in this analysis, compared to only Terminal sired lambs; or the lower consumer and animal numbers in the current study (consumers n = 2,160, animals n = 164) compared to Pannier et al. (2014) (consumers n = 5640, animals n = 1434). Furthermore in a study by Dransfield et al. (1990), more favourable eating quality was reported for rams (n = 24) and wethers (n = 24) compared to ewes (n = 14), however with the magnitude of effect being low. Given the preference for female lambs in this study was only evidenced in a reasonable magnitude for tenderness in the LL, it could be argued that the importance of sex in eating quality estimates for lambs remains low.

Within this study, the second kill group had slightly higher eating quality scores than the first kill group. While both slaughter groups had been sourced from the same flock and processed at the same abattoir, it is difficult to ascertain a direct cause. Factors to consider would be lifetime nutrition, climatic variations, pre-slaughter handling, and proportion of each sire type within the lamb group. This emphasises the inherent variance we are often unable to account for, and the multitude of factors that may play a role in eating quality.

3.5 Conclusion

In conclusion, these results demonstrate that untrained consumers, regardless of cultural background tend to score sheepmeat eating quality very similarly. A country based relationship with eating quality was reported for liking of flavour, and liking of odour however these differences were very low in magnitude. The most pronounced impact of country was observed for tenderness, with lower scores in Chinese consumers, however despite high correlations between eating quality traits, lowered tenderness perceptions did not extend to overall liking for Chinese consumers. This work provides a valuable contribution to a global sheepmeat eating quality data base, and suggests that some minor adjustments to a potential sheepmeat eating quality prediction model may need to be made based on country specifics for muscle type, age class and sire type. Ongoing analysis of the combined sheepmeat eating quality scores, the accuracy of their prediction within each country, and the impact of demographic factors on sensory scores will yield further insights into the ability of an MSA sheepmeat model to predict consumer satisfaction for these key markets in the future.

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Chapter Four

4

Influence of Demographic Factors on Sheepmeat Sensory Scores of American, Australian and Chinese Consumers

Manuscript details

foods MDPI

Title: Influence of Demographic Factors on Sheepmeat Sensory Scores of American, Australian and Chinese Consumers

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Abstract

Along with animal production factors, it is important to understand whether demographic factors influence untrained consumer perceptions of eating quality. This study examined the impact of demographic factors and sheepmeat consumption preferences on eating quality scores of American, Australian and Chinese untrained consumers. M. *longissimus lumborum* (LL) and m. *semimembranosus* (SM) were grilled according to sheep Meat Standards Australia protocols and evaluated by 2160 consumers for tenderness, juiciness, flavour and overall liking. Linear mixed effects models were used to analyse the impact of demographic factors and sheepmeat consumption habits on eating quality scores. Consumer age, gender, number of adults in a household and income had the strongest effect on sensory scores ($P \leq 0.05$), although, the impact was often different across countries. Frequency of lamb consumption had an impact on sensory scores of American, Australian and Chinese consumers but larger sample sizes in some underrepresented subclasses for Australian and Chinese consumers are needed. Results suggest it is important to balance sensory panels for demographic factors of age, gender, number of adults and income to ensure sensory preferences are accurately represented for these particular populations.

4.1 Introduction

As in beef, the development of a sheep Meat Standards Australia (MSA) grading system is underpinned by sensory evaluations of vast numbers of untrained consumers (Pannier et al., 2018a; Pleasants et al., 2005; Thompson et al., 2005a). The MSA prediction model forecasts consumer eating quality of a final cooked product, and is based on consumer scoring of a variety of muscles using descriptors of tenderness, juiciness, liking of flavour and overall liking (Pannier et al., 2018a; Pleasants et al., 2005; Polkinghorne et al., 2008; Thompson et al., 2005a). This prediction model is successfully implemented for beef and is being developed for sheep (Pannier et al., 2018a). While the merit of using untrained consumers is that they are by definition unbiased, some potential drawbacks can include high variance of consumer scores, and the risk of sampling from discreet sectors of the community not representative of an entire population. Previously, O'Reilly et al. (2020) demonstrated minor differences in sensory scores of grilled Australian sheepmeat between American, Australian and Chinese consumers, with a consistent response across consumer groups to production factors of muscle type, animal age and sire type. However, the influence of demographic factors and meat consumption habits on sensory scores particular to these culturally unique groups remained unexplored. Lamb consumption rates in the USA are markedly lower than for Australian consumers, 0.6 kg compared to 8.6 kg per person annually (Meat and Livestock Australia, 2019b), therefore many American consumers are unfamiliar with this protein. Similarly, Chinese consumers would largely be unaccustomed to Western style grilled lamb with the top three sheepmeat cooking styles in China being stewing, roasting or hotpot (Mao et al., 2016; Meat and Livestock Australia, 2019a).

Previous research has shown that consumer demographic factors and meat consumption habits have some impact on eating quality scores in sheep (Thompson et al., 2005d) and beef (Bonny et al., 2017), however the magnitude of these effects are often low, inconsistent across eating quality traits, and differ across countries. Australian, French, Northern Irish and Polish consumers with a higher appreciation of red meat in their diet tend to score lamb and beef more favourably than those who classify themselves as indifferent to red meat (Bonny et al., 2017; Thompson et al., 2005d). This was not observed for Irish or Korean consumers rating grilled beef samples (Bonny et al., 2017; Hwang et al., 2008). A preferred higher degree of cooking doneness has also been shown to positively influence sensory scores compared to those who prefer medium doneness for Australian, Northern Irish and Irish consumers, however no effect was observed in French or Korean consumers, with Polish consumers demonstrating the opposite effect (Bonny et al., 2017; Hwang et al., 2008; Thompson et al., 2005d).

Similar to meat consumption habits, demographic factors of gender, consumer age, occupation, income level and household size have an inconsistent impact on eating quality scores across the literature (Bonny et al., 2017; Huffman et al., 1996; Hwang et al., 2008; Thompson et al., 2005d). For example, in European comparisons, Northern Irish, Irish and Polish males scored grilled beef up to two units higher than females (Bonny et al., 2017). Similarly, Kubberød et al. (2002) demonstrated higher scores for Norwegian males than females when assessing lamb and beef. Both studies attributed this effect to males, placing a higher degree of importance of meat in their diet compared to females (Bonny et al., 2017; Kubberød et al., 2002). In contrast, Thompson et al. (2005d) found Australian females to score lamb up to two units higher than males. While Huffman et al. (1996) and Hwang et al. (2008) found no effect of gender on sensory scores for American, Korean and Australian consumers scoring beef grilled and barbequed Korean style. Older consumers within Australia have demonstrated higher sensory scores than younger consumers (Hastie et al., 2020; Thompson et al., 2005d), while an inconsistent response to age was observed in the USA (Huffman et al., 1996). On the other hand, a small negative relationship in eating quality scores was observed with increasing consumer age for tenderness in France and Poland, and for juiciness in Ireland, Northern Ireland and Poland (Bonny et al., 2017). Huffman et al. (1996) found as income increased, sensory scores decreased, with the assumption that participants on higher incomes have greater expectations of the products they consume. In addition, a greater number of adults in the household has also yielded slightly higher eating quality scores in some studies (Bonny et al., 2017; Thompson et al., 2005d).

Largely, these studies imply that for sensory evaluations of beef and sheepmeat using untrained consumers, demographic factors pose a relatively unimportant source of bias on sensory scores (Bonny et al., 2017; Huffman et al., 1996; Hwang et al., 2008; Kubberød et al., 2002; Thompson et al., 2005d). However, to accurately assess American and Chinese consumer perceptions of sheepmeat, it is important to assess whether their demographic factors play a role in sensory scoring as this has not been reported before. In addition, lambs have demonstrated greater palatability than yearlings and mutton for Australian, American and Chinese consumers (O'Reilly et al., 2020; Pannier et al., 2018b; Pethick et al., 2005). Hence, it is important to investigate whether demographic factors have an effect on animal age preferences. Therefore, this study examined the effect of consumer demographic factors on eating quality scores of American, Australian and Chinese consumers testing grilled Australian lamb and yearling m. *longissimus lumborum* (LL) and m. *semimembranosus* (SM) muscles. We hypothesised that demographic factors would have a small and inconsistent effect on eating quality scores across countries, and that higher appreciators of meat and those that prefer their meat medium-well done will score more favourably. In addition, given similarities between Korean and Chinese culinary habits, we hypothesised that Chinese eating quality scores would be less responsive to changes in meat consumption preferences compared to American and Australian counterparts.

4.2 Materials and Methods

4.2.1 Animal and Muscle Collection

Carcasses used in this study were described in detail by O'Reilly et al. (2020). In brief, a total of 164 lambs (no erupted permanent incisors; average age 368 days) and 168 yearlings (2–4 erupted permanent incisors; average age 726 days) were included in this experiment. Lambs (females and wethers) were the progeny of Maternal (Border Leicester, and Dohne Merino), Merino (Merino, and Poll Merino), and Terminal (Poll Dorset, Suffolk, Texel and White Suffolk) sires, whereas yearlings (wethers) were the progeny of Merino (Merino, and Poll Merino) sires only. Animals were sourced from the Meat and Livestock Australia genetic resource flock at Kirby (NSW, Australia) (Fogarty et al., 2007). Animals were commercially slaughtered at an abattoir licensed for international export to China and the USA. Medium voltage electrical stimulation (Pearce et al., 2010) was applied to all carcasses, before being trimmed according to AUS-MEAT specifications (Anonymous, 2005), and chilled for 24 h at 3–4 °C prior to sampling. Left and right LL (AUS-MEAT 5150) and SM (AUS-MEAT 5077) muscles were collected from each carcass at 24 h postmortem, vacuum packed and aged for ten days at 2–3 °C prior to frozen transport to China and the USA or retained within Australia. All samples were transported according to commercial processing plant specifications with temperatures maintained below minus 10 °C. A total of 648 LL, 648 SM muscles were collected with every carcass represented in two of three countries at any one time through allocation of muscles collected.

4.2.2 Sample Preparation and Sensory Testing

Consumer assessment of the sheepmeat was performed according to MSA testing protocols detailed by Thompson et al. (2005a) and Watson et al. (2008b), with minor updates described by O'Reilly et al. (2020). In brief, 24 h prior to each session, muscle cuts were thawed at 2–5 °C, each muscle was then sliced into five 15 mm thick steaks (approximately 5 × 5 × 1.5 cm), and allocated to consumers using a 6 × 6 Latin square design. Steaks were grilled on a Silex griller (electric S-Tronic Single Grill S161GR, Hamburg, Germany) with top and bottom grill plates set to 180 °C and 195 °C to obtain a medium doneness (2.25 min; 65 °C internal temperature). Steaks were rested (1.5 min) before being halved and served to consumers seated in individual booths, resulting in 10 samples per muscle being served and tasted. The same model of grill was used in Australia, China and the USA.

A total of 2160 untrained consumers were recruited across Australia, China and the USA to participate in one of the 12 tasting sessions conducted per country (n = 720 consumers per country, 60 per session). Each consumer scored six samples (3 LL and 3 SM) for tenderness, juiciness, liking of flavour, and overall liking on a hedonic scale line of 0–100. Scale lines were anchored with 'not' and 'very' preceding the eating quality trait for tenderness and juiciness, and 'dislike extremely' and 'like extremely' for liking of flavour and overall liking. In Australia and the USA, participants largely consisted of community organisations and clubs recruited through a market research company and Texas Tech University. While in China, participants were recruited though China Agricultural University and localised to the community surrounding the university. Tasting sessions in Australia were conducted in the outer Melbourne suburbs of Victoria, at the China Agricultural University in Beijing, China and across ten American states: California, Colorado, Florida, Kansas, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas and Utah.

4.2.3 Consumer Demographics

In addition to scoring sheepmeat samples, consumers were asked to fill in a questionnaire on their demographic details and meat consumption preferences. Recruitment requested participants aged between 18 and 70 years old, preferred to be consumers of sheepmeat at least once per fortnight and have a preference for their meat to be cooked to a medium level of doneness. The questions asked were:

1. Consumer Age group, based on 6 categories: *(a)* <20, *(b)* 20–25, *(c)* 26–30, *(d)* 31–39, *(e)* 40–60, *(f)* 61–70;
2. Gender, based on two categories: *(a)* male, *(b)* female;
3. Number of adults in the household, based on 5 categories: 1, 2, 3, 4, ≥5;
4. Number of children in the household, based on 6 categories: 0, 1, 2, 3, 4, ≥5;
5. Income per annum, based on 5–8 categories depending on country: Australia in AUD: *(a)* <$25,000, *(b)* $25,000–$50,000, *(c)* $50,001–$75,000, *(d)* $75,001–$100,000, *(e)* $100,001–$125,000, *(f)* $125,001–$150,000, *(g)* >$150,000 *(h)* Prefer not to say; China in yuan: *(a)* ≤¥24,000, *(b)* ¥24,000–¥36,000, *(c)* ¥36,001–¥60,000, *(d)* ¥60,001–¥96,000, *(e)* ¥96,001–¥120,000, *(f)* >¥120,000, *(g)* Prefer not to say; and the USA in USD: *(a)* <$20,000, *(b)* $20,000–$50,000, *(c)* $50,001–$75,000, *(d)* $75,001–$100,000, *(e)* >$100,000.
6. Occupation, based on 8–11 categories depending on country: for Australia and China *(a)* manager, *(b)* professionals, *(c)* technician and trade workers, *(d)* community and personal service, *(e)* administration, *(f)* sales and service, *(g)* machinery operators and drivers, *(h)* labourers, *(i)* home duties, *(j)* student, *(k)* other; and for the USA *(a)* professionals, *(b)* tradesperson, *(c)* administration, *(d)* sales and service, *(e)* labourers, *(f)* home duties, *(g)* student, *(h)* other;
7. Consumption frequency, based on seven categories: for Australia and China *(a)* daily, *(b)* 4–5 times per week, *(c)* 2–3 times per week, *(d)* weekly, *(e)* fortnightly, *(f)* monthly, *(g)* never eat lamb; and for the USA *(a)* daily, *(b)* weekly, *(c)* fortnightly, *(d)* monthly, *(e)* every other month, *(f)* 2–3 times per year, *(g)* never eat lamb;
8. Preference for lamb, based on four categories: *(a)* Appreciator: 'I enjoy lamb. It's an important part of my diet', *(b)* Lamb is important: 'I like lamb well enough. It's a regular part of my diet', *(c)* Indifferent: 'I do eat some lamb although, truthfully it wouldn't worry me if I didn't', *(d)* Rarely/never eat: 'I rarely/never eat lamb';
9. Preferred degree of cooking doneness, based on 6 categories: *(a)* blue, *(b)* rare, *(c)* medium/rare, *(d)* medium, *(e)* medium/well done, *(f)* well done.

4.2.4 Statistical Analysis

The effect of demographic factors on eating quality scores (tenderness, juiciness, liking of flavour and overall liking) were examined using linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). All ten consumer responses for each muscle were included in the analysis to account for the consumer variation. Initially, base models were established for tenderness, juiciness, liking of flavour and overall liking. These included fixed effects for country (Australia, China, USA), muscle (LL, SM), sex within animal age class (female lamb, wether lamb and wether yearling), sire type within animal age class (Maternal lamb, Merino lamb, Terminal lamb and Merino yearling), and kill group (animals were slaughtered in two separate groups), which were only retained if significant ($P < 0.05$). These base models have previously been reported in O'Reilly et al. (2020) and enabled the models to account for any imbalance in animal type inadvertently occurring across demographic factor categories. Demographic factors were then included together in each of the base models as fixed effects. These included consumer age group, gender, income, occupation, adults in household, children in household, frequency of lamb consumption, preferred cooking doneness and importance of lamb in diet. Income level, occupation and frequency of lamb consumption were fitted within-country because their category options were defined differently between countries. In addition, preferred degree of doneness was also fitted within country, in this case because there were missing subclasses of 'blue' for the USA and 'blue and rare' for China. All demographic factors were interacted with muscle and with country, except those nested within country (income level, occupation, consumption frequency and preferred doneness). Non-significant terms ($P > 0.05$) were removed in a stepwise manner. Random terms included consumer identification within tasting session by country, and animal identification within sire identification. The Satterthwaite function was used in all models to approximate the degrees of freedom.

4.3 Results

4.3.1 Demographic Factor Distribution

Table 4.1 shows the demographic distribution of consumers recruited within Australia, China and the USA. Of the 2160 participants that attended tasting sessions, 2117 were included in the analysis as they had data for all demographic categories.

Consumer age group varied by country with Australian consumers generally being older with more than half over 40 years of age, while American and Chinese consumers were largely aged between 20 and 25 years old. Gender was consistent for Australia and the USA with 10% more males than females, while China had 20% more females than males.

The majority of American and Australian consumers came from households of one to three adults, while Chinese participants mainly came from households of three or above. All three countries leant towards less children (≤2), but this was more prominent for Chinese and American consumers. Australian and American consumers were evenly distributed across income brackets while Chinese consumers were largely within the lowest income category. Australians classified themselves primarily as managers, professionals and trade workers, Americans as administrators and homemakers, and Chinese as professionals and students. Lamb consumption habits were varied across the three countries. Most Australian and Chinese consumers eat lamb weekly to monthly, with a tendency towards higher and lower consumptions rates respectively. American consumers largely ate little to no lamb with over 70% of participants in the ‘2–3 times per year’ to ‘never eat’ categories. Australians were the highest appreciators of lamb, with the majority indicating lamb is important in their diet. Chinese consumers were largely indifferent to inclusion of lamb in their diet, and the majority of American consumers were either indifferent to lamb or never eat it. Preferred degree of cooking doneness was similar for American and Australian consumers with close to 90% of participants evenly distributed across medium/rare to medium/well done categories. In contrast, almost all Chinese consumers preferred their meat cooked from medium to well done.

4.3.2 The Impact of Demographic Factors on Sensory Scores

Table 4.2 presents significance levels of demographic factors included in base models for tenderness, juiciness, liking of flavour and overall liking. Consumer age group, number of adults in the household, income level and frequency of lamb consumption reached significance most often across the four sensory traits while occupation, consumer appreciation of lamb and preferred degree of doneness were not significant for any sensory trait. Consumer gender and number of children in a household had a limited effect on sensory traits (Table 4.2).

4.3.2.1 Consumer Age Group

On average, across the three countries and both muscles, scores for tenderness, flavour and overall liking scores varied between consumer age group ($P < 0.05$; Table 4.2). Consumers ≥40 years old scored tenderness 3.0 to 6.3 units higher than younger counterparts, while 26 to 30 year olds scored flavour and overall liking 3.0 to 5.7 units lower than both younger and older age groups.

The age group effect varied between countries and muscle types for tenderness, juiciness, flavour and overall liking ($P < 0.05$; Table 4.3). As a general trend, younger Australian consumers tended to score eating quality highest, while the reverse was observed for Chinese and American consumers with older participants scoring more favourably. In Australia, younger consumers tended to score tenderness and juiciness higher. Consumers ≤25 years old scored 5.0 to 9.1 tenderness units higher than 26 to 60 year olds. For juiciness, this trend remained for the SM muscle, with consumers ≤25 years old scoring samples 5.9 to 10.6 units higher than those aged 26 to 60 years old. However, for the LL muscle, juiciness scores differed across the older consumer groups ($P < 0.05$; Table 4.3).

In contrast, Chinese consumers ≥40 years old and American consumers ≥31 years old scored tenderness and juiciness 3.6 to 8.6 units higher than most younger age groups. Though, for Chinese consumers, improved scoring of juiciness (4.2 units) was only observed in the LL for 40 to 60 year olds compared to 20 to 25 years, whereas in the SM, the effect extended to those above 60 years compared to most age group categories under 40 years old differing by about 4.4–7.8 units. American consumers ≥40 years old scored LL samples 5.2 to 6.0 juiciness units greater than 20 to 30 year olds, while for the SM, 26 to 30 year olds scored juiciness 4.8 to 8.7 units lower than almost every other age group ($P < 0.05$; Table 4.3).

Aligning with tenderness and juiciness, when averaged across both muscles, younger Australian consumers scored flavour (4.7–6.1 units) and overall liking (5.1–6.3 units) more favourably than older consumers. Notably, those aged 26 to 30 years old scored flavour and overall liking on average 4.7 to 10.2 units lower than all other age groups. This trend was evident in the SM muscle for which flavour and overall liking scores were highest amongst those ≤ 25 years old, with increases of 6.2 to 14.5 units compared to categories upwards of 26 years old. However, this trend differed within the LL, as Australian consumers over 60 scored flavour higher than those aged 26 to 30 and 40 to 60 years old (6.2 and 4.8 units). Similarly, overall liking scores in the LL were significantly greater for those over 60 and under 20 compared to the 26 to 30-years-old category (6.6 and 6.2 units).

Older Chinese consumers scored flavour (≥40 years) and overall liking (≥60 years) 5.2 to 7.5 units higher than younger consumers (≤25 years old). There was no impact of age group seen for LL samples, however, in the SM muscle, older Chinese consumers (generally ≥40 years old) scored flavour and overall liking more favourably than those in categories ≤25 years old (4.7–11.7 units).

Similar to some Australian participants, American consumers aged 20 to 30 years old scored flavour and overall liking lower than younger and most older age groups by 3.2 to 7.3 units ($P < 0.05$; Table 4.3). This effect was seen in the LL samples with consumers aged 20 to 25 years old and 20 to 30 years old scoring flavour (4.4 units) and overall liking (~5 units) lower than consumers aged 40 to 60 years old. Similarly, for the SM muscle, 20 to 30 year olds scored significantly lower for flavour and overall liking than all other age groups (4.6–9.0 units) ($P < 0.05$; Table 4.3).

Country differences were also observed within consumer age groups ($P < 0.05$; Table 4.3). Across muscle types, American tenderness scores were greater than Chinese consumers for the age groups under 20, and 31–39 years old (~10.1 units), and Australian consumers 40–60 years old (6.8 units). In addition, Australian tenderness scores were higher than Chinese in the under 20-year-old category (12.7 units). Australian consumers scored juiciness higher than Chinese consumers ≤25 years old (10 units), and 31 to 39 years old (7.7 units) and American consumers 20 to 25 years old (5.4 units). American consumers within the 31 to 39-years-old category also scored juiciness 7.2 units higher than Chinese consumers. No differences between countries was observed for tenderness in age categories 20 to 30 years old and above 60 years old, and for juiciness in groups 26 to 30 and above 40 years old. Country differences across age groups were generally consistent for flavour and overall liking with Australian and American consumer scores greater than Chinese scores for those under 20 years old (7.2 to 12.4 units). Within consumer group 20 to 25 years old, Australian flavour and overall liking scores were greater than American and Chinese consumers by 6.1–8.8 units. There were no country differences for flavour and overall liking within age groups above 26 years old ($P < 0.05$; Table 4.2).

Table 4.1

Percentage distribution of consumers who scored sheepmeat samples (and number of consumers) within each demographic and meat consumption category for each country.

Consumer Age:	<20	20–25	26–30	31–39	40–60	>60
Australia	7.64 (55)	8.33 (60)	6.94 (50)	19.86 (143)	49.72 (358)	7.50 (54)
China	6.39 (46)	48.75 (351)	19.31 (139)	4.31 (31)	12.50 (90)	8.75 (63)
USA	10.39 (70)	41.25 (278)	9.20 (62)	11.57 (78)	23.00 (155)	4.60 (31)
Gender:	**Male**	**Female**				
Australia	54.17 (390)	45.83 (330)				
China	37.22 (268)	62.78 (452)				
USA	55.04 (371)	44.96 (303)				
Adults:	**1**	**2**	**3**	**4**	**≥5**	
Australia	7.36 (53)	51.11 (368)	20.14 (145)	14.72 (106)	6.67 (48)	
China	2.50 (18)	15.00 (108)	42.22 (304)	25.14 (181)	15.14 (109)	
USA	16.34 (110)	45.77 (308)	21.4 (144)	10.40 (70)	6.09 (41)	
Children:	**0**	**1**	**2**	**3**	**4**	**≥ 5**
Australia	34.03 (245)	20.28 (146)	26.67 (192)	12.64 (91)	3.75 (27)	2.64 (19)
China	69.31 (499)	23.89 (172)	5.00 (36)	1.39 (10)	0.28 (2)	0.14 (1)
USA	62.17 (419)	15.43 (104)	11.42 (77)	7.27 (49)	2.37 (16)	1.34 (9)

Income level 1:	***a***	***b***	***c***	***d***	***e***	***f***	***g***	***h***
Australia	6.39 (46)	10.42 (75)	14.58 (105)	17.36 (125)	13.61 (98)	10.97 (79)	15.28 (110)	11.39 (82)
China	48.33 (348)	15.97 (115)	12.08 (87)	8.19 (59)	2.64 (19)	4.44 (32)	8.33 (60)	
USA	19.88 (134)	19.88 (134)	19.14 (129)	17.95 (121)	23.15 (156)			

Occupation:	**Manager**	**Professional**	**Trade Worker**	**Community Service**	**Administration**	**Sales and Service**
Australia	17.36 (125)	22.22 (160)	13.06 (94)	4.58 (33)	8.75 (63)	3.06 (22)
China	3.75 (27)	20.97 (151)	9.86 (71)	1.81 (13)	5.42 (39)	3.06 (22)
USA		6.23 (42)	6.82 (46)		28.64 (193)	0.74 (5)

Occupation:	**Machinery Operators**	**Labourer**	**Home Duties**	**Student**	**Other**
Australia	5.56 (40)	3.47 (25)	5.00 (36)	5.28 (38)	11.67 (84)
China	1.81 (13)	10.69 (77)	0.83 (6)	28.75 (207)	13.06 (94)
USA		10.83 (73)	32.94 (222)	8.61 (58)	5.19 (35)

Frequency of Lamb Consumption:	**a**	**b**	**c**	**d**	**e**	**f**	**g**
Australia	0.69 (5)	1.94 (14)	14.31 (103)	36.11 (260)	23.61 (170)	22.64 (163)	0.69 (5)
China	0.83 (6)	1.39 (10)	12.36 (89)	21.81 (157)	24.44 (176)	37.08 (267)	2.08 (15)
USA	0 (0)	1.48 (10)	4.01 (27)	9.50 (64)	8.61 (58)	42.88 (289)	33.53 (226)

Importance of Lamb in the Diet:	Appreciator of lamb	Lamb is important	Indifferent to lamb	Rarely/never eat lamb
Australia	29.44 (212)	44.17 (318)	24.31 (175)	2.08 (15)
China	5.69 (41)	29.03 (209)	62.08 (447)	3.19 (23)
USA	7.27 (49)	14.54 (98)	35.16 (237)	43.03 (290)

Preferred Degree of Doneness:	Blue	Rare	Medium/Rare	Medium	Medium/Well Done	Well Done
Australia	0.28 (2)	3.33 (24)	32.78 (236)	28.19 (203)	25.28 (182)	10.14 (73)
China	0 (0)	0 (0)	0.28 (2)	1.94 (14)	23.75 (171)	74.03 (533)
USA	0 (0)	4.01 (27)	30.12 (203)	27.00 (182)	29.23 (197)	9.64 (65)

[1] Income categories different for each country. In all countries, income level per annum. Australia (AUD) *(a)* <$25,000, *(b)* $25,000–$50,000, *(c)* $50,001–$75,000, *(d)* $75,001–$100,000, *(e)* $100,001–$125,000, *(f)* $125,001–$150,000, *(g)* > $150,000 *(h)* Prefer not to say; China (yuan): *(a)* ≤¥24,000, *(b)* ¥24,000–¥36,000, *(c)* ¥36,001–¥60,000, *(d)* ¥60,001–¥96,000, *(e)* ¥96,001–¥120,000, *(f)* > ¥120,000, *(g)* Prefer not to say; and the USA (USD): *(a)* < $20,000, *(b)* $20,000–$50,000, *(c)* $50,001–$75,000, *(d)* $75,001–$100,000, *(e)* >$100,000’; [2] Consumption frequency categories different for the USA. For Australia and China (a) daily, (b) 4–5 times per week, (c) 2–3 times per week, (d) weekly, (e) fortnightly, (f) monthly, (g) never eat lamb; for the USA (a) daily, (b) weekly, (c) fortnightly, (d) monthly, (e) every other month, (f) 2–3 times per year, (g) never eat lamb.

Table 4.2
F-values, numerator and denominator degrees of freedom (NDF and DDF) for base linear mixed effects models for predicted eating quality scores of tenderness, and juiciness, liking of flavour and overall liking.

Effect	**Tenderness**		**Juiciness**		**Flavour**		**Overall liking**	
	NDF, DDF	***F*-value**	**NDF, DDF**	***F*-value**	**NDF, DDF**	***F*-value**	**NDF, DDF**	***F*-value**
Country	2, 2107	2.50	2, 2225	2.48	2, 2083	3.42 *	2, 2235	1.41
Muscle	1, 9944	69.12 **	1, 10000	105.97 **	1, 10000	104.85 **	1, 9978	146.96 **
Country*muscle	2, 9963	1.29	2, 9978	3.39 *	2, 9997	0.84	2, 9984	0.43
Age	5, 2029	5.45 **	5, 2060	2.01	5, 2055	2.80 *	5, 2054	3.49 *
Gender	-	-	1, 2063	0.14	1, 2061	2.49	1, 2058	2.45
Adults	4, 2021	3.25 *	4, 2050	3.90 *	4, 2052	3.52 *	4, 2048	3.46 *
Children	5, 2001	0.38	-	-	-	-	-	-
Income level (country)	17, 2021	2.68 **	-	-	17, 2052	1.88 *	17, 2047	2.13 *
Consumption frequency (country)	17, 2024	0.96	17, 2053	1.21	17, 2054	1.06	17, 2053	1.25
Country*age	10, 2032	2.58 *	10, 2063	3.01 **	10, 2058	2.55 *	10, 2058	2.36 *
Country*gender	-	-	-	-	2, 2062	4.71 *	2, 2058	3.88 *
Country*adults	8, 2023	1.11	8, 2051	2.76 *	-	-	-	-
Country*children	10, 2024	0.90	-	-	-	-	-	-

Effect	**Tenderness**		**Juiciness**		**Flavour**		**Overall liking**	
	NDF, DDF	***F*-value**	**NDF, DDF**	***F*-value**	**NDF, DDF**	***F*-value**	**NDF, DDF**	***F*-value**
Muscle*age	5, 9961	2.67 *	5, 9990	3.36 *	5, 10000	1.89 *	5, 9938	1.70
Muscle*gender	-	-	1, 10000	6.77 *	-	-	-	-
Muscle*adults	4, 9957	0.88	-	-	-	-	-	-
Muscle*children	5, 9942	1.17	-	-	-	-	-	-
Muscle*income level(country)	-	-	-	-	17, 10000	1.69 *	17, 9929	1.94 *
Muscle*consumption frequency(country)	17, 9952	2.71 **	17, 9989	1.71 *	17, 10000	2.11 *	17, 9935	2.37 *
Country*muscle*adults	8, 9961	4.15 **	-	-	-	-	-	-
Country*muscle*children	10, 9957	2.96 *	-	-	-	-	-	-
Country*muscle*age	-	-	10, 9987	2.02 *	10, 10000	2.67 *	10, 9934	3.30 **

*: $P < 0.05$: **: $P < 0.001$; - : effect not in final base model after stepwise regression.

Table 4.3

Least square means ± standard error (on a scale of 0–100) of tenderness, juiciness, flavour and overall liking scores of m. longissimus lumborum (LL) and m. semimembranosus (SM) samples by a consumer's country and age group. Values within brackets signify difference from mean of country and muscle type (italics = greater than 3 units from the mean).

Age (years)	Sensory Trait							
	Tenderness		Juiciness		Flavour		Overall Liking	
	Muscle Type: **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**
	Australian consumers							
<20	69.0 ± 2.8 ^{a} (1.1)	64.4 ± 2.8 ^{a} (*7.8*)	70.0 ± 2.6 ^{abc} (0.5)	65.7 ± 2.6 ^{b} (*5.6*)	71.4 ± 2.6 ^{ab} (2.3)	66.5 ± 2.6 ^{a} (*5.7*)	72.4 ± 2.6 ^{b} (2.3)	68.2 ± 2.6 ^{d} (*7.0*)
20–25	66.9 ± 2.9 ^{ac} (−1.0)	59.2 ± 2.9 ^{ac} (2.6)	69.6 ± 2.6 ^{abc} (0)	64.3 ± 2.6 ^{b} (*4.2*)	69.3 ± 2.5 ^{ab} (0.2)	65.9 ± 2.5 ^{ab} (*5.1*)	69.9 ± 2.6 ^{ab} (−0.2)	65.5 ± 2.6 ^{cd} (*4.4*)
26–30	65.4 ± 3.0 ^{b} (−2.5)	49.9 ± 3.0 ^{b} (*−6.7*)	67.9 ± 2.7 ^{ab} (−1.6)	55.1 ± 2.7 ^{a} (*−5.0*)	65.6 ± 2.6 ^{a} (*−3.6*)	54.0 ± 2.7 ^{d} (*−6.8*)	66.2 ± 2.7 ^{a} (*−3.9*)	53.6 ± 2.7 ^{a} (*−7.5*)
31–39	69.3 ± 2.3 ^{bc} (1.4)	53.8 ± 2.3 ^{bc} (−2.9)	70.4 ± 2.1 ^{bc} (0.9)	58.5 ± 2.1 ^{a} (−1.7)	69.9 ± 2.0 ^{ab} (0.7)	59.2 ± 2.0 ^{c} (−1.6)	70.9 ± 2.0 ^{ab} (0.8)	59.5 ± 2.1 ^{b} (−1.7)
40–60	68.0 ± 2.1 ^{bc} (0.2)	55.5 ± 2.1 ^{bc} (−1.2)	66.3 ± 1.8 ^{a} (*−3.2*)	57.3 ± 1.8 ^{a} (−2.8)	66.9 ± 1.7 ^{a} (−2.2)	58.9 ± 1.8 ^{c} (−2.0)	68.2 ± 1.8 ^{ab} (−1.9)	59.7 ± 1.8 ^{b} (−1.4)
>60	68.6 ± 3.1 ^{ac} (0.7)	57.0 ± 3.2 ^{ac} (0.4)	73.0 ± 2.7 ^{c} (*3.4*)	59.9 ± 2.7 ^{ab} (−0.2)	71.7 ± 2.7 ^{b} (2.6)	60.4 ± 2.7 ^{bc} (−0.5)	72.7 ± 2.7 ^{b} (2.7)	60.4 ± 2.7 ^{bc} (−0.7)
	Chinese consumers							
<20	60.5 ± 4.6 ^{a} (*−3.5*)	47.6 ± 4.6 ^{a} (*−4.2*)	61.0 ± 2.7 ^{ab} (−1.8)	54.7 ± 2.7 ^{b} (−2.5)	63.4 ± 2.9 (−1.6)	49.7 ± 2.9 ^{a} (*−6.3*)	66.4 ± 2.9 (−0.9)	51.2 ± 2.9 ^{a} (*−5.5*)
20–25	63.2 ± 4.1 ^{a} (−0.8)	51.0 ± 4.1 ^{a} (−0.7)	61.8 ± 1.7 ^{a} (−1.0)	56.6 ± 1.7 ^{b} (−0.6)	64.2 ± 1.9 (−0.8)	53.5 ± 1.9 ^{ac} (−2.6)	67.2 ± 2.0 (−0.1)	54.4 ± 2.0 ^{a} (−2.2)
26–30	63.7 ± 4.0 ^{a} (−0.2)	51.0 ± 4.0 ^{a} (−0.8)	64.2 ± 2.0 ^{ab} (1.4)	57.9 ± 2.0 ^{ab} (0.7)	65.4 ± 1.9 (0.4)	55.5 ± 1.9 ^{bc} (−0.5)	67.1 ± 2.0 (−0.2)	56.6 ± 2.0 ^{ab} (0)
31–39	61.9 ± 4.7 ^{a} (−2.1)	47.4 ± 4.7 ^{a} (*−4.4*)	59.9 ± 3.2 ^{ab} (−2.9)	53.2 ± 3.2 ^{b} (−4)	65.0 ± 3.1 (−0.1)	55.9 ± 3.1 ^{acd} (−0.1)	66.7 ± 3.1 (−0.6)	56.1 ± 3.1 ^{ab} (−0.6)
40–60	67.1 ± 4.0 ^{b} (*3.2*)	55.6 ± 4.0 ^{b} (*3.9*)	66.0 ± 2.1 ^{b} (*3.2*)	59.6 ± 2.1 ^{ab} (2.4)	65.5 ± 2.1 (0.4)	60.3 ± 2.1 ^{d} (*4.2*)	67.9 ± 2.2 (0.6)	60.4 ± 2.2 ^{b} (*3.7*)
>60	67.4 ± 4.3 ^{b} (*3.4*)	58.0 ± 4.3 ^{b} (*6.2*)	63.8 ± 2.4 ^{ab} (1)	61.0 ± 2.5 ^{ac} (*3.9*)	66.7 ± 2.5 (1.6)	61.4 ± 2.5 ^{d} (*5.4*)	68.6 ± 2.5 (1.3)	61.4 ± 2.5 ^{b} (*4.7*)

Age (years)	**Sensory Trait**							
	Tenderness		**Juiciness**		**Flavour**		**Overall Liking**	
	Muscle Type: **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**
				American consumers				
<20	72.0 ± 2.5 ^{a} (−1.2)	56.4 ± 2.6 ^{a} (−1.1)	67.9 ± 2.2 ^{abc} (−0.4)	57.8 ± 2.2 ^{ab} (−0.3)	69.5 ± 2.1 ^{ab} (1.5)	64.4 ± 2.1 ^{ac} (*3.2*)	70.0 ± 2.2 ^{ab} (1.4)	62.0 ± 2.2n^{b} (2.9)
20–25	69.6 ± 2.0 ^{a} (*−3.7*)	55.1 ± 2.0 ^{a} (−2.4)	65.3 ± 1.4 ^{a} (−2.9)	57.6 ± 1.4 ^{a} (−0.4)	65.6 ± 1.4 ^{a} (−2.3)	59.7 ± 1.4 ^{bd} (−1.4)	65.8 ± 1.4 ^{a} (−2.7)	57.4 ± 1.4 ^{ac} (−1.7)
26–30	72.2 ± 2.8 ^{a} (−1.1)	52.2 ± 2.8 ^{a} (*−5.4*)	65.6 ± 2.3 ^{ab} (−2.6)	52.8 ± 2.3 ^{b} (*−5.2*)	65.5 ± 2.2 ^{ab} (−2.5)	56.4 ± 2.2 ^{b} (*−4.8*)	65.9 ± 2.3 ^{a} (−2.7)	53.1 ± 2.3 ^{a} (*−6.0*)
31–39	72.5 ± 2.5 ^{a} (−0.7)	56.8 ± 2.5 ^{a} (−0.7)	68.4 ± 2.2 ^{abc} (0.2)	59.1 ± 2.2 ^{a} (1.1)	67.2 ± 2 ^{ab} (−0.7)	60.5 ± 2.0 ^{bcd} (−0.6)	68.1 ± 2.1 ^{ab} (−0.5)	59.3 ± 2.1 ^{bc} (0.2)
40–60	76.4 ± 2.3 ^{b} (*3.2*)	60.5 ± 2.3 ^{b} (3.0)	70.9 ± 1.8 ^{bc} (2.6)	59.3 ± 1.8 ^{a} (1.2)	70.0 ± 1.7 ^{b} (2.0)	61.8 ± 1.7 ^{acd} (0.7)	70.9 ± 1.7 ^{b} (2.4)	59.7 ± 1.7 ^{bc} (0.6)
>60	76.7 ± 3.6^{b} (*3.5*)	64.3 ± 3.7 ^{b} (*6.7*)	71.3 ± 3.1 ^{c} (*3.1*)	61.5 ± 3.2 ^{a} (*3.5*)	70.0 ± 3.0 ^{ab} (2.0)	64.1 ± 3.0 ^{acd} (3.0)	70.6 ± 3.1 ^{ab} (2.0)	63.1 ± 3.1 ^{bc} (*4.0*)

$^{a, b, c, d}$ Values within a column, country and muscle type with different superscript letters, differ significantly at $P < 0.05$.

4.3.2.2 Number of Adults and Children in a Household

Number of adults in a household when averaged across all countries and muscle types had an impact on tenderness, juiciness, flavour and overall liking scores ($P < 0.05$; Table 4.2; individual data not shown). In general, households with more adults present scored higher eating quality scores than those containing less adults. Households with 3 adults scored tenderness, and juiciness higher than households with 1 and 2 adults (3.0 units; $P < 0.05$), and 1, 2 and 5 adults (3.0 to 3.3 units; $P < 0.05$) respectively. Similarly, flavour and overall liking was also scored highest by households of 3 adults compared to 2 and 4 adult households (1.8 to 3.2 units; $P < 0.05$). These trends differed across country and muscle for tenderness and juiciness ($P < 0.05$; Table 4.2).

Within Australia, LL samples scored 6.6 tenderness units higher in households of 4 adults compared to 5, while households of 3 and 5 adults scored SM samples 6.2 to 7.2 units higher than 1 and 2 adults. Within China, households of 5 adults scored LL tenderness about 4.9 units higher than 1 and 4 adults, and within the USA households with 1 and 3 adults scored LL tenderness 4.7 and 5 units higher than 2 adults. Number of adults within a household did not have an impact on tenderness scoring of the SM for American and Chinese consumers. For juiciness, on average across both muscles, Australian consumers with households of 3 and 4 adults scored 3.8 to 5.8 units higher than all other categories. Within China juiciness scores did not differ based on number of adults in a household. American consumers of households with 1 and 3 adults scored juiciness 4.6 to 6.5 units higher than households of 2 and 5 adults.

Comparing within adult categories (Table 4.2; individual data not shown), American tenderness LL scores were greater than Australian for 1 and 5 adults (7.4 and 10.4 units; $P < 0.05$) and Chinese in 1, 3 and 4 adults in a household (9.3 to 12.4 units; $P < 0.05$). SM scores largely did not differ by country. Within adult categories, Australian consumer juiciness scores were greater than Chinese for 2, 3 and 4 adults (4.7 to 5.8; $P < 0.05$) and American for 4 adults in a household. American juiciness scores were also higher than Chinese for 1 and 3 adults in a household (9.6 and 4.7 units). There was no difference in countries for 5 adults in a household.

Number of children within a household only had an impact on tenderness scores ($P < 0.05$; Table 4.2; individual data not shown). American consumers reported no tenderness differences in LL samples across the number of children in a household, whereas for the SM households with 5 children scored tenderness 12.9 to 16.1 units higher than those with 0 to 3 children ($P < 0.05$). Within Australia and China, the number of children within a household had no detectable impact on tenderness scores. Differences across the three countries were similar to those found for other demographic traits. For households with 0 and 1 children, Australian and American consumers scored tenderness 7.0 to 10.3 units higher than China for the LL and SM. For households of 2 and 3 children, Americans scored the LL higher than Chinese consumers (9.5 and 12.3; $P < 0.05$), and for households of 5 children, Americans score the SM 13.9 units greater than Australians ($P < 0.05$). No country difference was reported for SM samples in 3 children, LL and SM samples in 4 children and LL samples in households of 5 children.

4.3.2.3 Consumer Gender

Consumer gender had a significant impact on flavour and overall liking, but only for American consumers ($P < 0.05$; Table 4.2). American males scored flavour and overall liking 3.6 and 3.5 units higher than females ($P < 0.05$; individual data not shown) However, country differences were detected with American and Australian males scoring flavour and overall liking higher than Chinese males (4.0–6.4 units; $P < 0.05$; individual data not shown), while female scores across the three countries were not significantly different.

4.3.2.4 Consumer Income

Within each country, consumer income bracket had a significant impact on sensory scores of tenderness, flavour and overall liking ($P < 0.05$; Table 4.2 and Table 4.4). This effect varied within each country, though a cross-country comparison could not be made as the local currency was used in questionnaires. Overall, income had the greatest influence on sensory scores for Australian consumers of low income, and middle-income Chinese consumers.

Australian consumers within lower income brackets tended to score tenderness, flavour and overall liking higher than those within higher income brackets with the exception of those within the >$150,000 category (Table 4.4). For tenderness, on average, consumers with income <$100,000 scored 3.9 to 9.3 units higher than those in higher income brackets. For flavour, the two income brackets ranging from $25,000 to $75,000 demonstrated scores 3.7 to 6.3 units higher compared to categories $75,000 to $120,000. Similarly, average overall liking scores were greatest for lower income earners (<$75,000) with increases ranging from 4.3 to 8.1 units compared to higher income categories. This income difference also varied slightly between muscle types for flavour and overall liking ($P < 0.05$; Table 4.2; individual data not shown) but typically lower income earners scored flavour and overall liking more favourably than higher income earners both in LL and SM muscle ($P < 0.05$; Table 4.2 and Table 4.4; individual data not shown).

Within China, there was no consistent trend observed for income bracket. Tenderness only differed amongst those who preferred not to divulge their income and earners within the ¥60,001–¥96,000 category. For flavour and overall liking, on average, consumers within the income bracket ¥36,001 to ¥60,000 scored 4.7 to 5.3 units lower than the income brackets immediately above and below. This varied between the muscles, flavour LL scores increased with higher income up to ¥96,000, while improvements in scoring were limited to bracket ¥24,000 to ¥36,000 for the SM. Similarly, greater overall liking scores of the LL were restricted to ¥24,000 to ¥36,000 ($P < 0.05$; Table 4.2 and Table 4.4; individual data not shown) with no detectable difference for the SM.

Similar to Chinese consumers, there was no consistent impact of income on sensory scores for American consumers. Participants within income bracket US$75,001 to $100,000 scored tenderness on average 3.5 units higher than income brackets immediately above and below. Flavour scores were on average 3.8 to 4.4 units higher amongst the income brackets <US$50,000 and US$75,001 to $100,000, following the same trend for LL and SM muscles (3.8 to 4.8 units higher). Overall liking scores were on average, 3.5 to 4.9 units higher in earners <US$50,000 per annum, again with LL and SM following the same trend ($P < 0.05$; Table 4.2 and Table 4.4; individual data not shown).

4.3.2.5 Meat Consumption Habits

Of all meat consumption habits analysed, only frequency of consumption had a significant impact on eating quality scores. This was observed for tenderness, juiciness, flavour and overall liking and varied across muscles ($P < 0.05$; Table 4.2 and Table 4.5). The general trend was similar across countries with higher consumption frequency having a positive influence on sensory scores, however statistical comparisons between countries was not possible given different scales were used. Typically, more frequent lamb consumption habits increased eating quality scores, however for LL samples, Australian and Chinese scoring was largely unaffected by frequency of consumption, with significant differences only observed for juiciness. Daily consumers of lamb within Australia scored LL juiciness 16.8 to 22.5 units higher than those in lower frequency categories, similarly Chinese consumers who more frequently eat lamb scored juiciness 11.4 to 11.7 units higher than those that never eat lamb ($P < 0.05$; Table 4.2 and Table 4.5). As for the SM, the more frequent consumption habits (daily consumers) of Australian consumers resulted in higher scoring for tenderness (15.1–17.7 units), flavour (13.9–14.3 units) and overall liking (20.4–26.5 units) than those who had lower consumption habits. Similarly, Chinese consumers with greater consumption frequency habits scored tenderness (9.6–19.7 units), juiciness (3.1–17.2 units), flavour (11.7–20.4 units) and overall liking (4.3–17.2 units) higher than those in lower consumption categories. Within the USA, consumers that eat lamb monthly consistently scored LL tenderness, juiciness, flavour and overall liking (4.9–8.4 units) higher than those in categories of more and less frequent consumption. In contrast to Australian and Chinese consumers, the highest American consumption group (once per week) scored LL flavour and overall liking (10.1–18 units) lower than those that eat lamb less frequently. SM scoring was unaffected by frequency of consumption across all eating quality traits.

Table 4.4

Least square means ± standard error (on a scale of 0–100) of tenderness, juiciness, flavour and overall liking scores of sheepmeat samples by a consumer's income bracket. Values within brackets signify difference from mean of country and muscle type (italics = greater than 3 units from the mean).

Income	**Sensory trait**			
	Tenderness	**Juiciness**	**Flavour**	**Overall liking**
Australian consumers (AUD)				
<$25,000	63.9 ± 2.6 ^{abc} (1.6)	67.3 ± 2.5 (2.8)	66.0 ± 2.4 ^{ab} (1.0)	67.4 ± 2.4 ^{bc} (1.8)
$25,000–$50,000	67.9 ± 2.3 ^{a} (*5.7*)	66.6 ± 2.2 (2.1)	68.4 ± 2.1 ^{b} (*3.4)*	70.3 ± 2.1 ^{c} (*4.7)*
$50,001–$75,000	64.1 ± 2.1 ^{ab} (1.8)	65.8 ± 2.0 (1.3)	65.8 ± 1.9 ^{ab} (0.8)	66.6 ± 2.0 ^{bc} (1.0)
$75,001–$100,000	63.1 ± 2.1 ^{bc} (0.9)	63.5 ± 2.0 (−1.0)	63.8 ± 1.9 ^{a} (−1.2)	64.4 ± 1.9 ^{ab} (−1.2)
$100,001–$125,000	58.6 ± 2.3 ^{d} (*−3.6*)	61.9 ± 2.1 (−2.7)	62.1 ± 2.0 ^{a} (−2.9)	62.2 ± 2.1 ^{a} (*−3.4*)
$125,001–$150,000	60.1 ± 2.4 ^{bcd} (−2.1)	63.1 ± 2.3 (−1.5)	64.4 ± 2.2 ^{ab} (−0.6)	64.1 ± 2.2 ^{ab} (−1.5)
>$150,000	62.4 ± 2.2 ^{bc} (0.1)	64.4 ± 2.1 (−0.1)	65.4 ± 2.0 ^{ab} (0.4)	65.7 ± 2.0 ^{ab} (0.1)
Prefer not to say	57.9 ± 2.3 ^{d} (*−4.4*)	63.6 ± 2.1 (−0.9)	64.0 ± 2.1 ^{a} (−1.0)	64.1 ± 2.1 ^{ab} (−1.5)
Chinese consumers (Yuan)				
≤¥24,000	57.3 ± 3.3 ^{ab} (−0.6)	59.5 ± 1.8 (−0.2)	60.4 ± 1.7 ^{ab} (−0.2)	61.3 ± 1.7 ^{a} (−0.7)
¥24,000–¥36,000	59.3 ± 3.5 ^{ab} (1.4)	62.3 ± 1.9 (2.6)	62.8 ± 1.8 ^{a} (2.3)	64.7 ± 1.8 ^{b} (2.7)
¥36,001–¥60,000	57.5 ± 3.6 ^{ab} (−0.4)	59.4 ± 2 (−0.3)	58.0 ± 1.9 ^{b} (−2.5)	60.0 ± 1.9 ^{a} (−2.0)
¥60,001–¥96,000	61.4 ± 3.7 ^{a} (*3.5*)	63.5 ± 2.3 (*3.8*)	63.4 ± 2.2 ^{a} (2.8)	64.1 ± 2.2 ^{ab} (2.1)
¥96,001–¥120,000	55.5 ± 4.6 ^{ab} (−2.4)	57.7 ± 3.5 (−2.0)	57.8 ± 3.4 ^{ab} (−2.7)	61.0 ± 3.5 ^{ab} (−1.0)
>¥120,000	58.7 ± 4.1 ^{ab} (0.8)	56.5 ± 2.9 (*−3.2*)	61.5 ± 2.8 ^{ab} (0.9)	62.8 ± 2.8 ^{ab} (0.8)
Prefer not to say	55.4 ± 3.6 ^{b} (−2.5)	59.0 ± 2.3 (−0.7)	59.9 ± 2.2 ^{ab} (−0.6)	60.2 ± 2.3 ^{ab} (−1.8)

Income	Sensory trait			
	Tenderness	Juiciness	Flavour	Overall liking
American consumers (USD)				
<$20,000	67.3 ± 2.2 [ab] (1.9)	65.2 ± 1.8 (2.0)	66.4 ± 1.7 [a] (1.9)	66.3 ± 1.7 [a] (2.5)
$20,000–$50,000	64.6 ± 2.0 [ab] (−0.8)	63.2 ± 1.7 (0.1)	66.0 ± 1.5 [a] (1.5)	65.2 ± 1.6 [a] (1.4)
$50,001–$75,000	64.0 ± 2.0 [a] (−1.5)	62.0 ± 1.7 (−1.2)	62.0 ± 1.6 [b] (−2.5)	61.6 ± 1.6 [bc] (−2.2)
$75,001–$100,000	67.4 ± 2.0 [b] (2.0)	64.0 ± 1.7 (0.8)	66.1 ± 1.6 [a] (1.5)	64.6 ± 1.6[ac] (0.7)
>$100,000	63.8 ± 1.9 [a] (−1.6)	61.4 ± 1.6 (−1.8)	62.2 ± 1.6 [b] (−2.3)	61.4 ± 1.6 [bc] (−2.4)

[a, b, c, d] Values within a column and country with different superscript letters, differ significantly at $P < 0.05$.

Table 4.5

Least square means ± standard error (on a scale of 0–100) of tenderness, juiciness, flavour and overall liking scores of LL and SM samples by a consumer's consumption frequency of sheepmeat. Values within brackets signify difference from mean of country and muscle type (italics = greater than 3 units from the mean).

	Sensory Trait							
	Tenderness		Juiciness		Flavour		Overall Liking	
Consumption Frequency	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**
Australian consumers								
Daily	72.5 ± 7.4 (*4.5*)	69.6 ± 7.3 ^{b} (*13.1*)	85.1 ± 7.2 ^{b} (*15.5*)	70.0 ± 7.1 (*9.9*)	77.6 ± 7.1 (*8.4*)	72.8 ± 7.0 ^{b} (*12.0*)	79.7 ± 7.2 (*9.6*)	81.0 ± 7.1 ^{b} (*19.9*)
4–5/week	63.7 ± 4.5 (*−4.3*)	53.4 ± 4.5 ^{a} (*−3.1*)	62.6 ± 4.3 ^{a} (*−7.0*)	55.2 ± 4.3 (*−5.0*)	63.3 ± 4.2 (*−5.9*)	60.3 ± 4.2 ^{ab} (−0.5)	65.7 ± 4.3 (*−4.4*)	60.6 ± 4.3 ^{a} (−0.5)
2–3/week	68.7 ± 1.9 (0.8)	55.4 ± 1.9 ^{a} (−1.1)	68.3 ± 1.7 ^{a} (−1.3)	59.6 ± 1.7 (−0.5)	69.7 ± 1.7 (0.6)	60.4 ± 1.7 ^{ab} (−0.4)	70.8 ± 1.7 (0.7)	59.4 ± 1.7 ^{a} (−1.7)
1/week	67.7 ± 1.6 (−0.2)	51.9 ± 1.6 ^{a} (*−4.6*)	67.3 ± 1.2 ^{a} (−2.3)	57.1 ± 1.2 (−3)	69.6 ± 1.2 (0.5)	58.5 ± 1.1 ^{a} (−2.3)	70.3 ± 1.2 (0.2)	56.8 ± 1.2 ^{a} (*−4.4*)
Fortnightly	68.6 ± 1.7 (0.6)	51.9 ± 1.7 ^{a} (*−4.6*)	67.6 ± 1.4 ^{a} (−1.9)	57 ± 1.4 (*−3.1*)	68.4 ± 1.3 (−0.8)	58.9 ± 1.3 ^{a} (−2.0)	70 ± 1.4 (0)	56.9 ± 1.4 ^{a} (*−4.2*)
Monthly	66.9 ± 1.7 (−1.1)	54.5 ± 1.7 ^{a} (−2.0)	67.1 ± 1.4 ^{a} (−2.4)	59.6 ± 1.4 (−0.5)	69.2 ± 1.3 (0.1)	59.5 ± 1.3 ^{ab} (−1.3)	69.6 ± 1.4 (−0.4)	58.7 ± 1.4 ^{a} (−2.4)
Never eat	67.8 ± 7.3 (*9.5*)	58.7 ± 7.6 ^{ab} (2.2)	68.9 ± 7.1 ^{ab} (7.6)	62.4 ± 7.3 (2.2)	66.2 ± 6.9 (*3.3*)	55.4 ± 7.2 ^{ab} (*−5.4*)	64.3 ± 7.0 (1.1)	54.6 ± 7.2 ^{a} (*−6.6*)
Chinese consumers								
Daily	58.2 ± 7.5 (*−5.5*)	54.2 ± 7.6 ^{abc} (2.2)	55.1 ± 6.5 ^{ab} (*−7.7*)	56.4 ± 6.6 ^{ab} (−0.7)	65.1 ± 6.4 (0.1)	60.0 ± 6.5 ^{a} (*4.0*)	69.1 ± 6.4 ^{ab} (1.8)	62.3 ± 6.5 ^{ac} (*5.6*)
4–5/week	59.4 ± 6.3 (*−4.3*)	62.2 ± 6.3 ^{c} (*10.2*)	64.1 ± 5.1 ^{ab} (1.3)	67.0 ± 5.1 ^{a} (*9.8*)	62.6 ± 5.0 (−2.4)	63.6 ± 5.0 ^{a} (7.6)	67.2 ± 5.1 ^{ab} (−0.1)	64.0 ± 5.1 ^{a} (*7.3*)
2–3/week	67.6 ± 4.0 (*3.9*)	52.9 ± 3.9 ^{bc} (0.9)	66.5 ± 1.9 ^{a} (*3.7*)	57.6 ± 1.9 ^{ab} (0.4)	66.1 ± 1.8 (1.0)	57.9 ± 1.8 ^{a} (1.8)	68.0 ± 1.9 ^{ab} (0.6)	58.1 ± 1.9 ^{a} (1.4)
1/week	68.0 ± 3.7 (*4.3*)	49.2 ± 3.7 ^{ab} (−2.8)	66.6 ± 1.5 ^{a} (*3.8*)	55.5 ± 1.5 ^{bc} (−1.7)	67.2 ± 1.5 (2.1)	54.9 ± 1.5 ^{a} (−1.2)	68.7 ± 1.5 ^{ab} (1.3)	53.8 ± 1.5 ^{bc} (−2.9)
Fortnightly	67.0 ± 3.7 (*3.3*)	52.1 ± 3.7 ^{bc} (0.1)	66.3 ± 1.5 ^{a} (*3.4*)	58.5 ± 1.5 ^{ac} (1.4)	66.7 ± 1.4 (1.6)	57.6 ± 1.4 ^{a} (1.6)	69.1 ± 1.5 ^{b} (1.8)	56.6 ± 1.5 ^{ac} (−0.1)
Monthly	66.5 ± 3.7 (2.8)	51.0 ± 3.7 ^{b} (−1.0)	66.3 ± 1.3 ^{a} (*3.4*)	55.5 ± 1.3 ^{b} (−1.7)	66.6 ± 1.2 (1.6)	55.2 ± 1.2 ^{a} (−0.9)	68.4 ± 1.3 ^{ab} (1.1)	55.3 ± 1.3 ^{ac} (−1.4)
Never eat	59.3 ± 5.5 (*−4.4*)	42.5 ± 5.5^{a} (*−9.6*)	54.9 ± 4.3 ^{b} (*−7.9*)	49.7 ± 4.3 ^{b} (*−7.4*)	61 ± 4.2 (*−4.1*)	43.2 ± 4.2 ^{b} (*−12.8*)	60.8 ± 4.2 ^{a} (*−6.5*)	46.8 ± 4.2 ^{b} (*−9.9*)

	Sensory Trait							
	Tenderness		**Juiciness**		**Flavour**		**Overall Liking**	
Consumption Frequency	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**	*Muscle Type:* **LL**	*Muscle Type:* **SM**
American consumers								
Daily	-	-	-	-	-	-	-	-
1/week	70.8 ± 5.3 ^{ac} (−2.4)	59.0 ± 5.3 (1.3)	62.8 ± 5.0 ^{ab} (*−5.5*)	57.7 ± 5.0 (−0.3)	59.4 ± 4.9 ^{ac} (*−8.6*)	60.8 ± 4.9 (−0.4)	56.3 ± 5.1 ^{a} (*−12.2*)	58.5 ± 5.0 (−0.6)
Fortnightly	72.9 ± 3.5 ^{ac} (−0.3)	57.5 ± 3.4 (−0.2)	69.1 ± 3.2 ^{ab} (0.9)	57.5 ± 3.2 (−0.5)	70.5 ± 3.1 ^{bd} (2.5)	60.3 ± 3.1 (−0.8)	72.3 ± 3.1 ^{bc} (*3.7*)	58.1 ± 3.1 (−1.0)
Monthly	78.1 ± 2.6 ^{a} (*4.9*)	58.8 ± 2.6 (1.1)	72.6 ± 2.1 ^{a} (*4.4)*	58.4 ± 2.2 (0.4)	72.8 ± 2.1 ^{b} (*4.9*)	61.4 ± 2.1 (0.3)	74.3 ± 2.1 ^{b} (*5.8*)	59.8 ± 2.1 (0.7)
Every other month	69.6 ± 2.7 ^{bc} (*−3.5*)	57.4 ± 2.7 (−0.3)	66.6 ± 2.3 ^{b} (−1.6)	57.1 ± 2.3 (−0.9)	68.7± 2.1 ^{abc} (0.8)	61.1 ± 2.2 (−0.1)	69.6 ± 2.2 ^{bc} (1.1)	59.8 ± 2.2 (0.7)
2–3/year	74.5 ± 1.8 ^{a} (1.4)	55.4 ± 1.8 (−2.2)	69.4 ± 1.3 ^{ab} (1.1)	58.2 ± 1.3 (0.2)	69.5 ± 1.1 ^{b} (1.6)	62.5 ± 1.1 (1.4)	70.3 ± 1.2^{bc} (1.8)	59.4 ± 1.2 (0.3)
Never eat	73.2 ± 1.8 ^{bc} (0)	57.9 ± 1.8 (0.3)	69.0 ± 1.3 ^{ab} (0.8)	59.1 ± 1.3 (1.1)	66.8± 1.2 ^{acd} (−1.2)	60.8 ± 1.2 (−0.4)	68.5 ± 1.2^{c} (−0.1)	59.0 ± 1.2 (−0.1)

$^{a, b, c, d}$ Values within a column and country with different superscript letters, differ significantly at $P < 0.05$.

4.4 Discussion

4.4.1 The Effect of Consumer Age Group

In agreement with our hypothesis, consumer age had an impact on all eating quality traits, with older consumers generally scoring samples more favourably than younger consumers, particularly American and Chinese. For Chinese consumers, the tenderness scores of those that were 40 and above were higher across both cuts compared to younger age groups. For juiciness, flavour and overall liking scores a similar pattern was observed, although in this case, it did show some variation across cuts. American consumer tenderness scoring was similar to the Chinese, with those aged above 30 scoring tenderness higher than younger American consumers across both cuts. This trend was also evident for juiciness, flavour and overall liking, yet similar to the Chinese, this also varied across both cuts. In contrast, Australians scored tenderness lower amongst older consumers in both cuts, with the same trend present for juiciness, flavour and overall liking scores in the SM. The reverse was observed for the LL, whereby older consumers tended to score higher than some younger age groups (Table 4.3).

The results for American and Chinese consumers generally align with previous research in sheepmeat (Hastie et al., 2020), where Australian consumers ≥31 years old scored tenderness 11.5 units, and juiciness 9.5 units higher than younger counterparts. In addition, Thompson et al. (2005d) also found Australians 40 to 50 years old scored juiciness 3.5 units higher than 20 to 25 year olds. The magnitude of difference between age categories within this study was comparable to the findings of Hastie et al. (2020) and Thompson et al. (2005d), however, in this study, the impact of age also extended to flavour and overall liking. The consistency of the age group effect across tenderness, juiciness, flavour and overall liking was expected as these traits are all highly correlated, an association shown in this dataset (O'Reilly et al., 2020) and numerous previous studies (Bonny et al., 2016; Pannier et al., 2014b; Polkinghorne et al., 2011). Nonetheless, demographic factors do not routinely impact on all eating quality traits (Hastie et al., 2020; Hwang et al., 2008; Thompson et al., 2005d). Interestingly, Australian consumer scores did not align neatly with previous Australian findings of Hastie et al. (2020) and Thompson et al. (2005d). Discrepancies with previous results could be due to the larger sample size used in the current study compared to Hastie et al. (2020) (n = 720 versus n = 75), or due to generational changes in consumer attitudes over time, given our testing was conducted at least ten years after Thompson et al. (2005d). Alternatively, in contrast to the current findings, there are also studies where there was negligible or no effect of consumer age on eating quality scores in beef for Australian, French, Irish, Korean, Northern Irish and Polish consumers (Bonny et al., 2017; Hwang et al., 2008). The differences found between age groups in the current study suggests tasting sessions should be balanced across age groups to ensure the eating quality preferences represented for the population of interest are not biased. Notably, differences found between Australian consumers in the current study and those of previous studies highlight the importance of testing large numbers of consumers, as well as continued testing over time to capture current population preferences.

4.4.2 The Effect of Number of Adults and Children in a Household

The number of adults in a household had a significant impact on average scores of all sensory traits, while the number of children in a household specifically affected tenderness (P < 0.05; Table 4.2). Participants from American and Australian households largely comprised of one to three adults, while Chinese consumers mainly came from households of three or above, which is consistent with traditional Chinese living arrangements of housing shared with extended family. In each country, a large proportion of consumers had 2 or less children, particularly in America and China, which is perhaps unsurprising given a large proportion of participants were aged 20–25 years old in these countries. When averaged across countries and muscle types, households with three adults consistently scored more favourably than households of more and less adults (up to 3.3 units; P < 0.05). This did however differ by country and muscle for tenderness and juiciness, for example higher tenderness scores corresponded with more adults in a household for Australian and Chinese consumers but not American (Table 4.2). Results partially align with previous research, whereby more adults in a household yielded higher sensory scores, however in the current study the effect on sensory traits varied somewhat and the magnitude of difference was much higher compared to Bonny et al. (2017) (tenderness and overall liking, range 0.5–1.0 units) and Thompson et al. (2005d) (juiciness, range 1.7 to 3.7 units). The effect of the number of children in a household, was restricted to tenderness scores of the SM samples for American consumers, where consumers of households of 5 children scored higher than those of 0 to 3 children (up to 16.1 units; $P < 0.05$). This particular sub-class consisted of only 9 consumers, and as such should be interpreted with caution. Country differences were also observed in scoring for tenderness and juiciness within the adult and children sub-classes. Overall, American and Australian scores were higher than Chinese consumers ($P < 0.05$), these particular subgroup differences may help explain some drivers of the country effect observed for tenderness in the production factor analysis of the same dataset (2020).

4.4.3 The Effect of Consumer Gender

In support of our hypothesis, gender had an impact on eating quality scores but was only evident in American consumers for flavour and overall liking traits. American males scored flavour and overall liking around 3.5 units higher than females. This aligns with previous research of Bonny et al. (2017) and Kubberød et al. (2002) with higher scores observed for males within some countries tested, however the magnitude of effect was almost double in this study compared to Bonny et al. (2017). Some speculation surrounding gender scoring differences, has attributed higher scores to a greater appreciation of meat in the diet, for males in particular (Bonny et al., 2017; Kubberød et al., 2002). Our findings may support this, as there were ten percent more American males than females (Table 4.1), and a higher proportion of males were more frequent lamb consumers and higher appreciators of lamb compared to females (data not shown). Notably, previous research by Huffman et al. (1996) found no impact of gender on sensory scoring for American consumers. Similarly, within our study, there was no difference in scoring between the genders for Australian and Chinese consumers, which aligns with Hwang et al. (2008) testing Australian and Korean sensory responses to grilled and Korean barbequed beef. Chinese females tended towards lower consumption and appreciation of lamb in the diet compared to males, and with around twenty percent more females recruited within the China cohort, a possible negative gender effect was expected but was not apparent. These results are in contrast to findings of Thompson et al. (2005d) and Hastie et al. (2020) demonstrating an improvement in scoring for Australian females compared to males. Lack of a consistent gender effect across the countries suggests the differences found may be a reflection of other societal or inherent red meat consumption preferences, rather than gender alone. However, regardless of the driver, eating quality preferences particular to gender in America were demonstrated and as such require consideration when evaluating palatability of sheepmeat.

4.4.4 The Effect of Consumer Income

Validating our hypothesis, income bracket had an impact on average sensory scores for tenderness, flavour and overall liking, and differed by country and muscle for flavour and overall liking ($P < 0.05$; Table 4.2). The most prominent trend was within Australian consumers, with lower income earners scoring more favourably than higher income earners except for those earning above \$150,000 per annum (up to 9.3 units higher; $P \leq 0.05$; Table 4.4). This result is consistent with Huffman et al. (1996) who demonstrated higher income earners to score sensory traits lower when conducting in home evaluations of beef, with the suggestion that product expectations may be greater in higher income earners. It stands to reason that higher income earners may have easier access to protein sources and premium products, therefore be more frequent consumers and thus more discerning. However, for Australian consumers, distribution of participants across consumption frequency and lamb appreciation categories was very consistent across all income brackets (data not shown), demonstrating Australian income groups were homogenous in regards to consumption preferences.

In contrast to Australian results, there was no consistent impact of income on sensory scoring for Chinese consumers. A tenderness difference was detected for the group who did not want to divulge their income compared to one income bracket, as thus no conclusion can be drawn. Flavour scores increased with rising income up to ¥96,000 for the LL and were higher only for income bracket ¥24,000 to ¥36,000 in the SM, similarly, overall liking increases were restricted to the ¥24,000 to ¥36,000 bracket for the LL and no difference in the SM. Mao et al. [8] reported that in urban areas, income is a strong driver of consumption frequency of sheepmeat with positive attitude changes to sheepmeat accompanying increased income categories. However, within this study, there were no marked differences in frequency of consumption distribution across the income brackets measured (data not shown). Following the same trend as Chinese scoring, there was no consistent pattern of scoring for American consumers across income brackets. Tenderness was scored most favourably by those earning US\$75,000 to \$100,000 per annum, higher flavour scores were reported for those earning under US\$50,000 and US\$75,000 to \$100,000, while overall liking increases were restricted to those earning under US$50,000 (up to 4.9 units higher; $P \leq 0.05$; Table 4.4). This is in partial agreement with Huffman et al. (1996) whereby lower income earners scored tenderness, juiciness and flavour more favourably than higher income earners. Income had a significant influence on eating quality scores for all three countries. As such, sensory panels should strive for a balanced representation of different incomes, achieved through sampling of large numbers of consumers and inclusion of different geographic locations.

4.4.5 The Effect of Meat Consumption Habits

Contrary to our hypothesis, appreciation of lamb in the diet and preferred degree of cooking doneness did not have an impact on eating quality scores within this study. In contrast to previous studies (Bonny et al., 2017; Bonny et al., 2016; Hwang et al., 2008; Thompson et al., 2005d), the only meat consumption habit to influence sensory scores was frequency of consumption, which was significant for all sensory traits and varied across muscles (Table 4.1 and Table 4.2). Examination of the number of lamb appreciators spread across consumption frequency categories, showed those that selected highest consumption rates were largely the highest appreciators and vice versa (data not shown). As such, it appears consumption habits and attitudes are largely intertwined. Higher frequency of consumption had positive effect on juiciness scores in the LL for Australian and Chinese consumers ($P \leq 0.05$; Table 4.5), and tenderness, juiciness, flavour and overall liking in the SM ($P \leq 0.05$; Table 4.5). These results should be interpreted with caution as significant differences were detected mainly between the highest and lowest consumption categories within Australian and Chinese consumer groups (these being, daily consumers within Australia (n = 5) and those that never eat lamb in China (n = 15); Table 4.1). Therefore, these results are unlikely to be representative of the wider population.

For American consumers, frequency of consumption had no impact on scores of the SM, however monthly consumers of lamb (n = 64) scored LL tenderness, juiciness, flavour and overall liking up to 8.4 units greater than more and less frequent consumers ($P \leq 0.05$; Table 4.5). Given previous studies have demonstrated a greater appreciation of red meat to impact on sensory scores (Bonny et al., 2017; Bonny et al., 2016; Thompson et al., 2005d), a suggestion for more favourable scores in the American once a month category is that they have a greater proportion of higher appreciators than every other category. Monthly consumption of lamb would likely be considered a higher frequency category in the USA, given annual per capita consumption rates are quite low (Meat and Livestock Australia, 2019b). Therefore, while close to 70% of monthly consumers identified lamb as important in their diet (data not shown), the weekly consumption category who scored LL flavour and overall liking lower, actually had a higher proportion of appreciators, negating this theory. This negative response observed in the most frequent consumers of lamb in the American cohort (weekly; Table 4.1) could be attributed to a preference for locally sourced lamb, as more favourable eating quality scores have been observed for domestic products compared to imported Australian lamb (Phelps et al., 2018b). However, similar to Australia and China, consumer numbers were very low (n = 10) for this group and as such should be interpreted with a degree of caution.

4.5 Conclusions

Confirming our hypothesis, demographic factors had a variable impact on eating quality scores of Australian, Chinese and American consumers testing Australian lamb and yearling samples grilled according to MSA protocols. Demographic attributes of consumer age, gender and number of adults in a household, and income bracket had a significant but different effect within the three countries, occasionally varying by muscle and sensory trait. There was minimal effect of the number of children in a household and no effect of consumer occupation on sensory scores. Contrary to our hypothesis, the importance of sheepmeat and preferred degree of cooking doneness did not impact on eating quality scores for these consumer groups. Frequency of consumption had a significant effect in all three countries, contrasting with previous studies examining the effects of meat consumption habits on sensory scores. However, under-represented consumption categories at either end of the spectrum were largely driving results in this study. Overall, the magnitude of effect for significant attributes in this study were generally greater than those previously reported. This suggests that sensory panels within Australia, China and the USA should be balanced where possible, for demographic factors of age, gender, number of adults in a household and income, with the aim of reducing any bias on sheepmeat sensory scores. Challenges of bias can be overcome through recruitment of sufficiently large populations, and inclusion of geographically diverse locations to help ensure the most accurate representation of sensory preferences is captured for the population of interest.

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Chapter Five

5

Defining Sheepmeat Eating Quality Thresholds for Chinese, American and Australian Consumers

Manuscript details

Title:	Defining Sheepmeat Eating Quality Thresholds for Chinese, American and Australian Consumers
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Declaration of interests: None

Abstract

The objective of this study was to examine the eating quality weightings and categorisation of Australian lamb and yearling products by American, Chinese and Australian consumers. Grilled *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles from 164 lambs and 168 yearlings were scored and assigned quality grades by 720 untrained consumers per country. Linear discriminate analyses were used to weigh the importance of the eating quality traits (tenderness, juiciness, liking of flavour and overall liking), and determine quality thresholds and accuracy of predicted quality grades compared to actual consumer assigned grades. Chinese consumers allocated a higher proportion of samples to higher quality grades, while American and Australian consumers were more critical. An optimised discriminate function was most accurate for Chinese consumer assignment to quality grades compared to Australian and American predictions. Overall accuracy ranged from 60 to 66% suggesting the MSA model provides adequate accuracy for product segregation on eating quality for these consumer groups.

5.1 Introduction

Providing consistent eating quality of red meat products ensures consumer satisfaction and continued product demand, enhancing economic sustainability for beef and sheep meat industries (Pethick 2006). The Meat Standards Australia (MSA) system is a quality assurance scheme with the ability to reliably predict the eating quality of red meat products is and is well established in Australia for beef (Watson et al., 2008a; Watson et al., 2008b) and under development for sheepmeat (Pannier et al., 2018a; Thompson et al., 2005a). It has proven accurate in predicting beef palatability for Australian consumers (Polkinghorne, 2006; Thompson, 2002), and its application has been examined internationally for consumers in France, Ireland, Japan, Korea, Northern Ireland, Poland, South Africa and the USA (Bonny et al., 2016; Hocquette et al., 2014; Legrand et al., 2013; Polkinghorne et al., 2011). A new cuts-based sheepmeat MSA model has been developed to predict eating quality grades based on untrained Australian consumers with commercialisation activities underway (MLA, 2022). However, it is important to examine the reliability of sheepmeat prediction models in meeting the expectations of consumer groups from other nationalities especially given Australian consumption of lamb is one of the highest in the world (Meat and Livestock Australia, 2020), potentially making Australian consumers more accepting of lamb sensory attributes. American consumers on average have a very low intake of lamb and thus represent a low exposure consumer group, while Chinese consumers generally have higher consumption rates of sheepmeat but utilise very different cooking methods (MLA, 2021b, 2021c). Previous comparisons of American, Australian and Chinese consumers demonstrated minor differences in scoring of Australian grilled sheepmeat, with a consistent response to production factors observed (O'Reilly et al., 2020). However, whether prediction of quality grades differs between Australian, American and Chinese consumers remains unexplored.

The MSA testing protocols require untrained consumers to score samples on tenderness, juiciness, flavour, and overall liking on a scale from 0-100, and allocate these samples to one of four quality grades: unsatisfactory ‘fail’, good everyday ‘3 star’, better than everyday ‘4 star’, or premium quality ‘5 star’. These scores for tenderness, juiciness, flavour, and overall liking contribute to a discriminate analysis. In this analysis a single composite meat quality score is constructed based on the weighted sensory scores and boundaries between the four quality grades, calculated for cut allocation within each grade (Watson et al., 2008a; Watson et al., 2008b). Weightings describe the coefficients assigned to the four sensory traits and give an indication of the relative importance of each trait to the final score. Initial beef research within Australia indicated that tenderness had the largest impact on a quality grade (Watson et al., 2008a), however with testing over time, flavour has proven to have an equal weighting to tenderness and beef models have been adjusted accordingly (Bonny et al., 2016). Notably, cross-cultural comparisons in beef have demonstrated variability in the coefficients assigned to sensory traits for different countries across a range of cooking methods (Bonny et al., 2016; Liu et al., 2020; Polkinghorne et al., 2011, 2014; Thompson et al., 2008). Comparisons of the prediction accuracy of optimised weightings (particular to the country tested) versus pre-existing MSA model weightings (fixed values) have yielded inconsistent results. Polkinghorne et al. (2011) and Thompson et al. (2008) reported a small loss (up to 7%) in grading accuracy of optimal compared to fixed weightings in Japanese and Korean consumers, whereas Bonny et al. (2016) demonstrated up to a 20% reduction in prediction accuracy when the most current beef MSA model coefficients were used versus optimal weightings in European consumer groups. Thus if variation exists between the different countries, this may suggest adjustments to the new sheepmeat model may be required for exported products.

This study examined the ability of optimised discriminate procedures for American, Australian and Chinese untrained consumer scores to accurately predict eating quality grades for Australian lamb and yearling *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles. Given previously demonstrated cross-cultural disparities, we hypothesised that allocation of samples to quality grades, and that the impact of the four sensory traits on a single quality grade would differ between the three countries. In addition, we expected that consumer assessed sensory scores obtained through the MSA testing protocols would accurately predict quality grades within the consumer groups tested.

5.2 Materials and methods

5.2.1 Carcase information and muscle collection

The animals utilised in this study are described in detail by O'Reilly et al. (2020). Briefly, 164 lambs (average slaughter age~ 368 days) and 168 yearlings (average slaughter age~ 726 days) were sourced from the Meat and Livestock Australia genetic resource flock at Kirby, NSW (Fogarty et al., 2007). Lambs (females and wethers) comprised of Maternal, Merino and Terminal sire types, and yearlings were strictly Merino wethers. All animals transported to the abattoir the day prior to slaughter, held in lairage overnight with access to water, and slaughtered the following morning. Medium voltage electrical stimulation was applied to carcases 40 mins post slaughter (Pearce et al., 2010), and chilled at 3-4°C for 24 hours to reach ultimate pH prior to sample collection. Left and right LL (AUS-MEAT 5150) and SM (AUS-MEAT 5077) muscles were collected from every animal for consumer testing. All muscles were trimmed, vacuum packed and aged for ten days prior to frozen transport, either export to China and the USA or retained within Australia. Both left and right muscles (648 LL and 648 SM) were collected from each carcase to allow for a pair-wise allocation of cuts across countries, whereby every carcase was represented in two of three countries for consumer testing at any one time.

5.2.2 Sample preparation and consumer testing

Consumer testing of sheepmeat samples was conducted in accordance with existing MSA grill protocols (Thompson et al., 2005a; Watson et al., 2008a), with updates detailed in O'Reilly et al. (2020). In brief, each muscle was prepared and served to ten consumers, sample allocation was designated using a 6 x 6 Latin square design. All samples were grilled to a medium level of doneness (65 °C internal temperature) using a Silex griller (electric S-Tronic Single Grill S161GR, Hamburg, Germany), and rested before being served to consumers seated in individual booths.

Across Australia, China and the USA a total of 2160 untrained consumers were recruited to participate in one of the 36 tasting sessions (12 sessions per country). Sixty consumers participated in each session totaling 720 consumers per country. Each consumer tasted and evaluated 6 grilled sheepmeat samples (3 LL and 3 SM) for tenderness, juiciness, liking of flavour and overall liking on a scale line of 0 – 100. To indicate the acceptability range of each sensory trait, tenderness and juiciness scale lines were anchored with 'not' and 'very' preceding the trait, and 'dislike extremely' and 'like extremely' were used for liking of flavour and overall liking. In addition to sensory traits, consumers were asked to allocate each sample to one of four quality grades: unsatisfactory 'fail', good everyday '3 star', better than everyday '4 star', or premium '5 star'.

5.2.3 Consumer demographics

Demographic details of the consumers utilised in this study were published by O'Reilly et al. (2020). Consumers were recruited through China Agricultural University and Texas Tech University within China and the USA, and a market research company in Australia. Chinese participants were localised to the community surrounding the university as sessions were run on site. American consumer sessions spanned ten states, and Australian sessions were conducted in the outer suburbs of Melbourne, Victoria. Chinese and American consumer groups largely consisted of 20 to 25 year old participants (49% and 41% respectively), while over half the Australian consumers greater than 40 years old (57%). Gender was consistent for Australia and the USA with 10% more males than females, while the China group had 20% more females to male participants. Lamb consumption rates were highest for Australian consumers, followed by Chinese with 77% and 61% of participants consuming lamb at least once per fortnight. Conversely American consumers had little to no lamb in their regular diet with over 70% of participants consuming lamb 2-3 times per year or less.

5.2.4 Statistical Analysis

The relationship between sensory traits (tenderness, juiciness, liking of flavour and overall liking) and quality grades (unsatisfactory, good everyday, better than everyday, or premium) was determined using a linear discriminate function. Analyses were performed using the statistical computing language R (4.0.4) with the MASS suite of packages for data manipulation and visualization (R Core Team, 2021). Ten consumer scores per muscle were retained in the dataset and the analyses repeated for Australia, China, and the USA and also animal age class (lamb, yearling) within each country.

Optimal weightings of the sensory scores to develop a single composite meat quality score were calculated using the Watson et al. (2008a) method, whereby two discriminate procedures are averaged. The first being the three variable discriminate function, including the tenderness, juiciness, and liking of flavour attributes but excluding overall liking, and the second where all four variables are included. The weightings of each variable between the two functions are averaged to create a compromise, whereby the relative importance of overall liking is reduced in the final function (Watson et al., 2008a). The defined composite meat quality score from this method is referred to as Meat Quality 4 (MQ4) for sheepmeat. Boundary points between two adjacent quality grades can be determined using this method, by assuming the cut-off points are where two adjacent functions are equal. An optimized discriminate analysis and boundary determination was conducted for each country and animal age class within country to examine any differences in the coefficients and boundaries, and compare the accuracy of the discriminate analyses at allocation of quality grades compared to consumer assigned grade for each sample.

5.3 Results

5.3.1 Allocation of sheepmeat samples to eating quality grades

Figure 5.1 demonstrates the proportion of lamb and yearling samples allocated to each of the four quality grades by American, Australian and Chinese consumers. Chinese consumers tended to allocate samples more favourably, consistently designating more samples to better than everyday (37% lamb; 35% yearling) and premium quality grades (27% lamb; 22% yearling) compared to American and Australian consumer allocations to the same categories (better than everyday 25-31%, premium 12-18%). Similarly, the number of samples deemed unsatisfactory (or fail), was lowest for Chinese consumers at 7% for lambs and 10% for yearlings, while American and Australian consumers classified 14 and 16% of lamb samples and 17% of yearling samples unsatisfactory. American and Australian consumer groups allocated their samples relatively consistently with the highest proportion of samples in the good everyday category (41 and 39% for lambs; 46 and 45% for yearlings). In contrast, Chinese consumers had the highest proportion of samples classified as better than everyday quality (37% for lambs; 35% for yearlings). The proportion of samples allocated to better than everyday and premium categories was higher in lambs compared to yearlings for all consumer groups (Figure 5.1).

5.3.2 Sensory score weightings

The importance of the four sensory traits (tenderness, juiciness, liking of flavour and overall liking) as part of the composite meat quality score (MQ4) in determining a final quality grade is demonstrated in Table 5.1. Liking of flavour was the most important factor for Australian consumers for lamb samples and overall, with overall liking contributing more to yearlings quality grades than liking of flavour. Chinese consumer weightings followed the same pattern as Australian consumers however the degree of importance varied little between liking of flavour and overall liking (only up to 0.04). For the American consumers, overall liking was consistently the most important factor contributing to the composite quality grade. For all three consumer groups, juiciness was of least importance when it came to determining a final quality grade for sheepmeat.

The differences between lamb and yearling weightings were most pronounced for American and Australian consumers, with minimal difference detected for Chinese consumers. For American and Australian consumers, the importance of flavour was reduced by 0.06 and 0.14 in yearling samples compared to lambs. Conversely the importance of juiciness increased by 0.04 and 0.07 for yearlings compared to lamb.

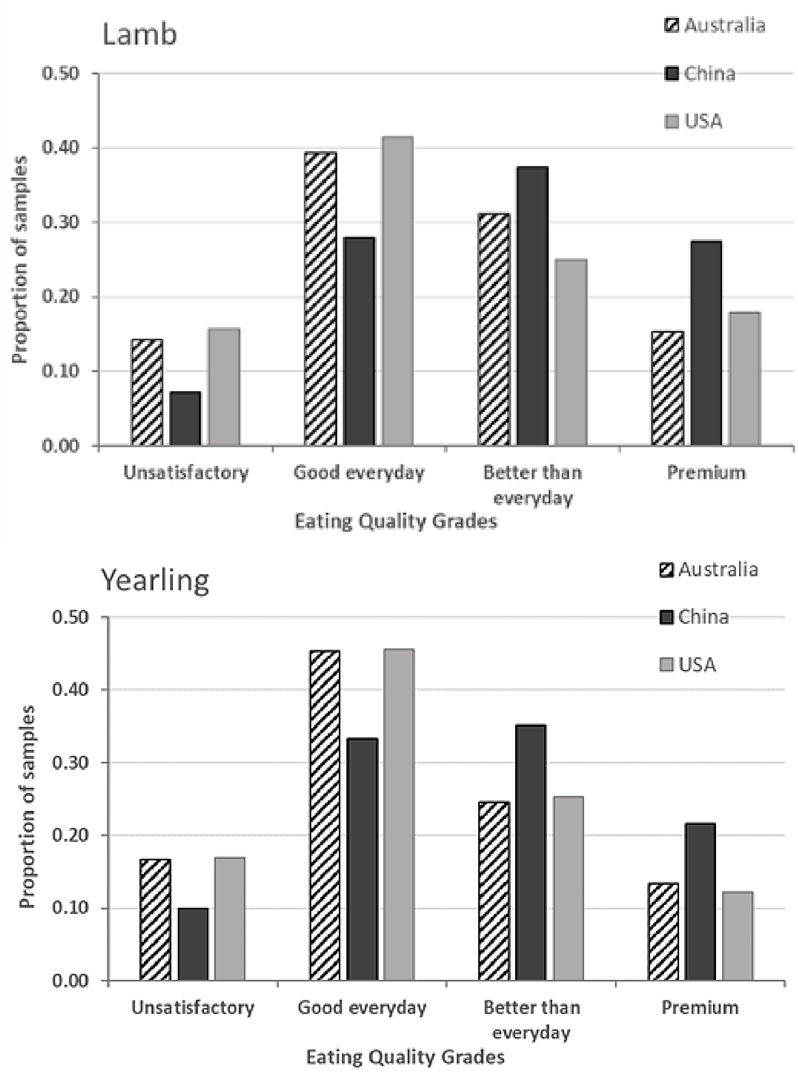

Figure 5.1
Frequency distribution of eating quality grades as allocated by untrained American, Australian and Chinese consumers for lamb and yearling samples. Unsatisfactory (2 star), good everyday (3 star), better than everyday (4 star) and premium (5 star).

Table 5.1
Optimal weightings of sensory traits for the composite meat quality score (MQ4) derived from American, Australian and Chinese consumers eating meat from lamb and yearling sheep.

		Optimal weightings for the composite meat quality score (MQ4)			
Country	**Sheep Category**	**Tenderness**	**Juiciness**	**Flavour**	**Overall liking**
Australia	Lamb + Yearling	0.29	0.08	0.33	0.30
	Lamb	0.28	0.05	0.40	0.27
	Yearling	0.29	0.12	0.26	0.33
China	Lamb + Yearling	0.20	0.04	0.38	0.37
	Lamb	0.21	0.03	0.40	0.36
	Yearling	0.20	0.05	0.37	0.39
USA	Lamb + Yearling	0.25	0.11	0.28	0.36
	Lamb	0.26	0.09	0.31	0.34
	Yearling	0.23	0.13	0.25	0.38

5.3.3 Boundaries between eating quality grades

Table 5.2 presents the boundaries between consumer selected eating quality categories of 2 star (unsatisfactory), 3 star (good everyday), 4 star (better than everyday), and 5 star (premium). These boundaries are the optimal points at which the consumer distinguishes between a 2 to 3 star, 3 to 4 star, 4 to 5 star sample. Chinese consumers had lower cut-offs than American and Australian consumers with all grade boundaries ranging from 6 to 11 points lower. There was little difference between the American and Australian quality boundaries for 3 to 4 star, and 4 to 5 star, while at the 2 to 3 star boundary, the American cut-off was ~3 points higher than the Australian. The range between the upper and lower boundaries was very similar for American, Australian and Chinese consumer groups at 35, 38, and 36 points. Within each consumer group, there was minimal difference between the cut-off points for meat derived from lambs or yearling sheep.

Table 5.2
Grade boundary cut-offs calculated from the discriminate analysis of the composite meat quality score (MQ4) score for American, Australian and Chinese consumers, for lamb and yearling groups.

		Optimal weightings for the composite meat quality score (MQ4)		
Country	**Sheep Category**	**2 to 3 star**	**3 to 4 star**	**4 to 5 star**
Australia	Lamb + Yearling	43	65	81
	Lamb	43	65	81
	Yearling	43	65	81
China	Lamb + Yearling	37	56	74
	Lamb	37	57	74
	Yearling	37	56	74
USA	Lamb + Yearling	46	67	82
	Lamb	46	67	83
	Yearling	47	66	81

5.3.4 Accuracy of the discriminate analysis function

The accuracy of the discriminate function in allocating samples to quality grades using optimally weighted attributes for each country, and animal age class group are demonstrated in Table 5.3. The average accuracy of allocating the samples to the correct quality grade was 60, 63, and 66% for American, Australian and Chinese consumer groups. For American and Australian consumer groups, accuracy was consistently the highest within the 3 star (good everyday) category with 73 to 78% of samples correctly allocated to this quality grade. While only 46 to 59% of samples were correctly identified as 4 star (better than everyday) and 5 star (premium) across the American and Australian consumer groups (Table 5.3). In contrast, for Chinese consumers the highest proportion of samples were correctly identified in the 5 star (premium) category for the lamb and overall groups, while the 3 star category had the greatest accuracy for the yearling group. Within the 4 and 5 star categories the Chinese discriminate function was a minimum of 7% more accurate than American and Australian counterparts, and 6% less accurate in the 2 star quality category.

If results are examined through the scope of satisfaction, that is, the proportion of samples correctly estimated at their actual quality grade combined with the proportion of underestimated samples predicted as 3 and 4 star quality levels (e.g. predicted as 3 star with a actual grade of 4 star), Chinese consumers would be the most *satisfied* with the highest proportion of samples accurately predicted. The number of samples either 3 star and above, 4 star and above, and 5 star were 93%, 80% and 69%. Followed by Australian and then American consumers with satisfaction met or exceeded for 3 star, 4 star, and 5 star 93%, 66% and 57% of the time for Australian consumers, and 92%, 59% and 56% of the time for American consumers.

Table 5.3

Percentage accuracy of the composite meat quality score (MQ4) discriminate function to allocate sheepmeat samples to consumer assigned quality grade for American, Australian and Chinese consumers for lamb and yearling samples. The true grade represents the quality grade allocated by the consumer, while the assigned grade (MQ4) represents the predicted quality grade.

Assigned grade (MQ4)	True grade (consumer)											
	Australia Lamb + Yearling				**China Lamb + Yearling**				**USA Lamb + Yearling**			
	2 star	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**
2 star	**61.6**	37.4	0.8	0.2	**51.6**	46.0	2.3	0.2	**59.9**	38.0	1.8	0.3
3 star	7.3	**75.7**	16.1	0.9	6.1	**67.2**	25.6	1.1	7.9	**73.1**	17.9	1.2
4 star	0.8	33.9	**55.3**	10.0	0.4	18.1	**66.5**	15.0	0.9	41.1	**46.7**	11.2
5 star	0.1	5.7	37.7	**56.5**	0.0	1.1	28.2	**70.7**	0.0	9.5	34.7	**55.8**
	Australia Lamb				**China Lamb**				**USA Lamb**			
	2 star	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**
2 star	**62.3**	36.5	1.0	0.3	**52.3**	45.1	2.6	0.0	**59.3**	39.0	1.3	0.4
3 star	6.9	**72.1**	19.8	1.2	5.3	**65.8**	27.6	1.3	7.6	**73.3**	17.5	1.7
4 star	0.7	30.6	**58.5**	10.2	0.4	18.2	**66.1**	15.3	0.9	38.5	**46.4**	14.2
5 star	0.0	5.2	39.3	**55.5**	0.0	1.2	27.7	**71.1**	0.0	7.1	33.5	**59.5**
	Australia Yearling				**China Yearling**				**USA Yearling**			
	2 star	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**	**2 star**	**3 star**	**4 star**	**5 star**
2 star	**61.1**	37.9	0.8	0.2	**52.5**	45.2	1.9	0.3	**58.6**	39.1	2.1	0.2
3 star	7.5	**78.0**	13.9	0.5	8.2	**71.2**	19.9	0.7	7.8	**72.9**	18.4	0.9
4 star	1.0	35.4	**52.0**	11.6	0.4	22.3	**65.7**	11.5	0.9	40.2	**48.6**	10.3
5 star	0.0	5.2	35.8	**59.0**	0.0	1.2	32.8	**66.0**	0.0	12.7	35.9	**51.4**

5.4 Discussion

5.4.1 Allocation of sheepmeat samples to quality grades

In agreement with our hypothesis, differences existed between the countries in assigning quality grades, with American and Australian consumers downgrading more samples compared to Chinese consumers for grilled lamb and yearling products. It is conceivable that familiarity with a grill cooking method for American and Australian participants produced more critical appraisal of samples compared to the Chinese participants, whom would be more accustomed to traditional cooking methods of hotpot, roasting and stewing for sheepmeat (Mao et al., 2016). This aligns with the stricter categorisation of samples into quality grades by Japanese and Korean consumers compared to Australians when beef was cooked using traditional methods of yakiniku, shabu shabu and Korean barbeque. In these studies, Japanese and Korean consumers deemed up to 40% of samples unsatisfactory and gave less than 10% a premium grade (Polkinghorne et al., 2011, 2014; Thompson et al., 2008).

Of note, American and Australian consumers distributed samples similarly across the quality grades despite very different consumption habits reported by O'Reilly et al. (2020) using the same consumers. American participants rarely ate lamb (76%) and were largely indifferent to its inclusion in their diet (78%), compared to most Australian participants eating lamb at least once per fortnight (77%) and identifying it as an important protein in their diet (74%). Perhaps the familiar "Western" grill method explains the similar differentiation of quality grades despite varied sheepmeat appreciation levels. Furthermore, American and Australian results align well with previous research in grilled and roasted beef for Australian, French, Irish, and Polish consumers, where the highest proportion of samples were allocated as good everyday quality, with proportions ranging from 30 to 45% (Bonny et al., 2016; Polkinghorne et al., 2014; Thompson et al., 2008). Similar cooking styles can be found across all these countries and may have contributed to these consumer preferences. A small point of difference in this study was that American and Australian consumers were more accepting of sheepmeat samples, with unsatisfactory allocations of less than 17%, compared to 23-33% in beef (Bonny et al., 2016; Polkinghorne et al., 2014; Thompson et al., 2008).

Chinese consumers consistently allocated more samples to better than everyday and premium categories and less samples to unsatisfactory. The overall more favourable quality allocation of samples by Chinese consumers was in contrast to the other consumer groups in this study and previous international beef studies (Bonny et al., 2016; Polkinghorne et al., 2011, 2014; Thompson et al., 2008). Lamb consumption rates were comparable to Australian participants in this study (O'Reilly et al., 2020), however the cooking method was less familiar. Thus, greater quality rankings could be explained by positive Chinese consumer perceptions of Australian lamb, with surveys demonstrating that Chinese consumers identify Australian product to have advantages of superior quality, consistency, tenderness and nutritional value compared to locally sourced product (MLA, 2021b).

For all three consumer groups, age class influenced categorisation of quality grades with a greater proportion of samples in higher quality categories for lamb compared to yearling. This aligns with previous eating quality research in American, Australian, and Chinese consumers demonstrating a preference for lamb samples compared to yearling regardless of cultural background (O'Reilly et al., 2020; Pannier et al., 2018a; Pannier et al., 2015; Pethick et al., 2005). These results also highlight the acceptance of yearling meat in these export markets, given the majority of yearling samples were still allocated to good everyday or higher quality categories.

5.4.2 Sensory score weightings and boundaries between quality grades

Confirming our hypothesis, the optimal weightings of the sensory scores varied between countries. The most important trait in determining the MQ4 score was on average, liking of flavour for Australian and Chinese consumers, and overall liking for American consumers, and juiciness the least important trait for all countries. Overall, Australian consumers ranked flavour most important, followed by overall liking and tenderness, then juiciness. There are no comparisons to be made to sheepmeat, however these results largely align with Australian consumers testing beef cooked using yakiniku, shabu shabu style, and grill (Polkinghorne et al., 2014; Thompson et al., 2010). Grilled beef results historically ranked tenderness as most important, followed by overall liking, flavour and then juiciness (Bonny et al., 2016; Watson et al., 2008a). However more recently, the weightings in the MSA beef model have shifted to equal weightings of 0.3 for tenderness, liking of flavour and overall liking based on updated Australian consumer testing (Polkinghorne et al., 2014; Thompson et al., 2010). Suggesting the importance of these eating quality attributes could reflect evolving product quality over time, i.e. tenderness becomes less important once a consistently high tenderness level is reached for all products (Liu et al., 2020). Therefore we can expect as sheepmeat quality improves, through more informed genetics and supply chain feedback systems, that untrained consumers will need retesting and adjustments should be made to the MSA model, something the system has been designed to accommodate (Polkinghorne et al., 2008). Chinese consumers had a similar ranking of traits to Australian consumers, however the magnitude of difference between flavour and overall liking was minimal (less than 0.04) and could be considered close to equivalent in importance. In addition, there was a larger disparity between these two traits and tenderness (0.17 to 0.19). This is perhaps unsurprising, given flavour features prominently in Chinese consumer studies; a survey spanning 16 provinces demonstrated ~ 80% of consumers liked sheepmeat with a primary reasoning of its nutritional value, then liking of flavour. Alternatively, another survey demonstrated only 40% of Chinese participants liked the flavour of sheepmeat (Mao et al., 2016). The consumers recruited in this study were somewhat akin to the latter survey with only 35% identifying lamb as important in their diet (O'Reilly et al., 2020), however the motivating factors contributing to "importance" were not categorised. In addition, lower rankings for tenderness and juiciness may be carry-over from the traditional Chinese eating experience, as these attributes are not important for the majority of Chinese cooking styles of hotpot, highly sauced meats, stir-fry, and deep-fried foods (Mao et al., 2016; Waldron et al., 2007). For American consumers overall liking was rated most important in discriminating between the quality grades, followed by flavour, tenderness and juiciness. There was a smaller difference between flavour and tenderness than the Australian and Chinese consumers. Results partially agreed with previous international findings with similarities to French and Irish consumers tasting grilled and roasted beef (Bonny et al., 2016; Legrand et al., 2013), however the majority of international consumer groups prioritised flavour (Bonny et al., 2016; Liu et al., 2020; Pogorzelski et al., 2020; Polkinghorne et al., 2014). Nevertheless, correlations between all sensory traits were strong for these consumers (O'Reilly et al., 2020), and highest between liking of flavour and overall liking indicating consumers are likely to score similarly across all dimensions, diminishing the relative importance of weightings.

Results suggest age class has some influence on the relative importance of sensory traits for American and Australian consumers, with reduction in liking of flavour and an increase in the weight of juiciness compared to the other traits for yearling samples compared to lamb. This was more prominent for Australian consumers where juiciness increased by 0.07, and flavour reduced by 0.14 for yearling samples. These findings suggest there was no adverse response to flavour in yearling samples, although it has been reported that increased branch chain fatty acids can contribute to stronger flavour profiles as sheep age (Channon et al., 1997; Watkins et al., 2021). As such a corresponding increase in the weighting of flavour for the older animals compared to lamb may be expected. However, only small differences in liking of flavour were observed between lamb and yearling samples by Pannier et al. (Pannier et al., 2018b) and this effect was largely restricted to the SM over the LL muscle. Furthermore, the data used in this analysis demonstrated a flavour difference of 1.8 scores lower for yearling samples compared to lamb samples (O'Reilly et al., 2020). These studies indicate small flavour differences which may not be strong enough to negatively influence the relative importance of the traits for the yearlings. Conversely, no substantial shift in the relative importance of tenderness was observed, despite American and Australian consumers scoring yearling samples up to 10 units lower than lambs (O'Reilly et al., 2020). Thus, eating quality scores do not necessarily translate into the relative importance of that trait to the consumer. In addition, overall liking became relatively more important for both consumer groups indicating uncaptured age class related factors may influence consumer satisfaction of sheepmeat.

The weightings for Chinese consumers remained consistent across the animal age class categories suggesting their perceptions of quality are unaffected when presented with products of known variation in eating quality (Pannier et al., 2018b; Pethick et al., 2005). This is reinforced by age class results of the same dataset (O'Reilly et al., 2020), where by Chinese consumers scored eating quality higher in lambs than yearlings, demonstrating they do prefer the palatability of lambs however the relative importance of eating quality traits remain stable when ranking the quality of either product.

In partial agreement with our hypothesis, the MQ4 boundary values between quality grades were similar for American and Australian consumers, and higher than Chinese consumers for each quality threshold (unsatisfactory, good everyday, better than everyday, and premium) (Table 5.2). These results reflect the pattern of sample allocation to quality grades (Figure 5.1), with more samples deemed unsatisfactory, and less premium quality for American and Australian consumers. Thompson et al. (Thompson et al., 2008) also found allocation of samples to quality grades by Korean and Australian consumers represented differences found in boundaries. The thresholds for American and Australian consumers in this study are consistent with beef results in Japanese, Korean and Australian consumers (Polkinghorne et al., 2014; Thompson et al., 2008) and higher than those previously reported for most European countries (Bonny et al., 2016). In contrast, Chinese boundaries were lower than most previously published results (Bonny et al., 2016; Polkinghorne et al., 2014; Thompson et al., 2008), with the exception of the better than everyday to premium boundary with Polish consumer thresholds at 73.7 and 74.2 for 6mm and 25mm beef steaks (Pogorzelski et al., 2020). Despite the lower thresholds for Chinese consumers, it appears all three groups utilised a similar range of the hedonistic scale, with differences between the lower (unsatisfactory to good everyday) and upper boundaries (better than everyday to premium), within the range of 35.7 to 37.8 MQ4 scores for all consumer groups. These results are similar to reported values for Australian, Irish and Japanese consumers (Bonny et al., 2016; Polkinghorne et al., 2014; Thompson et al., 2008), suggesting these consumer groups employ similar use of the scale lines to score samples. Not as liberal as French consumers using extreme ends of the scale (Bonny et al., 2016; Legrand et al., 2013), nor as conservative as Polish consumers with a tendency to cluster scores in the middle of the scale (Bonny et al., 2016; Pogorzelski et al., 2020) . These findings suggest that where a product might not meet adequate eating quality standards in one market, it might be exceeding expectations in another.

5.4.3 Accuracy of assigned grade relative to true grade based on composite MQ4 score

The overall accuracy of the MQ4 score for assigning samples to their true quality grades as assigned by consumers was 60%, 63% and 66% for American, Australian and Chinese participants. This aligns well with previous accuracies found in Australian (64-72%), Japanese (60-67%), Irish (64-71%), Korean (65-68%), Polish (64 - 69%), and South African (55-65%) consumers (Bonny et al., 2016; Polkinghorne et al., 2011, 2014; Thompson et al., 2010; Thompson et al., 2008; Watson et al., 2008a). Given the high degree of variation inherent to untrained consumer scores, it will never be possible to achieve perfect categorisation of quality for products. However distinct patterns of allocation to each category can still be observed despite overlapping distributions (Watson et al., 2008a). The consistency of the overall results for each country included in this study indicates that the MSA model is an applicable tool for prediction of quality grades for these diverse consumer groups.

The accuracy of allocation to specific quality categories varied between countries and was contrary to most previous findings. For American and Australian consumers, the discriminate analysis was most accurate for categories good everyday (72-78%), followed by unsatisfactory quality (59-62%). Thompson et al. (2008) reported a similar trend for Australian and Korean consumers testing grilled and BBQ beef, however their accuracies were higher for unsatisfactory and good everyday categories (71-88%), and lower for the better than everyday and premium categories (25-67%). The majority of international MSA consumer testing demonstrates the highest accuracy at extremes of the quality range, with premium and unsatisfactory accuracy of allocation ranging from 72 to 86%, and accuracy of good everyday and better than everyday categories ranging 34 to 75% (Bonny et al., 2016; Pogorzelski et al., 2020; Polkinghorne et al., 2011; Thompson et al., 2008; Watson et al., 2008a). It is proposed the overlap in functions for the two mid-quality grades is responsible for the lower accuracies observed for these categories (Pogorzelski et al., 2020), thus the results of this study are difficult to explain. Further to this, for Chinese consumers, the discriminate analysis was most accurate for allocation of samples to premium and good everyday categories (66-71%) which is largely inconsistent with previous findings.

Perhaps more pertinent would be the proportion of satisfied consumers within each country, this would be all samples that met the expected quality standard based on the MQ4 assigned grade plus those that exceeded it. Eating satisfaction is a strong driver of purchasing intent, and assurances of quality will generate willingness to pay premiums for label claims in sheepmeat, demonstrated by American and Australian consumers (Hoffman et al., 2016; Tighe et al., 2018). Polkinghorne et al. (2011) suggested application of a broader quality assurance system that reflects the satisfaction for the majority of consumers would prove valuable for industry.

In addition, it will also be essential to compare the accuracy of the current optimal weightings for American and Chinese consumers to the accuracy of quality allocation when using the fixed weightings developed for the new sheepmeat MSA model. In beef, a loss in accuracy was found using the fixed MSA model weightings compared to optimal, with a varied response depending on whether the original beef weightings were used (accuracy reduced by 2-7%)(Bonny et al., 2016; Thompson et al., 2010; Thompson et al., 2008), or more recent values were used (accuracy reduced by up to 20%)(Bonny et al., 2016). Further exploration of this data would indicate whether adjustments should be made to the sheepmeat MSA models to ensure accurate assignment quality grades for product destined for these markets.

5.5 Conclusion

These results suggest that the sensory evaluation of Australian sheepmeat is relatively similar for American and Australian consumers despite distinctive preferences and consumption habits for sheepmeat products. Chinese consumers demonstrated the most generous consignment of samples to higher quality grades, while American and Australian consumers were similarly more critical. Thresholds between the quality grades reflected the more critical appraisal of sheepmeat by American and Australian consumers, with higher boundaries compared to Chinese consumers. However, these thresholds aligned with many previous international studies, proving Chinese consumer perceptions of quality to be more unique. Optimal weightings of the eating quality attributes were relatively consistent between the three countries, with an influence of animal age class detected by American and Australian consumers. The accuracy of overall allocation to specific quality grades was highest for Chinese consumers, followed by Australian and American consumer groups, with accuracy aligning well with previous findings in beef. This demonstrates the MSA testing protocols are appropriate means of predicting eating quality for these particular consumer groups and encourage its application in these markets. Finally, with the roll out of the sheepmeat MSA system underway, it is important to determine whether optimised coefficients for sensory traits would be more accurate for American and Chinese consumers compared to the fixed values currently developed for the sheepmeat MSA model. Adjustments will need to be made where necessary in order for industry to adequately meet international consumer quality expectations of Australian sheepmeat products.

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Chapter Six

6

Chinese Consumer Assessment of Australian Sheepmeat Using a Traditional Hotpot Cooking Method

Manuscript details

Title:	Chinese Consumer Assessment of Australian Sheepmeat Using a Traditional Hotpot Cooking Method
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Abstract

Hotpot is a widely popular cooking method for sheepmeat in China. This study measured the sensory responses of 720 untrained Chinese consumers to Australian sheepmeat cooked using a hotpot technique with methods based on Meat Standards Australia protocols. Shoulder and leg cuts of 108 lambs and 109 yearlings were scored on tenderness, juiciness, flavour and overall liking with linear mixed effects models used to analyse the influence of muscle type and animal factors on these scores. On average, shoulder cuts were more palatable than legs cuts for all sensory traits ($P < 0.01$), and lambs compared to yearlings ($P < 0.05$). Intramuscular fat and muscularity were identified as strong drivers of eating quality ($P < 0.05$), with greater palatability for both cuts as intramuscular fat increased, and muscularity decreased (as measured through loin weight adjusted for hot carcase weight). Consumers were unable to detect differences between animal sire type and sex in sheepmeat hotpot. These findings suggest shoulder and leg cuts performed comparatively well in hotpot compared to previous tested sheepmeat cooking methods and emphasise the importance of balanced selection for quality and yield traits to ensure consumer satisfaction is maintained.

6.1 Introduction

China is one of the world's fastest growing economies, and with this growth, a corresponding increase in demand for sheepmeat products is expected with wealthier consumers seeking variety in their protein sources (Liu et al., 2009; MLA, 2021b). While Chinese consumption of sheepmeat is much lower than beef and pork, domestic sheepmeat consumption far exceeds local production rates, providing a valuable market for Australian frozen sheepmeat products (MLA, 2021b). Australian sheepmeat exports to China primarily include cuts such as breast, flap, manufacturing meat, neck and entire carcasses, with a large proportion further processed into thin slice rolls used in hotpot restaurants (MLA, 2021b). Hotpot is one of the top three cooking methods for sheepmeat in China (Mao et al., 2016), and with hotpot restaurants accounting for approximately 20% of national restaurant revenue (MLA, 2021b), it's important to understand the palatability of Australian sheepmeat when using this widely popular cooking method.

Hotpot meat is thinly sliced rolls of meat, often sold frozen, and fabricated from either whole-tissue or a restructured "block" consisting of layers of lean tissue and fat (Mao et al., 2016), generally sourced from boneless shoulder and leg sheepmeat cuts. Chinese consumers have shown a preference for a higher degree of visible fat content in their sliced hotpot beef (Farouk et al., 2019), and its well reported that fat improves flavour profiles, with lipids providing species specific flavours that increase with greater volumes present (Frank et al., 2016a). In addition, lipids create a lubricative effect, increasing the perceived juiciness of a product (Frank et al., 2016b; Savell & Cross, 1988). Considering the positive association between fat and eating quality, shoulder cuts may prove more palatable for hotpot, with higher fat to lean ratios reported in the lamb forequarter compared to hindquarter (Anderson et al., 2015b).

Palatability can be described through the sensory attributes of tenderness, juiciness, liking of flavour and overall liking (Forrest et al., 1975), with a positive eating experience improving consumer satisfaction and subsequent repurchase intent (Grunert et al., 2004). The Meat standards Australia (MSA) system is underpinned by these eating quality attributes and has been used to evaluate large numbers of untrained consumers both domestically and internationally using a variety of cuts and cooking methods (Pannier et al., 2014b; Park et al., 2008; Pethick et al., 2006b; Polkinghorne et al., 2014; Thompson et al., 2005a). In beef, Japanese and Korean consumer sensory scores are influenced by cooking method, muscle type and slaughter conditions when using traditional cooking methods of yakiniku, shabu shabu, and barbeque for local and Australian product (Park et al., 2008; Polkinghorne et al., 2014). Similarly, previous research in sheepmeat (2020), demonstrated that untrained Chinese consumers could also differentiate animal factors during eating quality tests, preferring lamb rather than yearling, loin cuts rather than topside, and samples from Merino and Maternal sired lambs rather than Terminal. In addition, increasing intramuscular fat (IMF) levels had a positive influence on sensory scores for sheepmeat (O'Reilly et al., 2017). However, all results were from a grill cooking method rather than the traditional hotpot. A positive association between eating quality and phenotypic factors of higher IMF levels, greater fatness, and lower muscling is also reported in Australian consumers (Hopkins et al., 2006; Pannier et al., 2018a; Pannier et al., 2014b). Whether thinly sliced shoulder and leg cuts would be as heavily influenced by these carcase attributes is unknown.

This study developed an MSA sheepmeat hotpot testing protocol to examine the sensory responses of Chinese consumers to Australian lamb (no erupted permanent incisors) and yearling (2–4 erupted permanent incisors) shoulder and leg cuts cooked using a traditional Chinese hotpot cooking technique. We hypothesised that shoulder cuts would score greater than leg cuts, particularly for flavour and juiciness, lambs greater than yearlings, and a preference for Merino and Maternal sired lambs would be evident rather than Terminal. In addition, we hypothesised that scores would improve in carcasses with decreasing loin weight and increasing carcase fatness

6.2 Materials and Methods

6.2.1 Carcase details and muscle collection

Lambs and yearlings (n=217) utilised in this study were sourced from the Meat and Livestock Australia genetic resource flocks located in Katanning, WA, and Kirby, NSW. Details of this flock design have been published elsewhere (Fogarty et al., 2007; Van der Werf et al., 2010). Lambs and yearlings from the Katanning site were on average 341 days and 701 days old respectively at slaughter. Lambs and yearlings sourced from Kirby were on average 351 days and 716 days old at slaughter. Consistent for both sites, lambs (females and wethers) were sired by Maternal (Border

Leicester, and Dohne Merino), Merino (Merino, and Poll Merino), and Terminal (Poll Dorset, Suffolk, Texel, and White Suffolk) sires, while yearlings were strictly wethers and progeny of Merino (Merino, and Poll Merino) sires. Animals were slaughtered at commercial abattoirs licensed for export to China and processed according to resource flock protocols; including application of medium level electrical voltage, trimming according to AUSMEAT specifications, and chilling for 24 h at 3-4°C to allow optimal pH decline (Anonymous, 2005). Entire boneless shoulder (AUS-MEAT 5050 and leg (AUS-MEAT 5070) cuts were collected from each carcase at 24 h post slaughter, vacuum packaged and aged for 10 days at 2-3°C prior to frozen export to China. A total of 216 shoulder, and 216 leg cuts were collected from 217 carcasses, of which two carcasses did not have both cuts available (n= 2).

6.2.2 Carcase compositional measurements

Hot carcase weight (HCW) of each animal was recorded immediately after slaughter. Each carcase was split at the 10th/11th thoracic rib 24 hours post mortem to collect the full *longissimus lumborum* (LL) from the saddle region of each carcase (AUS-MEAT 4880) (Anonymous, 2005). The subcutaneous loin fat was trimmed and weighed (LLFAT) and remaining lean muscle tissue weighed (LLWT). IMF, expressed as a percentage, was measured by sampling 40g of lean LL tissue. Each sample was freeze dried using a Cuddon FD 1015 freeze dryer (Cuddon Freeze Dry, NZ) and IMF was measured using near infrared spectroscopy (NIR) in a Technicon 450 Infralyser Spectrophotometer (19 wavelengths). NIR readings were validated against for determination of chemical fat content, Soxhlet extraction (Anonymous, 2000). Measurement protocols for IMF have previously been detailed by Perry et al. (2001a).

6.2.3 Sample preparation and sensory testing

This research was approved through the Murdoch University Human Research Ethics Committee (Project No. 2016/015).

Tasting sessions were conducted in Beijing, China (China Agricultural University) where a total of 720 consumers were recruited to participate in one of twelve hotpot sessions. Each consumer tasted and scored six samples (3 shoulder and 3 leg) for tenderness, juiciness, liking of flavour and overall liking on a scale of 0 to 100, consistent with standard MSA testing protocols (Thompson et al., 2005a). Scale lines were anchored with ‘not’ (0 score) and ‘very’ (100 score) preceding the eating quality trait for tenderness and juiciness, and ‘dislike extremely’ and ‘like extremely’ for liking of flavour and overall liking. While the MSA tasting session structure was consistent with previous grilled sheepmeat sensory research within China and Australia (O'Reilly et al., 2020; Pannier et al., 2014b; Thompson et al., 2005a), a new MSA traditional Chinese hot pot cooking method was developed for this study.

Within 24 hours of each sensory session commencing, shoulder and leg cuts were trimmed to a uniform 50 x 50 x 100 mm block whilst partially frozen, and ten 1.6 mm slices were prepared from each block. The 10 slices per cut where uniformly spread across the entire block to represent slices across the entire cut and stored in the fridge at 0 – 5 °C in designated cooking order until the start of each session.

Within one hotpot session, a total of 36 cuts were tested, with appropriate cooking and consumption order allocated by a 6 x 6 Latin square design (Thompson et al., 2005d). Each slice was cooked in unseasoned boiling water in self-contained bain-marie pots (one pot for the 10 slices of the same cut), for 2 min before prompt service to the consumer. The 10 slices per cut were served to 10 different consumers to obtain 10 sensory scores per cut. A total of 4320 sensory responses were recorded across the 12 tasting sessions.

6.2.4 Statistical analysis

Sensory scores of tenderness, juiciness, liking of flavour, and overall liking were analysed using linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). Consumer variation was accounted for with the inclusion of all 10 consumer responses for each cut. The base model for each sensory trait included fixed effects of muscle type (shoulder, leg), sire type-age class as one single term (Maternal lamb, Merino lamb, Terminal lamb, and Merino yearling), sex within sire type-age class (female and wether lambs with each sire type group, and Merino wether yearling), and site (Katanning, Kirby). The Satterthwaite function was included in all models to approximate the degrees of freedom. Random terms included animal identification within sire, and consumer identification within hot pot session. Partial correlation coefficients were also calculated between the four sensory traits within each cut, and between the shoulder and leg cuts using multivariate analysis of variance in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). Significant class variables of base models were included in the independent part of the multivariate model.

In order to test whether differences in fixed effects could be explained by carcase composition differences, phenotypic covariates of IMF, LLFAT, LLWT, and HCW were included in the base models mentioned above to evaluate their association with tenderness, juiciness, liking of flavour, and overall liking. To test the association between muscularity or carcase fatness with eating quality LLWT or LLFAT were used as indicators. In each instance HCW was included in the models in order for these terms to act as proxies for carcase muscling and fatness rather than just acting as simple correlates of carcase weight. As IMF was only measured in the loin muscle, the impact of IMF on eating quality traits for shoulder and leg cuts was assessed using the loin IMF.

6.3 Results

The number of lambs and yearlings included in the base model analyses for each category is detailed in Table 6.1. Of the 217 carcasses included in the analyses, 215 were represented by both shoulder and leg cuts. Age class comparisons were made across Merino groups given yearlings were entirely Merino sired. Given low Maternal and Merino lamb numbers within each site, site comparisons were only made across Terminal lamb and Merino yearling groups. Sire-type and sex comparisons were made only within the lamb groups with the acknowledgement of low animal numbers within the maternal and merino sired classes. The outcomes of the base models for tenderness, juiciness, liking of flavour, and overall liking are presented in Table 6.2. The variance accounted for by these models was 33%, 33%, 35%, and 35% for tenderness, juiciness, liking of flavour, and overall liking respectively. Table 6.3 presents the mean and range for the phenotypic covariates of HCW, LLFAT, LLWT, and IMF percentage included in the base models.

The predicted mean eating quality scores for the significant effects of sire type-age class and sire type-age class by site between shoulder and legs cuts are detailed in Table 6.4. Results are largely indicated as the magnitude of difference in sensory score units of 0-100, and where the effect of covariates are included in base models, results are presented across the range for each covariate trait as determined by the mean ± two standard deviations for each trait.

Table 6.1
Number of lambs and yearling included in the base models (n = 217), categorised by site, age class, sire type and sex

Site	Age class	Sire type	Sex	Count
Kirby	Lamb	Maternal	F	3
			M	3
		Terminal	F	22
			M	19
		Merino	F	1
			M	2
	Yearling	Merino	M	70
Katanning	Lamb	Maternal	F	2
			M	3
		Terminal	F	27
			M	13
		Merino	F	10
			M	3
	Yearling	Merino	M	39

6.3.1 Impact of cut, age class, sire type and site on sensory scores

The shoulder cut had greater palatability compared to the leg cut for all sensory traits, with total average shoulder scores being 64.0, 62.7, 66.7, and 67.8, compared to the leg scores at 60.5, 60.0, 63.6, and 64.1 for tenderness, juiciness, liking of flavour and overall liking respectively ($P < 0.01$; Table 6.2 & 4). For tenderness, the magnitude of this cut effect differed between sire types with the greatest difference in cuts detected in Maternal lambs (5.7 ± 2.6; $P < 0.05$), followed by Terminal lambs (3.8 ± 0.9; $P < 0.001$), with no significant cut differences observed within wither Merino lamb or yearling subgroups.

Age class had a significant effect on palatability with Merino yearlings on average scoring lower for all sensory traits compared to Merino lambs ($P < 0.05$; Table 6.2). Comparisons could only be made between Merino groups as yearlings were entirely Merino sired. On average, Merino lamb had higher eating quality than yearlings with increases of 6.6, 4.2, 3.9, and 4.5 units for tenderness, juiciness, liking of flavour and overall liking, (Table 6.4). For tenderness, the age class difference varied between cuts, with lamb shoulders scoring 8.0 units greater than yearling (*P* < 0.001; Table 6.4), whereas lamb leg scored 5.1 units greater compared to yearling legs (*P* < 0.05; Table 6.4). In addition, the age class effect varied by site with Katanning Merino lambs scored greater than Merino yearlings by 4.4 flavour, and 5.3 overall liking units, compared to Kirby sourced animals whereby no age effect was evident.

Comparisons across all the sire type-age class groups, demonstrated Terminal lambs on average were also preferred to Merino yearlings for tenderness, juiciness, flavour and overall liking by up to 3.8 scores and Maternal lambs to Merino yearlings for tenderness by 5.6 scores (*P* < 0.05; Tables 2 and 4).

Overall, site had a significant effect on palatability with Katanning sourced animals scoring higher than those obtained from Kirby for tenderness, juiciness and liking of flavour with average increases of 1.7, 2.4 and 2.5 units respectively (P < 0.05; Table 6.2). Comparison across sites, demonstrated that Terminal lambs at Katanning had higher liking of flavour and overall liking scores compared to animals from Kirby with increases of 5.8 and 5.2 sensory units (*P* < 0.001; Table 6.4). There was no difference between sensory scores of Merino yearlings between the two sites.

Sire type comparisons could only be made within the lamb group in this dataset given yearlings were strictly Merino sired. There were no significant differences observed between Maternal, Merino, and Terminal sired lamb sensory scores when testing shoulder and leg cuts using a hotpot cooking technique. Similar to sire type, true sex comparisons could only be made within lambs, and there was no significant effect of animal sex on any sensory traits within this study.

Table 6.2

F-values, NDF and DDF for base linear mixed effects models for predicted eating quality scores of tenderness, and juiciness, liking of flavour and overall liking.

Effect	Tenderness		Juiciness		Flavour		Overall liking	
	NDF, DDF	*F*-value	NDF, DDF	*F*-value	NDF, DDF	*F*-value	NDF, DDF	*F*-value
Cut	1, 3654	15.8**	1, 3419	24.61**	1, 3424	37.46**	1, 3420	51.79**
Sire type-age class	3, 197	9.76**	3, 190	4.23*	3, 194	4.31*	3, 196	5.8**
Site	1, 193	4*	1, 187	10.6*	1, 201	4.48*	1, 203	2.53
Cut * Sire type-age class	3, 3729	2.7*	-	-	-	-	-	-
Site * Sire type-age class	-	-	-	-	3, 202	3.16*	3, 204	3.21*

NDF, DDF: numerator and denominator degrees of freedom; - : not present in final models after stepwise regression; *: *P*< 0.05: **: *P*<0.001.

Table 6.3

Number of sires, number of animals (n = 217), and their mean ± SD (min – max) for the phenotypic traits included in base model analyses.

Sire type		No. of sires	No. of lambs	Hot carcase weight (kg) Mean ± SD (min - max)	Loin fat weight (g) Mean ± SD (min - max)	Loin weight (g) Mean ± SD (min - max)	IMF % Mean ± SD (min - max)
Lamb	Maternal	8	11	25.2 ± 3 (20.5 - 29.7)	355.8 ± 147.4 (118 - 550)	429.5 ± 75.1 (296 - 531)	5.9 ± 1.1 (4.4 - 8)
	Merino	10	16	22.1 ± 3.7 (16.6 - 30.4)	215.4 ± 100.5 (111 - 435)	369.8 ± 65.4 (263 - 483)	5.3 ± 1.2 (3.3 - 7.7)
	Terminal	42	81	27.1 ± 5.6 (17.4 - 39.5)	410.2 ± 211.2 (129 - 939)	498.5 ± 129.9 (259 - 784)	5.3 ± 1.1 (3.3 - 10.6)
Yearling	Merino	47	109	21.4 ± 3 (15 - 29.9)	149.9 ± 68.9 (44 - 386)	374.2 ± 62.1 (243 - 544)	5.1 ± 1.3 (2.4 - 8.9)

Table 6.4

Least square means ± SE for effects of sire type-age class, and sire type-age class by site between shoulder and leg cuts for degree of tenderness, juiciness, liking of flavour and overall liking.

Site	Age class	Sire type	Cut	Tenderness	Juiciness	Flavour	Overall liking
Kirby	Lamb	Maternal	shoulder	68.5 ± 3.1	64.3 ± 2.8	68.3 ± 2.7	69.7 ± 2.7
			leg	61.4 ± 3.1	56.9 ± 2.8	62.4 ± 2.7	63.2 ± 2.7
		Merino	shoulder	73.6 ± 5.3	69.8 ± 4.8	70.9 ± 4.5	72.2 ± 4.6
			leg	66.3 ± 4.4	61.3 ± 4	61.9 ± 3.8	62.8 ± 3.8
		Terminal	shoulder	63.0 ± 1.2	62.1 ± 1.1	65.2 ± 1.1	66.5 ± 1.1
			leg	56.8 ± 1.2	56.7 ± 1.1	59.5 ± 1.1	60.8 ± 1.1
	Yearling	Merino	shoulder	58.2 ± 1	59.4 ± 0.9	63.2 ± 0.9	64.3 ± 0.9
			leg	57.4 ± 1	57.7 ± 0.9	61.4 ± 0.9	62.1 ± 0.9
Katanning	Lamb	Maternal	shoulder	64.5 ± 3.4	63.6 ± 3.1	67.5 ± 2.9	67.8 ± 3
			leg	60.6 ± 3.4	58.5 ± 3.1	64.0 ± 2.9	64.4 ± 3
		Merino	shoulder	66.3 ± 2.1	66.1 ± 1.9	70.7 ± 1.8	72.0 ± 1.9
			leg	62.9 ± 2.1	62.6 ± 1.9	65.4 ± 1.8	66.3 ± 1.9
		Terminal	shoulder	65.0 ± 1.3	64.6 ± 1.2	69.4 ± 1.1	70.6 ± 1.1
			leg	63.6 ± 1.3	63 ± 1.2	66.9 ± 1.1	67.1 ± 1.1
	Yearling	Merino	shoulder	59.0 ± 1.3	60.4 ± 1.2	64.7 ± 1.1	65.4 ± 1.1
			leg	57.9 ± 1.3	59.3 ± 1.2	62.7 ± 1.1	62.2 ± 1.1

6.3.2 Impact of intramuscular fat on sensory scores

Loin IMF percentage had a significant positive relationship with tenderness, juiciness, liking of flavour and overall liking consumer scores for both the shoulder and leg cuts ($P < 0.05$). Across the loin IMF range of 2.5% to 7.5%, sensory scores increased by 4.4, units for tenderness, liking of flavour and overall liking and 3.3 units for juiciness (Figure 6.1). When IMF percentage was included in the base models (Table 6.3), site and cut by sire type-age class no longer had a significant effect on tenderness scores, and site by sire type-age class was non-significant for flavour and overall liking results.

(a) Shoulder Cut

(b) Leg Cut

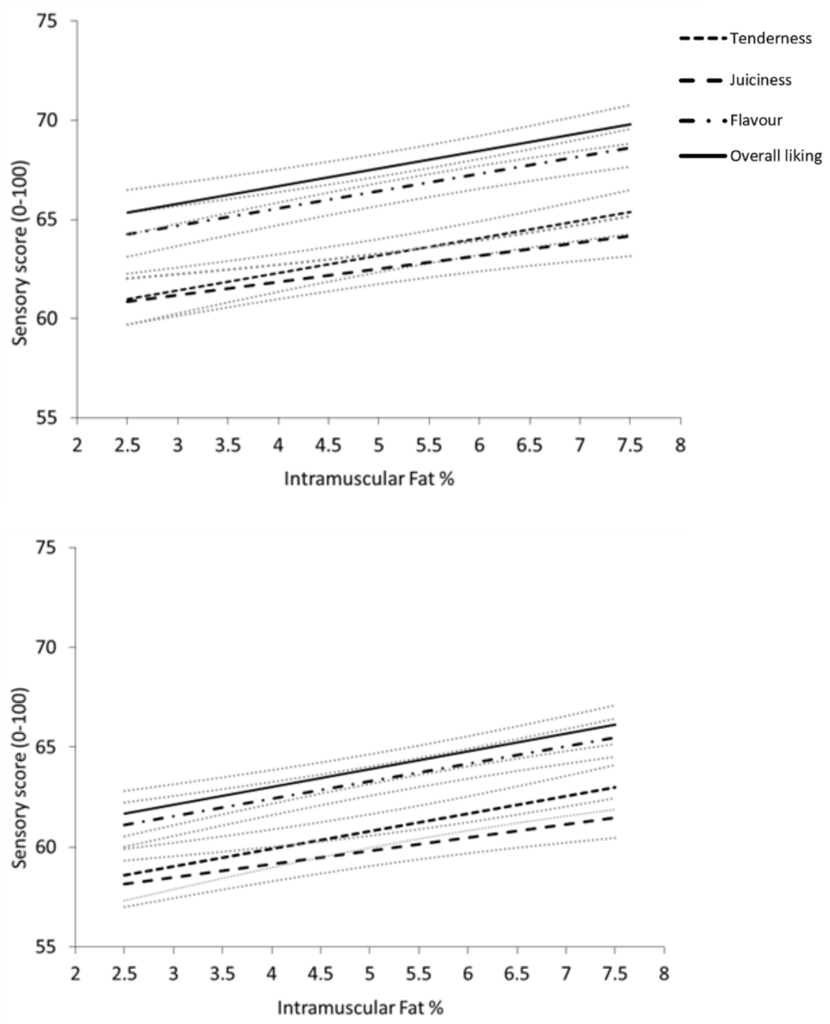

Figure 6.1

Relationship between intramuscular fat (%) of the loin muscle and tenderness, juiciness, liking of flavour and overall liking scores of the (a) shoulder cut; (b) leg cut. Lines represent least square means of each cut (±SE) across an increasing intramuscular fat % range.

6.3.3 Impact of carcase compositional indicators on sensory scores

Muscularity measured through LLWT adjusted for HCW had a significant and generally negative effect on all sensory traits ($P < 0.05$; Figure 6.2). Increasing LLWT reduced average sensory scores for all traits up to 500g, beyond which there was little change. Flavour liking and overall liking decreased by 7.2 and 8.2 units, while tenderness and juiciness varied across cuts with shoulder scores reduced by 9.1 and 6.7 units, and leg cuts by 6.5 and 10.0 units. For only tenderness, the impact of LLWT varied between sire type-age class groups and cuts. Following the general trend, tenderness decreased for Terminal lamb cuts, Merino lamb shoulders and yearling legs from 5.8 to 10.4 units. In contrast Merino lamb legs and yearling shoulders increased in tenderness by 5.3 and 9.2 units. When LLWT was included in the base models (Table 6.3), there was no longer a significant difference between the average sire type-age class groups for flavour and overall liking.

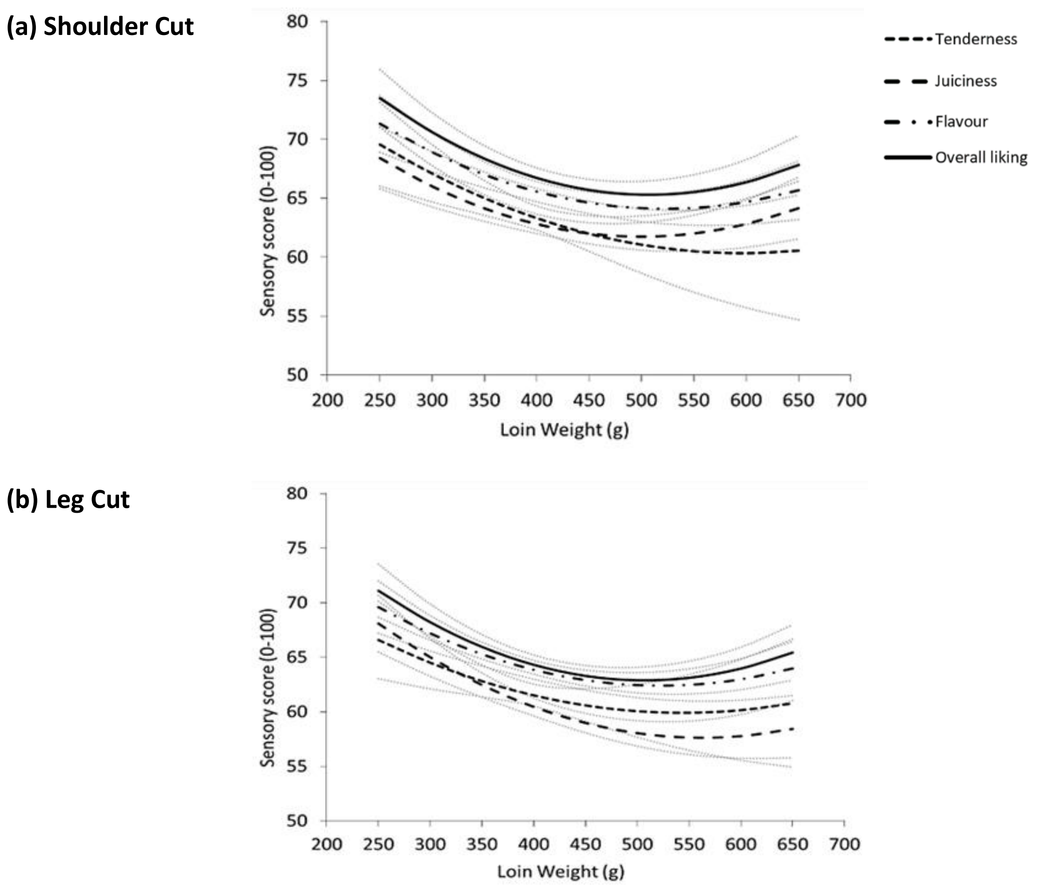

Figure 6.2

Relationship between loin weight (g) adjusted for hot carcase weight for tenderness, juiciness, liking of flavour and overall liking scores of the (a) shoulder cut; (b) leg cut. Lines represent least square means of each cut (±SE) across an increasing loin weight range.

Whole carcase adiposity represented by LLFAT adjusted for HCW, had a significant effect only within juiciness scores at the Katanning site ($P < 0.01$). Increasing LLFAT from 50 to 650g improved juiciness of Katanning sourced animals by 12.1 units. Inclusion of LLFAT within the juiciness base model (Table 6.3), removed the significant effect of sire type-age class.

6.3.4 Correlations between sensory traits and cuts

The partial correlation coefficients between tenderness, juiciness, liking of flavour and overall liking within the shoulder and the leg cuts are presented in Table 6.5. All correlations were high, with the strongest association between liking of flavour and overall liking. Between muscle partial correlation coefficients were not significant.

Table 6.5

Partial correlation coefficients for tenderness, juiciness, liking of flavour and overall liking for the shoulder (above diagonal) and leg (below diagonal) samples for Chinese consumers.

	Sensory traits			
	Tenderness	**Juiciness**	**Flavour**	**Overall liking**
Tenderness		0.81	0.73	0.77
Juiciness	0.79		0.74	0.77
Flavour	0.71	0.72		0.92
Overall liking	0.76	0.76	0.92	

6.4 Discussion

6.4.1 Impact of cut on sensory scores and correlations

In agreement with our hypothesis, shoulder cuts consistently scored higher than leg cuts using a hotpot cooking method, however the greatest improvements were found for overall liking (3.7 unit increase) and tenderness (3.5 unit increase), followed by liking of flavour and juiciness (2.7 unit increase) ($P < 0.01$; Table 6.3 & 4). These findings agree with eating quality observations in grilled and roasted lamb muscles, where Australian consumers in general, scored forequarter muscles more favourably than hindquarter muscles (Pethick et al., 2006b; Thompson et al., 2005a). Across all sensory traits, roasted forequarter sensory scores ranged from 58.7 to 64.4, compared to an easy carve leg, ranging from 52.4 to 60.8 (Pethick et al., 2006b). Similarly, grilled *serratus ventralis* scores ranged from 70.1 to 73.4 compared to rump and topsides, ranging from 37.3 to 67.1 (Thompson et al., 2005a). In comparison to the Australian studies (Pethick et al., 2006b; Thompson et al., 2005a), hotpot shoulder and leg sensory scores were slightly greater than if using a roast cooking method, but shoulder scored lower than if they were grilled (shoulder scores 62.7 to 67.8; leg scores 60 to 64.1). This indicates that hotpot is an equivalent if not more favourable cooking method compared to roast for these cuts, and shows potential for inclusion in the sheepmeat MSA cut by cooking method eating quality grid (Pannier et al., 2018a). However it should be considered that a traditional cooking method was used for the culturally relevant group, so whether the same results would be evident using hotpot with Australian consumers is unknown. Nevertheless, the ability of Chinese consumers to discern eating quality differences between cuts within this study aligns with previous testing of grilled loin and topside muscles, where the loin was routinely scored higher than the topside (O'Reilly et al., 2020). This provides further evidence of the value of using MSA testing protocols in the assessment of palatability of sheepmeat products for international consumer groups, with numerous similar comparisons in beef for a variety of cuts and cooking methods (Bonny et al., 2016; Pogorzelski et al., 2020; Polkinghorne et al., 2014; Thompson et al., 2008).

Shoulder and leg cuts both demonstrated strong correlations between sensory scores of tenderness, juiciness, liking of flavour and overall liking (Table 6.5). The strongest correlations were observed between liking of flavour and overall liking for both cuts at 0.92 which aligns with previous findings in China, with r values of 0.86 and 0.90 reported for grilled loin and topside (O'Reilly et al., 2020). This relationship is consistent with international research findings in lamb for Australian, and American consumers (Pannier et al., 2014b; Phelps et al., 2018b), and in beef for French, Irish, Japanese, and Polish consumers (Bonny et al., 2016; Polkinghorne et al., 2011). This demonstrates that regardless of cultural background, consumer eating quality scores are strongly associated with one other, and should be interpreted with a degree of caution due to the consumers' inability to differentiate between the traits (Kunert, 1998; Shorthose & Harris, 1991). In agreement with O'Reilly et al. (2020) and Thompson et al. (2005a), correlations between the different cuts were low and non-significant for all sensory traits, thus emphasising the importance of testing the palatability of each individual cut when developing new cooking methods.

6.4.2 Impact of age class, sire type and site on sensory scores

In support of our hypothesis, the Merino lambs scored higher than Merino yearlings for tenderness, juiciness, flavour and overall liking. In addition, there was a greater age class improvement observed for tenderness in the shoulder compared to the leg. Comparisons to previous research are challenging due to the novel cooking method and use of different cuts in this study. However, results generally align with previous research demonstrating improved palatability in younger animals for some sensory traits, and variation across cuts (O'Reilly et al., 2020; Pannier et al., 2014b; Pannier et al., 2018b; Pethick et al., 2005). For untrained Australian consumers tasting lamb and yearling samples, increases of 5 to 10 scores were observed in grilled lamb topsides for tenderness, liking of flavour and overall liking (1337 consumers; 185 lambs & 206 yearlings) (Pannier et al., 2015). Further to this, roasted lamb topsides and *M. biceps femoris* (outsides) extracted from the easy carve leg, had improved sensory scores compared to yearling, ranging from 4.5 to 7.9 and 10.2 to 16.1 units for tenderness, juiciness and overall liking (480 consumers; 18 lambs & 18 yearlings) (Pethick et al., 2005). Conversely for both studies, minimal or no significant improvements were reported in the eating quality of loins in lambs compared to yearlings across all traits (Pannier et al., 2018b; Pethick et al., 2005). Perhaps more comparable, would be the results of untrained Chinese consumer testing of grilled sheepmeat, with Merino lambs loin and topsides scored 8.4, and 6.9 tenderness units, and 4.7, and 5.1 overall liking units greater than Merino yearlings (720 consumers; 112 lambs & 106 yearlings (O'Reilly et al., 2020). This is comparable to tenderness scores in the current study with Merino lamb shoulders and legs scoring 8.0 and 5.1 units greater than yearlings ($P < 0.001$). While discrepancies exist depending on cut, cooking method and cultural background, it is clear that age at slaughter does have some effect on eating quality between lambs and yearlings. Declining eating quality associated with animal age is attributed to several factors including the build-up of undesirable flavours in fat deposits (Thompson, 2001), and increased cross-linking between collagen fibers resulting in reduced tenderness as the animal ages (Pannier et al., 2015).

Contrary to our hypothesis, sire type did not have an impact on the average palatability of shoulder and leg cuts using a hotpot cooking method. These results are in contrast to previous findings for Australian and Chinese consumers (O'Reilly et al., 2020; Pannier et al., 2014b), with Merino sired animals reported to have higher eating quality than their Maternal and Terminal sired counterparts for Australian consumers, with increases in all sensory traits, ranging from 2.9 to 5.2 units (Pannier et al., 2014b), while Chinese consumers reported tenderness improvements specific to Merino topsides (9.3 units) (O'Reilly et al., 2020). Given the latter studies have utilised grilled sheepmeat, and sire type influenced only tenderness in topsides for Chinese consumers, it is perhaps unsurprising that sire type differences were not detected in the thinly sliced hotpot samples. In addition, Maternal and Merino lamb numbers were low in this study (11 and 16), suggesting these results should be interpreted with caution, and further testing with increased lamb numbers may be warranted.

Katanning sourced carcasses were preferred to those obtained from Kirby, for sensory traits of tenderness, juiciness and liking of flavour. This site effect combines flock composition (different sire type proportions), nutritional management, and slaughter conditions. Site, flock, and killgroup differences are commonly reported as a source of variation in eating quality studies and can encompass a wide range of extrinsic factors leading up to slaughter and processing, including but not limited to, lifetime nutrition, inclement weather, stock handling, and chilling regimes (O'Reilly et al., 2020; Pannier et al., 2014b; Pannier et al., 2018b). Cross comparisons of the sites within this study identified Katanning Terminal sired lambs had greater flavour and overall liking scores than Kirby animals, up to a difference of 5.8 units which is of a reasonable magnitude and likely a driver of improved site results given Terminal lambs comprised approximately forty percent of the Katanning cohort (Table 6.3). Levels of IMF for this Terminal lamb group provide a plausible explanation for palatability improvements, particularly given the effect was no longer significant when IMF was included in base models.

6.4.3 Impact of intramuscular fat on eating quality

Confirming our hypothesis, increasing intramuscular fat had a significant positive effect on all sensory traits for shoulder and legs cuts using the hotpot cooking method. For every one percent increase in IMF, consumer scores increased by 0.9 units for tenderness, liking of flavour and overall liking, and 0.7 units for juiciness. These results are similar to previously demonstrated consumer responses to IMF in grilled sheepmeat, with Chinese scores increasing at a rate of 0.8 units for all traits except for juiciness (O'Reilly et al., 2017), and lower than Australian scores increasing from 1.2 to 2.4 units across all sensory traits (Hopkins et al., 2006; O'Reilly et al., 2017; Pannier et al., 2014b). While the magnitude of effect was lower than previous Australian findings, the positive IMF influence aligns with prior studies demonstrating its strong association with eating quality in sheepmeat (Hopkins et al., 2006; Pannier et al., 2014b). The thin slicing of the hotpot meat did not entirely negate the effect of IMF on palatability, indicating selection for IMF is still important for carcasses destined for the hotpot market. The inclusion of IMF in base models rendered several factors non-significant. Average site differences were eliminated for tenderness, along with the flavour and overall liking preference for Katanning sourced Terminal lambs compared to Kirby. Katanning Terminal lambs had a much higher IMF range (3.8 to 10.6%), than Kirby (3.3 to 6.3%), thus it's reasonable to suggest IMF as a primary driver of these differences. In addition, IMF explained the greater tenderness discrepancies between lamb and yearling shoulder cuts compared to legs.

6.4.4 Impact of muscularity and whole carcase adiposity on sensory traits

Validating our hypothesis, muscularity (LLWT adjusted for HCW) appeared to have a negative influence on all sensory traits. Across an increasing 400g range, eating quality declined 6.5 to 10.0 scores ($P < 0.05$; Figure 6.2). These results were comparable to Pannier et al. (Pannier et al., 2014b) who observed eating quality reductions from 3.4 to 7.0 units for loin samples across an increasing 360g loin weight range, and 4.5 to 9.3 unit declines in palatability of the topside for a 480g topside weight range. The impact varied by cut for tenderness and juiciness, with a surprising effect observed in Merino yearling shoulders and Merino lamb legs with increasing scores across the range instead of the expected decline. This is somewhat difficult to explain as each cut was fabricated to the same dimensions for slicing. However, it is conceivable that the greater lean to fat ratio observed in higher muscling animals could have prompted perceptions of better value with "larger" servings, creating greater satisfaction for Chinese consumers. Inclusion of IMF in these models did not negate the LLWT effect in any covariate models.

Contrary to expectations, whole carcase adiposity as measured by LLFAT adjusted for HCW did not have a significant impact across all the eating quality traits, or shoulder cuts specifically. This is despite the supposition that shoulder cuts would be preferred to legs based on greater intermuscular fat levels (Anderson et al., 2015b), and the positive association between fat and sensory attributes (Frank et al., 2016b; Savell & Cross, 1988). Further to this LLFAT only had a significant effect for juiciness within the Katanning site. Correction for the IMF trait yielded LLFAT non-significant, suggesting results were driven through greater IMF levels in Katanning animals rather than intermuscular fat.

6.5 Conclusion

In conclusion, this study demonstrated that Chinese consumers scored thinly sliced sheepmeat shoulder more favourably than legs using a traditional hotpot cooking method, and regardless of these differences, scored both cuts reasonably well compared to other cooking methods. Age at slaughter had a significant influence on acceptability, with yearling cuts consistently scoring lower for tenderness, juiciness, flavour and overall liking. Similarly, site had an effect across all traits with Katanning sourced animals scoring on average higher than Kirby. This variation was largely explained by differences in Terminal sired lambs. IMF was a strong driver of eating quality, and while the effect was lower in magnitude than previously reported for Chinese and Australian consumers testing grilled sheepmeat, it explained many of the site and sire type differences observed for tenderness, flavour and overall liking. Variation between Terminal lamb groups across the two different sites was explained by IMF differences, reinforcing that a wide phenotypic range can be found within breed types and its important impact on palatability. Further to this, increasing carcase muscularity saw a steady decline in all sensory scores, highlighting that quality and yield attributes can be detected by consumers, even at the level of a 1.6 mm slice. Thus, producers should be mindful of heavy selection for lean meat yield and strive for higher IMF levels given balanced selection will reap positive returns with greater consumer satisfaction.

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Chapter Seven

7

General Discussion and Conclusions

7.1 Introduction

The eating quality of sheepmeat has been the subject of extensive research in the last few decades, particularly in Australia through the development of the sheep Meat Standards Australia (MSA) system (Thompson et al., 2005a; Thompson et al., 2005c). Consistent eating quality is paramount to consumer satisfaction, which in turn ensures continued demand leading to a robust quality assurance scheme that was developed to manage customer expectations, initially for beef and then for sheep (Thompson et al., 2005a; Watson et al., 2008b). The sheepmeat MSA system was originally applied as a "pathways" system, which involved a series of best-practice requirements for animals being marketed through this pathway. More recently a cut by cooking method prediction model (Pannier et al., 2018a; Pethick et al., 2018) has been developed that uses a series of individual carcase measurements to inform a prediction of eating quality. Evolution of the model was enabled through advancements in technologies that measure individual carcase quality and yield traits at chain speed (lean meat yield and intramuscular fat) (Gardner et al., 2021). Thus, equipping the Australian red meat industry with a tool for greater product segregation based on quality, will create opportunity for financial rewards across the entire supply chain.

Australia is the worlds' largest sheepmeat exporter, accounting for 6% of global sheepmeat production. The two primary export destinations for frozen and chilled product are China and the USA. Consumers within these two countries vary substantially from Australian consumers, both in terms of the volume of consumption of sheepmeat products, and the ways in which it is prepared. For example, Australian sheepmeat consumption is at 6.5kg per year, while Chinese and American rates are 3.9kg and 0.4kg respectively (MLA, 2021b, 2021c). Further to this, Chinese consumers have overtly positive perceptions of Australian lamb, in contrast American consumers have more negative views of imported lamb products (Hoffman et al., 2016; Kantono et al., 2021; MLA, 2021b). This is pertinent given that untrained Australian consumer scores underpin the MSA sheepmeat models, the original pathways scheme and the new cut by cooking method model. Hence it is important to understand whether the MSA model would accurately predict consumer perceptions of quality for these international groups, or if adjustments are required. In beef, there has been extensive international testing using MSA protocols, where consumers of a range of cultural backgrounds have demonstrated sensitivity to muscle differences, processing factors, country of origin, and cooking methods of beef products (Bonny et al., 2016; Park et al., 2008; Pogorzelski et al., 2020). In addition, the application and feasibility of an MSA-type system to predict eating quality in several European countries has been explored (Bonny et al., 2016; Hocquette et al., 2014; Legrand et al., 2013).

Therefore, the general aim of this thesis was to quantify the eating experience of American and Chinese consumers to Australian lamb and yearling products. Australian consumers were included to provide a baseline to compare international consumer responses against, given they underpin the current sheepmeat MSA system. Various aspects were explored through the scope of the MSA framework, including the influence of production and processing factors on eating quality in Chapters 3 and 6, the impact of demographic factors in Chapter 4, and accuracy of the MSA prediction model at allocating quality grades for these consumer groups in Chapter 5. Further to this, a new hot-pot cooking technique for the MSA cut by cooking method grid was developed and tested for Chinese consumers in Chapter 6.

7.2 Eating quality perceptions of American, Australian and Chinese consumers

Overall, there were no significant differences in untrained American, Australian and Chinese consumer scores for juiciness and overall liking, and some variation in tenderness, liking of flavour and odour scores were observed (Chapter 3). American consumers scores were consistently higher than Australian and Chinese consumer scores for tenderness, liking of flavour and odour, and Chinese consumer scores the lowest.

The lower tenderness and flavour scores observed for Chinese consumers could be attributed to extrinsic cultural factors not specifically captured within the scope of this study. In China there are eight traditional cooking styles classified within the four distinct regional cuisines of east, west, south and north, each with unique flavour profiles, ingredients and cooking methods (Nam et al., 2010). For example, greater chewiness of meat is a positive attribute in some provinces, hence greater tenderness of samples may translate into more negative scoring for this trait. Therefore, understanding underlying associations with tenderness would have been useful in this context. In addition, presentation of an unseasoned sample, void of any spices or sauce as used in the trials of this study, may have reduced flavour scores for consumers whose common cuisine types include hotpot, stir-fry, deep fried foods, and highly sauced proteins all featuring flavour as a high priority (Nam et al., 2010; Waldron et al., 2007). In Chapter 3 it was proposed that cooking samples to a medium level of doneness may have also caused slightly reduced scores, however the analysis of meat consumption preferences in Chapter 4 demonstrated no effect of cooking doneness on sensory scores even through the majority of participants preferred their meat cooked well done (75%) and medium to well done (24%). Chinese consumer allocation of samples to quality grades as detailed in Chapter 5, might suggest that the lower scoring is actually a reflection of their use of the scale bar (generally scoring samples lower), given that Chinese consumers allocated the most samples to better than every day and premium categories for both lamb and yearling products. This indicated a far more positive perception of samples than American and Australian consumers in this study. Nevertheless, the use of a composite eating quality score and quality grade allocation for a particular consumer group should negate the variability observed in scale bar use. However, this is an interesting finding for consideration in future cross-cultural studies.

Contrary to expectations, average American consumer scores were significantly higher than Australian scores for tenderness of both the *longissimus lumborum* (LL) and *semimembranosus (*SM), and liking of flavour of the SM (Chapter 3). Given Australian consumers are high appreciators of lamb with greater consumption rates it was assumed they would score all samples more favourably than their American counterparts (MLA, 2021c, 2021d). The participants recruited for this study reflected published meat consumption habits with 78% of American consumers indifferent to or rarely eating lamb in their diet and 76% only consuming lamb 2-3 times per year or never. While 74% of Australian consumers indicated they were high appreciators or lamb was important in their diet, and 77% ate lamb once a fortnight or more (Chapter 4). Perhaps unfamiliarity with the product in American consumers yielded higher than expected scores for this group. In a study by Sañudo et al. (1998), previous exposure to lamb and flavour preferences affected overall appraisal with both British and Spanish panellists preferring more familiar domestic product to imported lamb products. Similarly, Phelps et al. (2018b) demonstrated an American consumer preference for domestic product compared to imported Australian lamb products. And while no comparisons between product country of origin were included in this thesis, the most frequent consumers of lamb in the USA in Chapter 4 scored lamb 10 to 18 units lower for flavour and overall liking than the less frequent consumption subgroups, thus familiarity with domestic American product could have been a factor in their lower scoring. All sensory scores for the LL and SM in Chapter 3, were slightly higher than those assigned to Australian product tasted by American consumers in the work by Phelps et al (2018b), but still scored lower than American sourced lambs samples. Long aging periods during transit and finishing diet have been attributed to negative consumer perceptions of imported Australian lamb (Phelps et al., 2018a; Phelps et al., 2018b), therefore future studies could involve testing grass versus grain in Australian product to determine if there truly is a difference in eating quality associated with finishing system, or other extrinsic factors have a stronger role to play. Nevertheless, if optimised MSA models were used as outlined in Chapter 5, the lower weightings attributed to tenderness, and flavour for American consumers compared to Australian for the composite MQ4 score would likely absorb these differences observed between these two consumer groups.

7.3 Influence of production and processing factors on eating quality for American and Chinese consumers: grill and hotpot cooking methods

Chapters 3 and 6 used linear mixed effects models to assess the influence of various animal and processing factors on eating quality of grilled LL and SM for the three consumer groups, and shoulder and leg cuts using a hotpot cooking method for Chinese consumers. This is the first study to measure the sensory responses of American and Chinese consumer groups to Australian lamb and yearling. All animals included in these taste panels were sourced from the Information Nucleus Flock (INF), where lifetime information for each animal is measured: genetics, phenotypic traits, and processing factors (Fogarty et al., 2007), hence allowing for examination of a range of background factors and comparison of these factors across consumer groups within each study.

7.3.1 Muscle type and eating quality

Muscle type or cut described the greatest amount of variation in eating quality for tenderness, juiciness, liking of flavour and overall liking in both the grill and hotpot experiments. This was consistent for American, Australian and Chinese consumer groups and confirms previous research in sheep and beef demonstrating a broad range of eating quality is experienced for different muscle types and readily identified by consumers regardless of cultural background (Bonny et al., 2016; Park et al., 2008; Pethick et al., 2006b). Further to this, the LL muscle was routinely scored higher than the SM muscle endorsing its status as a more premium product compared to the SM for these international consumer groups. For Chinese consumers the degree of variation accounted for by cut in the hotpot models was much lower than that for the grill cooking method, and accordingly the magnitude of difference in sensory scores between shoulder and leg cuts was much lower; grill ranged from 10.4 to 17.8 units different compared to 2.7 to 3.7 units in the hotpot (Chapter 3 and 6). The very thin slicing of meat used in hotpot (1.6mm in this experiment), provides a plausible explanation for reduced importance of cut type for this cooking style. Many of the intrinsic factors of various muscle types that respond to cooking are removed through physical disruption to the muscle structure with thin slicing. For example, reduced tenderness associated with shrinkage of collagen fibres in muscles with higher levels of intramuscular connective tissue content (Tornberg, 2005), would be less significant for this cooking style. This is unsurprising given the well-established critical control point of cut by cooking method in the MSA model, which recognises primal/muscle preparation plays a pivotal role in the eating quality of the final product (MLA, 2012). Future work could involve testing Australian shoulder and leg cuts using a roast cooking method given this cooking style is used commonly for sheepmeat in China (Mao et al., 2016; Zhang et al., 2014) and a recommended style for lamb in the USA (American Lamb Board, 2022). Roast is one of the two commercial cooking method outputs of the new MSA cut by cooking method model, thus application of the model could be examined by comparing American and Chinese results to the large volume of pre-existing Australian data.

7.3.2 Intramuscular fat, carcase fatness and muscularity

For Chinese consumers, increasing intramuscular fat (IMF) had a significant positive impact on the eating quality of shoulder and leg cuts using a hotpot cooking method in Chapter 6. Analysis of the grilled LL and SM results of experiment one also demonstrated a similar magnitude of effect on sensory scores for Chinese consumers (O'Reilly et al., 2017), both ~ 0.8 unit improvement in scores per 1% IMF increase. These results were lower than previous values reported for Australian consumers 1.2 to 2.4 units per 1% IMF increase across all sensory traits (Hopkins et al., 2006; O'Reilly et al., 2017; Pannier et al., 2014b), however still align with the consensus that positive eating quality outcomes are associated with higher levels of IMF (Pannier et al., 2014b; Realini et al., 2021a). In addition, including IMF in the hotpot models explained the variation in eating quality observed for several other factors including site and cut by sire type for tenderness, and site by sire type for liking of flavour and overall liking. In IMF corrected models, the effect of cut on tenderness reduced by one third, while changes to site and sire type effects were generally low in magnitude (less than 1.0 eating quality score). Whole carcase adiposity was represented in models using loin fat weight (LLFAT) adjusted for hot carcase weight (HCW) given its strong association with entire carcase fatness (R^2 = 0.65) (Anderson et al. 2015a), and it was hypothesised that shoulder cuts would score higher than legs due to greater levels of intermuscular fat observed in the forequarter compared to the hindquarter (Anderson et al., 2015b). It was expected higher eating quality scores would be realised through greater flavour found in higher volumes of fat (Frank et al., 2016b; Savell & Cross, 1988), and Chinese consumer preference for fattier meat in hotpot rolls (Farouk et al., 2019). However, LLFAT was only significant for the juiciness trait, and when corrected for IMF no longer had an effect, thus results may have been explained by differences in IMF rather than intermuscular fat. Of note, the association between IMF and LLFAT was low in the hotpot study with a partial correlation coefficient of 0.31, indicating each trait should still be examined independently. LLFAT reportedly has strong correlations to whole carcase fatness (Pannier et al., 2018a), thus should adequately represent whole carcase adiposity, therefore it would be interesting to examine if other fat measures as predicted by new on-line measurements of composition such as DEXA (Connaughton et al., 2020), would also demonstrate minimal effect on eating quality scores for the hotpot cooking method given the lack of significance observed using the indicator of fatness (LLFAT) used in this study.

Increasing muscularity as measured through LLWT adjusted for HCW in the hotpot experiment (Chapter 6) had a significant negative impact on all sensory traits across a 400g range. This is in agreeance with previous findings in Australian consumers (Pannier et al., 2014b). Some exceptions existed for tenderness, where a significant interaction between shoulders and legs in the Merino yearling and lamb groups had a converse relationship, showing higher tenderness scores with increasing LLWT. It could've been surmised that low lamb leg numbers (n=16) for this subgroup skewed the results, however there were ample yearling shoulders in this study (n=109) negating this theory. Further research on muscularity and Merino eating quality using a hotpot cooking method could be considered, however overall results align with accepted findings that higher muscling animals have lower eating quality outcomes. The impact of IMF and muscularity on shoulder and legs cut eating quality scores using a hotpot cooking technique indicates that producers will still find benefit in genetic management of IMF and LMY traits using the new ASBV eating quality index (Sheep Genetics, 2018), even for products destined for further manufacturing channels, in this case thinly sliced hotpot rolls.

7.3.3 Animal age at slaughter and sire type effects

An influence of animal age at slaughter was detected in both grilled LL and SM, and shoulder and leg cuts using a hotpot cooking method in Chapters 3 and 6, respectively. Within this study age class was confounded by sire type with yearlings strictly Merino wethers in both grill and hotpot collections. This affected both age class and sire type comparisons, as age at slaughter could only be compared between Merino lambs and yearlings, and sire type across the lamb group which reduced total carcase numbers in the analyses.

For the grill study, American, Australian, and Chinese consumers generally scored tenderness and overall liking of LL and SM greater in lambs than yearlings, with the exception of Australian consumers detecting no difference in overall liking for the SM between age groups. The magnitude of effect was greatest for tenderness in the LL samples (Chapter 3). Chinese consumers also detected a significant age class effect across all sensory traits in the hotpot study with lamb preferred to yearling (Chapter 6). Specifically, for tenderness there was a greater improvement in palatability for lamb shoulder cuts compared to legs. These results align with previous published data that lamb generally has superior eating quality to yearlings however some variable effects across sensory traits and muscles have been published (Pannier, Gardner, & Pethick, 2018; Pethick et al., 2005). The latter has been attributed to changes in connective tissue solubility and build-up of flavour compounds in fat deposits resulting in stronger flavours (Watkins et al., 2013; Young & Braggins, 1993). Consumer allocation of grilled lamb and yearling samples to quality grades in Chapter 5 reflected this lamb preference with the proportion of samples allocated to better than every day and premium categories higher in lambs compared to yearlings for all three consumer groups. The ranking of importance of the sensory traits also shifted between lamb and yearling groups for American and Australian consumers indicating they may be more responsive to physiological changes observed with age in the samples served in this study.

The influence of sire type was evident for tenderness and overall liking in the grill experiment with differences observed between countries and cuts (Chapter 3). Merino sired lambs were preferred to Terminal with no impact of the Maternal sire type on eating quality in this study. American consumers preferred the Merino LL, and Chinese consumers the Merino SM with no effect in the alternative cut. Australian consumers scored only overall liking of the Merino lamb LL higher than Terminal with no difference in the SM. These results were in partial agreement to previous findings in Australian consumers, given the sire type effect did not extend across all sensory traits and was not observed in Maternal sired progeny (Pannier et al., 2014b). Increased selection for muscling and leanness in Terminal sired animals has been shown to have a negative effect on eating quality (Hopkins, Hegarty, & Farrell, 2005; Pannier et al., 2014), hence inclusion of LMY, IMF and HCW in the new MSA model should account the compositional factors associated with eating quality specific to these sire types. In the hotpot experiment, there was no effect of sire type on the eating quality of shoulder and leg cuts for Chinese consumers (Chapter 6), however Maternal and Merino lamb numbers were low (11 and 16 compared to 81 Terminals). For future work, it would be ideal to have more balanced animal numbers in the sire type groups tested. For grill and hotpot experiments animal selection was based on availability of INF animals, a resource that is utilised by many projects, hence sire type was as balanced as was practical. In regards to Merino sired yearlings, they could be considered an adequate representation of yearling sheep in Australia, as they are typical to the sheep industry with producers benefiting from both meat and wool products from these animals, with final slaughter age dependent on feed availability, market specifications and production priorities (Ponnampalam et al., 2020).

7.3.4 Kill group and site effects

In both the grill and hotpot experiments (Chapter 3 and 6), the slaughter group or flock (kill group) had a significant effect on eating quality. The grill study animals were sourced from a single site, with the two groups processed several months apart at the same abattoir, while the hotpot study contained animals sourced from two separate INF sites (Katanning in Western Australia and Kirby in New South Wales), and processed at two different plants. Factors that could contribute to eating quality differences observed across these groups would include lifetime nutrition, environmental factors, pre-slaughter stressors, processing effects (temperature, pH decline) and proportion of each sire type within the group. In the case of the hotpot study (Chapter 6), the inclusion of IMF in models explained the significant site differences observed between Kirby and Katanning, as higher IMF levels in the Terminal lambs at Katanning were driving greater sensory scores for this site. While for the hotpot study these kill group sensory differences were explained, there will always be some variance we are unable to account for with animals sourced at separate time points, locations and through different processing facilities.

7.4 Demographics and meat consumption preferences and eating quality

In chapter 4, the grill analysis demonstrated that demographic factors of consumer age, gender, number of adults in a household and income had the strongest effect on sensory scores but varied across the three countries with no consistent trends observed. It was difficult to draw parallels with previous research as demographic results are so variable (Bonny et al., 2017; Hastie et al., 2020; Hwang et al., 2008; Thompson et al., 2005d). In addition, of the three meat preference parameters tested, only frequency of lamb consumption had an effect on sensory scores. This contrasted with several studies of international consumers demonstrating appreciation of lamb and preferred degree of doneness also impacted on eating quality (Bonny et al., 2017; Hwang et al., 2008; Thompson et al., 2005d). Several significant findings in this study comprised of the underrepresented subgroups with these categories encouraging further studies. These findings indicate it is important to balance the model reference data for demographic factors of age, gender, number of adults and income, and meat consumption preferences that are reflective of the target consumer group to ensure sensory preferences are accurately represented in the MSA prediction models within these particular populations. Therefore, to construct a robust model for international consumer groups, more data is required. In America and China recruitment within the appropriate regions would be necessary, for example communities with higher lamb consumption rates, and relevant purchasing capabilities. For China this would mean further testing in tier one cities with larger numbers of middle-class residents, as they typically offer the greatest consumer base for imported products (MLA, 2021b) , these cities would include Beijing, Tianjin, Shanghai, Chongqing, Guangzhou, and Shenzhen. In addition, testing in a variety of regions with distinct cooking styles is relevant for incorporation of different cooking techniques and cuts into the grid (Mao et al., 2016; Nam et al., 2010). Within the USA, areas to target would be regions of growing consumption rates including California, the mid-south and north east and the millennial generation with their willingness to try new foods (MLA, 2021c). In addition, including participants of a broad range of age categories, income brackets, and including equal numbers of each gender would assist in building a model that can provide a quality assurance with a greater chance of meeting consumer expectations.

7.5 Use of a single composite score to predict eating quality outcomes

In Chapter 5 the grill dataset was subdivided into consumer country (America, Australia, China) and then age class within country (lamb and yearling) subsets to follow the MSA procedures for calculating: optimal weightings of the sensory scores to create a composite meat quality score (MQ4), the boundaries between quality grades, and the accuracy of prediction of model quality grade versus the consumer allocated quality grade (Watson et al., 2008a; Watson et al., 2008b).

Allocation of samples to a quality grade, showed Chinese consumers consistently assigned more samples as better than every day and premium quality grades compared to Australian and American consumers. Interestingly, American and Australian consumers assigned samples similarly across the quality grades despite very different consumption habits (Chapter 4) and the fact American consumers generally assigned higher sensory scores compared to Australian consumers (Chapter 3). Boundaries between quality thresholds were also lower for Chinese consumers, compared to American and Australian thresholds. Chinese allocation of samples and thresholds were unique in that almost all international studies utilising MSA protocols indicated a greater number of downgraded samples and higher quality thresholds than the Chinese consumers in this study and more downgraded samples in initial quality assignments (Bonny et al., 2016; Polkinghorne et al., 2011, 2014; Thompson et al., 2008). Greater quality rankings could be explained by Chinese consumers positively identifying Australian lamb as having superior quality, consistency, tenderness and nutritional value compared to locally sourced product (Kantono et al., 2021; MLA, 2021b).

For all three consumer groups, animal age class influenced assignment of quality grade with a greater proportion of samples in better than every day and premium quality categories for lamb compared to yearling. This supports the trend of better eating quality in lamb compared to yearlings in this thesis (Chapter 3 and 6) and more broadly in Australian consumers (Pannier et al., 2018a; Pannier et al., 2015; Pethick et al., 2005). Similarly, the relative importance of sensory traits in contributing to a composite MQ4 score was affected by age class for American and Australian consumers, while Chinese consumer weightings remained stable when ranking quality of either product.

The optimised discriminate function was most accurate for Chinese (66%) consumer prediction of quality grades compared to their true grades as assigned by the consumer compared to Australian (63%) and American (60%) predictions. These results align with previous accuracies found in Australian, Japanese, Irish, Korean, Polish, and South African consumers (Bonny et al., 2016; Polkinghorne et al., 2011, 2014; Thompson et al., 2010; Thompson et al., 2008; Watson et al., 2008a), confirming the models perform to a reasonable standard across these groups. The next steps would involve comparing the accuracy of the current optimal models to the accuracy when using the fixed weightings developed for the new MSA sheepmeat cut by cook model which has been based on extensive untrained Australian consumer testing (MLA, 2022). Comparisons of existing fixed weightings for beef MSA and optimal models showed some loss in accuracy for several international consumer groups examined (Bonny et al., 2016; Thompson et al., 2010; Thompson et al., 2008).

Moreover, a significant challenge for Australian sheepmeat exporters to the USA are low consumption rates, and negative consumer perceptions to imported lamb products compared to domestically produced products (American Lamb Board, 2022; Hoffman et al., 2016). Therefore, while performance of the American model appears similar to Australian consumers, assurance of quality doesn’t automatically overcome a broad range of extrinsic cues which influence purchasing decisions, country of origin being a common one (Font i Furnols et al., 2011; Sañudo et al., 2013). Further to this, expectations induced by information can affect quality perception (Anderson, 1973; Cardello & Sawyer, 1992), therefore whether a "premium" quality label is enough to override "product of Australia" labelling is unknown. Further consumer testing in the USA using a combination of blind tasting and samples with country-of-origin information could provide a clearer picture on the disparity in eating quality between domestic and imported products.

7.6 Conclusion

This thesis was the first to measure the sensory scores of untrained American, Chinese and Australian consumers to Australian lamb and yearling LL and SM using a grill cooking method and Chinese consumer scores of shoulder and legs cuts using a hotpot cooking technique. The first experiment explored the sensory scores of untrained consumers across the three countries to grilled lamb and yearling muscles, with linear mixed models demonstrating no significant difference in scoring for juiciness and overall liking, while for the traits of tenderness, liking of flavour and odour, the highest scores were observed in American consumers followed by Australian and Chinese consumers. These differences were unexpected given previous findings suggesting negative perceptions of Australian lamb in American consumers. Irrespective of consumer country, there was a preference for the LL muscle compared to SM, lambs to yearlings, and Merino compared to Terminal sired animals, indicating consistency in international consumer responses to known influencers of eating quality as demonstrated in Australian consumer testing of sheepmeat. The second experiment examining untrained Chinese consumers scores of lamb and yearling cuts cooked using a traditional hotpot demonstrated some similar results to the grill cooking method. Differences in cuts were discerned with higher scores for shoulders compared to legs, and lamb samples were preferred to yearling. Moreover, increasing IMF levels was shown to have a positive influence on eating quality while increasing muscularity had a negative effect, aligning with previous Australian research.

Further analysis of the grill data for the three countries showed demographic factors also have an influence on sensory scores with age, gender, number of adults in a household, and income have significant effects, however no consistent trends were discerned. And of the sheepmeat consumption habits analysed, only frequency of consumption had an effect within each country. This was in contrast to previous studies, where appreciation of lamb in the diet and preferred degree of cooking doneness had an impact on eating quality scores. Future studies would benefit from a more balanced recruitment of consumers across the meat preference and consumption categories to establish more robust results. The final analyses of the grill data included linear discriminate analyses to determine the quality thresholds, and accuracy of predicted quality grades compared to actual consumer assigned grades for each country. Results showed Chinese consumers to consign the most samples to higher quality grades, while American and Australian consumers were similarly more critical with a higher number of samples allotted to lower quality grades. The similarities between American and Australian results were surprising given the vastly different sheepmeat consumption habits between consumer groups recruited within this study. Utilisation of an optimised discriminate function showed higher prediction accuracy for sample consignment to quality grades for Chinese consumers compared to the Australian and American predictions. However overall, the accuracy of optimised prediction models for quality grades aligned well with previous international testing using the MSA methodology in beef, indicating value in categorisation of quality grades based on predictions using these models. There was some variation in magnitude of effect for several inputs which will be used in the recently developed MSA sheepmeat cut by cooking method model, hence adjustments should be considered for particular consumer groups. Chinese consumer response to IMF were lower than those previously reported in Australian consumers, therefore improvements to the MQ4 score based on increasing IMF levels should be adjusted after further data collection to reflect this. In addition, demographic factors and meat consumption preferences have a role to play, suggesting collection of further consumer data is warranted in order build confidence in prediction outputs. In summary, this thesis demonstrated that the MSA methodology was able to adequately capture the perceptions of international consumer groups to Australian sheepmeat, identified some differences to Australian consumers, and suggests the system could be used to underpin quality claims for international consumer groups but requires inclusion of greater numbers of untrained consumers. Thus, this research provides a valuable contribution to the MSA sheepmeat database and forms the preliminary data set on which to expand within China and the USA.

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