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Animal factors affecting the meat quality of Australian lamb meat

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Abstract

This paper integrates the key industry findings from the twelve preceding papers in this special edition of Meat science. In so doing, various animal factors important for the quality of Australian lamb meat are highlighted for sensory, visual appeal and human health attributes. Intramuscular fat concentration (IMF) was found to be a key element of eating quality that interacts both positively and negatively with a range of other factors. Shear force, IMF, colour stability and docosahexaenoic acid (DHA) will likely respond to genetic selection whilst other omega-3 fatty acids require nutritional intervention. Australian lamb meat can generally be regarded as a good source of the minerals iron and zinc; and a source of omega 3 fatty acids when finished on green pasture. Breeding priorities for meat quality will likely depend on breed type with improvement of meat colour stability more important for the wool focused Merino breed and improvement of sensory quality for the Terminal sire breeds.

Keywords: Lamb, eating quality, human health, colour, pH, flavour

1. Introduction

Sheep meat is a niche product that accounts for only about 3% of the meat market worldwide. As well as having to satisfy very specific market requirements, the sheep meat industry has to keep pace with productivity gains made elsewhere in the agricultural sector. The land allocated to sheep production in Australia has reduced at the rate of 4% and ewe numbers by 10% per annum since about 1990 (Barson, Mewett, & Paplinska, 2011). Despite this, prime lamb productivity has been maintained due to changes made to flock structure and increases in the yield of meat per lamb from increases in carcase weight and leanness (Pethick, Banks, Hales, & Ross, 2006). The weight of the average Australian lamb carcass increased from 17.5 kgs to approximately 21 kgs between early 1990 and 2006 (CIE, 2008). Lamb meat exports increased during this period, by an average rate of 14% per year to the U.S.A. for example (CIE, 2008). The lamb meat industry is now worth in excess of $3.5 billon (AUS) to the Australian economy, up from $1.5 billion (AUS) in 1999 (CIE, 2008).

Linked to this, meat consumer's value quality and nutritional attributes, but also seek value for money (Pethick, Ball, Banks, & Hocquette, 2011). In this context, there is little doubt that the Australian lamb meat industry needs to continue to research, develop and adopt appropriate technology to achieve gains for productivity, quality and nutritional value simultaneously. To this end the papers in this special edition collectively report a successful outcome for one major component of a very large and ambitious research program conducted by the Cooperative Research Center for Sheep Innovation (Sheep CRC). In so doing this builds on previous Australian work began circa 1999 and largely satisfies the goals of the program that were to:

- Build a large phenotypic data base of carcase and eating quality traits,
- Use the data base to develop breeding values for lean meat yield and objective measures of eating quality and meat quality,
- Understand the genetic and non genetic factors affecting the carcase, eating quality and meat science traits,
- Quantify the associations between biochemical measures of muscle aerobicity and the eating quality and meat science traits,
- Quantify the relationships between sensory and objective measures of eating quality.

Following the introductory paper by Pethick, Ball, Banks, Gardner, Rowe & Jacob (2014), this special edition consists of twelve papers that are linked by a common data set, created from the information nucleus flock (INF) (van der Werf, Kinghorn, & Banks, 2010). The theme of these papers is predominantly the description of animal traits that could be used to improve the eating/meat quality and or nutritional value of Australian lamb meat. Lean meat yield traits were also measured, but will be reported in other publications. An implicit and very important finding is that animal factors were found to have a significant and large effect on meat quality, once processing conditions had been optimized with a standard slaughter protocol between sites. This general finding provides a clear role for the production sector of the lamb meat industry to be an active participant, in endeavors to improve market acceptance of Australian lamb meat by improving its meat and eating quality. An example of this is the effect of intramuscular fat concentration (IMF) on tenderness that was influenced by animal more so than processing factors. Whilst processing factors such as the rate of pH decline are clearly important, maximising tenderness will require attention to IMF and this depends to a large extent on a lamb's genotype (heritability of 0.48, Mortimer et al., 2014) as well as carcase weight and fatness. Processing factors obviously influence the myofibrillar components of shear force, but have no effect on the IMF component. Supply chains will in the future need to consider animal breeding objectives therefore, as a vital component of their overall strategy for improving eating quality. This confirms the value of genomic information and resource flocks (Banks & van der Werf, 2009), since many of the important traits like IMF cannot be directly measured in sires, thus a reliance on genomic breeding values coupled with continual verification.

2. Genetic tools

A major goal of the INF was to provide genetic tools, particularly Australian Sheep Breeding Values (ASBVs), for eating quality and carcase lean meat yield traits. So a key output has been to discriminate traits that can be manipulated genetically from those for which non genetic management strategies will be more important. Two of the twelve papers might be considered as methodology development that better specify traits for different research and industry applications, both genetic and non genetic. This includes the paper by van de Ven, Pearce, & Hopkins (2014) on the modeling of pH decline and the paper by Jacob, D'Antuono, & Gilmour (2014) on colour stability. The modeling of pH decline post slaughter represents an enhanced method to predict the temperature of the lamb loin at pH 6 which is assessed in the Meat Standards Australia (MSA) grading system for lamb carcasses. More accurate prediction of pH and temperature conditions post mortem will be important for processing systems to be more tightly managed so as to optimise tenderness (Hwang, Devine, & Hopkins, 2003; Pearce, Hopkins, Toohey, Pethick, & Richards, 2006). Colour stability can be influenced by a range of processing factors as discussed by Jacob & Thomson (2012). The rate of colour change varies with time during the retail display period and this varies between animals (Jacob, Mortimer, Hopkins, Warner, & D'Antuono, 2011; Khliji, van de Ven, Lamb, Lanza, & Hopkins, 2010). To overcome this Jacob, D'Antuono, Gilmour, & Warner (2014) described a method using splines to predict the time required for the colour to reach a benchmark value for redness (R630/R580). This is an alternative to measuring colour at one time point at the end of simulated retail display (Calnan, Jacob, Pethick, & Gardner, 2014). Whist this has improved our understanding of colour stability; more work is required to develop a simple and practical method to predict meat colour stability. Ideally, this could be done early in the post mortem period without a need to expose meat to a simulated display period and potentially then integrated into breeding programs.

The paper by Mortimer et al. (2014) provides clear evidence that many of the meat quality traits are highly correlated with other traits and have moderate to high heritability's. Pannier et al (2014a) showed there were significant effects of sire type and sire (within sire type) on sensory scores for lamb loin. Further the genetic correlation between shear force after 5 days aging (SF5) and IMF levels was found to be -0.65 (Table 1) suggesting that selection for one will cause a change in the other. This will underpin the future use of both shear force and IMF as indirect predictors of the eating quality; allowing sires to be ranked for the likely eating quality of meat from their progeny with Australian Sheep Breeding Values (ASBV's). The cost of measuring sensory parameters means such indirect predictors must be used.

2.1 Single nucleotide polymorphism (SNP) associations

Novel associations between SNP's and phenotypes for shear force and omega 3 fatty acid concentrations were shown by Knight et al. (2014). These specific SNP's have been added to genomic association studies to strengthen the accuracy of genomically enhanced breeding values, especially for shear force (Daetwyler, Swan, van der Werf, & Hayes, 2012). Furthermore, breeding values can now be efficiently estimated for the hard to measure slaughter traits using the data generated in the INF.

2.2 Eating quality traits that are heritable

Intramuscular fat, SF5 and retail colour (hue, lightness, redness -measured after 3 days of simulated retail display) all had heritability estimates > 0.25. The pH of the loin 24 hours post slaughter (pH24LL, an estimate of ultimate pH) had a very low heritability at 0.07 and DHA had the highest heritability (0.22) of all the long chain fatty acids measured. The composition of the fatty acids in meat is very sensitive to diet (Ponnampalam, Butler, Pearce, Mortimer, Pethick, Ball, & Hopkins (2014a) and therefore manipulation through genetic selection would appear unattractive. A potential exception might be for the DHA content of muscle which is insensitive to diet, unlike the other omega 3 long chain fatty acids (Scollan, et al., 2005). IMF, SF5, and retail colour stability and perhaps DHA could all be considered either directly or indirectly in sire breeding programs. This in turn justifies the inclusion in future resource flock protocols for ongoing verification of genomic breeding values of these traits.

2.3 Genetic correlations between parameters

The scale of the INF program and the extensive list of traits have resulted in genetic correlations between traits with high precision (i.e. low standard errors). Some of the most important correlations are outlined in Table 1.

Insert table 1 about here

The genetic correlation between iron and myoglobin concentrations was extremely high suggesting these parameters effectively describe the same genetic trait in lambs. Iron concentration is important from a nutritive value point of view (FSANZ, 2012) and myoglobin concentration clearly affects the colour of meat.

The strength of the correlation between IMF and SF5 supports similar studies in beef cattle (Reverter et al., 2003) and further underpins the importance of IMF as an eating quality trait in prime lambs. IMF was also correlated with several of the colour parameters, but these associations appear complex. The correlation between IMF and b* values for example was positive for fresh meat and negative after simulated retail display (Table 2). A simple explanation may be that when meat is fresh, the colour of the fat affects the meat colour directly, so more IMF causes more yellow and less blue light to be reflected from the meat surface. Then after retail display, the effect of IMF on meat colour is different and due to the oxidation of myoglobin that makes the meat browner in colour, indicated by higher hue, lower redness (R630/R580) and lower chroma. A higher IMF would likely increase the propensity for lipid and subsequently myoglobin oxidation (Faustman, Mancini, Sun, & Suman, 2010). Jacob et al. (2014) also found a phenotypic association between IMF and colour stability, but more specifically this was likely due to linoleic acid. Lastly, the finding that loin meat with a low pH at 24 hours (pH24, an estimate of ultimate pH) was more stable in colour adds to the importance of pH24 as a component of meat quality for lamb.

There were several correlations between different colour traits that warrant further investigation. Lamb loin meat with high concentrations of myoglobin tends therefore to be dark in colour. McKenna, Mies, Baird, Peiffer, Ellebracht, & Savell, (2005) also found a phenotypic correlation of -0.43 between L* (lightness) and myoglobin in beef muscle. Factors that cause an increase in myoglobin concentration, such as animal age, might therefore be expected to make meat appear darker in colour regardless of hue or chroma. Understanding these relationships further could assist with practical options to manage them.

Insert Table 2 about here

Aerobicity of muscle fibres, as measured by the marker enzyme isocitrate dehydrogenase (ICDH) and myoglobin content is an important trait that needs to be indirectly managed with balanced breeding objectives (Kelman, Pannier, Pethick & Gardner, 2014). On the one hand ICDH was correlated favourably with SF5 and so tenderness and eating quality (Table 1). However this effect was unlikely due to IMF as the genetic correlation between IMF and ICDH was only 0.03 (Mortimer, et al., 2014). Calnan et al. (2014) showed that ICDH and IMF were antagonistic to redness after retail display. Previous work in ruminants has linked selection for muscularity and/or leanness with a decreased aerobicity of skeletal muscle (Gardner, Pethick, Greenwood & Hegarty, 2006; Jurie et al. 2007; Hocquette, Cassar-Malek, Jurie, Bauchart, Picard & Renand, 2012).

2.4 Correlations between eating quality parameters and existing production trait ASBV's

Several of the papers tested for associations between eating quality traits and production ASBVs used currently in industry. Examples of these traits are breeding values for muscling (post eye muscle depth), fatness (post weaning fat depth) and weight (post weaning weight). The findings overall support the continued use of these existing breeding tools to improve lean meat yield, although this will be reported in detail elsewhere as already mentioned. However Calnan et al. (2014) found that selection for lean meat yield will likely increase retail colour stability and Kelman et al. (2014) found that selection for yield will decrease the oxidative capacity of loin muscle which is consistent with our mechanistic understanding of colour stability (McKenna et al., 2005). However selection for lean meat yield alone could lead to a decrease in tenderness, IMF and consumer acceptance of lamb (Pannier et al., 2014a; Pannier, Pethick, Geesink, Ball, Jacob, & Gardner, 2014c), but not iron and zinc concentration (Pannier, Pethick, Boyce, Ball, Jacob, & Gardner, 2014b). The initiation of the new breeding values for SF5 and IMF will allow ram breeders to manage both lean meat yield and eating quality traits simultaneously, when incorporated into breeding objectives.

2.5 Breed priorities

Inclusion of the range of breed types used in the INF was done primarily to create a range of phenotypes rather than to compare different breeds. Breed differences in this data therefore need to be treated with caution as any apparent differences may not represent a true breed average difference. Furthermore, variation within a breed was generally greater than between breeds, which means that achieving a particular result can be done with any of the breeds tested if so desired. However, an apparent difference common to several of the analyses was that between Merino sire types and other breeds. In summary, meat from Merino lambs was generally speaking darker and less stable in colour (Calnan et al., 2014; Jacob et al., 2014) an outcome endorsing previous work (Warner, Ponnampalam, Kearney, Hopkins, & Jacob, 2007). Meat from Merino lambs also tended to be more tender (Pannier et al., 2014a), although this latter finding was contrary to previous work (Hopkins & Fogarty, 1998; Hopkins, Stanley, Martin, Toohey, & Gilmour, 2007) and so requires further investigation. The potential significance of this if real is multifaceted. Firstly in some parts of Australia, Merino genotypes contribute a large number of lambs for slaughter and Merino breeders need to consider wool attributes as a priority in selection indices. Of the meat quality traits, meat yield and dressing percent (Gardner et al., 2010) and colour stability are the traits most likely to need improvement for Merino sire types; sensory less important, if intended to be used as a terminal sire for lamb meat production. On the other hand improvement of sensory qualities is a greater priority for terminal sire types in the short and long term (Pannier et al., 2014a). Lastly further exploration of the differences between Merino and other breeds could assist to better understand mechanisms underlying eating quality attributes of lamb meat.

3. Non genetic tools

3.1 Benchmark data for eating quality and nutritional value of Australian lamb meat

This is the largest study undertaken so far on the eating quality for Australian lamb meat, in terms of lamb numbers, breeds, sires and the breadth of investigation across different environments. Accordingly the data is indicative of the range of genotypes and environments commonly used in Australia with the qualification that the INF was not completely representative of the Australian lamb industry in a “survey” sense. An obvious example to demonstrate this is that site effects were due to location and many other factors were confounded with site. So there is a need to be aware of such limitations when interpreting the findings. The general conclusions are that the levels of iron and zinc are sufficient to represent important sources in the human diet (Pannier et al., 2014b). This equally applies to the omega 3 content of lamb meat derived from lambs that have previously been grazing growing green pasture (Ponnampalam et al., 2014). However, for lambs finished on dry pastures or currently available concentrate diets, nutritional strategies will need to be developed to achieve a similar status. Overall the loin of lambs is of high eating quality; at better than every day using the MSA beef terminology (Pannier et al., 2014a) while the topside is closer to being marginal or good every day at best.

3.2 Provided important validation data for processing operations

The program described in this special edition has reinforced the need for optimal processing methods, especially for lamb meat that is purchased by the consumer after relatively short aging periods. In particular it has emphasized the need for regular monitoring of pH and temperature decline to verify electrical stimulation (Pearce et al., 2010; van de Ven et al., 2014) systems with lamb carcases. This has in part contributed to a significant uptake of the MSA lamb system in Australia during the last 3 years.

4. Future directions and industry programs

In summary, the findings of the studies in this special edition provide a description of the range of eating quality expected for lamb in Australia and an insight into some of the associations that might cause the ranges observed. This provides clear direction for technology development and adoption by the Australian lamb meat industry for the purpose of improving eating quality further to existing systems. Inclusion of eating quality traits in breeding objectives, directly or indirectly, development of "on line" measurement technology for lean meat yield and eating quality traits and an updating of the MSA grading scheme for lamb and sheepmeats are obvious considerations to be made to take advantage of these findings. The studies also demonstrate the extra value obtained when research and development are combined across disciplines, in this case genetics and meat science linked by a large resource flock.

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Table 1 Examples of traits found to be closely correlated from Mortimer et al., 2014) pH24LL = the pH of the loin 24 hours post mortem, ICDH = isocitrate dehydrogenase activity. Retail colour parameters were measured after a 3 day simulated retail display period commenced 5 days after slaughter.

Trait 1	Trait 2	Genetic correlation	Phenotypic correlation
Myoglobin	Iron	0.97	0.35
Retail hue	Retail redness (R630/R580)	-0.90	-0.52
Retail chroma	Retail redness (R630/R580)	0.80	0.83
Myoglobin	Fresh L value	-0.81	-0.21
pH24LL	Retail hue	0.62	0.21
IMF	SF5	0.65	0.30
Linoleic acid	IMF	0.63	0.34
HCWT	pH24LL	-0.32	-0.12
ICDH	SF5	-0.27	-0.12
Arachadonic acid	IMF	-0.22	-0.05

Table 2 Correlations between a range of different colour parameters and intramuscular fat (IMF) from Mortimer, et al., (2014)
Fresh colour parameters were measured 24 hours post slaughter. Retail colour parameters were measured after a 3 day simulated retail display period commenced 5 days after slaughter.

Colour Trait	Genetic correlation	Phenotypic correlation
Fresh *b**	0.81	0.25
Retail b*	-0.06	0.02
Retail redness (R630/R580)	-0.27	-0.12
Retail hue	0.17	0.10
Retail chroma	-0.17	-0.04

Highlights

1. Papers in this special edition were summarised
2. Eating quality is heritable
3. Meat colour stability priority for Merino
4. Sensory quality priority for terminal breeds