Final report

Shelf life experience in chilled lamb export supply chains

Project code: V.MFS.0001

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Date published: 9 April, 2021

PUBLISHED BY
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NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The shelf-life of chilled lamb meat is significantly consumed during shipment to distant markets such as North America and Europe. Successfully growing the value of international trade and maximising opportunities for sale of chilled sheep meat would benefit from a longer shelf-life than can currently be achieved. Using a mixed methods approach, quantitative and qualitative data was collected from lamb processors and exporters about their experience of lamb shelf-life. This was achieved through an online survey and semi-structured interviews. While bone-in products were most often reported to experience shelf-life issues, variability existed in the evidence of end-of-life, the quantity of consignments affected and the frequency of shelf-life issues due to the complex nature of lamb supply chains and processing operations. Common themes suspected to influence shelf-life included: cold chain management (internal and external); customer/consumer product care and shelf-life education; economic pressures; packaging type, product handling and hygiene; season, livestock condition and meat quality attributes; and transportation time. Such information will contribute to future investigations to determine the causes and potential practical solutions for shorter lamb shelf-life. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

Executive summary

Background

When chilled lamb meat is transported by ship to distant markets, such as North America or Europe, the potential shelf-life of product is significantly consumed. Successfully growing the value of international trade and maximising opportunities for sale of chilled sheep meat would benefit from a longer shelf-life than can currently be achieved.

The usual end-of-shelf-life of lamb may be characterised by strong dairy, cheesy odour, followed by a more persistent unpleasant odour. Shelf-life may also end prematurely due to the presence of specific spoilage bacteria that may produce odours or greening of the meat.

The shelf-life of chilled, vacuum-packed lamb is significantly less than the shelf-life of beef products held under the same conditions.

Bone-in products are generally considered to have shorter shelf-life, though this may not always be so. The reason for shorter shelf-life of bone-in products is not well understood, but the characteristics of the animals processed, the presence of bone dust in the pack, holes in packaging caused by mechanical action of the bones against the packaging, or contamination associated with the bone or joints themselves, have all been speculated as contributing to shorter shelf-life.

While extensive research into the common factors affecting lamb product shelf-life has been conducted, interactions between these factors and other less common or unknown influencing factors may vary according to the meat processors business. Therefore, difficultly in addressing shelf-life issues may be experienced by businesses regardless of this knowledge. The collection of qualitative data from lamb processors and exporters about their experience of lamb shelf-life, and for bone-in product in particular, was central to this project. This will contribute to investigations to determine the causes and potential practical solutions for shorter lamb shelf-life. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

Objectives

The project successfully aimed to describe lamb shelf-life problems experienced by the Australian export industry, particularly:

- the types of products experiencing shelf-life issues
- the perceived reliable shelf-life of the product
- the frequency with which problems occur
- customer complaints about product not reaching expected shelf-life
- a description of the shelf-life problem
- observations that may explain the expected reliable shelf-life and the experienced shorter-than-desired shelf-life.

Methodology

The study was conducted from February to March of 2021 and included several phases, beginning with a review of the literature relating to lamb shelf-life issues and key impacting factors which should be addressed in subsequent research. A mixed methods research design, involving an initial quantitative survey, followed by qualitative semi-structured interviews was used to address the research objectives. Sixteen potential participants were drawn from a list of existing lamb processors and exporters held by MINTRAC and contacted by a member of the research team to secure involvement. While interest to participate was expressed by all processes who were contacted, twelve completed the study. Data was analysed by descriptive and thematic data analysis.

Results/key findings

The study found that the shelf-life issues experienced among exporters of Australian lamb differed according to the unique shelf-life incident. Bone-in product transported by sea freight was more commonly reported to have experienced reduced shelf-life, with processors often alerted to shelf-life issues by the customer in the export market. No particular trends were apparent across the reported evidence of end-of-shelf-life. Many processors had validated product shelf-life to between 70 and 90 days, and where incidences occurred, actual shelf-life achieved varied between 28-63 days. With some shelf-life complaints being infrequent, often issues were experienced seasonally with many processors noting issues to occur either in the Australian autumn-winter months or importers' Summer period. From themes identified in semi-structured interviews, suspected causes of shelf life issues included:

- Cold chain management (external)
- Cold chain management (internal)
- Customer/Consumer education
- Economic pressures
- Packaging/Product handling/Hygiene
- Season/Livestock condition/Meat quality attributes
- Transportation time

Benefits to industry

From the study a greater understanding of the shelf-life issues experienced for chilled, vacuumed-packed product exported by Australian lamb exporters was developed. This information will contribute to investigations to determine the causes and potential practical solutions for shorter lamb shelf-life. In addition, the development of the recommended education materials and programs may prove to fill knowledge gaps and reduce shelf-life issues within the lamb supply chain. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

Future research and recommendations

With many processors experiencing difficulties in identifying and overcoming shelf life issues experienced with vacuum packed, chilled lamb product, such information can be used to direct future research in this space. Specifically, investigations into the relationships between suspected causes of shelf-life issues and shelf-life incidences should occur to confirm causation and further allow the development of practical solutions for achieving a longer shelf-life. In combination with this, the development of training materials and customer/consumer education programs relating to determining end of shelf-life may prove valuable in ensuring that there is universal understanding of product care requirements and product shelf-life expectations.

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1. Background

The shelf-life of meat and meat products is determined by the length of time that the quality characteristics of the product remain suitable for human consumption under the specified conditions for packaging and storage (Meat & Livestock Australia, 2016). End of shelf-life is the point whereby meat product is no longer suitable for human consumption and the freshness and safety of product has been compromised (Haines and Sumner, 2007).

The shelf-life of chilled sheep meats (lamb) is significantly consumed in transport to distant markets and logistics, particularly when shipped to North America or Europe. Successfully growing the value of international trade in these products and maximising opportunities for sale of product would benefit from a longer shelf-life than can currently be achieved. The shelf-life of chilled, vacuum-packed lamb is significantly less than the shelf-life of beef products held under the same conditions. The usual end of shelf-life of lamb may be characterised by strong dairy, cheesy odour, followed by a more persistent unpleasant odour. Shelf-life may also end prematurely due to the presence of specific spoilage bacteria that may produce odours or greening of the meat (Meat & Livestock Australia, 2016). Bone-in products are generally considered to have shorter shelf-life, though this may not always be so (Kiermeier et al., 2013). The reason for shorter shelf-life of bone-in products is not well understood, but the characteristics of the animals processed, the presence of bone dust in the pack, holes in packaging caused by mechanical action of the bones against the packaging, or contamination associated with the bone or joints themselves, have all been speculated as contributing to shorter shelf-life.

While extensive research into the common factors affecting lamb product shelf-life has been conducted, interactions between these factors and other less common or unknown influencing factors may vary according to the meat processors business. Therefore, difficultly in addressing shelf-life issues may be experienced by business regardless of this knowledge. The collection of qualitative data from lamb processors and exporters (technical and salespeople) about their experience of lamb shelf-life, and for bone-in product in particular, will contribute to investigations to determine the causes and potential practical solutions for shorter lamb shelf-life. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

2. Objectives

The project aimed to describe lamb shelf-life problems experienced by the Australian export industry, particularly:

- the types of products with which shelf-life issues were experienced
- the perceived reliable shelf-life of the product
- the frequency with which shelf-life problems occur
- customer complaints about product not reaching expected shelf-life
- a description of the shelf-life problem
- observations that may explain the expected reliable shelf-life and the shorter-than-desired shelf-life

The objectives of the project were met and are discussed in the relevant results section of this report.

3. Methodology

The study was comprised of three key research phases conducted from February to March of 2021. Phase 1 included a review of the literature relating to lamb shelf-life issues and key impacting factors which should be addressed in the subsequent research. Phases 2 and 3 involved a mixed methods research design, which included an initial quantitative survey, followed by qualitative semi-structured interviews.

3.1 Phase 1 – Review of the literature

A review of the literature produced overseas and within Australia, relating to lamb shelf-life, was conducted. These articles included industry generated reports, peer-reviewed research papers, as well as regulatory documents and publications. Content ranged from regulatory standards relating to food production, food safety and shelf-life requirements to specific factors impacting upon the shelf-life achieved for lamb product. Key information describing lamb-shelf life standards, issues and impacting factors was extracted and used to inform online survey development.

3.2 Phase 2 - Online survey

An online survey, informed by the findings of the literature review, was developed in Microsoft Office Forms (Microsoft, 2019) and aimed to capture general information about the enterprises processing operations, identify commonalities and differences across industry processing establishments, and to inform areas for discussion during a follow up interview. The online survey was deployed to participating lamb processors and comprised of 40 multiple choice and short-answer response questions relating to key shelf life information (Appendix A).

3.2.1 Ethics

Advice on whether ethics approval for the study was required was sought from The University of Tasmania's Human Research and Ethics Committee (HREC). The activity and objectives of the study were deemed to constitute business activity, looking toward quality assurance (with evaluation) and thus, ethics approval for all components of the work were deemed unnecessary. Despite this, all efforts to ensure that the activities of the research were conducted in an ethical manner were made.

3.2.2 Participant recruitment

Participant interest in the project was initially generated through publishing details of the project in the MINTRAC newsletter. Subsequently, a list of all the lamb export plants and non-packer establishments across Australia was generated from the MINTRAC database. Sixteen potential participating enterprises were contacted by a member of the research team to secure involvement. A welcome email was sent to all establishments who expressed interest, and this included detail of the project and the execution process, as well as a link to the online survey and required completion date. Follow up emails were sent approximately once per week to ensure all responses were generated in a timely manner. Evidence of consent to participate in both the online survey and semi-structured interviews was obtained from participants via the submission of the online survey. The survey introduction included the statement: *"By completing and submitting this survey you acknowledge that you have received the participant welcome letter/information sheet for the Shelf-life Experience in Chilled Lamb Export Supply Chains project and give your consent to being involved in both Phase 1 and Phase 2 of the project."*

While interest to participate was expressed by all processes who were contacted, twelve participated in the study. A database of those who had initially expressed interest and those whose involvement was secured by phone call was kept allowing ongoing management of participants.

3.2.3 Data

An online survey comprising of 40 short answer and multiple response questions was deployed to participants (Appendix A) along with the welcome letter. This was open for responses across a ten-day period. Questions were targeted at understanding the enterprises processing operations and conditions which may impact on chilled lamb shelf-life and were organised according to themes identified from the review of the literature as well as discussions with project stakeholders. These included key markets and transport; supply chain stakeholders; product types; employee training; livestock type and condition; carcase monitoring and hygiene controls; processing temperatures; and shelf-life factors (i.e. evidence of end of shelf-life, products experiencing issues, frequency of issues, feedback, source identification). Participants were also asked to indicate their availability for scheduling of the follow-up semi-structured interviews. Here, consent to record such interviews, for data transcription purposes only, was obtained through a multiple response question.

3.2.4 Statistical analysis

Online survey responses were obtained from 12 participants and data exported to an excel file for descriptive analysis. Where ranges were given for numerical quantitative responses, the average was taken. Where a less than or equal sign was indicated for these questions, the value of this was taken as the threshold for that processor. Where shelf-life data was given for both a hard-chill and normal chilling program, data for the hard-chill program were included only. Where no data was given due to processors not producing a product, this was excluded. For short-answer questions, themes were drawn from responses and reported.

3.3 Phase 3 - Semi-structured interviews

Semi-structured interviews were conducted across a one-week period, following the closure of the online survey. These aimed to gain a deeper insight into the shelf-life issues experienced by processors with questions being informed by the research objectives and the results of the online survey (Appendix B).

3.3.1 Participant recruitment

All participants who completed the online survey were interviewed via Zoom and appointments scheduled as per the participants availability indicated in the online survey. Permission to record interviews, for data transcription purposes only, was also indicated in the online survey. On occasion, both the primary and an additional researcher were present for note taking purposes.

3.3.2 Data

Semi-structured interviews of approximately 30 minutes duration were conducted with Quality Assurance (QA) personnel from the processing enterprises. Guided by the interview template (Appendix B), information captured included anecdotal experiences relating to the types of products experiencing shelf-life issues; expected and actual shelf-life periods; the frequency of shelf-life issues; the evidence of product end of shelf-life; complaints received on shelf-life issues; and observations which may explain the shorter than expected shelf-life of chilled lamb products. Participants were also given opportunity during the interview to expand on actions taken to address the shelf-life issues which had been identified.

3.3.3 Statistical analysis

Interview recordings were transcribed into a word document for analysis. Where permission was not given for interviews to be recorded, the notes taken during the appointment were either relayed to the interviewee for confirmation or sent to the interviewee for minor editing to ensure details were captured correctly. All interview transcripts were analysed thematically with major themes including those identified from the literature and online surveys. Sub – themes were then used to capture consensus and minority views on a subject.

4. Results

4.1 Literature Review

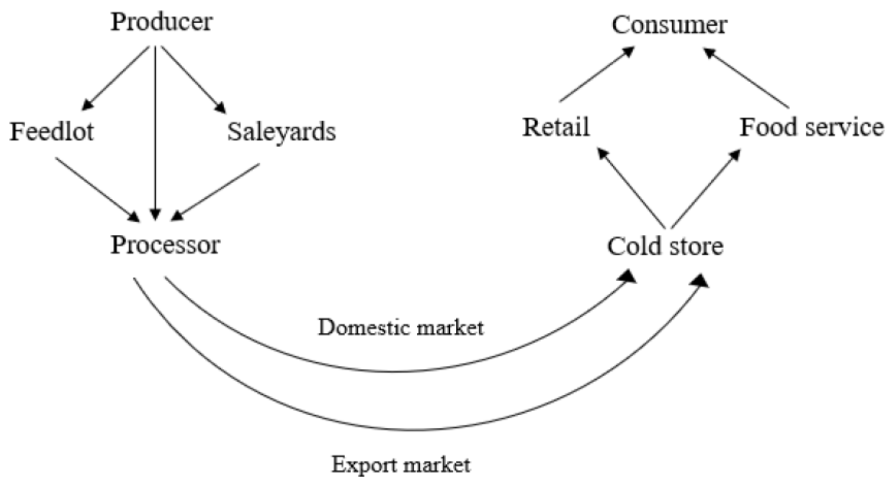
4.1.1 Food Safety in the Australian Lamb Industry

The Australian sheep meat industry accounts for approximately $7.2 billion of Australia's export income, with domestic expenditure being $2.5 billion. In 2019, 731, 281 tonnes cwt of sheep meat was produced with 25% of this being mutton exports, 38% being lamb exports and the remainder for domestic purposes. As the largest exporter of sheep meat globally and accounting for 7% of global production, demand for Australian product is underpinned by a high level of product quality with key export markets being China, the United States and the United Arab Emirates (Meat & Livestock Australia, 2020).

Product freshness and safety are two significant components constituting product quality (Lütke Entrup, 2005). Freshness can be defined as having the qualities of new or natural conditions for product that is not preserved by processes such as freezing (Cambridge University Press, 2021). Safe foods are those which, according to the foods reasonable intended use and being properly subject to all of the processes relevant to its intended use, are considered unlikely to cause physical harm before or after the time of being consumed (Australia New Zealand Food Authority, 2001). While consumers may use sensory information such as sight, smell and taste to aid in determining product freshness, safety cannot be reasonably discerned due to the inability to detect microbial pathogens (Meat & Livestock Australia, 2016). Further, consumers may not come into contact with product prior to purchase and thus rely on product shelf-life date to determine product quality (Lütke Entrup, 2005). Product shelf-life date, based on either quality or safety attributes, provides consumers with the length of time which the food should be kept before it begins to deteriorate or become unsafe for consumption and this is indicated by either a 'best-before' or 'use-by' date. These dates respectively indicate the length of time which quality attributes (e.g. colour, odour, taste, texture) will be maintained and the last date on which the product can be safely consumed, providing the product package remains unopened and is stored according to stated conditions (Food Standards Australia New Zealand., 2013).

The lamb supply chain is a highly complex value chain which involves several key stakeholders who process, package, transport and store product. Product may be acquired by many or few stakeholders along the chain with these namely including producers, processors, cold stores, retailers/food services, transporters and consumers (Figure 1.). Travel time to export destinations for lamb products may range from 4-6wks, with consignment rejections, due to product having reached end of shelf-life, not being uncommon (McPhail et al., 2014). It is estimated that deficiencies in the cold chain result in losses of 3.5% of the annual production of meat (including beef) or $0.14 billion in sheep meat annually (Barnes et al., 2020).

Figure 1. Australian lamb supply chain (after (Government of Western Australia, 2019)).



Food safety risks and outcomes are not limited to any particular sector of the supply chain as any break in the management of conditions, whether by failure to follow requirements or faulty equipment, may reduce the shelf-life of product (Australian Food and Grocery Council., 2017). Therefore, the responsibility to manage product safety, quality and shelf-life extends to all supply chain stakeholders. Wholesomeness is a key term used in the Australian meat industry which describes product that is safe for human consumption as determined by (1) not being likely to cause food-borne illness, (2) not containing excess residues, (3) being free of contamination, (4) being free of objectionable defects, (5) being produced and transported under adequate hygiene and temperature controls and (6) not containing additives or having undergone treatments contrary to the Food Standards Code, Commonwealth or State/Territory law (Anon., 2007). With this term encapsulating product safety and thus shelf-life, it is essential that controls to manage product wholesomeness are implemented throughout the supply chain to maximise food safety and product marketing opportunities, minimise product wastage and ensure that Australia's reputation for producing quality and safe meat is not compromised. These controls are outlined in the *Australian standard for the hygienic production and transportation of meat and meat products for human consumption* (AS 4696) and are summarised in Table 1.

Table 1. Summary of controls for the management of wholesomeness throughout the lamb supply chain (after Anon. (2007))

Supply Chain Activity	Controls	Key Examples
Operational hygiene	Ensure that operational hygiene process controls are in place.	• The premises are cleaned before and conclusion of operational shift. • Cleaning and sanitisation is implemented wherever necessary to prevent contamination of product. • Materials and chemicals are used only for the intended purpose. • Product is not contaminated throughout operational processes.
Supply and admission of animals for slaughter	Animals are sourced from holdings whereby the potential to jeopardise wholesomeness is minimised. Livestock with contamination potential are managed to minimise to prevent jeopardization of wholesomeness.	• Systems are in place to identify livestock with contamination potential. • Livestock are raised with good husbandry and feeding practices. • The livestock source property complies with sampling, monitoring and testing programs. • Animals are inspected prior to admission for slaughter by a meat safety inspector. • Systems are in place to allow the traceability of carcases and carcase parts back to live animals.
Slaughter and dressing	Livestock slaughter and dressing processes prevent jeopardization of wholesomeness.	• Carcases are quickly dressed post slaughter in a hygienic manner. • Primary bleeding is completed prior to dressing. • Contact between carcases is disallowed until post mortem inspection is completed. • Skinning of the carcase is completed before evisceration. • Discharge of bodily material from the organs and nodes is prevented. • Any evidence of disease or contamination is removed prior to the completion of post mortem inspection.
Post mortem inspection and disposition	Unwholesome meat is rejected for human consumption and removed from the supply chain.	• Carcases and carcase parts for human consumption are inspected by a meat safety inspector. • Suspected unwholesome carcases and carcase parts are not passed for human consumption.
Chilling and freezing	Wholesomeness is not jeopardised during chilling and freezing.	• Chilling and freezing of meat does not jeopardise wholesomeness. • All carcases and carcase parts are refrigerated for chilling or freezing within two hours of stunning.

		• Continuous temperature reduction to no warmer than 7°C on all surfaces for carcases, quartered or bone-in major cuts is achieved within 24 hrs of stunning and for any carcase site of microbiological concern 5°C. • There is no contact between carcases during primary chilling. • The entry of hot carcases into chillers does not contaminate chilled carcases or create condensation. • Other than when a process is being applied, carcases and carcase parts are maintained at the specified chilling temperature.
Thawing, tempering and boning and other processing of raw meat	Wholesomeness is not jeopardised during thawing, tempering and boning and other processing of raw meat.	• If removal from refrigeration for processing is likely to result in a temperature of greater than 7°C on all surfaces for carcases, quartered or bone-in major cuts and 5°C for any carcase site of microbiological concern, then processing environment must be no warmer than 10°C. • After processing is completed, meat immediately undergoes further processing or is chilled to 7°C on all surfaces for carcases, quartered or bone-in major cuts or 5°C on any surface for all other cuts.
Packaging	Wholesomeness is not jeopardised during the packaging of meat	• Packaging and packing materials do not contaminate and are free from substances capable of contaminating meat products. • Packaging and packaging materials are sufficiently strong enough to ensure wholesomeness is not jeopardised during storage, handling and transportation of meat and meat products. • Packaging of raw product meets the time and temperature requirements for processing.
Storage and handling	Wholesomeness is not jeopardised, and product is not contaminated during the storage and handling process.	• Meat and meat products are stored at a temperature no warmer than 7°C on all surfaces for carcases, quartered or bone-in major cuts and 5°C on any surface for all other cuts at the site of microbiological concern. • Meat and meat products are not removed from a chiller for transport unless all their surfaces are visibly dry and they are at a temperature of no warmer than 7°C on all surfaces for carcases, quartered or bone-in major cuts and 5°C on any surface for all other cuts at the site of microbiological concern.
Transport	Wholesomeness is not jeopardised during the transportation of meat and meat products	• Exposed meat and meat products do not come into contact with potential contaminant surfaces • There is adequate air flow • Products are transported at a temperature of no warmer than 7°C on all surfaces for carcases, quartered or bone-in major cuts and 5°C on any surface for all other cuts at the site of microbiological concern. • Product must not be loaded onto a vehicle for transport where the carrying compartment and loading equipment does not meet requirements set by the Standard.

The controls specified in the Australian Standard ensure that a level of product wholesomeness and shelf-life is maintained and that product remains safe for consumption following cooking, provided the stated shelf-life is adhered to (Meat & Livestock Australia, 2016). These controls are a minimum requirement and not best practice for maximising the shelf-life of chilled lamb. Therefore, these may be advanced in a processor's approved arrangement (document stating approved business operations and conditions by the controlling authority) where equivalence can be demonstrated and thus potentially allow for a greater level of product quality and shelf-life to be achieved (Anon., 2007).

Lamb shelf-life

Specifically, the shelf-life of meat and meat products is determined by the length of time that the quality characteristics of the product remain suitable for human consumption under the specified conditions for packaging and storage (Meat & Livestock Australia, 2016). End of shelf-life is the point whereby meat product is no longer suitable for human consumption and the freshness and safety of product has been compromised. Specific meat quality characteristics influencing consumer acceptability of such products have been reported to include meat colour and appearance; rancidity; and texture, odour and flavour changes (Haines and Sumner, 2007).

Being a perishable product, the shelf-life of lamb is typically preserved by a combination of refrigeration and packaging conditions (Bellés et al., 2017). Lamb product outputs from meat processing plants may include both bone-in or boneless product ranging from carcases through to primal cuts or retail ready product. Common packaging methods include modified atmosphere packed (MAP) or vacuum packed (VP) (Bellés et al., 2017, Peck et al., 2020). MAP traditionally uses O_2, CO_2 and N_2 gasses, whereby O_2 concentrations range from 60-80% in order to preserve the red colour of meat desired by consumers, as this is generally perceived to be a sensory indicator of product quality and shelf-life (Bellés et al., 2017, Gutiérrez et al., 2011). VP product refers to that which has been placed in packaging of low oxygen permeability and sealed via vacuum to create an anoxic environment (Mills et al., 2014). Table 2 outlines the quality characteristics of product suitable for human consumption and for that which has reached the end of shelf-life for various packaging methods. For comparative purposes, the expected shelf lives for both lamb and beef retail products under common temperature and packaging conditions are shown in Table 3. It is reported that the lower shelf-life of lamb product, when compared to beef, is due to differences in the chemical properties of the product such as having a greater pH and therefore chemical and microbiological deterioration of product occurs more rapidly (Stahlke et al., 2019).

Table 2. Sensory criteria indicating shelf-life state of meat and meat products by packaging type (Meat & Livestock Australia, 2016).

Retail product	Positive quality characteristics	End of shelf-life characteristics
Overwrapped tray (non-aged)	Pink-red bloom. Odour of fresh meat.	Loos of bloom, brown discolouration. Off-odours, off-flavours, slime.
MAP – high oxygen (non-aged)	Pink-red bloom. Odour of fresh meat.	Loos of bloom, brown discolouration. Off-odours, off-flavours, slime. Excessive purge/drip.
Vacuum Packed (VP)	Purple meat colour, tight pack. Short-lived confinement odour. Minimal drip.	Unacceptable, persistent confinement odour. Meat discoloured (brown, grey or green) in in intact pack. Excessive purge/drip/
Overwrapped (from VP aged meat)	Good pink-red bloom. Odour of fresh meat. Minimal drip.	Loss of bloom, brown. Sour odour and flavour. Excessive purge/drip.
MAP – high oxygen (from VP aged meat)	Good pink-red bloom. Odour of fresh meat. Minimal drip.	Loss of bloom, brown. Sour odour and flavour. Excessive purge/drip.

Table 3. Expected shelf-life for both beef and lamb products, in weeks (w) and days (d), under different packaging and storage conditions (after Prime Safe (2021)).

		Shelf-life	
Retail product	**Temperature (°C)**	**Lamb**	**Beef**
Carcase	<7	6d	7-10d
Carcase quarters	0-2	10-13d	3-4w
Overwrapped carcase quarters	0-2	10-13d	12d
Unpackaged primal cuts	<5	3-5d	3-5d
Overwrapped retail cuts	<5	3-4d	4-5d
VP Raw primal chilled	<5	7w	9w
VP Raw primal chilled	0	7w	12w
VP Machine/Diced Chilled	<5	3w	3w
VP Hand Diced/Sliced Chilled	<5	2w	2w
MAP (80% O_2)	<5	4-7d	5-10d
MAP low O_2 (<500ppm)	<5	2-4w	3-6w

Factors impacting end of shelf-life

End of lamb product shelf-life may be due to a number of factors, most notably including temperature, microbial growth, meat quality characteristics and chemical changes over time/product deterioration (Meat & Livestock Australia, 2016). Typically, these factors do not individually influence shelf-life but rather operate interactively. Thus, difficulty in managing and predicting shelf-life may be experienced by businesses (Lütke Entrup, 2005). Meat processors are required by regulations to date-mark any pre-labelled packages of fresh lamb product and are increasingly requested by retailers to provide dates for larger packs of meat such as VP primal cuts, taking into account a retail display life of two to three days. With this, processors are further being requested to validate product shelf-life claims (Haines and Sumner, 2007). Developing an understanding the factors impacting end of shelf-life is important when managing food safety risks, improving product quality and thus sale opportunity.

Temperature

Temperature is an important factor in managing product quality and shelf-life as it slows the natural deterioration and spoilage of fresh product as well as microbial growth. Most microbial growth is slowed under temperatures of 5^{o}C or less and this is reflected by the refrigeration conditions set by the Australian Standards (Australian Food and Grocery Council., 2017). Storage temperature is a critical factor enabling the export of VP lamb product to overseas markets, allowing a shelf-life of 60-70 days. With anoxic packaging options such as VP minimising the growth of obligate aerobic spoilage bacteria and allowing a greater shelf-life to be achieved, a storage temperature of -1.5^{o}C is recommended to slow product deterioration rates. Alternatively, for fresh wrapped or MAP product storage temperatures of approximately 2^{o}C are recommended due to such products typically having shorter transportation times and usually being intended for more local markets. Therefore, such product require short shelf lives (Mills et al., 2014).

Microbial growth

Microbial growth is one of the principal factors or mechanisms causing spoilage (off odour and/or slime) of meat products. Microbial pathogens impact shelf-life by compromising both product quality and food safety with the number of microbial pathogens present typically being a function of the initial level of contamination. Product contamination predominantly occurs during slaughter, skin removal and dressing of carcases where pathogenic bacteria are transferred onto fresh carcase surfaces (Haines and Sumner, 2007). The rate of spoilage is dependent on processing and meat quality attributes including pH, temperature and packaging type (Mills et al., 2014, Haines and Sumner, 2007). Many pathogenic bacteria found on meat such as *Salmonella, Campylobacter jejuni* and*, E. coli*, proliferate at temperatures of greater than 7^{o}C, therefore only become a health hazard when temperature control (as regulated by the Australian Standard) becomes compromised (Mills et al., 2014).

Tamplin et al. (2012) investigated extrinsic and intrinsic factors (such as temperature, packaging and atmosphere) determining microbial communities in VP beef product which impact upon product quality and shelf-life. It was found that bacterial strains on VP primal cuts with low bacterial growth have increased sensitivity to pH, lactic acid and to low glucose concentrations, with a higher proportion of the strains present producing inhibitory compounds. This indicated that successful dominance of Lactic Acid Bacteria (LAB) may be due to early suppression of harmful *Enterobacteriaceae* and *Pseudomonas.* As reported by Haines and Sumner (2007) *Pseudomonas* bacteria on fresh wrapped product, and when in concentrations of greater than 100 million per cm^2, typically dominate bacterial species causing the onset of spoilage i.e. putrid odours and slime. At these concentrations, such product is generally regarded as having reached end of shelf-life. Under VP conditions, CO_2 tolerant LAB bacteria cause spoilage of meat products several weeks after reaching concentrations of 10 to 100 million per gram and produce cheesy and sour milk odours. Other spoilage bacteria such as *Brochothrix thermosphacta*, *Shewanella putrefaciens*, and psychrotrophic *Enterobacteriaceae* will cause souring and off odours where fresh VP meat with a pH greater than 5.9, and bacterial count of more than 100 million per cm^2, are stored at temperatures of 5-10°C or the packaging environment is not anoxic. Blown pack spoilage of VP lamb product is a result of the fermentation of lactate resulting in the release of CO_2 and the blowing of the pack. Associations between *Enterobacteriaceae* as well as *Clostridium* spp. (gas producing and cold tolerant) have been made in these instances (Mills et al., 2014).

Chemical changes

Similar to microbial growth, chemical changes to the properties of meat product, namely oxidation of myoglobin (browning) and oxidation of lipids (rancidity), is a principal factor or mechanism causing spoilage of meat products (Haines and Sumner, 2007). Myoglobin is a heme protein responsible for the red pigment or colour of meat. Discolouration of meat is the result of the oxidation of the central iron atom within the heme group. Being favoured by higher temperatures and lower pH (<5.5 (Haines and Sumner, 2007))(Warner et al., 2007). The rate of this discolouration is muscle group specific, with those containing more lipids and having a greater oxygen consumption rate browning more quickly (Faustman et al., 2010).

Lipid oxidation is considered a leading indicator of shelf-life as it results in significant changes to meat properties that are detectable via sensory means. This includes changes in odour, flavour and texture (Ross and Smith, 2006). This lipid oxidation involves the reaction of unsaturated fatty acids with free radical oxygen, resulting in the production of unstable and odourless hydrogen peroxides. Breakdown of these peroxides results in the formation of secondary compounds such as aldehydes which are the primary compounds contributing to rancid off-flavours and odours (Ross and Smith, 2006). Bell (2001) reports rancidity to occur most rapidly at -2°C to -4°C and ceasing below -30°C. Lipid oxidation mechanisms are activated immediately post death, whereby blood flow and metabolic processes are inhibited. Pre and post slaughter events such as stress, nutrition, pH, electrical stimulation and packaging oxygen concentrations have been identified as influencing the rate of rancidity onset in meat (Linares et al., 2007).

Greening of chilled lamb meat typically presents within a short time interval after repackaging VP into MAP and is caused by the oxidation of myoglobin to cholemyoglobin, due to the presence of compounds such as hydrogen peroxide produced by LAB (Mills et al., 2014). The condition has been identified in VP lamb after a storage time of as little as six weeks, where such product was expected to store for at least 10 weeks under 0°C temperatures (McPhail et al., 2014). Greening has been well research in beef with previous studies identifying *Pseudomonas* spp. to produce hydrogen sulphide, a compound which binds to myoglobin molecules and results in green pigmentation. The compound is produced by the bacteria under low oxygen tension in packaging and high pHu (ultimate pH) conditions (>6) (Nicol et al., 1970). As the pHu of lamb carcasses is not routinely assessed in Australian processing plants, it is possible that high pH cuts are packaged for export and thus result in the occurrence of greening and consignment rejection. McPhail et al. (2014) investigated factors influencing the occurrence of greening in the blade, knuckle and rack of lamb carcases and concluded that muscles with a high occurrence of dark cutting (high pHu), particularly blade and knuckle, were at greater risk of greening and thus a reduced shelf-life. This was influenced by breed, season, electrical stimulation and carcase weight, with heavier carcases being at greater risk.

Product type

Chilled lamb product sent to export markets may take a number of forms including whole carcase, primal or retail packed product as either bone-in or boneless. Kiermeier et al. (2013) investigated the growth of microbial communities in VP and MAP (100% CO_2) bone-in and bone out lamb shoulders for export markets following anecdotal evidence suggesting bone-in product to have a shorter shelf-life than corresponding boneless product. Findings of the study were not in support of such evidence with no difference in shelf-life observed between the two product types when stored at an average temperature of -3^{o}C for 12 weeks. Despite increased levels of LAB, visual appearance and odour remained acceptable. This indicates that shelf-life for such product when kept under controlled temperatures with pack integrity may extend beyond 12 weeks. MAP product experienced greater issues with pack integrity due to CO_2 absorption and shrinkage. Kiermeier et al. (2011) further reported this to result in MAP damage to bone-in products with three of fifteen packs being punctured. It was suggested that varying MAP gas ratios or introducing gas mixtures may overcome this issue. Later in the storage period, Kiermeier et al. (2013) observed the microbial communities in bone-in VP product to shift to a higher proportion of common spoilage bacteria such as *Serratia spp.* Having no sensory impact, it was suggested that perceptions of bone-in product having a shorter shelf-life may be due to storage conditions not being adequately controlled, resulting in the proliferation of such bacteria and subsequent spoilage.

Kiermeier et al. (2011) observed the pH of bone-in product to be significantly higher than that of boneless product, while VP product was greater than that of MAP product. Mean pH for MAP bone-in and boneless was 5.97 and 5.81 respectively, while pH for VP bone-in and boneless was 6.07 and 5.87 respectively. High meat pH has been associated with reduced shelf-life (in VP product) due to an increase in spoilage bacteria (Meat & Livestock Australia, 2016) and reduced tenderness and consumer acceptability (McPhail et al., 2014). Thus, it is possible that the higher pH of bone-in product may account for anecdotal reports of shorter bone-in shelf-life where other moderating factors are not adequately controlled.

While reduced shelf-life of VP lamb product can usually be attributed to packaging or temperature factors, early spoilage of VP chilled lamb product under normal pH and adequate temperature and packaging conditions continues to occur (Broda et al., 1996). Bone taint or deep tissue spoilage is a spoilage condition of bone-in lamb product which results in the presence of sour or putrid odours in the deep musculature, bone marrow, hip or stifle of shoulder region joints. This has typically been associated with a high pH, tissue temperature, poor carcase cooling, and low muscle O_2 concentration (Boerema et al., 2002). Broda et al. (1996) investigated bone taint in chilled VP lamb legs identifying *C. algidicarnis* as a possible causative organism for the condition with samples exhibiting strong odours characteristic of bone taint. While no evidence of the bacterium was identified in the drip or surface tissue of product it was speculated that organisms were present in the deep tissue prior to slaughter. Tissue entry through cuts and/or abrasions of the hind leg may have resulted in bacterium entering the lymphatic system and travelling to the stifle joint. Being reproduced only under poor temperature conditions during carcase cooling and not under chilled storage conditions, it was deemed that such tissue spoilage occurs within a short time post slaughter. This was supported by De Lacy et al. (1998) who determined certain strains of *Clostridium spp.* to be the primary causative agents of bone taint in hot beef legs under reduced cooling temperatures (38 to 20°C in 20 hours).

Packaging

VP chilled primal cuts sent for export are typically recognised for their long shelf-life when stored between -1 and 3°C (Tamplin et al., 2012). Being the more common method of packaging lamb product, end of shelf-life has been reported to extend to 78 days (Kiermeier et al., 2011). This is due to the exclusion of oxygen during the packaging process creating a 'skin-tight' seal between the surface of product and the packaging which can be further enhanced by shrink wrapping. The anoxic environment prevents the growth of obligate aerobic spoilage bacteria such as *Pseudomonas* spp. However, the exclusion of oxygen results in a CO_2 rich environment due to muscle respiration and the growth of CO_2 tolerant microaerophilic (requiring little oxygen) bacteria such as LAB (Mills et al., 2014, Rubio et al., 2016).

With meat colour being a major determinant of consumer product acceptability, the exclusion of O_2 in VP packaging results in a purplish hue due to the formation of deoxymyoglobin and a reduction in consumer acceptability in retail markets. MAP packaging typically involves a gas composition of 70-80% O_2 and 20-30% CO_2.. Resultingly, the attractive, red bloom desired by consumers and slowing of bacterial growth is respectively achieved (Rubio et al., 2016). However, due to the presence of O_2, biochemical and microbial processes resulting in product deterioration and end of shelf-life such as myoglobin and lipid oxidation as well as spoilage, are accelerated (Fernandes et al., 2014). Thus, where meat is packaged directly for retail markets, MAP is generally the favoured method of packaging while VP is used for products requiring a longer shelf-life i.e. those intended for export markets.

Both intrinsic (product factors at the time of packaging) and extrinsic (environmental and packaging factors) variables influence the impact of packaging on lamb shelf-life. Intrinsic factors namely include temperature, water activity, composition, pH, redox potential and initial microflora. Environmental factors include packaging properties, gaseous environment, vapour, packaging opacity and the degree of protection. These factors, in combination influence the in-pack environment which includes temperature, pack atmosphere water activity, relative humidity, light, substrates and microflora. Collectively, these factors influence product shelf-life. Therefore, many factors should be considered when determining the impact of packaging on product shelf-life (Bell, 2001). These complexities are highlighted in research by Rubio et al. (2016) who observed the gas concentration of MAP lamb meat cuts under differing post mortem temperature treatments to change over the storage life. Initial O_2 concentrations decreased by 12% from day four onwards of the 18-day experiment, while CO_2 increased from day 13. With similar findings reported by Fernandes et al. (2014), it was suggested that these changes in gas composition may be due to muscle and microbial respiration which occur in the first days post slaughter and during storage respectively. While all treatment microbial counts remained stable until day 7 of storage, at 28 days of storage under conditions of 1°C, lamb loin samples in 100% CO_2 packs produced lower aerobic and LAB microbial counts than those that were VP or 25% CO_2 and 75% O_2. Conversely, Kiermeier et al. (2011) found no difference in shelf-life beweep VAP and MAP bone-in and boneless product, while greater variability in microbial growth was observed under VP conditions observed over time.

In summary, such complexities in factor interactions may contribute to difficultly in industries ability to maintain consistent product shelf-life.

Meat quality characteristics

Meat quality characteristics such as flavour, colour and tenderness are considered key consumer indicators of freshness and shelf-life. Such characteristics are influenced by various pre and post slaughter factors including chilling.

Meat colour

Meat colour is considered a primary indicator of product freshness and shelf-life influencing consumer buying choices. Specifically, the pink-red bloom of meat is considered indicative of these qualities. This bloom is enhanced under high O_2 conditions such as those created in MAP or overwrapped retail product. Oxygen binds to myoglobin forming oxymyoglobin over a progressive period of 30 minutes and to a depth of 3-4mm from the surface of muscle tissue when at 0°C (narrower at >0°C)(Meat & Livestock Australia, 2016). Overtime, this exposure to oxygen results in the browning of meat where oxidation results in the formation of deoxymyoglobin. This is perceived by consumers to be associated with end of shelf-life and occurs more rapidly in muscles with a greater portion of red muscle fibres, higher lipid concentration and greater oxygen consumption rates (Faustman et al., 2010).

Dark cutting and pH

Being a measure of muscle acidity, pH is an important factor influencing many aspects of meat quality such as colour, tenderness, flavour and shelf-life (Stahlke et al., 2019, Meat & Livestock Australia, 2016). In the living animal, muscle pH is approximately 7. As rigor mortis sets in post slaughter, lactic acid accumulates resulting in a decline in pH (Meat & Livestock Australia, 2016). The ultimate pH (pHu) post rigor is dependent on the muscle glycogen level at the time of slaughter. Typically, the lower the muscle glycogen level at slaughter, the higher the pHu post rigor and the darker the muscle or meat colour (McPhail et al., 2014). The mean pHu of beef carcases is reported to be 5.5, with those having a pHu of >5.8 being considered 'dark cutters' or dark, firm, dry (DFD) beef and this is determined during chiller assessment (Mills et al., 2014, Meat & Livestock Australia, 2016). Lamb is known to have a slightly higher pHu than beef carcases, with this being 5.6-5.7 in the large muscles i.e. rump and backstrap and a mean pHu >6.0 in smaller muscles of the shank and shoulder (Mills et al., 2014, Stahlke et al., 2019). Meat with a higher pHu has been associated with reduced shelf-life (of VP product) due to an increase in spoilage bacteria such as those causing greening (Meat & Livestock Australia, 2016), reduced tenderness and reduced consumer acceptability due to darkened meat colour (McPhail et al., 2014). Similarly, low pH (<5.5 (Haines and Sumner, 2007)) has been linked with browning of meat and thus reduced consumer appeal and shelf-life (Warner et al., 2007, McGeehin et al., 2001).

Post mortem pH decline is impacted by several factors including animal handling and processing as well as animal factors. These include stress, electrical stimulation, chilling temperature, sex, species, breed, season and potentially animal age (McGeehin et al., 2001). Both McGeehin et al. (2001) and Warner et al. (2007) reported Merino lambs to have a higher pHu in the knuckle than other breeds, while McPhail et al. (2014) further found lambs processed in the autumn as well as electrically stimulated carcases to have a higher dark cutting percentage and pHu. The inverse was true for heavier carcases. Kiermeier et al. (2011) observed the pH of bone-in product to be significantly higher than that of boneless product, while VP product pH was greater than that of MAP product. Mean pH for MAP bone-in and boneless was 5.97 and 5.81 respectively, while pH for VP bone-in and boneless was 6.07 and 5.87 respectively. Dark cutting beef carcases are not typically vacuum packed or sent for export due to having a shorter shelf-life. In lamb, dark cutting animals are not typically identified and therefore are more likely to be exported resulting in shelf-life issues (McPhail et al., 2014).

Processing and supply chain factors

It is evident that the shelf-life of lamb is significantly influenced by factors such as temperature, meat quality, microbial growth, packaging, chemical changes and product type. Temperature and packaging are the two significant technologies available to assist in the preservation of shelf-life through controlling these factors. In addition, and as outlined by the Australian Standards, hygiene and contamination management processes, under the control of processing establishments and product handlers, are also essential in maximising shelf-life through controlling the bacterial contamination of chilled lamb (Mills et al., 2014).

Preslaughter and dressing processes have been recognised as key areas of the processing system whereby carcases are most at risk of microbial contamination. This is a result of preslaughter washing (where implemented) and slaughter floor activities, namely skin/pelt removal and evisceration. Contamination of previously sterile carcase tissues predominantly results from the transfer of microbial populations from contaminated skins and rupturing of the gastrointestinal tract. The origin of bacterial contamination of skins includes faeces, must, dust, sand and vegetable matter contracted on-farm, during transport or in lairage (Biss and Hathaway, 1996b). In addition, cross contamination can result from environmental surfaces, workers and equipment (Mills et al., 2014). Commonly the visible identification of contaminants on the carcase surface is used as an indicator of dressing hygiene, with below standard hygiene leading to microbial growth and product spoilage (Biss and Hathaway, 1996c). In New Zealand the practice of pre-slaughter washing was implemented to reduce visible contamination transferred from skins. However, research by Biss and Hathaway (1996b) demonstrated that while preslaughter washing of lambs decreases visible carcase contamination, microbial contamination is increased. Similarly, there is reported to be limited value in pre and post evisceration washes, with the trimming of visible contamination over carcase washing being assumed less likely to spread existing contamination (Biss and Hathaway, 1996c). Biss and Hathaway (1996a) found visible contamination levels to principally be affected through changes in the levels of wool contamination. Additionally, shorn lambs were shown to have lower levels of microbiological and visible contamination than woolly lambs. It was recommended that control of microbiological and visible contamination should be addressed through good technique and practice at each point of processing. In support of this, Biss and Hathaway (1995) reported carcases from long wool and/or dirty lambs which underwent a preslaughter wash to have greater levels of microbial contamination and this was carried through to post chilling. While pre evisceration washing removed most wool contamination, faecal material was still visible on carcases. It was suggested that preslaughter animal presentation and correct operating procedures at pelting were more critical than on-line monitoring of contamination in order to manage bacterial loads. Education and hygiene discipline were highlighted by Mills et al. (2014) as being essential in reducing cross contamination of product by workers. Further, contamination resulting from the contact of lamb product with environmental surfaces, such as at primal packaging, allows for the proliferation of psychotropic (favouring 7°C) spoilage bacteria at chilling temperatures. The use of water during processes further allows for this cross contamination, where surfaces are not adequately clean or dry, while also enhancing bacterial growth.

While extensive research into the common factors affecting lamb product shelf-life has been conducted, it is evident that interactions between such factors and other less common or unknown influencing factors may vary according to the meat processors business. Therefore, difficultly in addressing shelf-life issues may be experienced by business regardless of this knowledge. Obtaining anecdotal evidence of processor experiences with lamb product shelf-life will provide valuable insights into the potential factors creating shelf-life difficulties for businesses in the lamb supply chain. This will direct future research and industry corrective action/training programs through respectively identifying and addressing factors limiting shelf-life. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

4.2 Phase 2 - Online survey and Phase 3 – Semi-structured interviews

Processor descriptions

Location and throughput

Twelve processors participated in the study, being from NSW (*n* = 3), WA (*n* = 2), SA (*n* = 2) and VIC (*n* = 5). All enterprises processed lamb, with all but one additionally processing sheep. Five of these enterprises also processed goats. Across the processing establishments, the mean number of 5, 542 sheep/lambs were processed daily, with carcases having a mean HSCW of 25.1kg (range = 20-30kg).

Key markets

The key markets to which chilled lamb product was exported are listed in Table 4 below. On average, processors exported to three different markets (range = 1-5), with product being handled by six other stakeholders (range = 2-10) once leaving the enterprises facility.

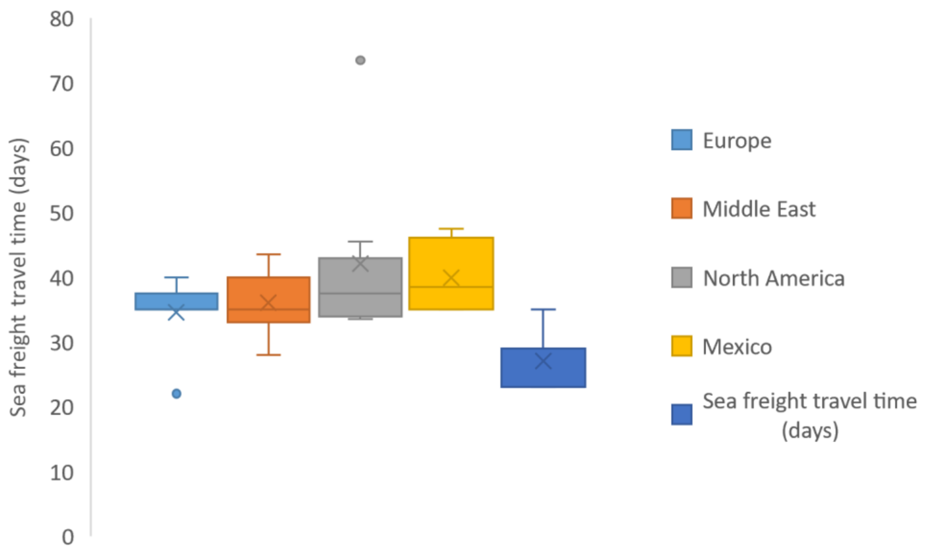
Table 4. Key export markets for Australian sheep/lamb export processing plants.

Key market	Number of Processors
Europe	6
Middle East	10
North America	11
Mexico	2
China	2
Other (Asia, Japan, not advised)	4

Travel time of chilled lamb product to export destinations by sea freight ranged between 22 to 73.5 days depending on the market, with North America, on average, having the greatest travel time at

42 days. The mean travel time to China was far less than any other destination at 27 days (Figure 2.). Interviews revealed that the Middle East (and UAE) market typically included Qatar, Kuwait, Saudi Arabia, Jordan and Iran, while Asian markets were not limited to China, but also included Japan and Malaysia. North American markets included both the United States and Canada.

Figure 2. Travel time of Australian chilled lamb product to export destinations by sea freight.



Airfreight as a mode of export was very efficient, with product arriving in the intended market as early as three days post slaughter and commonly only used for the export of whole, chilled carcases. This was due to the cost of freight and such product having a shorter shelf-life, as one processor commented after conducting shelf-life trials.

"Yeah, once we hit our targets. We're around that 10-13-day mark with our chilled lamb".

Other reasons for sending product, other than whole, chilled carcases, by airfreight included correcting order issues, for urgent deliveries or sending sample product to new markets.

"We only use airfreight mostly to replace product where there is an issue or there is an urgent request, due to high cost with this mode of transport".

Staff training

Each of the twelve enterprises indicated that, as part of staff training, all staff went through some sort of initial role induction program or training program delivered in-house. This may have included any one or more of: theoretical training; an on-the-job buddy system and training; additional supervision and sign-off by training staff and/or section supervisor for competency. Eight of the twelve processors indicated that their staff underwent mandatory or optional formal training through an accredited training program for skill development, while two processors indicated they had frequent competency checks and refresher training programs in place for staff. These two processors incorporated all three of the mentioned training themes as part of staff development.

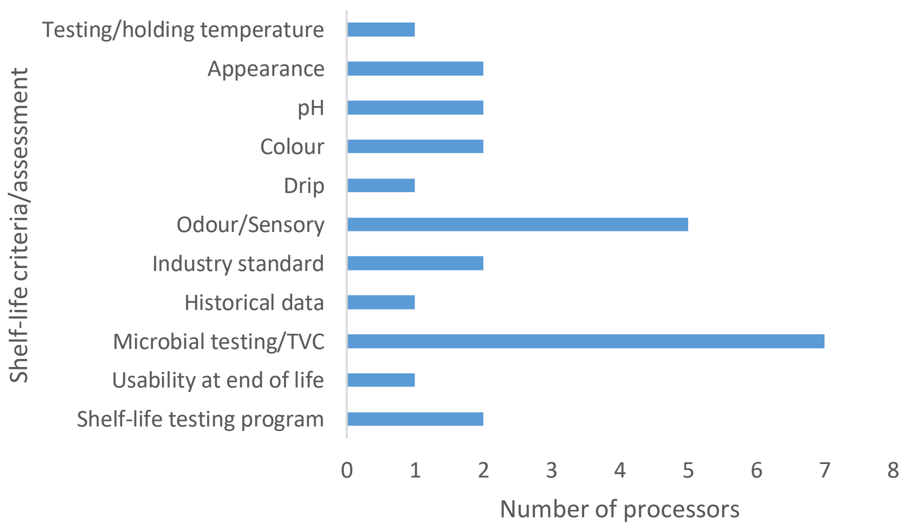
Shelf-life Parameters

The number of criteria or assessment strategies used by processors to determine end of shelf-life for chilled lamb product ranged from 1-6 for any one processor (mean = 2.4). Microbial testing or use of TVC counts was the most common factor used for determining end of shelf-life followed by odour or sensory characteristics. Where processors indicated 'Industry standard', this referred to information released by MLA relating to shelf-life of Australian red meat (Meat % Livestock Australia, 2016) (Figure 3.). With the spoilage rate of meat products due to microbial growth being influenced by a combination of factors such as temperature, pH and packaging (Mills et al., 2014, Haines and Sumner, 2007), one processor reported favouring indicators such as odour and physical appearance due to the time and economic cost of testing carcases.

Additionally, variability in the microbial thresholds set by various customers created confusion for some processors in relation to the necessity of microbial testing or the point at which they should consider product to be at end-of-shelf-life.

Therefore, there may be opportunity for the development and delivery of a national microbiological assessment program or more broadly, shelf-life assessment program, to all members of the lamb cold chain. Such a program may detail theory behind microbial testing and other shelf-life parameters and set a standard for unsafe levels for various microbiological organisms as well as other end-of-life indicators.

Figure 3. Shelf-life assessment criteria implemented by Australian sheep/lamb processors.



Most processors had validated bone-in and boneless vacuum packaged product to have a shelf-life of between 70-90 days, far beyond that reported by Prime Safe (2021), and routinely conducted shelf-life testing of product both within the enterprise and with external laboratories. However, consistent with findings by Kiermeier et al. (2013), no differentiations between the validated life of bone-in and boneless products by processors were made. Where one shelf-life parameter failed during shelf-life testing, processors commonly considered product to be at end of shelf-life.

"Shelf-life ends when meat becomes unfit for human consumption, use or sale because of sensory reasons. So, any of the parameters could fail and that would be end of shelf-life for us. Yeah, so if the bacteria was out but it smelt good, it fails. If it smelt terrible but the bacteria was fine, it fails… It gets a bit subjective around the shelf-life, you have to bring the smell into it… the appearance, the leakage and also the [microbiological] count as well."

Where shelf-life issues had been reported back to processors, the actual shelf-life achieved ranged from 28-63 days.

"A USDA rejection notice was issued on receival at 30-35 days. Product had an expected shelf-life of 70 to 90 days (working towards 90)."

Evidently, where shelf-life issues occur, the actual life of product may fall far below that which is expected. In other instances, complaints may be received closer to the end-of-life date which may create difficulty in determining causative factors.

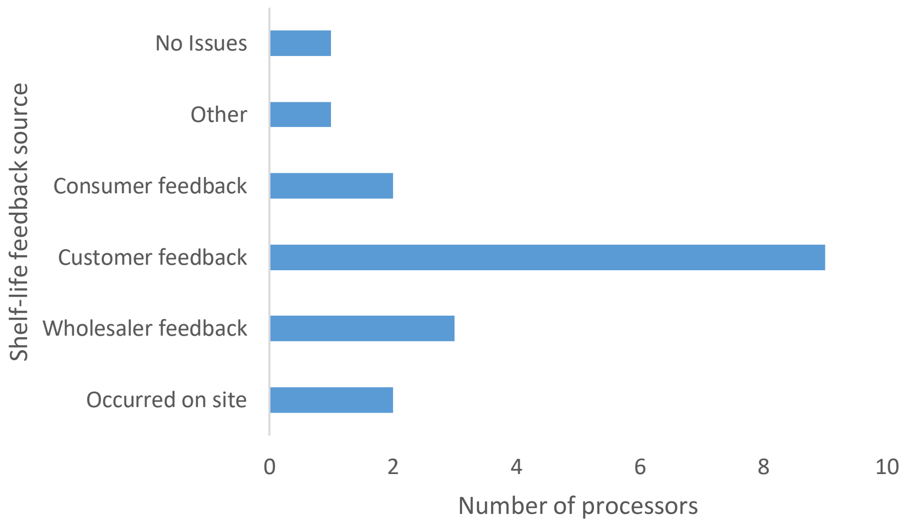
Shelf-life Experiences

Shelf-life complaints

Feedback for shelf-life issues ranged from not having shelf-life issues to receiving product feedback from three different sources for any one processor (Figure 4.). Most frequently processors were alerted to a product shelf-life issue by the product customer. These included buyers of product in the international market who then sold product directly to the consumer, were value-adders or wholesalers. Other sources of feedback included the enterprises salespeople stationed in the international market or regulatory inspection facilities.

"Feedback regarding shelf-life issues is typically first received by… salespeople located in the international marketplace. These people track the consignments as they arrive i.e. acceptance, transport to warehouse, discussions with the customers etc. and investigate and follow-up on delays. Most feedback is received from here unless there is a regulatory inspection and/or rejection."

Figure 4. Source of feedback for chilled lamb shelf-life issues experienced by Australian lamb processors.



The mode by which complaints regarding shelf-life were received, often depended on the relationship that the processor had with the customer and specifically how long they had been in business together, as well as the previous history of product issues. The severity of the issue also impacted how the enterprise was informed.

"So, they will either email, depending how angry they are, our marketing team who will forward it to us. Or if they've been dealing with the plant a long time, they will let us know direct."

The level of detail provided to the processor, regarding the specifics shelf-life issue varied greatly between incidences and markets.

"The Japanese are very methodical in their approach to inspecting consignments providing detailed feedback in the form of a spreadsheet which has information about their own shelf-life testing of product such as micro counts over time… consignment information… dates of product testing, micro info… They also provide a pass rating (e.g. acceptable, unacceptable, excellent etc.) and criteria/parameters around these ratings."

More commonly, limited information was provided by the customer which may have included any one or more of the following:

- Photographic evidence of end-of-shelf life issues. This was useful in showing evidence such as bubbling or packs, however difficult when depicting evidence such as colour.

  "We haven't found it very successful when they send us the photos, we can't quite see what they're seeing but when the sales guys go over to the Middle East and Europe and stuff they show them product and then they take a photo and say "oh no, this was green in real life it's just the photo doesn't show it."

- The return of data logger (temperature) information. This occurred where a good customer-processor relationship was in place, however, did not always occur for one-way data loggers.

  "We'll get the data back from those because it's going to a client who we know will return it."

  As a result, most processors who used data loggers to track temperature through transport had moved towards real-time data loggers to allow issues to be addressed as they occurred.

  "We've stopped a lot of complaints on the shelf-life with data loggers. We can actually tell exactly where it is, if it didn't go straight to the customer and when the carton was opened because its light sensitive as well. So, they tell us a lot of information and the salesmen, they're watching them constantly… It might be a couple of times with the shipping companies we've had issues as well and spotted a couple of issues with the shipping companies. We've been in contact with them "check these containers out, are they right?" ... So, we saved the load because the shipping container had faulted at a port."

- Reported evidence of shelf-life issues presenting. The amount of detail provided, again varied according to the complaint and criteria customers used to determine end-of-shelf-life.

  "We had an issue about 18 months ago with product going to the UAE that was blowing up like footballs… Other issues were off odours upon opening the bags at 8-9 weeks. The product had an expected shelf-life of 70 days and so was reaching the end of its life. In the blown-up product, sometimes there was a green tinge. We encourage the customers to include sensory evaluation when determining end of shelf-life."

- The amount of product affected within the consignment. This varied according to the complaint and included either whole cartons of product, single bags/items of product within cartons or an entire consignment of product. One processor received minimal information regarding this.

  "Within reason, the feedback we get from over there is that it's not all, but it's a reasonable percentage. They've never given us percentages back because their making a claim on the whole load. They don't give us accurate figures."

  While other processors were able to obtain more specific estimates.

  "In total, there was roughly about half a dozen bags over the whole container being affected."

Multiple processors highlighted difficulties in obtaining accurate and detailed descriptions of shelf-life issues with customers generally only sharing data where it is in their interest.

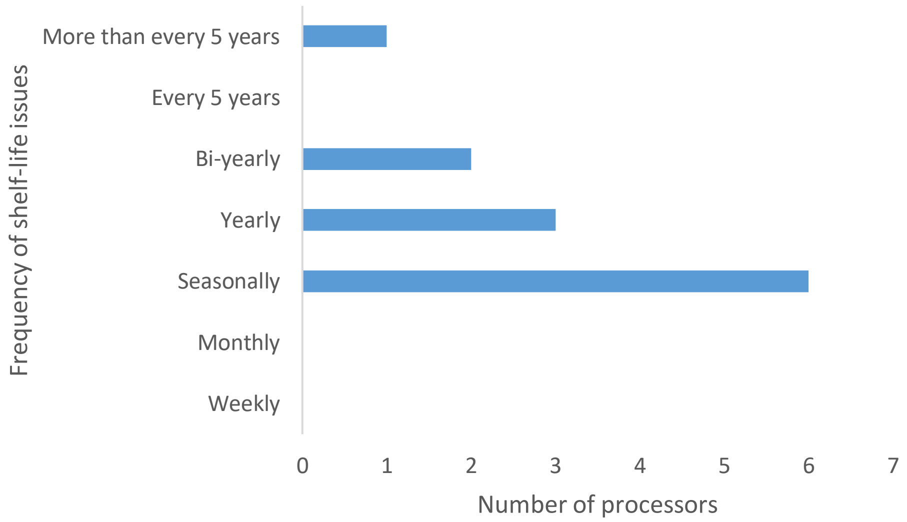
"…it was always difficult to get the data back from the temperature tracks+. The customer typically only shares it if it's in their favour no matter how many loggers we put in, but we'd never get all the track back."

While some detail as to the indicators of end-of-shelf-life may be provided back to processors in customer complaints, it is apparent that there is often difficulty in determining the origin of shelf-life issues due to a lack of information provided as feedback. The development of materials supporting customer education relating to acceptable end-of-shelf-life parameters as well as standardised and streamlined complaint processes which include requirements such as the submission of evidence and return of information loggers, may assist processors in identifying the origin shelf-life issues and the credibility of complaints.

Frequency of shelf-life issues

Fifty percent of processors reported shelf-life issues to be experienced seasonally with three seeing issues annually and two every couple of years. Only one processor saw issues more than five years apart (Figure 5.).

Figure 5. Frequency of shelf-life issues experienced by Australian lamb processors for chilled lamb product.



For processors reporting self-life issues to be of a seasonal nature, this predominantly referred to the Australian winter and was generally associated with stock type and stock cleanliness (resulting from wet weather) influencing physical or initial microbiological counts, as supported by Haines and Sumner (2007). Those seen in the importers summer were linked to cold chain issues, while one processor associated issues seen in the Australian summer with internal processing challenges (e.g. staff shortages, bad run of stock and onsite incidences). Another processor associated dust and windy weather in autumn with livestock cleanliness issues, dressing process difficulties and shelf-life (see Season/Livestock condition/Meat quality attributes). Other, more infrequent shelf-life issues were sporadic in nature and may have been a one-off issue or a series of issues over a shorter period of time as one processor reported complaints to be experienced from:

"Back to back shipments over a period of four or five months maybe."

In these cases, other causes of shelf-life issues were suspected or determined (see With no trends evident between the indicators of end-of-shelf-life and the product types experiencing shelf-life issues, this may be due to the reported high level of interaction between end-of-shelf life causative factors (Lütke Entrup, 2005). Additionally, and as previously discussed, processors often receive limited information regarding shelf-life issues from customers, including details of end-of-shelf life evidence. On top of this, with anecdotal information being gathered primarily through interviews, processors may not have remembered or relayed the full details of the shelf-life issue at the time. Therefore, there is no guarantee of certainty around having obtained all evidence of-shelf-life issues and thus, limited ability to draw associations between evidence and potential causative factors.

Identifying the Source of Shelf-life Issues).

Therefore, understanding the seasonality of shelf-life issues and the conditions under which product such product was produced, may assist in identifying end-of-shelf-life causative factors related to specific shelf-life incidences.

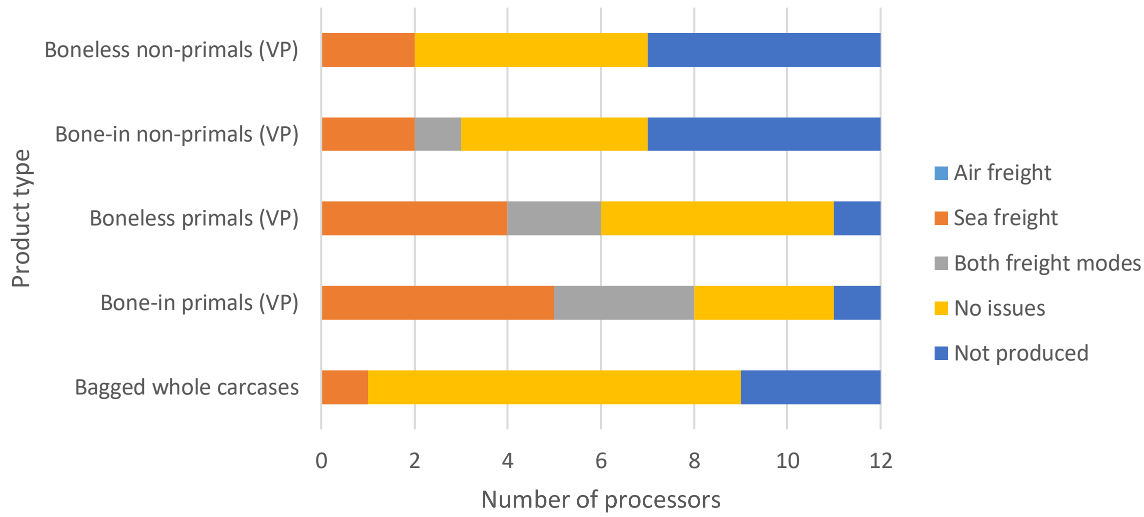
Product types and freight mode

More commonly, processors reported shelf-life issues to be seen in chilled lamb product transported by sea freight and particularly bone-in primal products. This was followed by boneless primal products, with the same trend then seen, to a lesser extent, in non-primal products. One processor had experienced no shelf-life issues at all and only one processor reported shelf-life issues to have been experienced with whole bagged carcases exported by sea freight (Figure 6.**Table *4***). However, from the follow-up interview this was deemed to be a survey error as the processor made no comments on experiences of such issues with this product.

"We air freight carcases… we get quite good feedback about the shelf-life of our air freight carcases".

Therefore, two of the twelve processors were deemed to have had no experience with shelf-life issues in vacuum packaged product of any type.

Figure 6. Chilled lamb shelf-life issues experienced by Australian sheep/lamb export processors by product type and freight mode.



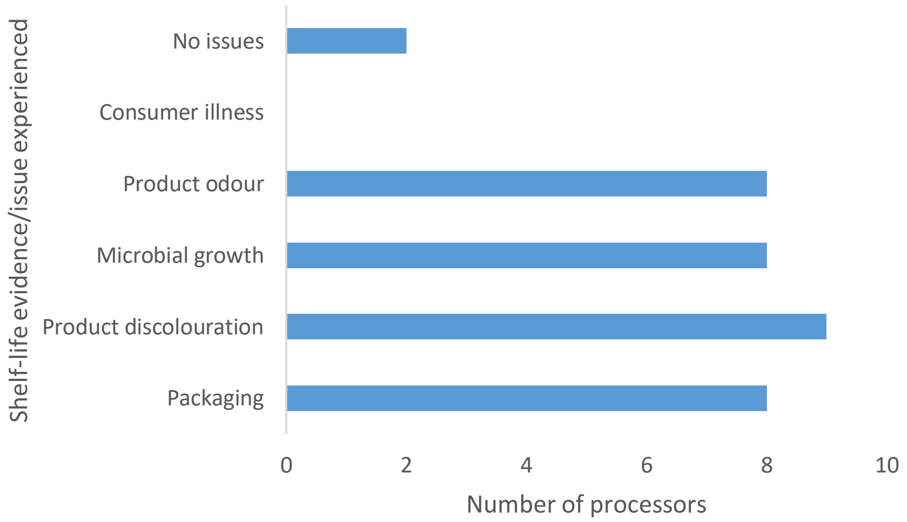
Most exported bone-in primal products reported to have experienced shelf-life issues included shoulders, legs and saddles, while bone-in retail cuts included racks and shanks. The type of packaging used and the frequency of product handling or movement during transport were mentioned as factors, by multiple processors, contributing to increased punctures of bone-in vacuumed packed product and thus reduced shelf-life. This was supported by Kiermeier et al. (2011) who reported three of fifteen bone-in, MAP products to result in punctured packs. Shelf-life issues experienced with boneless cuts were mostly linked to packaging faults from manufacturing or processor sealing as well as export cold chain control. Several processors reported that they supplied retail cuts, such as shanks, legs and boneless shoulders to the domestic market and that these often-experienced shelf-life issues due to inadequate integrity of the domestic cold chain (see With no trends evident between the indicators of end-of-shelf-life and the product types experiencing shelf-life issues, this may be due to the reported high level of interaction between end-of-shelf life causative factors (Lütke Entrup, 2005). Additionally, and as previously discussed, processors often receive limited information regarding shelf-life issues from customers, including details of end-of-shelf life evidence. On top of this, with anecdotal information being gathered primarily through interviews, processors may not have remembered or relayed the full details of the shelf-life issue at the time. Therefore, there is no guarantee of certainty around having obtained all evidence of-shelf-life issues and thus, limited ability to draw associations between evidence and potential causative factors.

Identifying the Source of Shelf-life Issues). Temperature is known to have a critical effect on the shelf-life of meat, slowing natural deterioration processes and spoilage due to microbial growth (Mills et al., 2014). Therefore, violation of temperature control within the cold chain may well account for the shelf-life issues experienced here. In addition, smaller muscles of the shank and shoulder have been reported to have a higher pH (Mills et al., 2014). With a higher pH being associated with increased microbial growth (Meat & Livestock Australia, 2016) and reduced consumer acceptability (Warner et al., 2007, McGeehin et al., 2001) it is possible, considering the cuts reported to have experienced shelf-life issues, that pH may have been a contributing factor.

End-of-shelf-life evidence

Through the online survey, processors reported that the type of end-of shelf life indicator across all product shelf-life issues ranged from one to a maximum of four indicators for any one processor (excluding those with no issues). The most common evidence included unusual product odours, microbial growth, product discolouration such as browning or greening and packaging related issues such as blown or punctured packs (Figure 7.).

Figure 7. Shelf-life evidence/issues experienced by Australian lamb processors for chilled lamb product.



Interviews revealed complaints of end of shelf-life to further include the presence of bubbles in the packs, textural changes and confinement odour and were consistent with quality characteristics reported to influence consumer acceptability fresh and safe to eat meat products (Haines and Sumner, 2007).

"There is definitely more odour in it, when you take it out and let it sit there, it will come up again… Where the bone sits in the product, the meat tends to lift away from it, it tends to separate. The meat tends to be slightly more open, less dense."

Across the interviews, the combination of shelf-life indicators reported for any one complaint varied regardless of product type (One processor was able to differentiate the evidence-of-end-of life experienced by different products within the consignment.

“There was purge as well, yep. I think there were some [blown packs] but the greening was the main issue and the green ones weren’t blown as far as I’m aware.”

Table 5). One processor was able to differentiate the evidence-of-end-of life experienced by different products within the consignment.

“There was purge as well, yep. I think there were some [blown packs] but the greening was the main issue and the green ones weren’t blown as far as I’m aware.”

Table 5. Shelf-life indicators reported in complaints received by Australian lamb processors regarding the shelf-life of chilled, vacuum pack product.

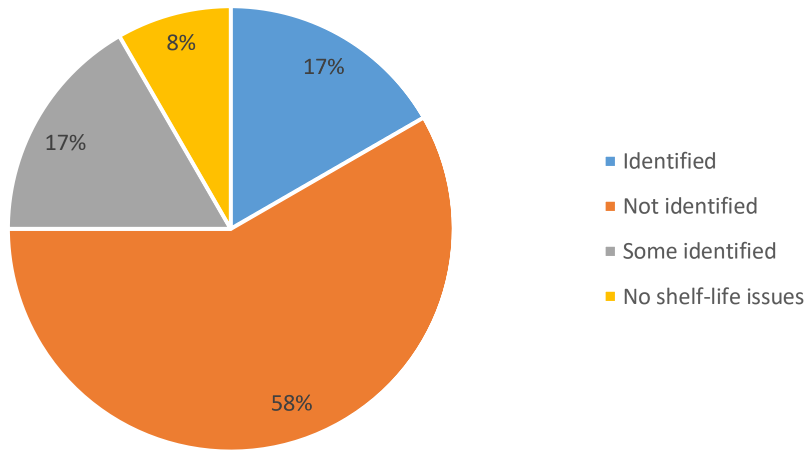
Vacuum-packed product in complaint	Greening	Browning	Blown-pack	Off-odour	Confinement odour	Drip/purge	Gas/bubbling	Texture
Bone-in (frenched cap-off rack)	x					x	x	
Bone-in (shoulders/legs)					x	x		x
Both (in same complaint)	x			x			x	
Bone-in (racks/legs)	x			x				
Boneless (shoulder meat/chuck rolls)				x				
Bone-in			x					
Both (in same complaint)		x						x
Bone-in (legs/shanks)				x	x			
Boneless	x		x	x				
Bone-in (racks/ shanks)			x	x		x		
Bone-in (racks/saddles)	x (not blown)		x (not green)	x		x		
Both (forequarter shank/boneless shoulders -domestic market)					x			
Bone-in (forequarter shank)						x (appearance)		x
Unknown		Darkening of pack						

With no trends evident between the indicators of end-of-shelf-life and the product types experiencing shelf-life issues, this may be due to the reported high level of interaction between end-of-shelf life causative factors (Lütke Entrup, 2005). Additionally, and as previously discussed, processors often receive limited information regarding shelf-life issues from customers, including details of end-of-shelf life evidence. On top of this, with anecdotal information being gathered primarily through interviews, processors may not have remembered or relayed the full details of the shelf-life issue at the time. Therefore, there is no guarantee of certainty around having obtained all evidence of-shelf-life issues and thus, limited ability to draw associations between evidence and potential causative factors.

Identifying the Source of Shelf-life Issues

From the survey, seventeen percent (or two) of the processors reported that they had successfully identified the causes of shelf-life issues for chilled lamb product (including whole carcases), while a further 17% had identified only some of the causes. The majority had not identified the cause and one reported not having experienced any issues at all (Figure 8.).

Figure 8. Successful identification of the source of chilled lamb shelf-life issues by Australian lamb processors.



In response to customer complaints, processors always investigated the shelf-life issue both internally and throughout the external cold chain where possible. However, attempts to identify the source of the issue were not always successful.

"When you go through things with a fine-toothed comb, you're always going to find something of course but when you're looking at it all the time and you can't see anything wrong, it's a bit hard."

"In some instances, the plants investigations into shelf-life issues, regardless of how clean/good the data is, are inconclusive."

Further, where processors were unable to obtain data relating to the integrity of the export cold chain, complaints were generally accepted:

"So, basically if you can't guarantee that the cold chain is intact for the entire journey. You've got to take the customers complaint with a grain of salt."

Many themes were identified in discussions relating to observations or potential causes of chilled lamb shelf-life issues experienced by Australian lamb processors (Table 6). Cold chain management beyond the processor was highlighted most by processors as being a major factor contributing to shelf-life complaints. This was followed by packaging and product handling related issues as well as customer or consumer education/understanding of product temperature requirements and indicators of end-of shelf life.

Table 6. The frequency of major themes arising from discussions relating to observations or potential causes of chilled lamb shelf-life issues experienced by Australian lamb processors.

Theme	Frequency
Cold chain management (external)	7
Cold chain management (internal)	2
Customer/consumer education	4
Economic pressures	2
Packaging/Product handling/Hygiene	5
Season/Livestock condition/Meat quality attributes	3
Transportation time	1

Cold chain management (internal)

As required by the refrigeration conditions set by the Australian Standards (Australian Food and Grocery Council., 2017, Anon., 2007) microbial growth slows at temperatures of 5°C or less. Further, Mills et al. (2014) previously recommended a storage temperature of -1.5°C for lamb product in order to slow quality deterioration rates. Combined with time to chill, this time-temperature interaction influences the proliferation of bacteria and subsequent spoilage and shelf-life (Broda et al., 1996). Through an internal system review processes, several enterprises had detected limitations in internal temperature control processes which were associated with or suspected to result in product shelf-life complaints. Small product temperature rises through the shrink tunnel process had been identified by one processor with another having extensively mapped the deep muscle temperature of product throughout its internal cold chain. Subsequently, the temperature at which product entered the boning room, as well as the cooling process post packaging, was reduced and significant changes in product temperatures observed.

"So, we found that reducing the temperature at which the carcase entered the [boning] room helped a lot. We mapped that from the temperature of the lidded carton through to storage. So that shift came down significantly and then it was a lot to do with the temperature reduction of the surface after the cryovac. So, the surface could be as warm as 8°C or 9°C, if it was lidded at that temperature it took quite a while to come down, even in the blast chiller."

Consistent with Mills et al. (2014), who reported pathogenic bacterial growth and the associated health risk to increase when temperature control becomes compromised (and particularly where product is not held at -1.5°C and above 7°C), another processor had identified their chilled storage space and chiller temperature fluctuations to impact on shelf-life. As a result, they were looking to update the system and meanwhile were focussing on reducing the time to load-out.

"If we've held it and handled it and moved it, our fridge space is limited, the longer we hold it here is when we've had our bad results. We're trying to hold it here at close to -2°C as we can. Our fridge space is relatively small… and it hooks itself up to another room which runs at plus 2°C and the

doorway is open transporting product from one room to another. So, we do have a bit of temperature fluctuation throughout the day."

Failure to apply the appropriate chilling method for the intended market was also identified as a cause of reduced product shelf-life, and was supported by Meat & Livestock Australia (2016) who reported that product storage time can be maximised through minimising chilling temperature. Bellés et al. (2017) further found that super-chilled lamb product (-1°C) had greater colour stability and slower microbial growth than that stored at 4°C.

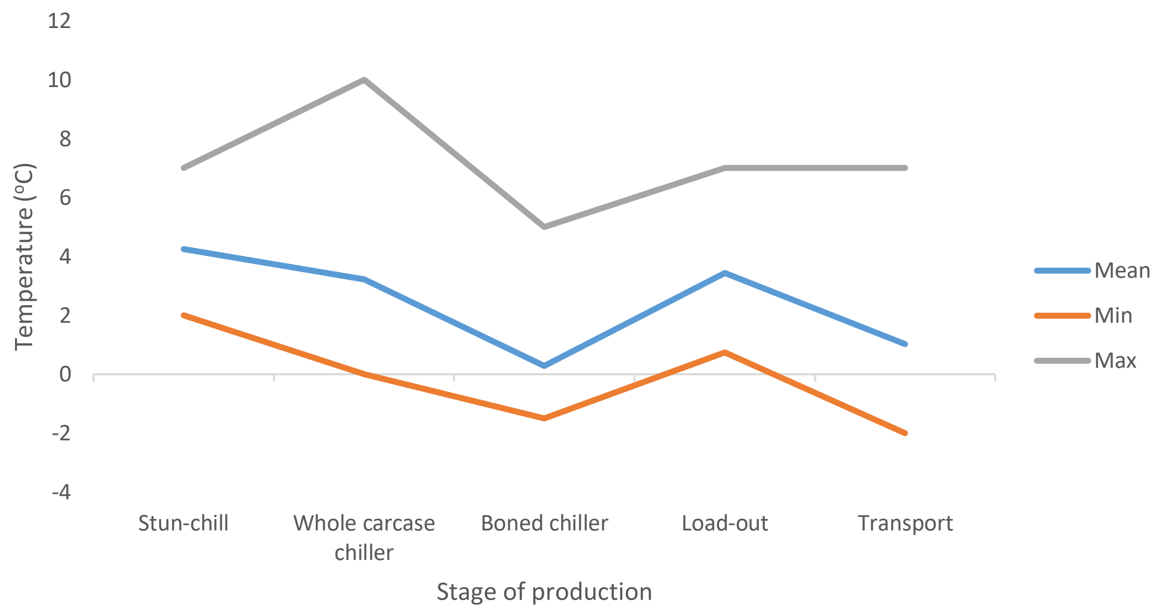
"…they were saying that it wasn't meeting the… 90-day shelf life and we worked out that it hadn't gone through our hard-chill program… So, by not having it chilled to the hard-chill program here, even though it was only for a 48-hour period, it still affected the shelf-life."

In that instance, while the product had not been hard-chilled, whereby a greater shelf-life would be guaranteed, the customer had still expected product to meet the extended shelf-life period. Therefore, greater customer education relating to chilling temperatures and shelf-life period may be required. Normal and hard-chill programs could be differentiated by the time period in which the chilling of product to below zero temperatures occurred.

"The normal process, it'll go through the chillers. It'll go into the boning room at about 2.5-3.5^{o-}C. Once it goes through the boning room it will then go into the carton chiller at -2°C at very low air speeds… the product would still be at about 3-3.5°C when we load it out… the hard chill program we put the product into two glass tunnels… and we put some fans on it that force cold air over it and we pull that down to about -1.8°C over a 36 hour period."

Consistent with requirements set by the Australian Standard (Anon., 2007), enterprises chilled lamb carcases to a mean of 4.25°C (range = 2-7°C) within 24 hours of stunning with this temperature decreasing to 3.2°C (range = 0-10°C) and 0.3°C (range = -1 – 1°C) for both whole carcase and boned chiller product respectively. One processor did not produce boned product. Temperatures increased at load out with a mean temperature of 3.4°C (range = 0.75-5°C) being maintained and saw a general decline into the transport phase with processors requiring the mean transport threshold temperature for product to be 1.0°C (range = -2-7°C) (Figure 9.). Under the *Construction and Equipment Guidelines for Export Meat* (Commonwealth of Australia, 1988), product marshalling areas should be maintained at a temperature of less than 10°C and protected from the elements with the dock area being designed so that, where possible, the area is enclosed. Therefore, the increase in temperature at load out, while not directly commented on by any of the processors, may be due to the limited temperature control during the movement of product from chiller to marshalling area and subsequent truck or container loading.

Figure 9. Temperature control by processing stage for individual processors.



Cold chain management (external)

The management of the export cold chain, particularly temperature control, beyond the processing facility, was highlighted most frequently by processors as a factor contributing to shelf-life issues (as previously discussed). Subthemes included freight route, freight temperature fluctuations, poor marshalling and storage of product by importers and domestic cold chain control.

One processor reported that they had discovered transport route to impact on the temperature fluctuation of containers travelling by sea freight through the tropics, noticing a rise of 2-5°C. Using the shelf-life prediction model, they noted for every week product was held at such temperatures, they would expect at least a one-day reduction in shelf-life.

"What we have found though is that containers that go through the tropics always have a one or two degree rise in temperature anyway, so if your container is at one or zero, chances are it's going to be a week or two at 2°C… Then if there is a higher rise when it's out, up to 4-5°C, which is quite normal for some places, you can lose half your shelf-life by the time it gets there and then you just don't have the shelf-life on it anyway."

Similarly, multiple processors had reported that the use of data loggers, returnable and real-time, had revealed periods of less than ideal temperature control throughout the export supply chain. This included transport within Australia, through to freight forwarders and product transport in the importing country. Such information was invaluable in ensuring temperature issues were addressed as they occurred or provided evidence to show that it was not a processing issue, with one enterprise commenting that data loggers were the "*cheapest form of insurance you'll ever have*".

This was particularly so for consignments of boneless product, where less shelf-life issues were reported overall, and typically included in a container where bone-in product was also affected and the whole container load rejected.

"Sometimes the shipping container also has those products in it [boneless product] … but again I think it was in that container where the entire container was affected across multiple products and multiple dates. So, it may not have been affected if the container had operated properly."

One processor noted that *"If we ever have problems [with boneless product], what we find is that if we put a couple of data loggers in and let it be known that we're logging it… we find that problem sort of goes away pretty quick."*

Another processor commented that for transport of refrigerated containers by train, a second position is required for a generator, implying that cost cutting by freight forwarders was another suspected cause for refrigeration failures in transport.

"It makes no sense for the freight forwarded to have half of it as airspace. I think a big one there would be if there was some technology that we could look into that is a generator for a chilled container that doesn't take up a position on a train."

Where real-time data loggers were not currently being used, most processors were looking at the technology as a form of temperature monitoring having experienced difficulties with obtaining this data through customers and freight companies.

"That is fairly hard information to get back from the sea freighters, they don't particularly like giving you that."

Poor marshalling or storage of product by the importer, particularly during their summer period, was raised by several enterprises as impacting shelf-life.

"So, depending on how long it hangs around in that marshalling zone, that's where the shelf-life goes astray as well."

One processor had investigated the issue by inspecting importer marshalling zones and cold stores. They concluded that this was a major issue impacting the shelf-life of product with one reoccurring complaint being associated with the customer holding product in unrefrigerated zones for unknown periods of time and having little regard for timeframes and defined control measures. They further queried whether such importers valued chilled beef product more highly than lamb, after comparing storage zones for the two products.

"Some of the warehouses in the UAE are fantastic and others not so great in regard to their cold management. Even in the better warehouses they tend to have dead zones where there is less air circulation and you can feel it is a warmer temperature. The few we visited, they tended to store lamb product in those spots… Sometimes they are loading out in the open environment and stacking down on pallets etc. which causes issues with delays at this step."

Temperature control failures within the domestic cold chain were frequently raised by those processors who also supplied product to the domestic market.

"It can sit on a shelf in a distribution centre somewhere at 3-4°C, even up as high as 5°C and that's why the domestic cold chain falls over."

To overcome this, one processor had restricted which type of products were available to the domestic market so as to avoid those which had a longer validated shelf-life being marketed on retail shelves under temperature conditions outside of the required range and resultingly not meeting the shelf-life.

Therefore, and similar to recommendations for the internal cold chain, there may be value in the development on an education program for customers of Australian lamb which outlines product care requirements (e.g. temperature cold) to maximise shelf-life. Further, with the investment in technologies such as data loggers, processors will be able to provide evidence of cold chain integrity when addressing complaints and use real-time information to address temperature violations in transport as they occur, subsequently minimising or preventing product shelf-life issues.

Customer/consumer education

Customer understanding of product chilling requirements and consumer education relating to indicators of end-of-shelf-life were raised by several processors as contributing to shelf-life issues. Specifically, this included a lack of understanding or appreciation for the impact of time and temperature on product shelf-life as demonstrated by observed breaks in cold chain management by importer marshalling facilities or warehouses. Additionally, one processor received a customer inquiry as to the possibility of raising the chilling temperature due to refrigeration affordability.

"Last week we had an enquiry from the UAE asking that it was quite expensive to keep the temperatures down as low as they are, and can they raise the temperatures to 5°C… So, we can see [with real-time data loggers] that they're storing the product at best 3.5°C. Defrosting patterns take it up frequently through the day to 7-8°C. Sale guys were like "this is fantastic, this supermarket always complains, we send them our best stuff repeatedly trying to avoid it and look, they keep it warm"."

Processors raised that better education of importers relating to temperature control is required to provide some guarantee that product chilling requirements will be maintained to achieve the specified shelf-life.

"It's about letting them know that you can't just get it there and keep it at 6°C for a month and then chuck it on the shelf and it's all going to be ok, because it ain't."

One processor reported a shelf-life complaint regarding the dark colour of product still within the vacuum pack. However, as noted by the enterprise, this is known to be a typical characteristic of product kept in an anoxic environment, whereby on opening the packaging, product will 'bloom up' with exposure to oxygen (Mills et al., 2014, Meat & Livestock Australia, 2016). Many complaints of shelf-life were suspected to be due to lack of understanding concerning confinement odour, with consumers mistaking this for off-odours.

"The main complaint we'll get is confinement odour, sometimes when you open up shanks or a shoulder or even a rump or something, there will be a bit of a whiff, a bit of a smell that dissipates quickly. The consumer, I think isn't necessarily educated to that effect. We do have a customer here who actually puts it on the back of their label and discuss confinement odour and tell the customer that there might be a slight smell when you open the product and just to rinse it off."

Confinement odour is a phenomenon of vacuum packaged meat, whereby a short-lived, unusual odour appears on opening of the package. While not occurring in every pack, this characteristic is often mistaken by consumers that product is spoiled, despite remaining microbiologically safe and wholesome (Reis et al., 2016). As concluded by Reis et al. (2016), particular volatiles associated with confinement odour were the products of bacterial processes (e.g. glucose fermentation), of which all bacteria were naturally found in meat and presented no risk to human health. Further, with time and storage temperature control, as previously discussed, being critical to achieving the desired shelf-life for lamb products, it is important that customers and consumers are educated in these areas to maintain cold chain integrity and minimise product wastage. Particularly where no evidence of processor fault regarding product spoilage and evidence of cold chain integrity throughout transport (with technologies such as data loggers) can be provided, a need for such programs is evident.

Economic pressures

Processors commented that where customers had difficulty in marketing product, often the motive behind complaints was to receive a refund. However, where enterprises were able to demonstrate cold chain integrity these complaints were not sustained.

"Some customers are more difficult, and they don't have a certain market at the end when they order so they try to back out of it… They make a claim to us and to appease them you try to pay it out and they'll order again but now they've stopped complaining because we send them straight back the GPS data of their wholesaler and they're like "Oh! carryon"."

Market politics between supply chain members were suspected to be driving complaints from immediate customers where the processor could not identify any potential issues with internal processes or cold chain integrity.

"So, we're not sure whether the client in the Middle East is just trying to push the client into cheaper product or a cheaper processing site or what… The product we kept in Australia bloomed up on the spine, so we don't think it's a vitamin [D or E] deficiency, we think it's just the buyer trying us on a little bit."

It is apparent, that where processors could demonstrate cold chain integrity through use of data logger technology, a device inserted in consignments of product which captures accurate temperature:time information (Meat & Livestock Australia, 2016), (suspected) non-genuine customer complaints were successfully reduced. In particular, this was most effective with real-time loggers as processors were not reliant on the return of the loggers by the customer. Thus, with the increased adoption of such technologies by processors the reduction of complaints of a political nature may be achieved and provide processors with a greater level of assurance that product integrity has been maintained.

"I suppose it's our responsibility even though once the container's shut they say we have no responsibility, we get paid for it and that sort of stuff, we've still got to make sure that the cold chain is robust enough because it's our product and we don't want our brand name associated with a load that's arrived in a poor condition."

Packaging/Handling/Hygiene

While product packaging materials are required by the Australian Standard to be sufficiently strong enough to maintain wholesomeness (Anon., 2007), assurance of package integrity was a challenge for several processors. Most processors (83%) used more than two bag types for vacuum packaged product, with only one processor using only one bag type. This allowed for an alternative bagging option where issues with bags were experienced. However, several processors reported having conducted bag tests prior to full implementation to ensure bags were effective for the intended use. Commonly, processors had leaker (punctured pack or faulty seal) detection processes whereby faulty packs were identified onsite, and product repackaged prior to transport. However, the type of packaging used and the frequency of product handling or movement during transport were mentioned as factors, by multiple processors, contributing to increased punctures of bone-in vacuumed packed product and reduced shelf-life. This was supported by CSIRO (2003) who reported, increased leakers for boneless primals to be related to poor sealing, puncturing or scuffing of the bag film during processing or transport, while that of bone-in primals is similarly often due to poor sealing or puncturing of the bag by sharp bone ends.

"The more times you handle the bags, the worse off at the end… The quality of the bag, the bag and the handling doesn't help. They mix in together a bit."

Other processors commented on the make-up of the plastic packaging with one suspecting the type of plastic to be influencing shelf-life after failed attempts at identifying the root cause of the issue. Another supported this, reporting variability in the construction and properties of the same type of vacuum-pack bags.

"So, your oxygen transmission rates, and permeability, puncture resistance and all that, whilst you may get a specification from your supplier, that doesn't guarantee that each run they make is going to be that."

A study by Reid et al. (2017) demonstrated that the shelf-life of beef product varied according to the makeup of different types of anti-microbial packs by inhibiting blown pack spoilage, therefore supporting packaging materials as being a potential factor impacting upon the shelf-life of lamb products. However, further investigations into the impact of packaging materials and chemical makeup of vacuum-packed bags on shelf-life are required.

Consistent with CSIRO (2003), shelf-life issues experienced with boneless cuts were mostly linked to packaging faults from manufacturing or processor sealing with one processor stating that nine times out of ten, sealing issues were due to manufacturing faults.

"As far as leakers on boneless product, they almost don't exist. For the odd one you get that might be a seal bar issue or something like that, but they really border on non-existence."

Additionally, a few processors suspected shelf-life issues for boneless product to be due to an increased number of touch points, resulting in higher microbial loads, on the product prior to packaging.

"It's mostly with the shanks and the shoulders, particularly with the boneless shoulders when you've got a lot more touch points."

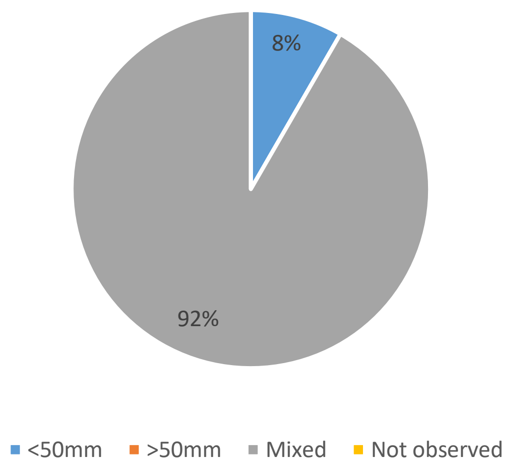
This was supported by another processor who additionally noted, cross contamination and Personal Protective Equipment hygiene to influence microbial loads. This was similarly highlighted by Mills et al. (2014) as being a point of concern with water, poor hygiene discipline and lack of education in this area being known to contribute to cross-contamination and higher loads of bacteria with spoilage potential.

With cross-contamination being identified as a cause for increased microbial loads (Mills et al., 2014), further understanding the impact of the number of times which product is handled prior to packaging may enable best practice hygiene and product handling processes, which lower microbial load and increase shelf-life, to be identified. Potential alterations to product systems, whereby the number of times product is handled prior to packaging may also be effective in reducing microbial loads due to cross contamination and thus address some shelf-life issues.

Season/Livestock condition/Meat quality attributes

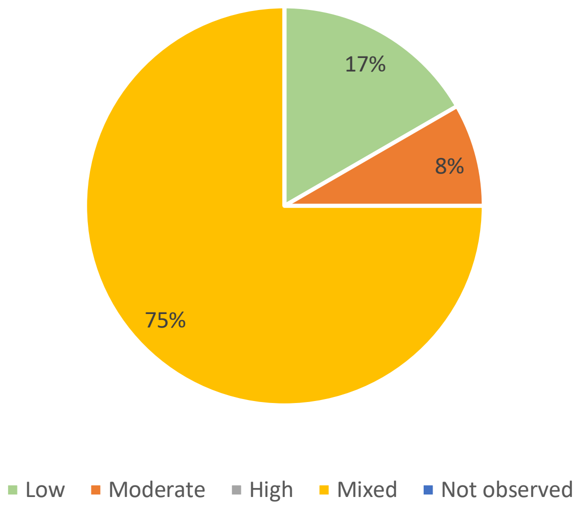
From the survey, the large majority of processors reported that they processed sheep with mixed wool lengths while only one processed those with a fleece length of <50mm (Figure 10.).

Figure 10. Fleece length of sheep processed by Australian sheep/lamb export processors.



Additionally, enterprises (45%) processed sheep with mixed fleece contamination risk scores (based on the MLA Dag Scoring System), with a further 17% having processed those that were low risk and one identified stock as being moderate risk (Figure 11.).

Figure 11. Fleece contamination score (based on the MLA Dag Scoring System) of sheep processed by Australian sheep/lamb export processors.



Approximately 50% of processors had noted the wetter Australian winter to influence livestock fleece condition (and more so in feedlot animals) along with later season, bigger lambs presenting for processing. The combination of these factors were reported to increase contamination risk at slaughter, and often shelf-life issues, by multiple processors.

"We mostly see a seasonal influence on shelf-life issues, particularly moving into winter and early spring with lamb. Paunches come in full as animals are flushed, this causes difficulties with dressing especially considering existing difficulties in finding skilled labour and livestock not being properly curfewed. At this time, stock are more mature and bigger, the skin is also more soiled which results in skins being harder to remove and issues with shelf-life due mostly to micro. These livestock are the left-overs, being more hoggets and ones, we wouldn't normally take."

This is consistent with Biss and Hathaway (1996a) who found levels of microbiological and visible contamination to be lower on carcases which had shorn fleeces. Similarly, Biss and Hathaway (1995) found an interaction between longer woolled sheep, preslaughter washing (which can relate to wet animals in the winter season) and microbial load. It was suggested that wet wool enables direct contamination of carcases during carcase dressing/ Longer wool was associated with increased faecal staining and remained damp for longer, creating a more favourable environment for bacterial growth.

Another processor emphasised the impact of the relationship between livestock environment and season, reporting that animals held in dirt yards or sourced from feedlots from autumn through to late spring were most associated with shelf-life issues. To overcome processing difficulties associated with wet livestock over the winter period, the processor utilised undercover dirt yards to dry livestock. However, due to autumn winds moving dust into the wool, this did not always reduce contamination risk.

"We use those for drying in wintertime but the condition of those yards, we clean them on a regular basis but when the dust and stuff gets in the wool, we get a bad run through more so Autumn.

Where you've got a wind and stuff gets up… So you get a bit more in the wool… and the day one [microbial] test would show that it doesn't matter how good a job we get the blokes to do inside, we're still going to get some sort of contamination on them. That usually parallels itself down the line that you'll end up with a worse result at the end."

One processor had investigated the impact of meat quality factors on shelf-life, after noticing a link between moving into the winter season, carcase pH and shelf-life complaints.

"We've found seasonally there is a correlation between the pH temperature of the carcases and the shelf life achieved. So, each June-July we start testing pH… We've tested, over the last… years, maybe 20 000 carcases. So, we know, that if we don't exclude the old season lambs with the higher pH then we will have issues. We know that. Even to the point where we will stop electric stimulation during those months."

This was reported as a consequence of stock being flushed with fresh, green feed following an extended period of previously limited nutrition. As a result of this rapid change, carcases in the pH range of 5.8-5.9 were processed. This was supported by another processor who had noted a similar impact of pH on the shelf-life of whole chilled carcases.

"Yeah, because they have a darker cut of meat which is obviously going to have a reduced shelf-life… I think it was by about three or four days we were losing on the dark, high pH carcases. So around about that sort of 7-8 [day] mark, you might just get a week."

In support of these observations, McPhail et al. (2014) previously investigated the predicted pH and dark cutting percentage of lambs processed in southern Australia. It was found that older lambs, processed in the autumn months, as well as electrically stimulated carcases, had a greater pH and dark cutting percentage than younger lambs processed during spring (McPhail et al., 2014). The inverse was also true for heavier lambs which interestingly supports the observation, during shelf-life trails by one processor, that products with greater fat coverage were found to maintain shelf-life better than lean product.

"It really depends how lean it is, I think leaner products suffer more, I think the ones with the fat tend to do a lot better."

While minimal literature exists to support this, it may be worth conducting further investigations into the potential relationship between fat coverage and shelf-life. pH is a known factor impacting on many aspects of meat quality such as colour, tenderness and shelf-life (Stahlke et al., 2019), with shelf-life being reduced from higher muscle pH and the associated proliferation of spoilage bacteria where temperature is not adequately controlled (Mills et al., 2014). Similar to findings by the processor, McPhail et al. (2014) concluded that seasonal differences in pH were most likely due to lower muscle glycogen levels from the reduced energy intake associated with pasture feeding.

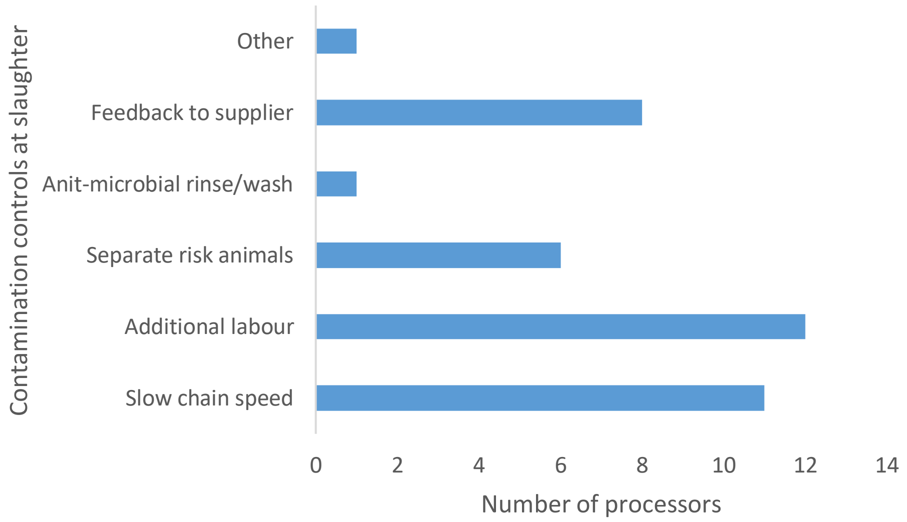
Where complaints were received during the Australian summer one processor linked this with internal processing issues:

"More often than not, shelf-life issues line up with our winter-spring season. Issues seen in our summer are usually due to ZTs, staff shortages, a bad run of stock, onsite incidences and not being able to handle the processing. The [export] cold chain at the Australian end is generally pretty good because we have to comply with the Australian Standards, and we have to allow for the distance product has to travel to reach markets."

As previously discussed (see Cold chain management (external)), cold chain control at the importers end of the supply chain, particularly in the summer months, was also suspected to influence shelf-life experiences.

Those processors who reported a link between product shelf life and internal slaughter floor and stock cleanliness management processes, often had a number of processes in place to minimise the impact on shelf-life. The number of controls implemented by any one processor ranged from 2-5, with the most common control being the addition of extra labour followed by the slowing of chain speed and the provision of contamination feedback to the livestock supplier (Figure 12.).

Figure 12. Controls implemented on the slaughter floor by Australian sheep/lamb export processors to manage carcase contamination.



Some processors reported that they actively took note of stock cleanliness and fleece length in lairage, and often recorded this on ‘run-up’ sheets which allowed slaughter floor supervisors to pre-empt stock condition and adjust internal slaughter floor processes to reduce contamination potential. Other strategies included manually pulling pelts, putting more experienced personnel in critical positions (with high contamination risk e.g. evisceration), putting papers on the opening cutting lines and reinspecting product before packaging. While some controls assisted in reducing contamination, others were less effective with one processor reporting that they had previously banned growers who had continuously supplied high risk livestock.

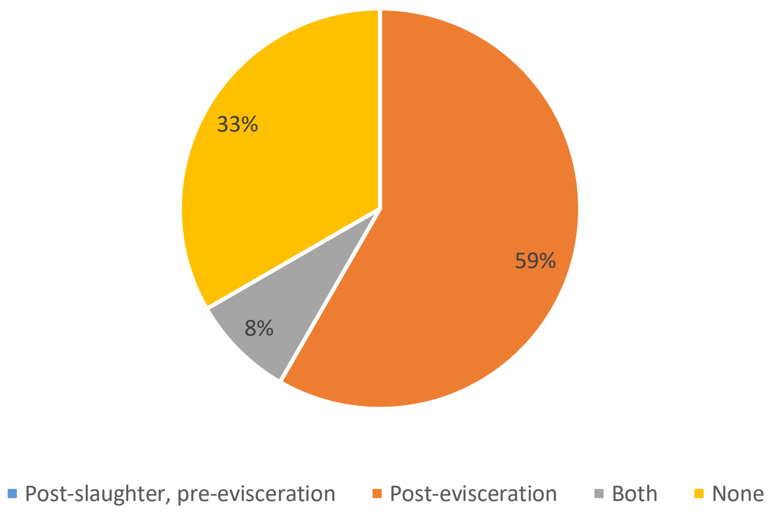
“Some we actually crutch on site here but others we get back in contact with them and hopefully it’s a one-off, but it doesn’t matter what they do there is still mud almost down on the skin.”

While one processor indicated that they implement both a post-slaughter and pre-evisceration wash to manage carcase contamination, they acknowledged that the majority of processors applied a post-evisceration wash only.

“Not many plants do that, some do, and some don’t, but we choose to do that.”

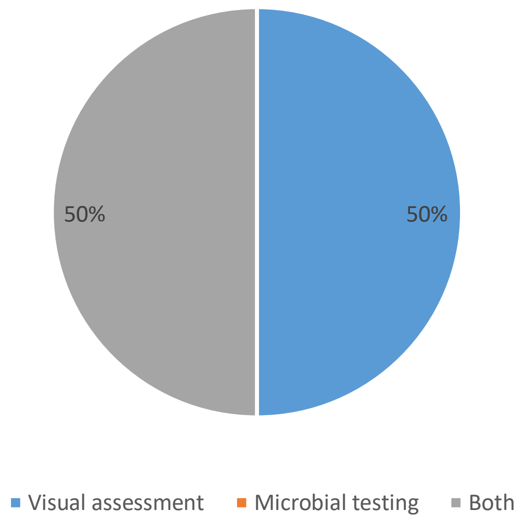
One third of the processors applied no washes to carcases during the slaughter and dressing phase (Figure 13.). This was consistent with Biss and Hathaway (1995) who found that pre-evisceration washing successfully removed almost all visible wool contamination but failed to impact on visible faecal contamination. While unwashed carcases had higher levels of visible contamination, those which underwent a wash process had higher levels of microbial contamination. It was suggested that monitoring of preslaughter presentation of livestock and adjustment to online processes, rather than online monitoring of visible carcase contamination would be more effective as a process control.

Figure 13. Carcase washes applied to sheep carcases post-slaughter by Australian sheep/lamb export processors.



Half of the processors identified contaminated carcases via visual identification only, while the remainder conducted both visual and microbial assessments. For those processors who conducted microbial testing, the mean TVC carcase counts were 88.7cfu/cm^2 (range 10-300cfu/cm^2) (Figure 14.). These were above the mean counts of 30cfu/cm^2 reported by AMPC under the *E. coli* and *Salmonella* Monitoring (ESAM) program. These had, like processors seasonal observations of shelf-life issues, historically increased with the number of extreme rain events with *E. coli* being affected by seasonal influences such as rainfall and pasture growth (Sumner et al., n.d.).

Figure 14. Method used to identify contamination of sheep carcases used by Australian sheep/lamb export processors.

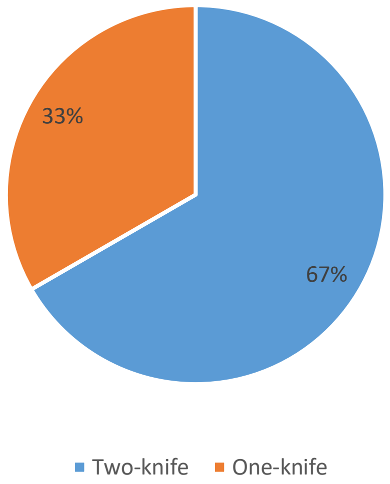


Another processor emphasised the importance of cold chain management and microbial load on shelf-life, considering these to be the two most influential factors.

"So, in the short term its temperature and in the longer term and medium term it is keeping the bugs off and getting it chilled down quicker."

After completing a review of their carcase opening system (pelting and evisceration), the processor looked to implementing systems such as air knives to lower the risk of microbial contamination. This was common among participating enterprises, with approximately two thirds of enterprises using a two-knife system and the remaining 33% using only one-knife (Figure 15.). The Food and Agriculture Organization of the United Nations (1991) specify that each operator of slaughtering processes should have two knives, one for operations while the other sterilizes in water at 82°C to prevent cross contamination of carcases and carcase parts. However, it was noted by processors that temperature control was most critical to achieving shelf-life.

Figure 15. Knife system implemented by Australian sheep/lamb export processors.



Thus, nutritional and seasonal factors relating to meat quality attributes (pH) as well as carcase contamination are likely suggested factors contributing to reduce shelf-life of lamb product. With processors implementing a variety of livestock, slaughter floor process and hygiene controls to manage and overcome these issues, there is opportunity for some processors to adopt already prevalent practices such as a two-knife system to further improve hygiene practices. Additionally, there may be value in developing a best practice guide or training materials which allow and assist processors across industry in more effectively managing these factors to increase shelf-life.

Transportation time

It is known that significant shelf-life time is consumed during the sea freight transport of chilled lamb product to distant markets. As well as this, microbial loads and product deterioration increases over time, and particularly where other shelf-life moderating factors such as temperature are not adequately controlled (Meat & Livestock Australia, 2016). Despite this, processors raised time in transport as a reason for shelf-life complaints, whereby these were received from customers or consumers when product was either very close to or had exceeded shelf-life. Combined with a lack of end-of-shelf-life evidence provided by the end consumer, difficulties in determining whether product had truly not met shelf-life were experienced.

"They might receive the product, some of those countries it might be 50-60 days old before it gets there, and you sort of only find out either the week before maybe or the same week of expiry or the week after expiry."

Thus, in combination with the recommended development of a standard complaint process (including requirements of end-of-shelf-life evidence), it is suggested customers are made aware of the impact of transport time on shelf-life and that complaints regarding shelf-life are required to be made within the shelf-life of the product. This may not only stop unreasonable complaints, but also enable processors to identify the source of the shelf-life issue, where genuine customer complaints regarding product quality and wholesomeness are lodged.

5. Conclusion

5.1 Key findings

Generally, through a mixed methods research design, the study found that the shelf-life issues experienced among exporters of Australian lamb differed according to the unique shelf-life incident. Both microbial and organoleptic indicators (typically odour and appearance) were considered primary determinants of shelf-life with, with bone-in product transported by sea freight more commonly reported to have experienced reduced shelf-life (over boneless product). Often processors were alerted to shelf-life issues by the customer in the export market. Evidence reported as indicating end-of-shelf-life through product complaints included, with no particular trends evident, greening; browning; blown-packs; off-odours; confinement odours; drip/purge; gas/bubbles in pack; and textural changes. With many processors validating shelf-life to between 70 and 90 days, where incidences occurred, actual shelf-life achieved varied between 28-63 days. In many instances, processors experienced difficulty in obtaining clear evidence of end-of-shelf-life, figures relating the amount of product affected (which ranged from a few items to whole container loads) and temperature control information in the external cold chain to allow the source of the shelf-life issue to be identified. With some shelf-life complaints being infrequent, often issues were experienced seasonally with many processors noting issues to occur either in the Australian autumn-winter months or importers Summer period. From themes identified in semi-structured interviews, suspected causes of shelf life issues included:

- Cold chain management (external)
- Cold chain management (internal)
- Customer/Consumer education
- Economic pressures
- Packaging/Product handling/Hygiene
- Season/Livestock condition/Meat quality attributes
- Transportation time

Where shelf-life issues were experienced many processors had conducted systems review (internal and external processes) to identify the cause of the incident and had processes in place to minimise the risk of shelf-life issues occurring. These namely included stock hygiene management and alteration of slaughter floor processors to minimise contamination risk. Processors were also working to obtain evidence of external cold chain integrity with many utilising returnable or real-time data loggers to obtain such information.

5.2 Benefits to industry

Through this research, a greater understanding of shelf-life issues experienced by Australian lamb exporters and the complexities of these issues has been obtained. With many processors experiencing difficulties in identifying and overcoming shelf life issues experienced with vacuum packed, chilled lamb product, such information can be used to direct future research in this space. Specifically, investigations into the relationships between suspected causes of shelf-life issues and shelf-life incidences should occur to confirm causation and further allow the development of practical solutions for achieving a longer shelf-life. In addition, the development of training materials and customer/consumer education programs relating to determining end of shelf-life may prove valuable in ensuring that there is universal understanding of product care requirements and product shelf-life expectations. Subsequently, this will grow the value of Australian lamb in international markets through minimising product wastage and maximising product saleability as a direct result of longer shelf-life.

6. Future research and recommendations

Issues with the shelf-life of chilled, vacuum packed products produced by Australian exporters of lamb were of a highly complex nature, with challenges in identifying and resolving or reducing future issues varying according to the individual circumstance. However, the study identified general themes across the shelf-life issues reported by processors which can be used to inform future research and recommendations. Such recommendations include:

- Development of training materials for processors regarding understanding shelf-life parameters; identifying and addressing causes of shelf-life issues; best practices to reduce risk of shelf life issues; and enhancing customer communication to streamline the complaints process and obtain useful evidence of and information relating to the specific shelf-life complaint
- Development of customer/consumer education materials regarding understanding product care requirements (e.g. time, temperature and handling); indicators of end of shelf-life; appropriate time frames in which to lodge complaints/feedback; and information to include when lodging complaints/feedback to best assist processors in identifying and overcoming shelf-life issues (e.g. submission of evidence of end-of-shelf-life, temperature logs, amount of product affected etc.)
- Promotion of technologies such as real-time data loggers as a means of obtaining evidence of cold chain integrity (both internal and external), addressing temperature violations as they occur and achieving the expected shelf-life for exported child, lamb product
- Conduct further investigations into the potential influence of season, meat quality attributes such as fat coverage and pH, and product handling on the shelf life of vacuum-packed lamb.

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8. Appendix

8.1 Appendix A

Shelf-life experience in chilled lamb export supply chains survey

Welcome to the Shelf-life Experience in Chilled Lamb Export Supply Chains survey. This survey should take approximately 15 minutes to complete. Please answer all of the questions to the best of your knowledge with respect to what occurs in the enterprise and select submit when finished.

By completing and submitting this survey you acknowledge that you have received the participant welcome letter/information sheet for the Shelf-life Experience in Chilled Lamb Export Supply Chains project and give your consent to being involved in both Phase 1 and Phase 2 of the project. Where you no longer wish to participate, please contact the project team and advise them of this decision. If you have any issues completing the survey please contact the project team (details can be found in the welcome e-mail).

1.What is the name of the enterprise (please include site if multiple)?

2.What species does the enterprise process (select multiple if applicable)?

☐ Sheep

☐ Lamb

☐ Goats

3.Where is the enterprise located?

○ NSW

○ QLD

○ WA

○ SA

○ VIC

- ○ NT
- ○ TAS

4.What is the enterprises approximate daily output for sheep/lamb carcases (please type number)?

[ ]

5.Where are the key markets for the enterprises chilled lamb product?

- ☐ Europe
- ☐ Middle East
- ☐ North America
- ☐ Mexico
- ☐ China
- ☐ Other

6.For chilled lamb product sent to Europe by sea freight, what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

[ ]

7.For chilled lamb product sent to the Middle East by sea freight, what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

[ ]

8.For chilled lamb product sent to North America by sea freight, what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

[ ]

9.For chilled lamb product sent to Mexico by sea freight, what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

10.For chilled lamb product sent to China by sea freight, what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

11.To which other export destinations does the enterprise send chilled lamb product by sea freight and what is the length of time between processing and product arriving at the port of receival in these markets in days? If not applicable please type NA.

12.For the enterprises chilled lamb product, please indicate the subsequent steps in the supply chain?

- ☐ Transporter (domestic)
- ☐ Independent boning room
- ☐ Value adder
- ☐ Wholesaler (domestic)
- ☐ Third party cold store
- ☐ Container terminal (domestic)
- ☐ Exporter (vessel)
- ☐ Container terminal (importing country)
- ☐ Transporter (importing country)
- ☐ Wholesaler (importing country)
- ☐ Retailer/food service (importing country)
- ☐ Other

13.For each product type produced by the enterprise, please indicate whether it is exported by air or sea freight or both. If any of the particular product types are not produced please select NA.

	Air freight	Sea freight	Both freight modes	NA
Bagged whole carcase	○	○	○	○
Bone-in primals (VP)	○	○	○	○
Boneless primals (VP)	○	○	○	○
Bone-in non-primals (VP)	○	○	○	○
Boneless non-primals (VP)	○	○	○	○
Other	○	○	○	○

14.If you selected "other" for mode of export by chilled lamb product type, please indicate the additional product types and mode of export. If not applicable please type NA.

15.How many types of vacuum-packed bags does the enterprise use for chilled lamb product?

○ One

○ Two or more

16.Does the enterprise have any programs in place to monitor the quality of lamb product such as a meat quality grading system, pH program etc.? If so, please list.

17.For critical roles relating to carcase contamination such as skinning, evisceration and hygiene trimming, please write a short description of training that staff undertake, including length, provider, any training modules and satisfactory assessment.

18.What is the average HSCW of the lambs that the enterprise typically processes in kg?

19.What type of lambs does the enterprise process?

- Shedding
- Wool
- Both

20.What is the typical wool length of lambs that the enterprise processes (please select most appropriate)?

- Fleece is less than 50mm in length
- Fleece is greater than 50mm in length
- Mixed
- Not observed/recorded

21.What is the typical fleece contamination condition of lambs that the enterprise processes prior to slaughter (please select most appropriate)?

- Low risk (fleece is dry and free from faecal, urine and dag contamination)
- Moderate risk (fleece moderately contaminated with faeces on belly and brisket, dry or slightly damp)
- High risk (fleece has heavy faecal and urine contamination on belly, brisket and legs. This may extend onto back with heavy dags, wool is damp or wet)
- Mixed
- Not observed/recorded

22.What washes do carcases undergo during processing (select multiple if applicable)?

- [ ] Post slaughter, pre-evisceration
- [ ] Post-evisceration
- [ ] None

23.How does the enterprise identify contaminated carcases post-slaughter?

- ○ Visual assessment
- ○ Microbial testing
- ○ Both

24.If you selected microbial testing as a method for identifying post-slaughter carcase contamination, please indicate the average total viable count (TVC) for carcasses processed by the enterprise. If not applicable please type NA.

[ ]

25.What processes does the enterprise have in place to minimise product contamination (select multiple if applicable)?

- [ ] Slow chain speed
- [ ] Additional labour
- [ ] Risk animals separated from lot and processed as suspects
- [ ] Anti-microbial rinse or wash
- [ ] Feedback to supplier
- [ ] Other

26.Does the enterprise use a two-knife system?

- ○ Yes
- ○ No

27.Please indicate the temperature that the enterprise chills lamb product to within 24hours of stunning (degrees Celsius).

28.At what temperature does the enterprise maintain whole lamb carcases in chiller storage at (degrees Celsius)?

29.At what temperature does the enterprise maintain chilled boned lamb product in chiller storage at (degrees Celsius)?

30.What is the maximum load-out temperature for the enterprises chilled lamb product (degrees Celsius)?

31.What temperature does the enterprise require chilled lamb product to be held at during the transport phase (degrees Celsius)?

32.What is the expected shelf-life of the enterprises chilled vacuum packed boneless lamb product in days (please type NA if not applicable)?

33.What is the expected shelf-life of the enterprises chilled vacuum packed bone-in lamb product in days (please type NA if not applicable)?

34.What is the key criteria that the enterprise uses to determine end of shelf-life for its chilled lamb products?

35.For each of the chilled lamb product types, please indicate those with which the enterprise has experienced shelf-life issues, currently or in the past, and for which mode of export. If any of the particular product types are not produced please select NA.

	Air freight	Sea freight	Both freight modes	No Issues	NA
Bagged whole carcases	○	○	○	○	○
Bone-in primals (VP)	○	○	○	○	○
Boneless primals (VP)	○	○	○	○	○
Bone-in non-primals (VP)	○	○	○	○	○
Boneless non-primals (VP)	○	○	○	○	○
Other	○	○	○	○	○

36.If you selected "other" for products which the enterprise has experienced shelf-life issues, please indicate what these are and for which mode of export. If not applicable please type NA.

37.What are the shelf-life issues that the enterprise has experienced across all of its chilled lamb products (select multiple if applicable)?

- ☐ Packaging related issues e.g. blown packs, punctured packs
- ☐ Product discolouration e.g. browning or greening
- ☐ Microbial growth
- ☐ Unusual product odours
- ☐ Consumer illness
- ☐ Other

- [ ] We have not had shelf-life issues

38.Across all of the enterprises chilled lamb product types, how frequently do issues with shelf-life occur for the business (select multiple if applicable)?

- [ ] Weekly
- [ ] Monthly
- [ ] Seasonally
- [ ] Yearly
- [ ] Bi-yearly
- [ ] Every 5 years
- [ ] More than every 5 years
- [ ] NA

39.How did the enterprise become aware of issues with chilled lamb product shelf-life (select multiple if applicable)?

- [ ] Occurred on site
- [ ] Feedback from wholesaler
- [ ] Feedback from customer
- [ ] Feedback from consumer
- [ ] Other
- [ ] NA

40.Has the enterprise successfully identified the cause of the shelf-life issues for its chilled lamb product?

- ○ Yes
- ○ Some
- ○ No
- ○ NA

41.Thank you for your time in answering this survey. For phase 2 of the project (follow up discussions), please select your preferred availability for each of the dates listed below. Please indicate as many availabilities as possible. If you are unavailable on any given date, please select the 'Not available option'. We will then contact you to schedule the follow up discussion according to your availability. These discussions will be of approximately 30min max duration.

	8-10am (Sydney time)	10am-12noon (Sydney time)	12noon-2pm (Sydney time)	2pm-4pm (Sydney time)	Any of these times	Not available
Monday (8/3/21)	○	○	○	○	○	○
Tuesday (9/3/21)	○	○	○	○	○	○
Wednesday (10/3/21)	○	○	○	○	○	○
Thursday (11/3/21)	○	○	○	○	○	○
Friday (12/3/21)	○	○	○	○	○	○

42.For phase 2 of the project (follow up discussions) we will be audio-visually recording online meetings for data collection and analysis purposes only. Please select the appropriate statement regarding your consent to this.

○ I agree to be audio-visually recorded during my scheduled online interview/discussion.

○ I do not agree to be audio-visually recorded during my scheduled online interview/discussion.

8.2 Appendix B

Semi-structured interview schedule

INTRODUCTION

Today's meeting will be a casual and informal discussion regarding the enterprise's experience with the shelf-life of chilled lamb product. Where you have given your permission, we will be recording this meeting for data transcription and analysis purposes only. Recordings will not be used in any other way. All information disclosed during this discussion will be deidentified and anonymous in any reporting. We hope that you have had a chance to look through the interview discussion topics for your preparation, these were sent with the meeting invite. If you haven't this is not an issue. This meeting should take approximately 30 minutes. We would specifically like to understand the enterprise's experiences with the shelf-life of chilled lamb products, particularly bone-in, and would like you to respond with reference to these experiences, giving examples where possible. Do you have any questions before we begin?

ENTERPRISE INFORMATION

DATE

TIME

COMPANY

INTERVIEWEE

CONTACT DETAILS

INTERVIEW QUESTIONS

Can you tell us about experiences you have had regarding chilled lamb product shelf-life recently or in the past? We would like you to talk through the issue from how it was identified, what product was affected, how much was affected and why this may have occurred.

1) What are some of the shelf-life issues you experience with different product types and what products are these? E.g. bone-in or boneless, VP primals or VP non-primals
    a. Do you notice a difference in which type of product is more commonly affected?
    b. Can you track shelf life issues to production days?
2) Can you explain how the expected shelf life of these products compares with the actual product shelf life?
    a. Does this vary according to any specific factors e.g. markets or seasons?
3) What does the shelf life issue look like in the product or what sort of evidence of end-of shelf life did/do you see for the different products?
    a. How does the evidence for end of shelf-life differ by product type?
4) How frequently do these shelf-life issues occur and are there any patterns in the occurrence or any factors that seem to be linked to? [EG. SEASON, TRANSPORTERS]
    a. How does the frequency of shelf-life issues differ by product type?
    b. For seasonal shelf-life issues, which months are you seeing these issues?
5) Where in the supply chain are the shelf-life issues identified and how is shelf-life feedback received e.g. customer complaints?
    a. What complaints or feedback have you receive about your shelf-life product?
    b. What was the nature of shelf-life feedback or complaints e.g. positive or negative?
6) What are the broad and specific impacts of these shelf-life issues for your business and other stakeholders?

   c. What percentage of the consignment was affected by shelf-life issues and what was the consequence of this?

7) What thoughts, or investigations has the enterprise done into where or why these shelf-life issues might be originating?
   d. Have you noticed shelf-life to be associated with any product or supply chain factors and if so, what are they?
   e. What have you done to address these shelf-life issues?
      i. Were these strategies effective, why/why not?
8) Are there any other comments or observations regarding chilled lamb shelf life that you would like to share with us?

Thank you for giving your time to participate today, MINTRAC really values the input into the project that given to the project. From here we will be analysing the results of the study and then providing this as a report to MLA which will likely be published on their website. If you have any further questions regarding this project, please contact us.