Final report

Development of frozen and thawed beef protocols for the China retail market

Project code: V.MFS.0014

Prepared by: Dr Ian Jenson
FIRST Management

Date published: 7 July, 2026

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
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

Due to safeguard tariffs imposed by China, frozen beef is likely to be exported to China, stored, and then thawed for chilled retail display. The Australian industry does not understand how best to do this, and therefore an inability to support a significant change in the supply chain from chilled only is required to maintain a premium market.

Scientific, technical and market perspectives on a frozen-thawed beef have been investigated, through review of literature, in-market discussions with supply chain representatives, and retailer visits. No single technique exists to date that can mitigate all the quality challenges caused by freezing and thawing. The biggest barriers to success with this approach to placing chilled beef onto the retail market are the customer's perception of colour and desirability of very red meat and the regulatory barrier of a Total Volatile Basic Nitrogen (TVB-N) specification which is enforced by both government food inspection and retailer specification. TVB-N appears to be acceptable in frozen Australian beef even after 6 months frozen storage.

A protocol for the thawing of frozen Australian beef for the purpose of retail sale was developed based on an understanding of the scientific literature, practices in the Chinese market, consumer-oriented and regulatory definitions of shelf life, and the potential for regulatory non-compliance at retail when using frozen Australian beef. The Australian industry can demonstrate to customers in China, and the subsequent businesses in the supply chain (through to retail), that it is committed to supporting the sector when it is faced with technical issues.

Executive summary

Background

From 1 January 2026, China has implemented a safeguard tariff of 55% for imports of beef above the allocation (changes slightly for 2026, 2027 and 2028).

The tariff allocation for Australian beef for 2026 will likely be filled in May. Competition for a share of the quota will likely favour high-volume lower-value products. Frozen beef will be exported in the early part of the year, due to its long shelf life, leaving established premium chilled meat programs leaving premium chilled products subject to 55% tariff for the remaining 6 months of the year.

Australian beef has a reputation in the Chinese market for being high quality and safe. Any plan to ameliorate this vulnerability for chilled product must not compromise its quality and safety reputation. One way of ensuring continuity of supply of chilled meat equivalent product at retail is to use frozen and thawed product and place it on retail display.

A protocol has been developed based on available technological knowledge and capability which will guide all participants in the supply chain in how to use frozen and thawed product and place it on retail display while meeting legal and customer requirements. It demonstrates the support that the Australian industry is willing and able to give to support Chinese customers.

Objectives

Develop and validate protocols for thawing of frozen beef primals, cutting and packing them, and putting on retail display, with similar quality and shelf life as is achieved in the China retail market when using chilled primals.

Methodology

- Literature review on effect of freezing and thawing on meat quality
- Survey of Chinese retailers selling Australian meat, their practices and expectations
- Survey of Chinese importers and processors of retail ready product to understand their practices, needs and expectations
- Survey of Australian frozen beef in the Chinese market to understand how well the product meets the Chinese national standards (National Standards of the People's Republic of China issued by the National Health and Family Planning Commission of the People's Republic of China & China Food and Drug Administration)
- Preparing a protocol that can be used by the entire Australian supply chain to ensure that product meets legal requirements and provides the best results for consumers

Results/key findings

The Chinese market has experience in thawing frozen meat for use, including for retail display. Slow thawing under controlled conditions is necessary to preserve the quality of beef, which can be cut and placed on retail display for several days. Maintaining the strong red colour expected in the Chinese market may be enhanced by using MAP packaging. The total volatile basic nitrogen (TVB-N), a 'freshness' marker for which there is a specification in the Chinese National Standards, in thawed beef should be low enough to allow product to maintain its usual retail shelf life (4-5 days from packing).

Benefits to industry

This research provides, for the Australian industry, an understanding of how frozen Australian beef can be prepared for retail sale in China. It provides guidance to the whole supply chain: processors and exporters, importers, processors, brand owners and retailers about how to provide the best experience for customers, as well as consumers, with the least risk of disruption due to not meeting legal specifications. This research provides confidence that exported frozen beef, even after having been frozen for 6 months, should have normal retail shelf life once thawed, without infringing Chinese standards. This research, and the protocol for the supply chain, demonstrate the Australian industry's support for, and commitment to, its customers.

Future research and recommendations

The implementation of this protocol in the Chinese market should be monitored so that modifications can be made if necessary.

A greater understanding of TVB-N, how it is formed, and its validity as a marker of technical or consumer-perceived quality should be further investigated.

Consideration should be given to extending the current shelf life models to understand how frozen storage time may impact on shelf life parameters at retail.

Acknowledgement

This project could not have been successfully completed without the support of the Greater China office of MLA. Murray Davis facilitated the project as a partner with R&D. Jane Zhang became a meeting organiser, interpreter, and research coordinator for activities in China, in addition to her usual role in market development. Without Jane's commitment and dedication to taking on an unfamiliar role, this project would have been very difficult to conduct. Vera Wei provided in depth knowledge of regulations and standards, laboratory contacts, and translation services, which were invaluable.

Table of contents

1. Background

From 1 January 2026, China has implemented a safeguard tariff of 55% for imports of beef above the allocation (changes slightly for 2026, 2027 and 2028).

The tariff allocation for Australian beef for 2026 will likely be filled in May. Competition for a share of the quota will likely favour high-volume lower-value products. Frozen beef will be exported in the early part of the year, due to its long shelf life, leaving established premium chilled meat programs leaving premium chilled products subject to 55% tariff for the remaining 6 months of the year.

Australian beef has a reputation in the Chinese market for being high quality and safe. Any plan to ameliorate this vulnerability for chilled product must not compromise its quality and safety reputation. One way of ensuring continuity of supply of chilled meat equivalent product at retail is to use frozen and thawed product and place it on retail display.

The practice of thawing frozen meat for retail display is usually frowned upon, as not providing the best for customers (see 4.1.1), but under the circumstances (insufficient time and resources to thoroughly investigate the options) this option may keep product on the shelves. Developing a protocol based on available knowledge and technological capability will help the supply chain to ensure the best outcome for customers.

2. Objectives

Develop and validate protocols for thawing of frozen beef primals, cutting and packing them, and putting on retail display, with similar quality and shelf life as is achieved in the China retail market when using chilled primals.

These objectives were met to the extent necessary. A project such as this can only discover and address major foreseen issues, in preparation for what may occur in practice with much greater quantities of meat, in many processing and retail chains throughout China.

3. Methodology

3.1 Literature and grey literature search

A search of existing literature was conducted, looking for advice on thawing of beef and placing into the retail market. Emphasis was placed on eating perceptions of consumers, rather than analytical and instrumental measurements. General internet searches and AI (Microsoft Co-pilot) searches were also conducted. AI outputs were verified or otherwise stated as such.

Searches were conducted of technologies that might assist the thawing process, with an emphasis on technologies that are commercially available.

A review was made of existing MLA/AMPC reports and work, particularly on frozen shelf life, frozen-thaw for retail display and Total Volatile Basic Nitrogen (TVB-N).

General internet searches and AI (Microsoft Co-pilot) searches were also conducted. AI outputs were verified or otherwise stated as such.

When the TVB-N specification was identified as an issue a specific search was conducted for TVB-N data on frozen beef and Australian beef (frozen or chilled).

3.2 China market discussions

3.2.1 Preliminary

Discussions with MLA China office commenced. A SharePoint site and a Teams site were implemented to allow sharing of documents, thoughts, requests and responses between Sydney and Shanghai.

The supply chain within China and the major companies at each stage of the supply chain were identified. The types of beef products on retail shelves were discussed and images previously collected were shared. Australian processors with export licences for chilled product were engaged for further enquiries because they were the most likely to supply frozen beef that would be thawed for chilled retail sale.

Objectives for a visit to Shanghai were discussed, and meetings were arranged with major actors in the market.

3.2.2 In-market

Discussion guides were prepared for each stage of the supply chain to clarify the kind of information we were seeking (either by observation or discussion) acknowledging that the ability to collect as much information as we desired would depend on availability of personnel and their willingness to divulge information about their business. The Guides can be found in Appendix 9.2.

Visits were made to the following retailers:

- Aldi – Shanghai Kaide Store
- Sam's Club – Shanghai Jiading Store
- Costco – Shanghai Minhang Store
- Freshippo – Shanghai Sun Moon Mall Store
- City Super – Shanghai iapm Store

Meetings were held with the following further processors (thawing, cutting, and preparing for retail display):

- Tender Plus China, Tony Mesiano, COO
- Huadong Food, Suzhou, Mr Gao Ziao Fang, General Manager
- TCT (Shanghai Paradise Garden Healthy Food Co.), Sabrina Shi, General Manager of Production

A roundtable of importers and traders was held:

- Exporter: Cargill China– Faye Pan, Sales Manager of Teys
- Exporter: Thomas Foods International China – Alice Zhang, Sales Manager
- Exporter: [Kilcoy] was invited but unable to attend
- Importer/retail supplier: Zhuo Chen, Betty Teng, GM of Shanghai(Bindaree)
- Importer/retail supplier: Harmony China – Summer, Marketing Manager (Harmony)
- Importer: JAC Shanghai – Vanessa Sun, COO (JBS)
- Trader/retail supplier: Zheng Ao – Wei Wong, General Manager (Stanbroke)

A PowerPoint presentation was prepared for the roundtable. It tried to distil some of the issues around frozen-thaw beef for retail, and was updated after the meeting with notes (Appendix 9.3)

3.2.3 Follow-up

Summaries of meetings, helpful information etc. were provided to the people we met, in the hope that it may elicit some response, and involvement in the next stage of the project.

3.3 Exploratory sampling and testing

As the preliminary work anticipated (3.2.1/4.1.2) and in-market work confirmed (3.2.2/4.3.2), TVB-N was a critical issue, and almost nothing is known about TVB-N for Australian meat in the Chinese market. With the cooperation of importers, a further processor and the Shanghai Food Research Institute Co., Ltd. a small survey to estimate the TVB-N of Australian product at the time of further processing in the Chinese market was conducted.

Three cuts were chosen (chuck roll, knuckle and cube roll) each from two different export processors (4 processors in total). For each cut-processor combination, 3 individual packs were purchased over as wide a range of processing dates possible.

Each frozen cut was unpacked, a surface sample removed and then repacked (vacuum). The repacked cut was then thawed at 4°C for 24h, after which another surface sample was collected along with a sample in the centre of the piece. All three pieces were tested for TVB-N as soon as possible (same day) as collection by Chinese National Standard GB 5009.228-2016 Automated Kjeldahl method). A plate count was also performed by method GB 4789.2-2022 which involves incubation at 36°C for 48h. The plate count was performed on duplicate plates incubated at 25°C for 96h.

Detailed testing protocol can be found in Appendix 1.

3.4 Protocol development

A draft protocol for the thawing of frozen Australian beef for chilled retail sale was prepared, utilising the literature, grey literature, opinions and suggestions from in-market discussions. It was validated through discussions with processors currently active in the market.

4. Results

4.1 Literature review

4.1.1 Freezing and thawing beef

The thawing of frozen beef and placing it on retail display, in the hope that consumers will perceive it as having qualities comparable to chilled (never frozen) beef, is a somewhat niche topic even for the meat trade.

At the outset it is worth quoting a recent review which states:

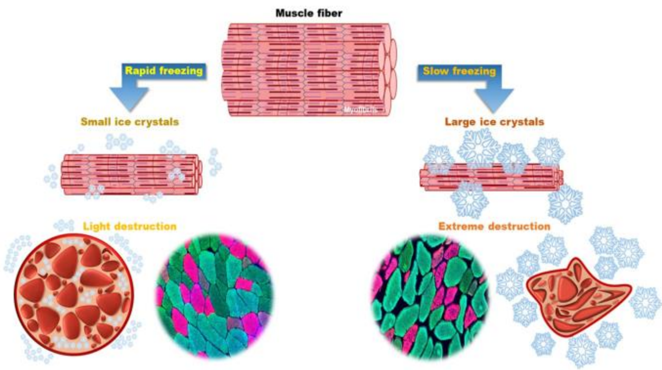
> freezing and thawing processes lead to physical (e.g., ice crystals formation and freezer burn) and biochemical changes (e.g., protein denaturation and lipid oxidation) in meat resulting in loss of quality. Over the last two decades, several attempts have been made to produce thawed meat with qualities similar to that of fresh meat to no avail. This is due to the fact that no single technique exists to date that can mitigate all the quality challenges caused by freezing and thawing.(Zhang et al., 2023)

The scientific literature on thawing of frozen beef is limited. Most scientific literature addresses thawing, but not subsequent shelf life. When the thawing process is examined, a meat science perspective is usually taken, making many measurements, but not relating what may be significant differences from a statistical perspective to the perceptions of consumers. There is usually little mention of microbiological quality, which is pleasing since shelf life is based on colour, odour and taste. Also, as noted by Zhang et al. (2023), a number of techniques have been tried, without success, and this review will not touch on techniques which have no proven value in the market.

Freezing

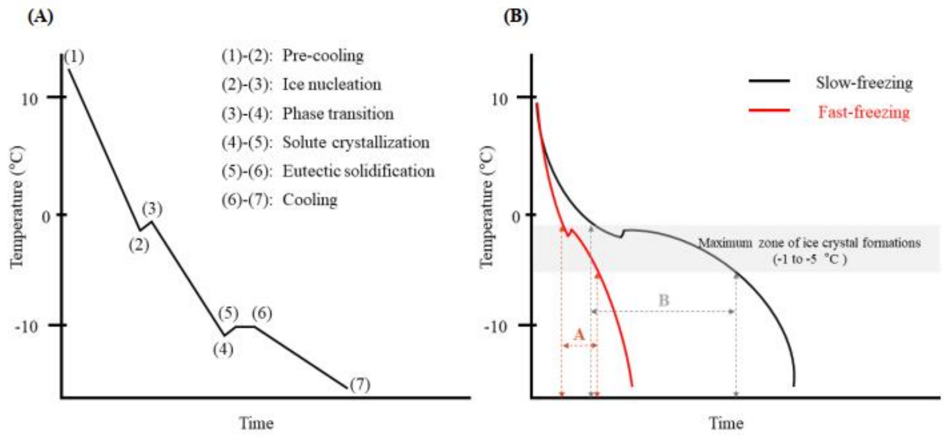
Freezing causes damage to the structure of meat. The freezing rate of meat determines the size and number of ice crystals, which affect the muscle fibre structure (Fig. 1). Rapid freezing leads to the formation of smaller ice crystals outside muscle fibres, whereas slow freezing leads to the formation of larger ice crystals. Ice crystal formation and physicochemical alterations within the muscle tissue owing to freezing are significant factors that directly or indirectly affect muscle food quality characteristics such as water holding capacity (WHC), meat colour, flavour, and texture (Im et al., 2024).

Figure 1: Schematic diagram of the physical destruction of meat tissue due to differences in freezing speed (Im et al., 2024)



Fast freezing is generally thought to result in better quality meat because of the formation of small ice crystals. All commercial freezing inside cartons is likely to be slow freezing (Fig. 2) (though blast freezers will generally be slower than plate freezers (Fig. 3)). Fast freezing of food occurs when the core temperature of the food passes through the maximum ice crystal formation zone within 35 min (Ban and Choi, 2012 cited by Jeong et al. (2025)).

Figure 2: Freezing curve showing slow- and fat-freezing rates (Jeong et al., 2025)



Storage period

The frozen-storage period influences meat quality. The size and number of ice crystals generally increase and decrease, respectively, during prolonged frozen storage, resulting in greater physical destruction of meat structures (Qian et al., 2022 cited by Jeong et al. (2025)). The oxidation of lipids and proteins in frozen meat increases with prolonged frozen storage. (Jeong et al., 2025).

Thawing

It is interesting to note the procedures used in the experimental work to collect data used in the development of the Meat Standards Australia (MSA) eating quality system. All eating quality tests are performed on meat that has been frozen. The principle of quick freeze, slow thaw is employed. Individual meat pieces are frozen as rapidly as possible in a blast freezer, spread out in single layers and exposed to the maximum possible airflows in the freezer (Gee, 2006a). To minimise cell damage, and consequent sample moisture loss, the deep frozen samples are thawed in a refrigerator operating between 2 and 5 °C, well separated to allow free air flow (Gee, 2006b).

Çalışkan Koç et al. (2025) note that products are often thawed by circulating air in a refrigerator at 4◦C, until the food's internal temperature matches the refrigerators. However, there are certain drawbacks to this method, namely, extended thawing durations and considerable drip loss. Thawing food in cold water expedites the process, which is safe and convenient for vacuum packed meat, though the faster thawing may result in quality loss.

Li et al. (2014) of the Institute of Agro-Products Processing Science and Technology, Chinese Academy of Agricultural Sciences, Beijing, describe the use of fluctuating temperature of cool room between 2-6 °C at high relative humidity during thawing can which can reduce thawing loss and improve quality. Initially, the fluctuations from 2-6°C. Initially the cycle of temperature fluctuation was 0.75 hours, extending to 4.5 hours at the end of the process. Compared to 4°C constant temperature, the authors claim that fluctuating temperatures resulted in lower drip loss and improved tenderness. Pan et al. (2019) working at the China Meat Research Centre, Beijing, suggested at 75% humidity was suitable to reduce thawing loss.

Quality parameters affected by freezing and thawing

The meat parameters that are affected by freezing and thawing include (Im et al., 2024):

Water-holding capacity – water is held in the space between the protein filaments of muscle and the capacity of muscle to hold this water is reduced due to freezing. Drip loss on thawing and cooking losses increase on freezing, and further when meat is held frozen. Longer thawing times can allow time for some water to be reabsorbed.

Colour – red colour depends on the chemical state of the heme iron molecule in myoglobin. Redness can increase on freeze-thawing.

Tenderness – damage to muscle fibres during freezing result in an increase in tenderness

Microbial growth – bacterial viability is hardly affected by freezing and thawing. The time that the product is at temperatures permitting the growth of bacteria must be taken into consideration

Lipid oxidation – lipid oxidation can occur due to the action of both bacterial and meat enzymes during the frozen storage period.

Im et al. (2024) argues that it is essential to consider the unique characteristics (proximate composition, pH, and muscle fibre characteristics) of individual muscles or cuts to develop enhanced the freeze-thaw processing technology.

Processes

Im et al. (2024), notes that methods such as rapid freezing, high-pressure treatment freezing and thawing, electric field, ultrasonic treatment thawing, and adjusting the sequence of aging and freezing reduce the degradation of the quality of meat subjected to freezing or freeze-thawing. A search of the internet (Microsoft Co-pilot) suggests that the methods cited by Im et al. (2024) have not (yet) been taken up commercially. In addition to air thawing, air thawing with fluctuating temperatures and controlled humidity, water thawing, the only technology mentioned in the Co-pilot search was the use of radiofrequency.

Du et al. (2022) point out that the synergy of freezing/thawing technologies may be more effective than considering the individual technologies.

Retail Shelf life

Only one study of the shelf life of thawed beef was found, despite organoleptic shelf life being the key measure of consumer acceptability. An et al. (2025) from Shandong Agricultural University took Beef Sirloin, and held for up to 11 months at -20°C for before thawing under running water at room temperature and storing steaks packed in vacuum skin packs up to 21 days at 0-4°C. They found that colour and blooming ability was insignificantly affected by freeze-thaw. Lipid oxidation (TBARS) increased on meat stored frozen (but James et al. (2025) suggest that these values are below the taste threshold). Long term frozen storage resulted in faster deterioration during retail display period with higher values of TBARS, total viable (bacterial) count and higher TVB-N (Total volatile basic nitrogen) and water loss.

TVB-N is significant because it is a requirement of the *National Food Safety Standard for Fresh and Frozen Livestock and Poultry Products*, that fresh or frozen products do not exceed at TVB-N of 15 mg/100g (GB 2707-2016). When the frozen storage period was within 1 month, the TVB-N content of the samples during the 21-day display period were all below the limit, for product stored up to and including 1 month. However, after 3 and 6 months of freezing, the TVB-N exceeded the standard at the 21st day of display; the meat sample with 11-month storage time exceeded the standard after 14-day display. Beef frozen for 3 and 6 months could only be displayed on the shelf for 14 d, and those frozen for 11 months only possessed a 7-day shelf life for display.

4.1.2 Total Volatile Basic Nitrogen (TVB-N)

Total volatile basic nitrogen (TVB-N) is a chemical measure of meat "freshness", frequently used for seafood, but adapted in some countries, such as China (Frank et al., 2019), Vietnam (TCVN12429-2:2020) and Egypt (Barlow et al., 2016), to meat. A maximum value is specified in the Chinese National Standard GB 2707-2016 *National Food Safety Standard: Fresh and frozen Livestock and Poultry Products*, and by doing so, the end of shelf life is defined because the product can no longer be sold once the specified TVB-N has been reached.

TVB-N determination measures the concentration of ammonia, trimethylamine and dimethylamine and is generally perceived as a reflection of the level of protein decomposition in meat, therefore used as an indicator for meat deterioration. A steam distillation method using the Kjeldahl system has been adopted as the standard by many laboratories and as the test method specified in the Chinese National Standard (Hopkins et al., 2020).

In a study of Australian vacuum packed chilled striploins in a Chinese supply chain, researchers found that microbial count data could not be used to produce useful models to predict sensory scores, however TVB-N was the best single parameter to predict the sensory attributes measured in the product (Frank et al., 2019). After 84 days storage at -1°C, the TVB-N was 4.8 mg/100g and at 140d was 7.2 (Frank et al., 2020). The specification in the Chinese National Standard is 15 mg/100g.

In a study of Australian vacuum packed beef air freighted to Egypt, TVB-N values remained within Egyptian Standard Specifications (ESS:3602/2013) limits (20 mg/100g – note that the method may not be the same as used in China) until 16 weeks of storage for OP ribs and 17 weeks of storage for striploin samples. The ribs consistently gave a higher result than striploin throughout the study (Mahmoud and et al., 2020)

In another Australian study, grass-fed and grain-fed striploins were vacuum-packed and stored at -0.5°C. TVB-N was measured based on GB5009.228-2016. At 0 weeks the mean TVB-N was 5.0 mg/100g and at 14w 8.3 mg/100g. The modelled TVB-N for grass-fed beef was 6.1 and for grain-fed, 5.8 mg/100g. (Holman et al., 2022).

A study of beef frozen using traditional air chilling in China. Striploin pieces were frozen in a refrigerator to -18°C and then stored. The meat had a TVB-N of 8.8 at 0 days storage, which increased to about 12 at 30 days and 14.5 at 120days (Ren et al., 2021).

Another study conducted in China, froze beef striploin cubes (5cm) to different temperatures and stored them (Qian, Li, Wang, Sun, Zhang, Cuan, et al., 2018). A TVB-N value of 15 mg/100g was reached at 84 and 126 day at 6 °C and 9 °C, respectively. However, the TVB-N values of the samples stored at 12 °C and 18 °C remained below 15 mg/100 g even on day 168.

4.2 Techniques for thawing frozen meat

In case it needs to be said, thawing should always be performed on vacuum packed product in intact bags.

4.2.1 Techniques generally available

There are three techniques that are either common or could easily be applied in the China market:

- Thawing in air
- Thawing in water

- Thawing with fluctuating temperatures and high relative humidity

Thawing needs to continue until the centre of the product exceeds 0°C.

Air thawing would be conducted in a chiller operating in the range 2-4°C. The advantage of this method is that it utilises existing infrastructure. Primals should be placed on racks in such a way that air circulation is allowed on all surfaces. The use of fans to encourage air circulation assists the process.

Thawing in water can be more rapid than air, as water temperatures tend to be higher. Water needs to be circulating and changed frequently. The use of VP bags protects the product, but higher temperatures lead to faster thawing, which is undesirable.

Fluctuating temperature and high relative humidity (Li et al., 2014) was mentioned in the literature review. It is mentioned again here, because, though we didn't confirm that the method is being used by the businesses we met with, there is familiarity with the method. It is also worth mentioning here because it is relatively easy to implement.

4.2.2 Techniques implemented in some businesses

Despite the negative comments that are associated with the use of microwaves (uneven warming), one business did mention using an industrial microwave system from Spain, costing around 2million RMB. They experience quality issues with its use.

One business is about to install an electrostatic heating system from Japan. There are a few recent descriptions of this method (Du et al., 2024; Hu et al., 2025). Quoting Hu, high voltage electric field (HVEF), as a non-thermal thawing method, performs well in maintaining product quality The mechanism by which a high-voltage electrostatic field accelerates the thawing of ice is that the micro-energy generated by the high-voltage electrostatic field can accelerate the breaking of hydrogen bonds in the ice layer structure, causing the ice to exist in the form of small ice crystals, which then gradually transition to the liquid state of small molecule water. It is expensive.

4.2.3 Technologies in the pipeline

Im et al. (2024), notes that methods such as rapid freezing, high-pressure treatment freezing and thawing, electric field, ultrasonic treatment thawing, and adjusting the sequence of aging and freezing reduce the degradation of the quality of meat subjected to freezing or freeze-thawing. and Zhu et al. (2025) mentions that optimized solid state microwave thawing could avoid overheating, improve efficiency and reduce loss in water holding capacity. A search of the internet (Microsoft Co-pilot) suggests that the methods mentioned by Im et al. (2024) and Zhu et al. (2025) have not (yet) been taken up commercially.

4.3 Practices in the China market

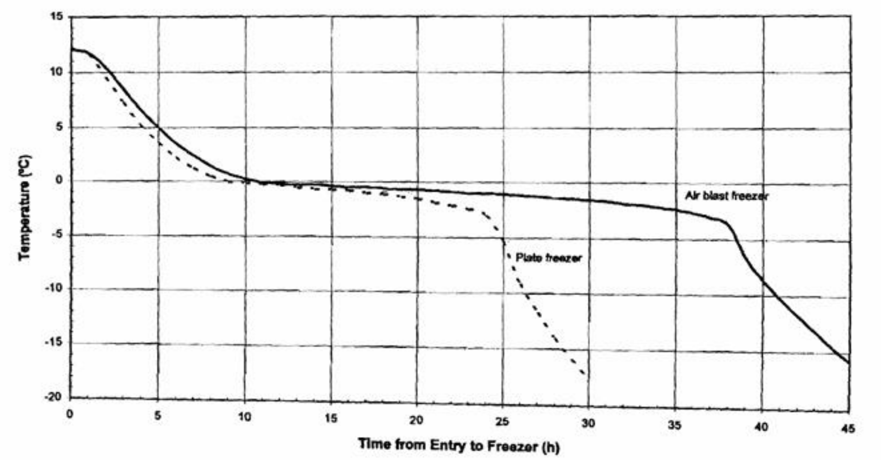
The report here is consolidated from the China market discussions (described in 3.2). Attempts were made to obtain as much detail as possible, consistent with maintaining a good relationship for ongoing work. As far as possible information, inferences etc. were confirmed through other discussions or observations. Uncertainties are expressed as clearly as possible.

Consistent with the note in the literature review pointing out the importance of freezing and thawing technologies together (Du et al., 2022), this description of practices starts with the freezing process in Australia.

4.3.1 Freezing in Australia

Whether the processing establishment uses a plate freezer or blast freezer, meat will likely spend several hours in the critical temperature range of -5 to -1°C, rather than half an hour to qualify as rapid freezing (Jeong et al., 2025) (Fig. 3).

Figure 3: Comparison of air blast freezing and plate freezing cooling rates (Graham, 1996)



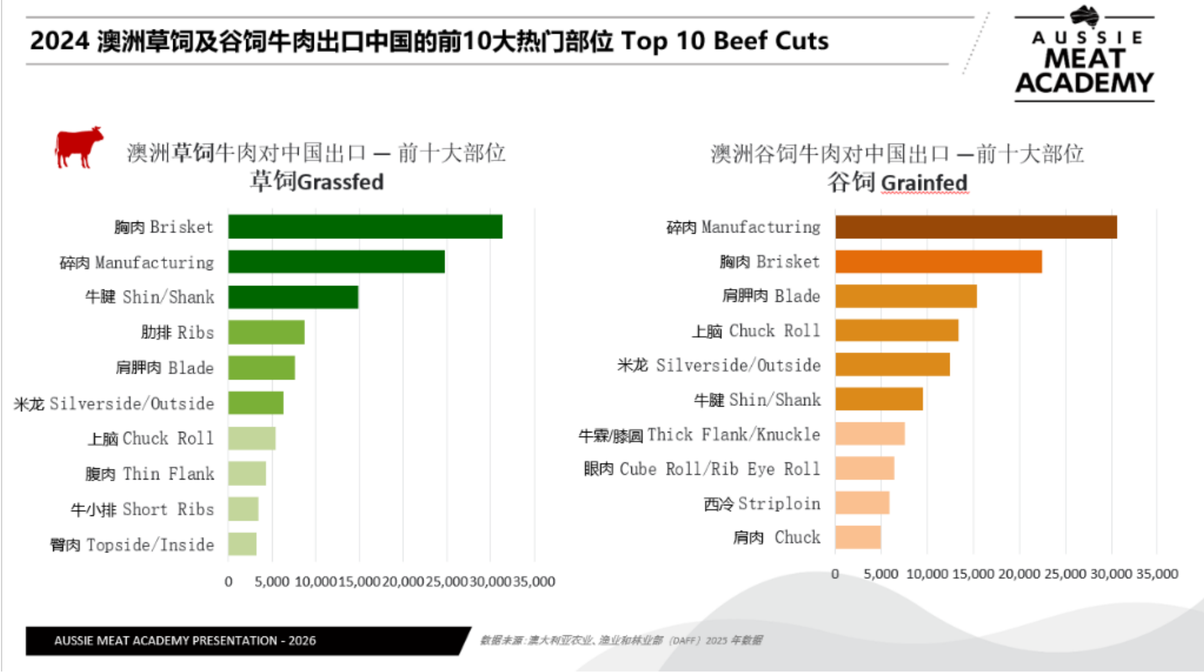
4.3.2 Products

The following figure (Fig.4) shows the volume of grass- and grain-fed beef exported to China in 2024 – both chilled and frozen. It becomes impossible to break these figures down to understand how much chilled (or frozen) product is sold through retail, the specifications of that product, and how much goes to high-end retailers and other prominent outlets.

Chilled beef does not penetrate further than Tier 1 and 2 cities.

High end retail is more likely to sell chilled, grain-fed beef.

Figure 4: Beef primal sales in China



4.3.3 Quality specifications

There are two important aspects of quality specification: Colour which is the signal to consumers that meat is fresh and good quality, and TVB-N which is a legal requirement. Both parameters must be met to keep product on the shelf and appealing to consumers.

Colour (bright red) was continually reported as a retail market expectation for in-person shopping (may not be so important for e-commerce). Drip loss was seen as an almost cosmetic issue with retail-ready packs. In retail visits excess drip was very rare; soaker pads are used and are adequate for the dripping that occurs.

The Chinese National Standard (GB 2707-2016) specification for TVB-N was continually mentioned by traders and processors, even if not by name. It was stated for example, 'there's a value that product has to meet.' 'We send for shelf life testing, and the 3rd party tells us how many days we can put on the label.' At this point in time, the random inspection reports released by the market supervision authority for products circulating in the market, do not reveal any imported beef products with excessive TVBN levels. Imported meat products are inspected at the border to ensure compliance with Chinese requirements and those selected for laboratory testing at the import entry stage will be examined for this indicator. Any products with non-compliant test results will be subject to return shipment or destruction, with the non-compliance reason recorded as filthy, putrid or deteriorated. Australian products have seen a small number of isolated cases of this kind in recent years.

Specifications from different retail chains are considered to be very similar to one another.

4.3.4 Supply chain

Beef is imported from Australia to importers/traders or sometimes the local office of the Australian exporter (examples of exporters with a chilled beef licence are listed in Appendix 9.1). Beef for retail may be delivered directly to the retailers who process the product for display in back-of-store operations (e.g., Sam's Club, Costco, City Super). Otherwise, product is shipped to processors who prepare retail ready product (e.g. TCT, Huadong, TenderPlus).

There don't appear to be any exclusive relationships, so there is no 1-1 correspondence between exporter, processor and retail chain; product from multiple exporters, and processors can be found in a retail store, even in those that process back-of-store will have some products prepared through a processor.

An example of the non-exclusive relationships in the supply chain, could be seen in the Aldi store visited. Mostly grain-fed (100-150 days) and some Wagyu, exported by O'Connor, Teys Beenleigh and JBS Riverina and processed by TenderPlus, Huadong (MAP) and TCT. Value-added products were also on the shelves (black pepper, onion/garlic and five spice). Not all the product was Australian; there was also domestic product, and product from other countries was relegated to an 'imported' section while Australia was signposted as Australian.

4.3.5 Thawing methods

None of the processors provided specific details of their thawing processes, and no meetings were held with retailers. In a project such as this, the willingness of supply chain participants to divulge their knowledge is a key constraint, however, enough can be gained to provide general guidance, which needs to be contextualised to the circumstances.

Thawing in air in a chiller, potentially for in excess of 48 hours (even 96 hours was mentioned for large primals) at 4°C seemed to be the common method. The use of microwave or electrostatic thawing was hardly mentioned. Slow thawing is important to minimise drip. Excess drip can shorten shelf life as the drip reacts with the meat.

One processor suggested that brisket and Oyster blade were good for thawing (perhaps because they are relatively thin and can warm more evenly than some other primals). Soaker pads are not usually added in primals for freezing but would be useful when product is thawed. Packaging film may be damaged when product is handled frozen and leaks may result.

Even with MAP, thawed product may only have a shelf life of 4-5 days. VSP shelf life may only be 2 weeks when thawed meat is used rather than 3 weeks. It was suggested that loin cuts may have 7d shelf life, but secondary cuts might only have 4-5d shelf life based on TVB-N limits.

Tempering to a low temperature prior to final thawing was mentioned. -5°C was mentioned. So was, tempering to -8°C with product still in the carton.

Presumably to meet commercial demand, product may be thawed up to several days before cutting.

Cutting and packing is conducted in a room at < 15°C. Product needs to be thawed; if product is cut at say -1°C there is more purge in the tray.

Concern was raised about how well frozen product might perform if it is older than currently used.

Product is often not refrigerated in the last step of transport to retail stores. Individual cartons are usually handled rather than being transported on pallets.

4.3.6 Retail product

Most beef was grain-fed, and usually for 100 days or more, with marbling a distinct selling point. Wagyu was not uncommon.

Most product was displayed in overwrap trays, but some was in MAP and some VSP. Some retailers also sold primals in their original vacuum pack. From casual observation, the temperature indicators on display cabinets were well below 4°C. There was a suggestion that grass-fed beef does not have as long retail shelf life.

Some retailers are using very short shelf life, presumably to maintain product appearance (red colour). Some product is needle tenderised but did not have observably more drip.

Value added products were reasonably common, often marinaded, with spices or seasoning. It is understood that value added products are not subject to TVB-N testing at retail, because they no longer sit within the scope of the GB2707-2016 standard.

The China team estimate that 60-70% of Australian chilled beef is sold through Sam's Club, which means that a lot of product is sold after back-of-store processing in overwrap packaging, with only 3 days 'best before'

4.4 TVB-N in-market survey of Australian frozen beef

The survey was designed to get an idea of the TVB-N of product in the market and available for use in retail-ready products. It was also an opportunity to make a preliminary test of hypotheses about differences between cuts, effect of age, effect of thawing etc. and to confirm the hygiene of Australian products. Since it was a survey of product in the marketplace conducted at a point in time, it was not sensitive to detecting small changes in TVB-N that might be observed if a single shipment of meat were tested repeatedly over a period of months.

The Aerobic Plate Count (APC) (Appendix 1), a measure of bacterial numbers and hygiene, in the sample collected on first opening the pack of frozen meat (sample A) was generally low (mean 3.06 $\log_{10}$, SD 1.22) indicating a high standard of hygiene, prompt freezing, and the product remaining frozen through its shelf life. Samples were not processed aseptically in the further processing operation but were collected with a high degree of care indicated by the very low count on the internal muscle samples (Sample B, APC 36/48, mean 2.01 $\log_{10}$ SD 0.68). There was essentially no increase in APC on the surface of the meat between the beginning (sample A) and end of the thawing process (Sample C. mean difference between samples A and C: 0.05 for APC 36/48 and 0.02 for APC 25/96).

The TVB-N data across all 18 meat pieces and 3 samples per meat piece (Appendix 1) display two trends. One is that two TVB-N results may differ significantly even though a significant difference may not be expected. The other is that TVB-N results were not greatly affected by time elapsed since processing.

The range of differences in TVB-N on individual pieces during thawing (sample C – sample A) is relatively large both increasing and decreasing (range -2.79 to 2.13). On average, the TVB-N results, like the APC results, show little increase during the thawing process (average sample C-sample A -0.12). An explanation for why post-thawing TVB-N would be almost 2-3 mg/100g different to the frozen sample from the same piece of meat is not easily explained, especially when the TVB-N has decreased between the frozen and thawed samples. The TVB-N result reported by the laboratory is the average of duplicate determinations (repeating the entire analytical procedure) that are different by only a small amount (results not shown). This raises the hypothesis that the result is sensitive to the piece of meat selected for analysis. For analysis skin, fat, bones, tendons are removed so that 10.0g of lean meat is used for analysis. The absolute difference between the results of two parallel determinations on the same sample must not exceed 10% of the mean. Multiple subsamples would need to be tested in parallel to find out how much variation in results the sampling / analytical method contribute to the variation seen in the results presented here. The internal sample (Sample B) had an average result slightly higher than the A and C samples (average 0.12 and 0.51 greater respectively). These results suggest that the development of TVB-N in these samples is not affected by TVB-N generating activity on the surface of the meat. Since bacteria are found only on the surface of the meat pieces, it suggests that microbial enzymes do not contribute to the development of TVB-N in Australian frozen cuts with excellent hygienic quality.

The increase in TVB-N over time suggests that time only has a small effect (Fig. 5, Fig. 6). The literature on TVB-N during storage (4.1.2) suggests that TVB-N either increases more rapidly (Qian, Li, Wang, Sun, Zhang, Guan, et al., 2018; Ren et al., 2021) or that the Australian beef has a lower TVB-N at the time of packing and freezing (Frank et al., 2020; Holman et al., 2022) or both, compared to these data. To generalise, based on the distribution of results at each point in time, the TVB-N of frozen beef up to 140 days after processing can be expected to be less than 8.8 mg/100g. Even up to 170-200 days after processing the TVB-N will not frequently be greater than 9.5 mg/100g.

After thawing, on average, the TVB-N results, showed little increase (average sample C-sample A - 0.12). The range of differences in TVB-N on individual pieces during thawing (sample C – sample A) is relatively large both increasing and decreasing (range -2.79 to 2.13). There is no obvious explanation why the TVB-N would decrease during thawing.

Figure 5: Total volatile basic nitrogen (TVB-N) concentration in frozen beef (surface samples) of various cuts from various processors against the time since processing.

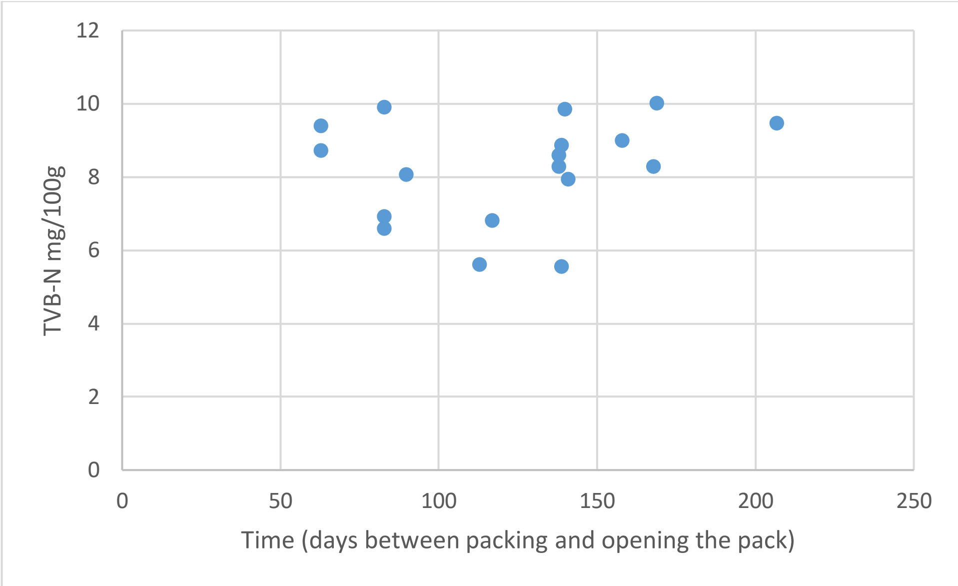
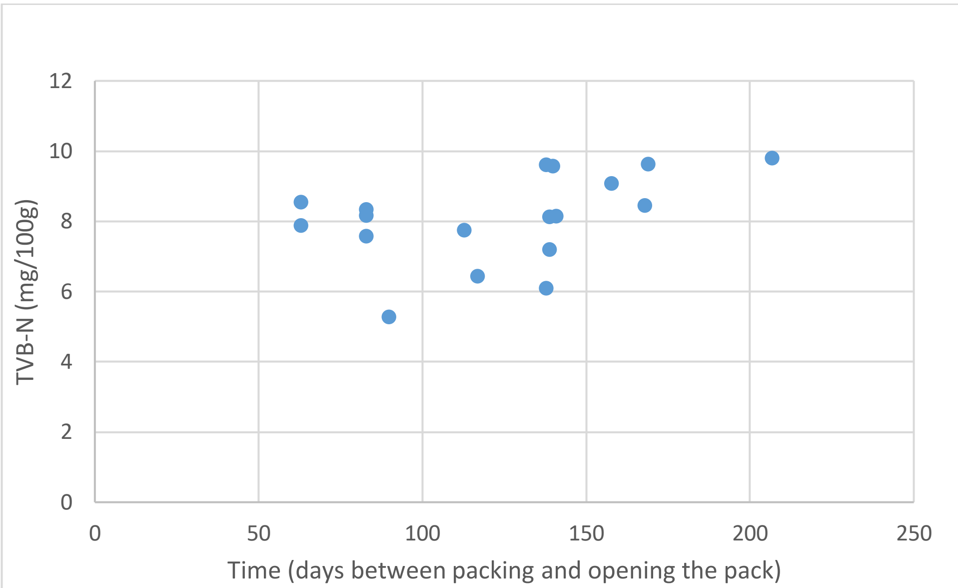


Figure 6: Total volatile basic nitrogen (TVB-N) concentration in thawed beef (surface samples) of various cuts from various processors against the time since processing.



The good news from these results is that none of them approach the limit of 15mg/100g, and only a few reach the anecdotal limit of suitability for retail packs of 10 mg/100g.

4.5 Protocol for frozen-thawed beef for retail sale

The following is a general protocol and advice for taking Australian frozen beef and thawing it for retail display. It is written as a general guide. Each value chain must develop their own process specifications, including product specifications, that are validated to meet customer requirements and are regularly verified

Australian frozen beef

Australian beef is processed under strict hygienic conditions and with consistently excellent eating quality and relatively low bacterial count. While no single technique exists that can mitigate all the quality challenges caused by freezing and thawing, this protocol suggests ways that quality challenges can be minimised.

Transport and storage

Frozen beef is stored and transported at -18°C. It is best to keep frozen beef as close to this temperature as possible; increases and decreases in storage temperature should be avoided.

The 'danger zone' for damage to the structure of beef muscle during thawing is from around -6°C to 0°C. If, for some reason, frozen beef should reach these temperatures, it should be completely thawed and processed for some application other than retail, such as foodservice, or immediate cooking.

Selecting product for thawing

The quality of beef for retail display prepared from frozen will reduce the longer the beef is stored. If beef that has been frozen for a long time is being used the colour can be expected to deteriorate more quickly than beef that has been frozen for a short time. The TVB-N of frozen beef up to 140 days after processing can be expected to be less than 8.8 mg/100g. Even up to 170-200 days after processing the TVB-N will not frequently be greater than 9.5 mg/100g.*

Older frozen beef might be more suitable for use in value added products with marinades, spices or seasonings that make colour deterioration less obvious. Value added products made from older frozen beef will still have good eating quality.

Thawing method

Tempering - Optionally, **frozen beef may be left in the carton and tempered over a period of several days to -8°C.** This temperature is below the 'danger zone' (from around -6°C to 0°C). It will take less time to complete the thawing of this product when it is required. Product can be held at this temperature for days – weeks and should not be returned to -18°C.

Thawing – **The most common method of thawing is to place vacuum-packed primals on racks in a cold room at 4-6°C with good air circulation until the whole primal is greater than 0°C**. Cutting the primal when parts are at a lower temperature will increase the amount of drip. **Care needs to be taken not to damage the vacuum packaging** as this will lead to drip from the meat contaminating surfaces in the cool room, and bacteria will more easily grow on the surface of the primal. **Thawing at 4°C for 24 hours is not expected to increase the TVB-N value.***

Another method, pioneered in China is to use fluctuating temperature and high relative humidity. This method appears to be more suitable than the method described above and seems relatively easy to implement with the assistance of refrigeration engineers.

There are some technological approaches to thawing meat, but these are expensive and not widely available. Before using any technology, the process must be validated to be effective and result in product of the required quality.

As far as possible, beef should be thawed only when required. It is undesirable to leave thawed beef for several days before processing it for retail sale.

Packaging

Processors should consider using larger or more efficient soaker pads when preparing thawed meat for retail sale.

Modified Atmosphere Packaging (MAP) may be more suitable for thawed beef because it is likely to retain its colour for longer under a typical 20% CO_2 / 80% O_2 mix.

Transport and storage

Beef packed for retail should be transported and stored at between 0 and 2°C as far as possible to maximise the shelf life. It is undesirable for the temperature to fluctuate once thawed.

Quality

Colour is a property that is difficult to manage in thawed beef. Keeping the temperature of display cabinets as low as possible (that is, close to 0°C) will assist in retaining colour. Educating consumers that the product retains its eating quality even if the red colour is less intense is another approach.

The factors that cause increases in TVB-N values as frozen beef moves through these supply chains has not been studied.

Shelf life

The shelf life will be shorter than for the same product that was not frozen and thawed. Loin cuts may have a longer shelf life (based on TVB-N) than secondary cuts. Beef frozen for a longer time will have a shorter shelf life than beef frozen for a shorter time.

** TVB-N Testing. TVB-N values for pieces of meat from a single vacuum-pack as received from the importer may vary significantly. If you decide to use TVB-N testing to decide how frozen meat will be used for retail-ready packs, then we would advise testing several samples so that an accurate understanding of the suitability for use can be obtained.*

4.6 Validity of the Protocol

The protocol was translated and provided to the three further processors with whom initial interviews were conducted (4.3.5). Two responded to the invitation to comment, both having nothing to add to the advice given.

5. Conclusion

A protocol for the thawing of frozen Australian beef for the purpose of retail sale was developed based on an understanding of the scientific literature, practices in the Chinese market, consumer-oriented and regulatory definitions of shelf life, and the potential for regulatory non-compliance at retail when using frozen Australian beef.

The protocol provides good general advice, but more specific advice, based on further knowledge may further improve the shelf life of frozen product for retail display.

5.1 Key findings

- The Chinese market has experience in thawing frozen meat for retail use/display and conducts research in this area.
- Thawing of frozen beef for retail display will not achieve the same standards as beef that was always chilled.

- Some practices employed by further processors in China might be below the standard required to ensure customer and regulatory acceptance at the end of the usual retail shelf life.
- Meat colour is likely to be the parameter that signals the end of shelf life from the consumer viewpoint. TVB-N will signal the regulatory end of shelf life.
- TVB-N appears to be acceptable in frozen Australian beef even after 6 months frozen storage
- The thawing conditions, time taken to thaw, and the temperature of product over the time taken to prepare into retail product and place on retail display, may all affect the quality of product (colour and TVB-N). The logistics of this part of the supply chain are critical to placing product on retail display with a long shelf life.

5.2 Benefits to industry

The Australian industry can demonstrate to customers in China, and the subsequent businesses in the supply chain (through to retail), that it is committed to supporting the sector when it is faced with technical issues.

The protocol, appropriately translated and identified as an MLA publication, can assist the Chinese part of the supply chain to work cooperatively to ensure that the

6. Future research and recommendations

This report was prepared in the first of three year period of safeguard tariffs. It is not possible to predict whether there may be changes to the system in the coming two years, let alone whether this regime may continue long term.

The protocol (4.5) should be translated and appropriately identified as an MLA publication and be provided to the supply chain (Australian exporters, importers, traders, further processors, retailers) as advice and demonstration of support. Providing the whole protocol to every participating link in the supply chain emphasises that issues such as this need to be addressed by cooperation through the whole supply chain.

The Greater China office of MLA should be alert to the implementation of the protocol by the supply chain (particularly close to retail) and evaluate how well it meets market requirements. Early assessments will alert MLA to the need to tweak the protocol or conduct more extensive work than was conducted within the scope of this current project.

If further work is required, consideration should be given to conducting the work in concert with research institutes or universities in China who are already active in this area.

A greater understanding of TVB-N, how it is formed, and its validity as a marker of technical or consumer-perceived quality should be further investigated.

Consideration should be given to extending the current MLA (predictive) shelf life models to understand how frozen storage time may impact on shelf life parameters at retail.

It is understood that the Meat Standards Australia methodology is being expanded to allow for a freeze-thaw option in predicting eating quality outcomes. It is recommended that attention be paid to the colour of meat and its maintenance in retail packaging.

7. References

An, Y., Wang, Q., Lu, P., Liu, Y., Gao, S., Fowler, S., Liang, R., Zhu, L., Wang, W., Zhang, Y., 2025. Characterization and identification of frozen-thawed beef: the interactions of frozen storage and chilled display time. Food Science of Animal Products 3, 9240098.

Barlow, R., McMillan, K., Stark, J., 2016. The effect of purge on the shelf life of vacuum packaged chilled meat. Meat & Livestock Australia Report G.MFS.0313.

Çalışkan Koç, G., Özkan Karabacak, A., Süfer, Ö., Adal, S., Çelebi, Y., Delikanlı Kıyak, B., Öztekin, S., 2025. Thawing frozen foods: A comparative review of traditional and innovative methods. Comprehensive Reviews in Food Science and Food Safety 24, e70136.

Du, J., Wei, J., Wang, L., Lin, Y., Kuang, J., Wang, Y., 2024. Effect of Combined High-Voltage Electrostatic Field-Ozone Thawing on Quality Characteristics of Frozen Pork. Meat Research 38, 43-50.

Du, X., Wang, B., Li, H., Liu, H., Shi, S., Feng, J., Pan, N., Xia, X., 2022. Research progress on quality deterioration mechanism and control technology of frozen muscle foods. Comprehensive Reviews in Food Science and Food Safety 21, 4812-4846.

Frank, D., Hughes, J., Piyasiri, U., Zhang, Y., Kaur, M., Li, Y., Mellor, G., Stark, J., 2020. Volatile and non-volatile metabolite changes in 140-day stored vacuum packaged chilled beef and potential shelf life markers. Meat Science 161, 108016.

Frank, D., Zhang, Y., Li, Y., Luo, X., Chen, X., Kaur, M., Mellor, G., Stark, J., Hughes, J., 2019. Shelf life extension of vacuum packaged chilled beef in the Chinese supply chain. A feasibility study. Meat Science 153, 135-143.

Gee, A., 2006a. Protocol Book 3 Fabricating, freezing & storage of taste test samples of Beef forMSA pathway trials. Grill, Roast, Stir Fry, Thin Slice, Yakiniku, Korean BBQ, Carrerole, Corn, Shabu Shabu, version 5.1 ed. Meat & Livestock Australia, [North Sydney].

Gee, A., 2006b. Protocol Book 4 for the thawing, preparation, cooking & serving of beef doe MSA pathway trials. Grill, Roast, Stir Fry, Thin Slice, Yakiniku, Korean BBQ, Carrerole, Corn, Shabu Shabu, version 5.1 ed. Meat & Livestock Australia, [North Sydney].

Graham, A., 1996. Consideration of relative advantages of small capacity plate and air blast freezers for the freezing of cartoned meat., Meat Research Report. Australian Meat Technology Acacia Ridge.

Holman, B.W.B., Bekhit, A.E.-D.A., Mao, Y., Zhang, Y., Hopkins, D.L., 2022. The effect of wet ageing duration (up to 14 weeks) on the quality and shelf-life of grass and grain-fed beef. Meat Science 193, 108928.

Hopkins, D.L., Holman, B.W.B., Bekhit, A.E.-D.A., Giteru, S.G., 2020. Total volatile basic nitrogen in meat products: occurrence, method of determination and use as a freshness indicator. Australian Meat Processor Corporation Report

Hu, R., Zhang, M., Qiao, J., Mujumdar, A.S., Lei, C., 2025. High Voltage Electrostatic Field (HVEF) Based Advanced Thawing: Effects of Thawing Process and Frozen Raw Meat Quality. Food and Bioprocess Technology 18, 7502-7517.

Im, C., Song, S., Cheng, H., Park, J., Kim, G.-D., 2024. Assessing Individual Muscle Characteristics to Enhance Frozen-Thawed Meat QUality. Food Science of Animal Resources 44, 758-778.

James, C., James, S.J., Purnell, G., Talbot, L., Hebishy, E., Bowers, S., Onarinde, B.A., Huynh, L., Jenson, I., 2025. The practical storage life of Australian frozen boxed beef and lamb. International Journal of Refrigeration 171, 51-65.

Jeong, S.-K.-C., Jo, K., Lee, S., Jeon, H., Kim, S., Han, S., Woo, M., Choi, Y.-S., Jung, S., 2025. Changes in the Properties of Frozen Meat with Freezing and Storage Conditions and Non-Destructive Analyses for Monitoring Meat Quality. Food Science of Animal Resources 45, 711-726.

Li, Y., Jia, W., Zhang, C.H., Li, X., Wang, J.Z., Zhang, D.Q., Mu, G.F., 2014. Fluctuated Low Temperature Combined with High-Humidity Thawing to Reduce Physicochemical Quality Deterioration of Beef. Food and Bioprocess Technology 7, 3370-3380.

Mahmoud, A.H., et al., 2020. Australian beef shelf life verification trial. Meat & Livestock Australia Report V.MFS.0438.

Pan, X., Zhang, S., Li, S., Zhao, B., Zhou, H., QIAO, X., Chen, W., Li, J., Qu, C., 2019. Effect of different relative humidities on thawing efficiency and quality sharacteristics of frozen beef. Meat Research 33, 25-29.

Qian, S., Li, X., Wang, H., Sun, Z., Zhang, C., Cuan, W., Blecker, C., 2018. Effect of sub-freezing storage (-6, -9 and -12 ^{O}C) on quality and shelf life of beef. International Journal of Food Science & Technology 53, 2129-2140.

Qian, S., Li, X., Wang, H., Sun, Z., Zhang, C., Guan, W., Blecker, C., 2018. Effect of sub-freezing storage (−6, −9 and −12 °C) on quality and shelf life of beef. International Journal of Food Science & Technology 53, 2129-2140.

Ren, W., Yuan, G., Lin, X., Guo, X., Wang, Z., 2021. Comparison of the immersion chilling and freezing and traditional air freezing on the quality of beef during storage. Food Science & Nutrition 9, 6653-6661.

Zhang, R., Realini, C.E., Kim, Y.H.B., Farouk, M.M., 2023. Challenges and processing strategies to produce high quality frozen meat. Meat Science 205, 109311.

Zhu, J., Zhu, Y., Li, H., Fu, C., Yin, W., Li, C., 2025. Thawing methods affect quality properties and protein denaturation of frozen beef. Food Chemistry 476, 143484.

8. Appendix

8.1 Total volatile basic nitrogen (TVB-N) during storage and thawing beef

Commercial objective

Collect and test samples that will provide assurance to the supply chain about the suitability of Australian frozen beef for preparing products for retail sale.

Samples

All samples are primals in original VP

Variables:

Fat level – just one level for all samples - levels most common in the market (low level grain-fed)

Cuts (choose small ones (at least 3 kg?) to minimise cost and thawing times but thawing process still needs to be realistic)

- Forequarter – oyster blade, chuck roll
- Loin -- strip loin, cube roll,

- Hindquarter -- knuckle, top side

Processor

- As many processors as far as EASILY possible
- different processors for each cut

Age since killing (approximately) as spread out as possible in age

- 2 month post slaughter (on or close to arrival)
- 4 months post slaughter
- 6 months post slaughter

Example of sample 'sets' for loin:

Teys 100 day grain fed cuberoll 35, 60 and 122 days post slaughter

O'Connors grain-fed striploin 30,55 and 115 days post slaughter

Number of samples to collect

1 feeding (fat) level x 3 carcase sites (forequarter, loin, hindquarter) x 2 processing establishments x 3 times (age of product since killing)

= 18 primal samples

Collection of samples

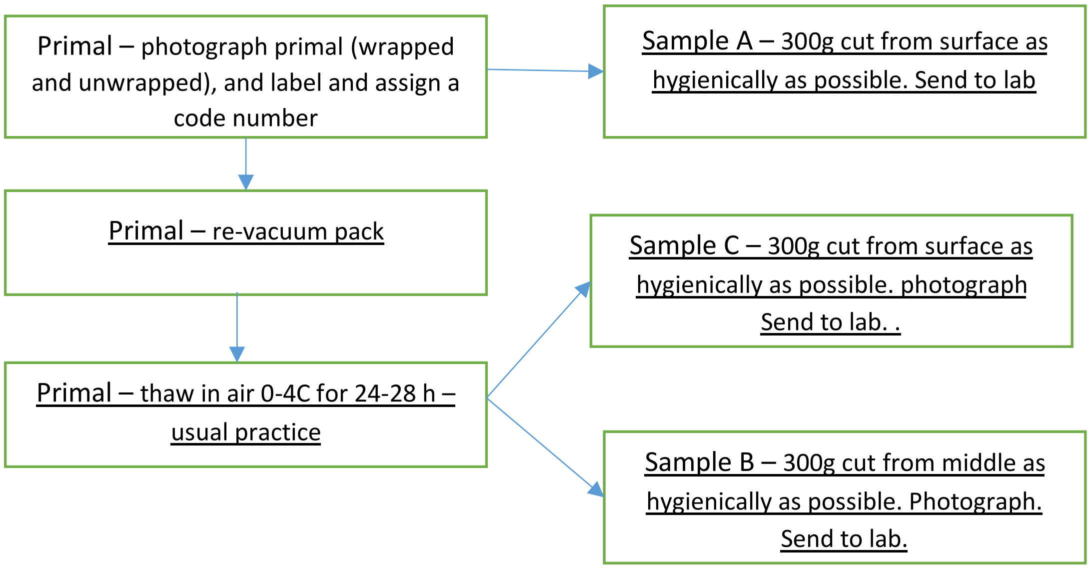
Collect samples from importers and/or processors

Collect the 3 times (age of product) per primal from the same processing establishment (as above examples)

Collect whole primals, in vacuum packing, with legible label (photograph the label). Preferably also collect (or photograph) carton label.

Samples to be kept at -18°C and processed promptly.

Processing of samples



1. Before cutting, disinfect the cutting tools with 85% ethanol by dipping and allowing the ethanol to evaporate (or burning)

2. Photograph the primal label and the primal itself and assign a code to the primal.

3. Remove 300g surface sample of primal as hygienically as possible into a sterile sample jar or bagfreeze and when the other samples are being collectedfrom the primal, this sample can be thawed. Label with a code) to indicate the source of the sample (No. column in the sample sheet) plus letter A.

Surface samples should be taken no deeper than 1 cm below the surface. Samples can be cut with a bandsaw and leaving the original bag in place. Samples for microbiological testing can be taken from the side with the original bag in place.

4. Vacuum-seal the meat piece remaining . Thaw in air at 0-4°C with air circulation (or similar commonly-used procedure) for 24-48 h (or similar commonly used procedure). Describe procedure in full. The thawing method should be the same for all samples of the same cut.

5. Central sample: 300g Take the centrel portion of the meat block. When dividing it, remove the edges as hygienically as possible into a sterile sample jar or bag. Keep on ice and send to the laboratory promptly. Label with a code to indicate the source of the sample plus letter B.

6. Remove 300g surface sample of primal as hygienically as possible into a sterile sample jar or bag. Keep on ice and send to the laboratory promptly. Label with a code to indicate the source of the sample plus letter C.

Surface samples should be taken no deeper than 1 cm below the surface.

7. The samples mentioned above must be marked with fixed identification numbers, with a uniform numbering sequence:

A represents the **before** thawing;

B represents the **central** portion **after** thawing;

C represents the **surface after** thawing.

So, 3 samples per primal sample = 3 (2 time points, 1xsurface frozen, then surface thawed and 1x internal thawed) x 18 primals = 54 laboratory samples

Laboratory testing

We will provide 300g samples in a sterile sampling jar or bag, transported on ice.

Samples to be tested promptly on arrival at the laboratory

Describe meat according to the sensory requirements of GB 2707-2016 clause 3.2

Determine TVB-N according to GB 5009.228

Determine the Aerobic Plate Count according to GB 4789.1-2022 except that two sets of dilutions should be plated (step 6.1.5); one set incubated at 36°C for 48 hours and the other set at 25°C for 96 hours (4 days). Samples for microbiological testing can be taken from the side with the original bag in place, where possible.

Provide a report of results for each sample.

Results

processor	cut	Age (days)	TVB-N (mg/100g) A	B	C	$\log_{10}$ bacterial count /g (36°C/48h) A	B	C	$\log_{10}$ bacterial count /g (25°C/96h) A	B	C
1	Chuck Roll	83	6.58	6.98	7.56	2.92	1.95	3.56	3.28	2.52	4.26
1	Chuck Roll	138	8.58	11.2	9.61	4.54	2.08	2.59	4.59	2.95	3.11
1	Chuck Roll	158	8.99	9.2	9.07	3.30	2.52	2.38	4.15	2.93	2.74
1	Knuckle	63	8.72	8.4	8.53	2.41	2.04	2.63	2.66	2.18	3.15
1	Knuckle	138	8.27	9.43	6.08	2.76	2.95	3.08	3.04	3.32	4.80
1	Knuckle	207	9.46	8.88	9.8	2.46	2.20	3.65	3.34	2.83	3.18
2	Chuck Roll	63	9.39	8.84	7.87	3.04	1.78	3.15	3.58	1.85	3.56
2	Chuck Roll	139	5.54	5.54	7.18	2.77	1.70	2.68	3.00	1.30	2.80
2	Chuck Roll	168	8.28	9.34	8.44	3.15	1.00	3.08	3.38	1.48	3.28
2	Knuckle	83	9.89	9.76	8.33	2.20	1.60	1.78	2.94	1.95	2.36
2	Knuckle	140	9.85	9.76	9.56	2.23	1.48	1.48	2.76	2.04	2.41
2	Knuckle	169	10	9.2	9.62	1.30	1.30	2.20	1.78	1.78	2.70
3	Cube Roll	83	6.92	8.5	8.16	3.26	1.28	2.90	3.53	3.28	3.56
3	Cube Roll	113	5.61	7.7	7.74	2.57	1.30	2.36	3.15	1.90	2.89
3	Cube Roll	141	7.93	8.44	8.14	2.04	1.78	2.43	3.30	2.26	2.83
4	Cube Roll	90	8.06	7.48	5.27	6.65	3.75	6.72	6.38	4.08	6.53
4	Cube Roll	117	6.8	8.48	6.42	4.83	2.72	4.38	4.91	3.08	4.63
4	Cube Roll	139	8.86	7.65	8.12	2.63	2.51	3.08	3.08	2.75	3.75