Final Report

# Rapid Chill technology evaluation,

## Phase 1: Evaluate and understand the pH temperature decline and value proposition of the Rapid Chill system

Project code

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Prepared by

M. Panuccio (FreshXpress)

K. Bryan & J. Teese (Greenleaf Enterprises)

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# 1.0 Abstract

Australian meat processors are looking for solutions to (1) reduce electricity usage, (2) increase throughput numbers of chilled carcases, (3) reduce pressure on existing carcase chiller space and (4) better utilise existing freezing capacities. The Rapid Chill system removes these bottlenecks without the use of nitrogen, ammonia glycol or liquid carbon dioxide. The modular system is a stand-alone unit that can be added to an existing processing plant facility. This research trial was undertaken in a retrofitted fruit chilling system to enable meat science data to be collected on lamb carcases. University of New England (UNE) research scientists investigated the impact of the Rapid Chill system on shear force, carcase temperature decline and ultimate pH. The trials showed the loin was below 0°C in less than 5 hours, which is the window identified in literature as necessary to avoid cold shortening (toughening) the meat. The results showed no difference in ultimate pH and meat colour. The loin *longissimus lumborum (LL)* had a lower shear force than the control group, noting there was a carcase weight interaction on shear force. The ex-ante value proposition identified the direct benefits that could be delivered to processors using a Rapid Chill system from an energy saving and efficiency gain perspective. There was a $6.42/hd gain and a payback period of 1.37 years for a plant processing 3,600 smallstock per day with a split of 80% lamb and 20% mutton. A commercial small stock installation is required to test and validate the overall value proposition for processing plants, which would enable existing carcase chillers to be used as buffer and storage zones after the Rapid Chill system removes the initial heat from the carcase.

# 2.0 Executive summary

From more than 20 years of research, FreshXpress have developed and refined a modular chilling system which rapidly chills fruit while retaining moisture and product integrity. The red meat processing sector is looking for solutions to reduce energy usage, improve processing plant efficiencies, increase throughput numbers of chilled carcases and reduce pressure on existing carcase chiller space while removing the need for carbon dioxide, nitrogen, and glycol to run their chilling systems.

A trial using 6 lamb carcases in 2007 identified there is an opportunity for application to the red meat industry using the Rapid Chill system (Jacob & Beatty 2007). To proceed to a commercialisation phase, the meat quality implications (pHu and shear force) needed rigorous assessment, as well as the potential benefits identified and validated for smallstock processing plants. This assessment was independently undertaken by the University of New England (UNE) with a control group of 23 carcases and a treatment group of 24 carcases. Eating quality traits were analysed comparing the control with the Rapid Chill treatment group.

**The project's purpose** was to validate the claim: The use of the Rapid Chill System can avoid cold shortening through carcases hitting 0°C in <5 hours post-mortem across the entire carcase.

To understand the financial and business implications from a smallstock processor's perspective, a business case analysis was undertaken modelling the impact of increasing carcase throughput and reducing carcase shrink compared to conventional chillers with and without the use of spray chilling.

The findings of the research are relevant for processing plants who are constrained in their chiller space and or have bottlenecks in their freezing capacity. The Rapid Chill system allows smallstock carcases to be chilled to <4°C before cutting and packing, reducing freezing time, which is relevant for mutton and goat products. Product sold as whole chilled carcases can be loaded out the same day, in theory, increasing the number of head which can be processed per day if chilling carcases is the throughput bottleneck.

The objectives included:

- Retro fit a fruit Rapid Chill system to enable the carcase chilling trial
- Validate the ability of the Rapid Chill system to chill lamb carcases in under 5 hours
- Determine the impact of using the Rapid Chill system on carcase attributes including shelf life, shear force, cold shortening (temperature and pH decline) and sarcomeres compared to conventional chilling regimes.
- Develop a commercialisation plan to help facilitate industry adoption which includes financing options, value propositions and a Benefit Cost Analysis for large and medium lamb and mutton processing plants.

The project objectives were achieved.

Methodology

A Rapid Chill tunnel was retrofitted to enable lamb carcase trials to be undertaken. 46 lamb carcases with a wide weight range were paired by Hot Carcase Weight and allocated to either the treatment or control group. Carcase temperature decline was analysed as well as pH and the meat colour and shear force for three cuts longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB). The cold carcase weight (CCW) was taken to calculate the shrink loss. Purge % and drip loss % of the samples at day 3 and 5 were measured.

The financial implications for Rapid Chill were modelled for (1) a lamb processing plant (80% lamb:20% mutton) and (2) mutton processing plant (80% mutton:20% lamb).

Key findings

- The retrofitted fruit tunnel which has 1/5$^{th}$ the planned cooling capacity of a commercial unit was able to reduce the carcase temperature of the loin to <4°C in less than 2 hours and the bolar blade in less than 4 hours.
- There was no detrimental impact on shear force for the loin by using Rapid Chill, with a reduced shear force compared to the control group.
- There is a $6.42/head benefit for a lamb plant if they aren't spray chilling due to increased throughput, reduction in chilling costs and reduced carcase shrink.

Benefits to industry

- Demonstration of the commercial opportunities for use of the Rapid Chill system by smallstock processing plants for carcase chilling.
- Validation eating quality is not unduly impacted (cold shortened) by the Rapid Chill system.

Future research and recommendations

- Installation of a commercial prototype to enable system parameters (temperature decline and time required in the Rapid Chill system) to be tested by carcase weight, fat coverage and animal type.
- Boxed product for example trim, offal and primals being chilled through the Rapid Chill system and analysing impact on temperature decline, shelf life and product quality.
- Investigation on the modifications and carcase chilling parameters required for use by beef processing plants to avoid cold shortening product.

# 3.0 Introduction

Traditional carcase chilling requires carcases to hang in chillers for 12-24 hours to decrease the carcase temperature to less than 8°C. This conventional carcase chilling system requires considerable space and has high energy draw. A very fast chilling system (Rapid Chill) currently used in fresh produce, which has not yet been applied to the meat sector, shows potential for application to red meat. Very fast chilling (VFC) or rapid chilling of red meat products can avoid cold shortening, improve meat quality and yield plus potentially reduce microbial counts. Fresh Xpress have been working for the last two years on developing an R&D trial unit to test VFC red meat carcase cooling. Potential benefits of using VFC include:

- Reduced energy usage,
- Improved processing plant efficiencies,
- Improved carcase yields,
- Improved meat quality, and
- Reduced chiller footprint at plant.

Other fast chilling technology exists; however it fails to consistently bring carcase temperatures to 0°C in < 5 hours post-mortem across the carcase with uneven cold-shortening of muscle. Fresh Xpress' technology is unique in that there are independent chambers where refrigeration specifications (air flow and air temperature) can be adjusted as required to bring carcase temperature to 0°C in < 5 hours post-mortem.

This project tested rapid chilling on lamb carcases. The University of New England (UNE) research scientists investigated the hypothesis:

This technology can avoid cold shortening through carcases hitting 0°C in <5 hours post-mortem across the entire carcase.

Using an existing facility, it was retrofitted to enable UNE researchers to evaluate the impact on carcase quality, including shear force and cold shortening incidence. The pHu and carcase temperature decline were measured. A demonstration was undertaken to showcase the technology to multiple stakeholders with the intention to design and build an operational prototype to test as a commercial trial.

A business plan and commercialisation strategy for Fresh Xpress was developed to move from an early R&D phase to prototype development, adoption and investment. A Business Case Analysis (BCA) for processing plants to understand ROI, profitability, business process and carbon footprint impacts was undertaken as part of the project.

# 4.0 Project objectives

The project objectives were:

- Retro fit fruit Industry rapid chilling module.
- Validate Fresh Xpress's ability to rapidly chill carcases in under 5 hours.
- Determine the impact Fresh Xpress has on carcase attributes including shelf life, shear force, cold shortening (temperature and pH decline) sarcomeres compared to conventional chilling regimes.
- Develop a commercialisation plan to facilitate industry adoption which includes BCA, ROI, automation requirements, pricing and service contract.

The project objectives were achieved.

# 5.0 Methodology

## 5.1 Retro-fitting fruit industry rapid chilling tunnel

Engineering works and modifications were undertaken on an existing Rapid Chill system built by FreshXpress for chilling grapes to enable meat science trials to be undertaken using lamb carcases.

## 5.2 Meat science testing

The meat science testing component of the work was conducted by the University of New England (UNE) and supported by New South Wales Department of Primary Industries and Regional Development (DPIRD). Lamb carcases of varying weight and fatness were utilised as per the project design to test the upper and lower limits and the impact on shear force and temperature decline on carcase weight and fatness.

### 5.2.1 Collection and measurement description

On completion of the upgrades to the fruit tunnel to a red meat prototype tunnel, FreshXpress completed some initial testing of 3 lamb carcases to ensure that the tunnel performed as expected, showing the temperature drop of the carcases in under 1.5 hours. Once these tests have been completed, UNE (P. McGilchrist), Greenleaf Enterprises (K. Bryan) and NSW DPIRD (B. Holman) were engaged to complete the meat science and industry value proposition work.

The experimental lambs were slaughtered at Mildura Abattoir (47 Gordon Ave, Mildura VIC 3500, Australia) on 17/09/2024 (25 head) and 18/09/2024 (22 head). After dressing, a hot carcass weight (HCW) was recorded. The carcasses were transported to Fresh Xpress facility in a fridge container truck. At the FreshXpress facility, the carcasses were divided into blocks of two based on their similar HCW, then randomly allocated into either conventional group (Con) or Rapid Chill treatment group (Fast). pH and temperature at *longissimus lumborum* (LL) and *semimembranosus* (SM) muscle were recorded, carcases were weighed again and temperature probes placed in the deep butt, loin and shoulder muscles.

The carcasses in the Fast group were placed in the fruit chiller for 5 hours under Rapid Chill regime. During fast chilling period, they were moved to different places in the chamber to make sure all of them exposed to the same temperature decline regime. After that, they were transferred to a conventional chiller for 19 hours. Meanwhile, the

Con carcases were chilled in a conventional chiller for 24 hours. The pH of short loins was measured hourly for the first 5 hours post-mortem.

At 24 hours post-mortem, cold carcase weight (CCW) of the whole carcases were recorded to determine carcase weight loss. The pH, temperature and GR fat depth (at 110mm from the midline over the 12th rib) were also measured. The carcases were boned out in the same chiller at 2-4 ̊C and muscles (*longissimus lumborum* (LL), *semimembranosus* (SM) and *triceps brachii* (TB) from 3 primal (short loin, topside and bolar blade, respectively) of each carcase were sampled. These samples were bloomed for 30 minutes and meat colour (L*, a*, b*) was measured using a Minolta Chromameter Model CR-400. Then they were packed separately in a plastic vacuum bag, transported to the UNE Meat Science lab and stored at 1.0°C and aged in a chiller until further analysis was undertaken.

At 3 days post-mortem, a set of LL and SM samples were frozen for a three-day-ageing shear force measurement.

On 5 days post-mortem, ultimate pH and temperature, meat colour and purge loss were recorded on LL, SM and TB samples. A set of LL, SM and TB samples were frozen for subsequent five-day-ageing shear force measurement.

A set of LL, SM and TB samples were butterflied and placed in a group of four on a plastic tray, over-wrapped with gas permeable cling wrap and displayed on shelves under refrigerated conditions (2 – 4 °C) with fluorescent lights set at 1500 Lux. The light was continuously turned on for the 120h display period. The surface colour of the meat was measured at 0 h (0 day), 24 h (1 day), 48 h (2 day), 72 h (3 day), 96 h (4 day) and 120 h (5 day) from the time samples were displayed using a HunterLab colour meter.

For drip loss evaluation, a sample from each muscle was cut 20 mm thick, perpendicular to the fibre direction, boring a sample in the fibre direction with a 25 mm thickness. The cube of 25 mm width by 25 mm depth and 20 mm thickness was placed in vertical fibre direction in an empty-weight-recorded EZ-DripLoss container (Rosti Verpackungen GmbH, Neumünster, Germany). The tubes were placed in a fridge (2 – 4°C). The tube with juice was weighed after 3-day and 5-day display period to calculate drip loss.

After freezing, SF samples were cooked from frozen in a vacuum-sealed bag within a water bath at 71°C for 35 minutes and then cooled by running water for 30 minutes. Subsequently, 6 sub-samples (3-4cm long, 1cm$^2$ cross-sectional) from each sample were sheared perpendicular to the fibre direction using a Lloyd texture analyser.

### 5.2.2 Research trial timelines

17/09/ 2024 – 19/04/2024: Slaughtering, measuring temperature decline, carcase traits and sampling in Mildura.

20/09/2024 – 30/09/2024: Measuring pH, colour, purge and drip losses, retail colour stability, freezing down shear force (SF) samples.

16/10/2024 – 15/11/2024: Cooking and measuring the SF samples.

16/11/2024 – 29/11/2024: Analysing data and documenting findings.

### 5.2.2 Statistical analysis

Statistical analyses were conducted in R (R Core Team, 2021). Carcase trait data was analysed using linear mixed models. Treatment and kill date were incorporated in the models as fixed effects; HCW block as a random effect. Muscle data was analysed using generalized linear models fitted with treatment, muscle type, kill date, ageing period, display period as the fixed effect; and HCW and GR fat depth as the covariates. The inclusion of HCW and GR fat depth data as covariates was based on its significant variation across the treatments and muscles identified in the previous analysis. The models were refined systematically to eliminate irrelevant and insignificant interactions. Differences between predicted means were considered significant if $P<0.05$; to be a trend of $0.05<P<0.1$.

## 5.3 Prepare ex-ante value proposition

The benefit cost analysis (BCA) utilised the findings from the meat science research to underpin assumptions in the modelling which was undertaken by Greenleaf Enterprises. The assumptions included:

1. minimum carcase shrink (weight loss between hot and cold carcases through chilling)
2. carcases can be chilled to $<4.0°C$ within 5 hours in the retrofitted fruit Rapid Chill System. With a purpose built system for carcase chilling, the entire carcase of medium sized lambs can be chilled within 2 hours.
3. increased processing plant throughput due to reduction in chilling bottlenecks of 10 to 15% which in turn reduces fixed costs per head processed.
4. reduced chiller energy usage

The impact of using a Rapid Chill system was calculated for different small stock business models with variables including

- number of head processed per day
    a. Small plant: 300-800 per 7.5 hour shift (modelled 200)
    b. Medium plant: 800-4000 per 7.5 hour shift (modelled 3,600)
- type of animal (lamb v mutton),
    a. Lamb plant: 80% lamb, 20% mutton
    b. Mutton plant: 80% mutton, 20% lamb
- type of product (carcases v boxed products) and
- if the processing plant was using spray chilling or not.

The ROI for the different scenarios was calculated using industry data with mutton carcase sale value at $3.74/kilogram and lamb carcase sale value at $11.41/kilogram with an average carcase weight of 22 kilograms per head. Cost per kilowatt for electricity of $0.15 and conventional shrink of between 2.1% to 3.1% without the use of spray chilling.

## 5.4 Development of a commercialisation plan

A business plan was prepared which analysed the market and identified adoption opportunities within the Australian red meat sector based on known and potential benefits. Discussions were held with potential financiers and business models were developed based on a lease agreement, per head fee and an outright purchase agreement. Future projects and research requirements were documented including:

(1) The design and build of a commercial carcase chilling system for a medium small stock processing plant and

(2) Prototype design and testing for beef carcases and

(3) Prototype design and testing for rapidly chilling cartons.

# 6.0 Results

The results of the trials are presented in this section. The first section is carcase based chilling results and the second section is meat science testing. The final section presents the results of the Benefit Cost Analysis.

## 6.1 Rapid Chill Tunnel validation of carcase temperature decline

Three probes were placed in each carcase in the loin, bolar blade and topside areas. The temperature was measured every second and the data is graphed in Figure 1.

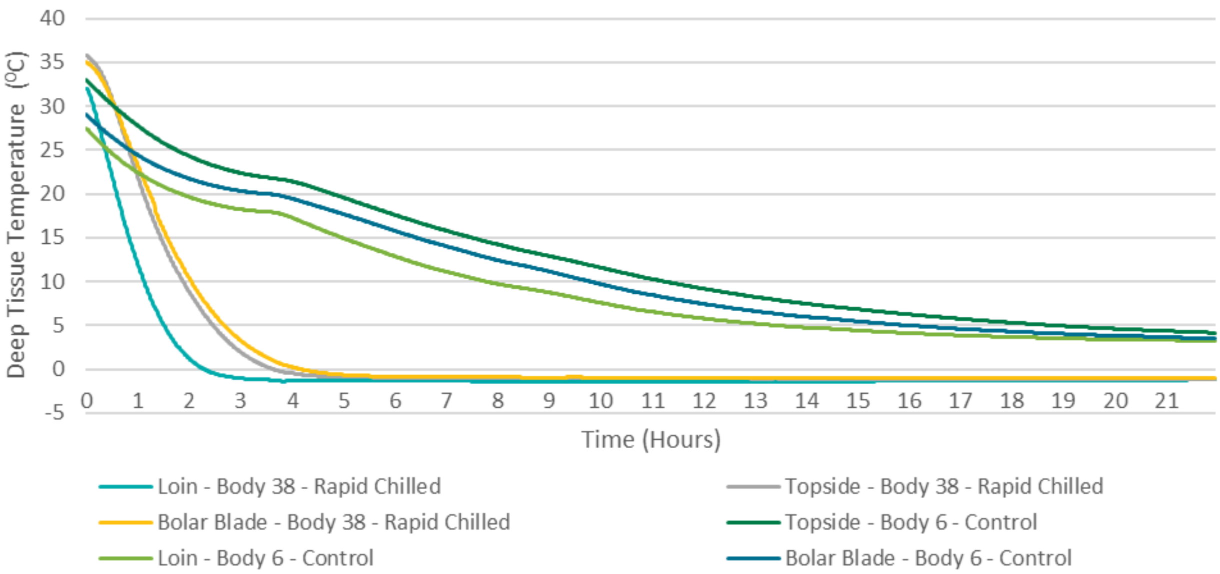



*Figure 1: Temperature decline curves of similar sized carcases under conventional (Con) and Rapid Chilling (Treatment)*

The following figures are aggregated data from all of the temperature decline curves for each treatment taken at a point in time. The carcases started at similar temperatures as shown in Figure 2.

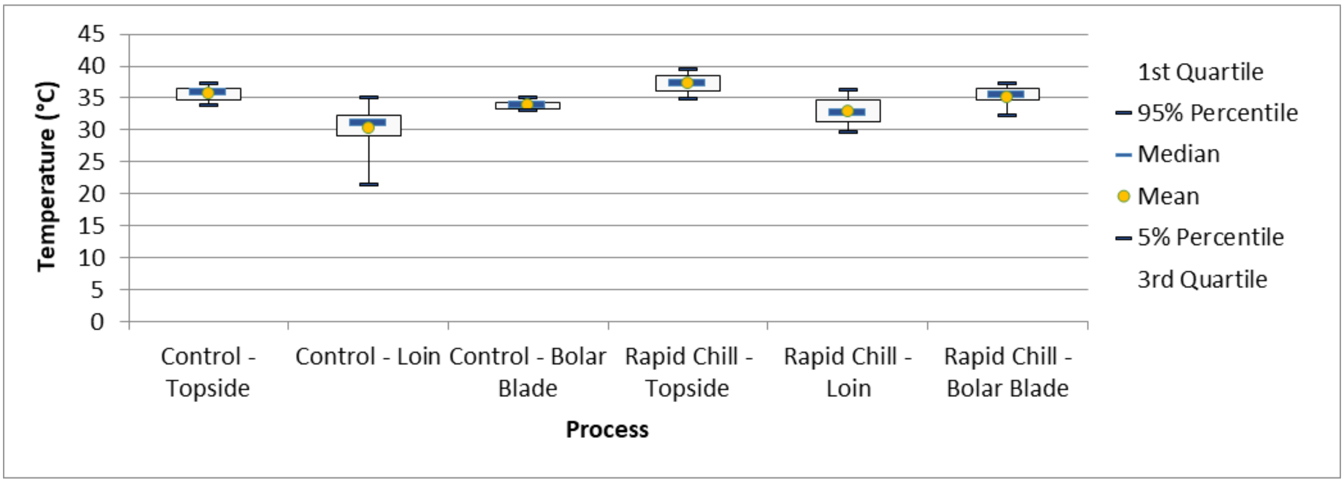



*Figure 2: Initial carcase temperature (°C) after embedding the temperature probes*

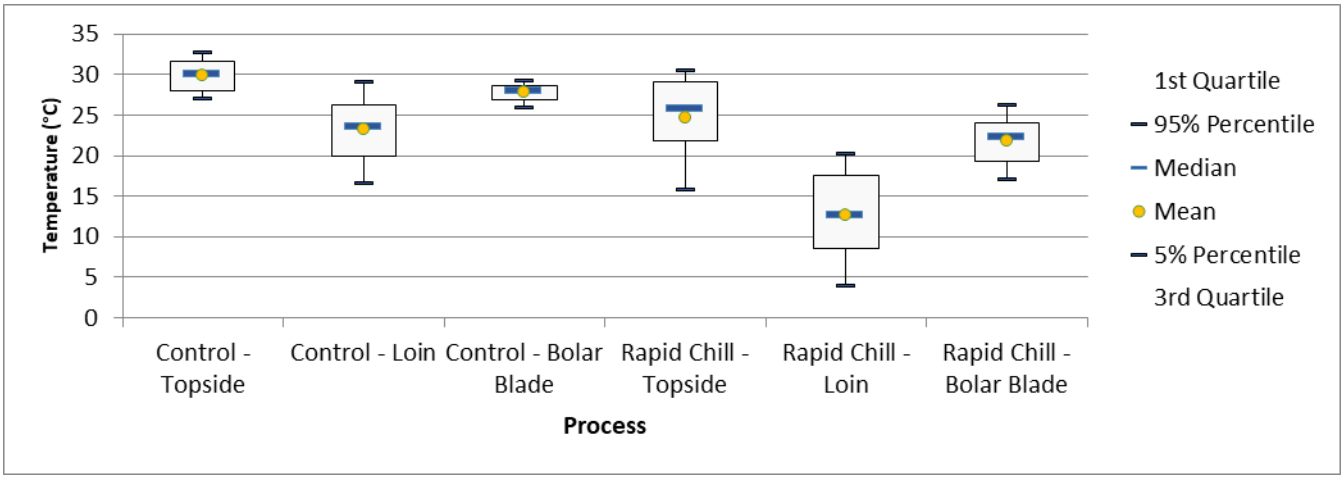



*Figure 3: One hour after embedding temperature probes by carcase location*

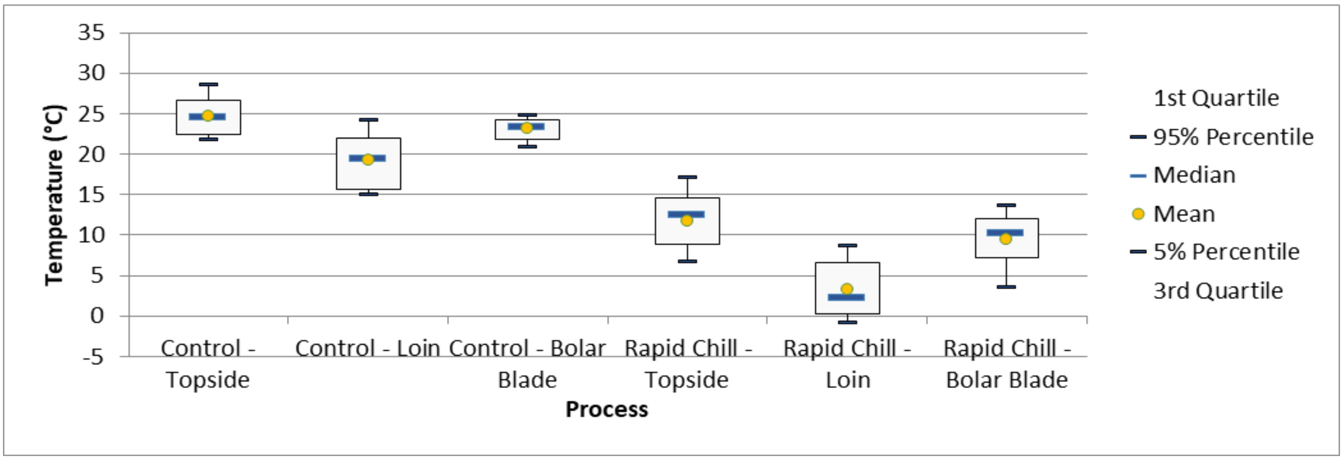



*Figure 4: Two hours after embedding temperature probes by carcase location*

At the two-hour mark all loins are below 10°C and the bolar blade and topside are starting to rapidly decrease in temperature.

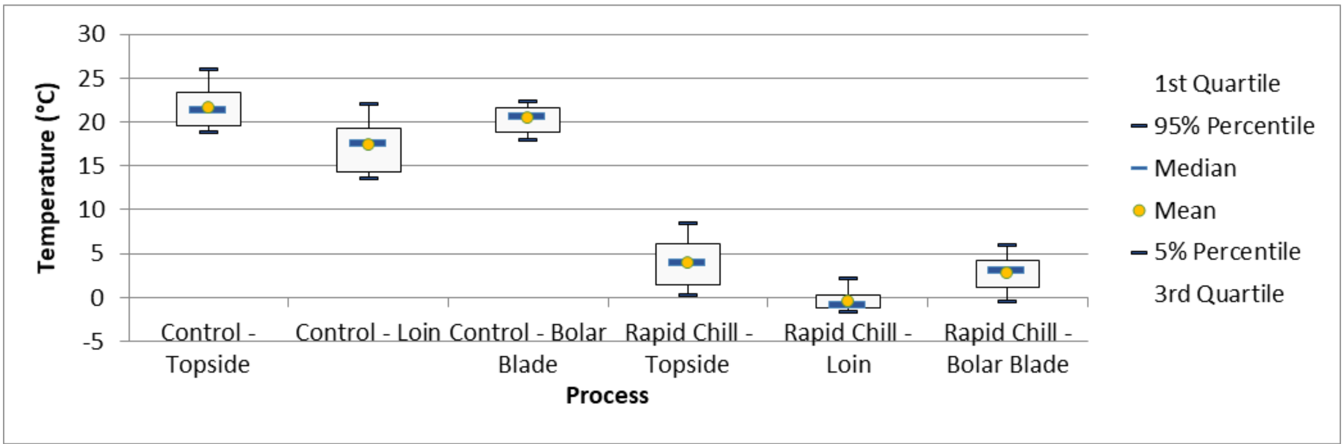



*Figure 5: Three hours after embedding temperature probes by carcase location*

The control (or conventionally chilled group is averaging between 17 and 21°C, whereas the rapid chilled group is averaging between -0.47 and 3.99°C for the loin and topside.

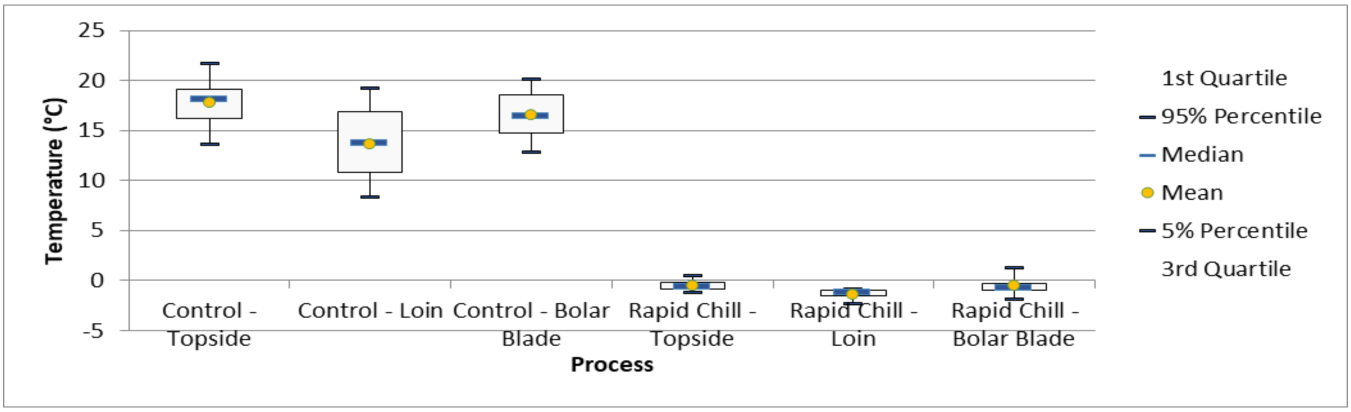



*Figure 6: Five hours after embedding temperature probes by carcase location*

*Table 1: Time (hours) for Rapid Chill treated carcase temperature probes to reach 0ºC*

| | | Time (hours) to 0'C | | | | |
|---|---|---|---|---|---|---|
| **Kill date** | **Body No** | **Loin** | **Topside** | **Bolar Blade** | **HCW (kg)** | **GR Fat Depth (mm)** |
| Day 1 | 24 | 1.47 | 4 | 3.18 | 15.4 | 3 |
| Day 1 | 7 | 1.5 | 4.37 | 3.67 | 19.75 | 4 |
| Day 1 | 18 | 1.58 | 3.35 | 4.92 | 16.25 | 8 |
| Day 2 | 42 | 1.68 | 3.28 | 4.13 | 15.8 | 5 |
| Day 2 | 39 | 1.82 | 3.33 | 3.67 | 15.35 | 4 |
| Day 2 | 36 | 1.9 | 3.67 | 2.55 | 16.5 | 4 |
| Day 1 | 1 | 2.03 | 3.4 | 3.3 | 18.5 | 6 |
| Day 1 | 5 | 2.23 | 4.07 | 3.07 | 16.7 | 7 |
| Day 1 | 16 | 2.27 | 3.77 | 3.67 | 17.8 | 4 |
| Day 2 | 26 | 2.28 | 3.65 | 4.18 | 18 | 8 |
| Day 2 | 35 | 2.37 | 4.85 | 5.08 | 28.4 | 6 |
| Day 1 | 13 | 2.53 | 4.08 | 4.22 | 24.65 | 16 |
| Day 1 | 17 | 2.65 | 4.4 | 3.07 | 27.9 | 16 |
| Day 2 | 37 | 2.65 | 5.37 | 6 | 33.2 | 15 |
| Day 1 | 21 | 2.8 | 5.05 | 4.5 | 26.05 | 20 |
| Day 1 | 15 | 2.83 | 4.83 | 4.03 | 26.4 | 21 |
| Day 2 | 30 | 3.1 | 4.57 | 3.48 | 25.65 | 21 |
| Day 1 | 4 | 3.13 | 3.07 | 3.82 | 28.4 | 15 |
| Day 2 | 41 | 3.23 | 5.42 | 6.2 | 36.15 | 13 |
| Day 2 | 27 | 3.28 | 4.73 | 6.67 | 29.7 | 12 |
| Day 1 | 8 | 3.35 | 5.6 | 3.87 | 34.7 | 25 |
| Day 2 | 34 | 3.45 | 4.88 | 4.33 | 31.1 | 16 |
| Day 1 | 25 | 3.82 | 2.38 | 4.78 | 23.5 | 19 |
| Day 2 | 25 | 3.82 | 2.38 | 4.78 | 23.5 | 19 |
| | | | | | | |
| Average | | 2.6 | 4.1 | 4.2 | 23.7 | 12.0 |
| Min | | 1.5 | 2.4 | 2.6 | 15.4 | 3.0 |
| Max | | 3.8 | 5.6 | 6.7 | 36.2 | 25.0 |

The loin temperature of carcases in the rapid chilling tunnel rapidly decreased in temperature with the lighter leaner carcases decreasing in temperature more rapidly than the heavier, fatter carcases.

The HCW and GR fat depth of the carcases used in the trial by research day and treatment group are shown in Figure 7 and Figure 8.

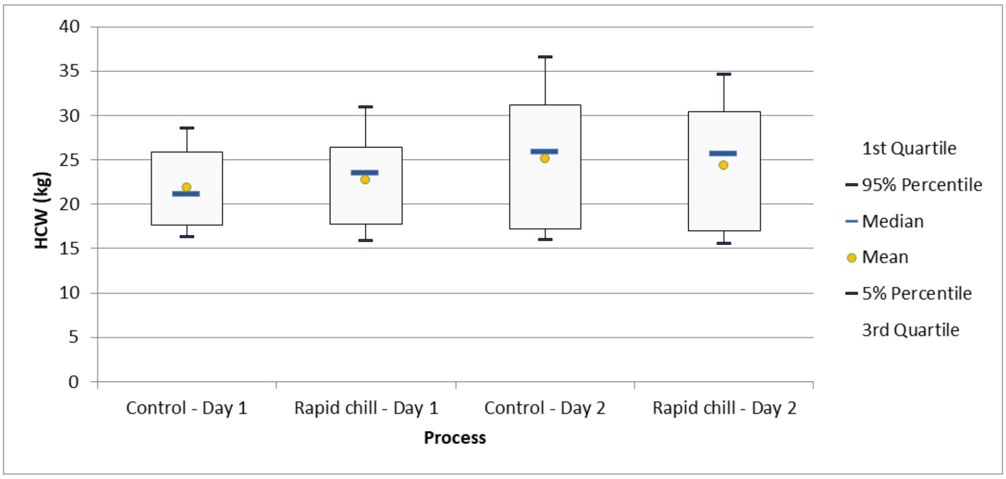



*Figure 7: Hot Carcase Weights for Control and Treatment groups by day*

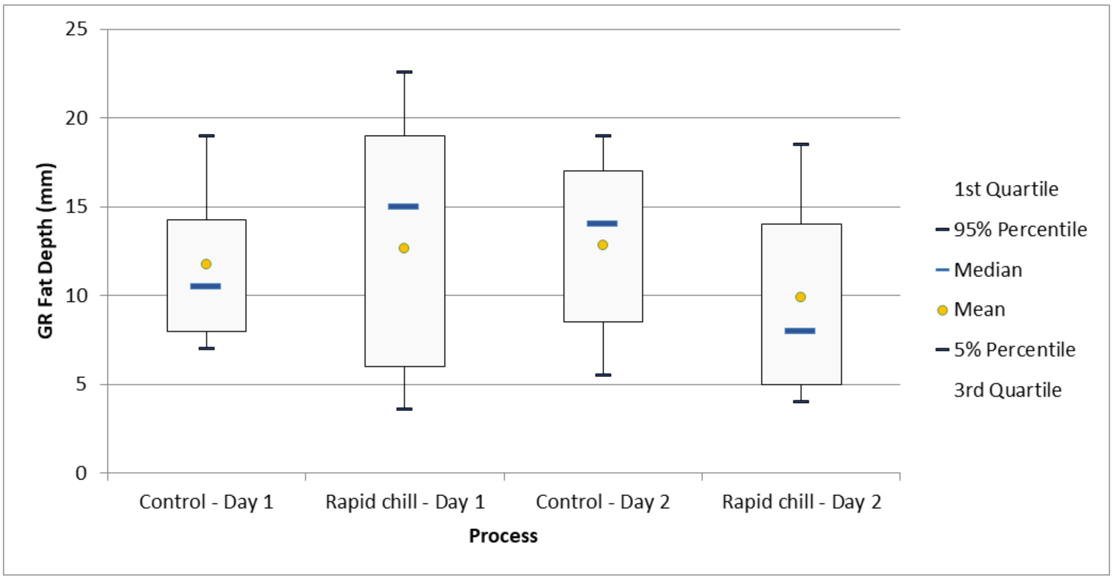



*Figure 8: GR Fat depth (mm) for Control and Treatment groups by day*

The trial design focused on a wide range in carcase weights and fat depth to understand the chilling impact and potential cold shortening of carcases at different body weights and fat depth as fat acts as an insulating layer.

## 6.2 Meat science testing

### 6.2.1 Shrink loss

On Day 1, carcass weight losses at 5 hours and one day post-mortem in the Rapid Chill group were considerably higher than conventional treatment (P<0.001). On Day 2, after system adjustments were made, one-day post-mortem carcass weight losses in the Rapid Chilling treatment were substantially lower than those in the conventional (control) group (P<0.001). On Day 2, treatment had a trend in influencing the difference in carcass weight losses at 5-hour post-mortem between the two treatments (0.05<P<0.10) with Rapid Chill trending to have lower carcase weight losses.

*Table 2: Carcase trait measurements for the conventional (Con) and Rapid Chill (Fast) lambs on Day 1 (KD1) and Day 2 (KD2)*

| | Kill date 1 | | Kill date 2 | | Both Kill dates | | SEM | P value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | Con | Fast | Con | Fast | | KD1 | KD2 | Both KD |
| n | 12 | 13 | 11 | 11 | 23 | 24 | | | | |
| HSCW (kg) | 21.5 | 23.3 | 24.9 | 24.0 | 23.1 | 23.2 | 0.94 | 0.072 | 0.792 | 0.977 |
| GR fat depth (mm) | 11.8 | 12.6 | 12.8 | 9.91 | 12.3 | 10.8 | 0.83 | 0.810 | 0.247 | 0.387 |
| 5-hour CCW (kg) | 21.2 | 22.3 | 24.5 | 23.7 | 22.8 | 22.5 | 0.94 | 0.448 | 0.807 | 0.878 |
| 5-hour CW loss (kg) | $0.24^{b}$ | $1.01^{a}$ | 0.42 | 0.28 | 0.33 | 0.67 | 0.05 | **<0.001** | 0.080 | **<0.001** |
| 5-hour CW loss (%) | $1.12^{b}$ | $4.59^{a}$ | 1.74 | 1.24 | 1.42 | 3.10 | 0.25 | **<0.001** | 0.098 | **<0.001** |
| 1-day CCW (kg) | 20.9 | 22.2 | 24.0 | 23.5 | 22.4 | 22.3 | 0.93 | 0.298 | 0.886 | 0.979 |
| 1-day CW loss (kg) | $0.55^{b}$ | $1.12^{a}$ | $0.89^{a}$ | $0.48^{b}$ | 0.72 | 0.82 | 0.04 | **<0.001** | **<0.001** | 0.211 |
| 1-day CW loss (%) | $2.66^{b}$ | $5.09^{a}$ | $3.84^{a}$ | $2.07^{b}$ | 3.23 | 3.76 | 0.22 | **<0.001** | **<0.001** | 0.213 |

HSCW=hot standard carcase weight; CCW=cold carcase weight; CW= carcase weight; a–b means different superscriptions within the same row in each factor (P<0.05)

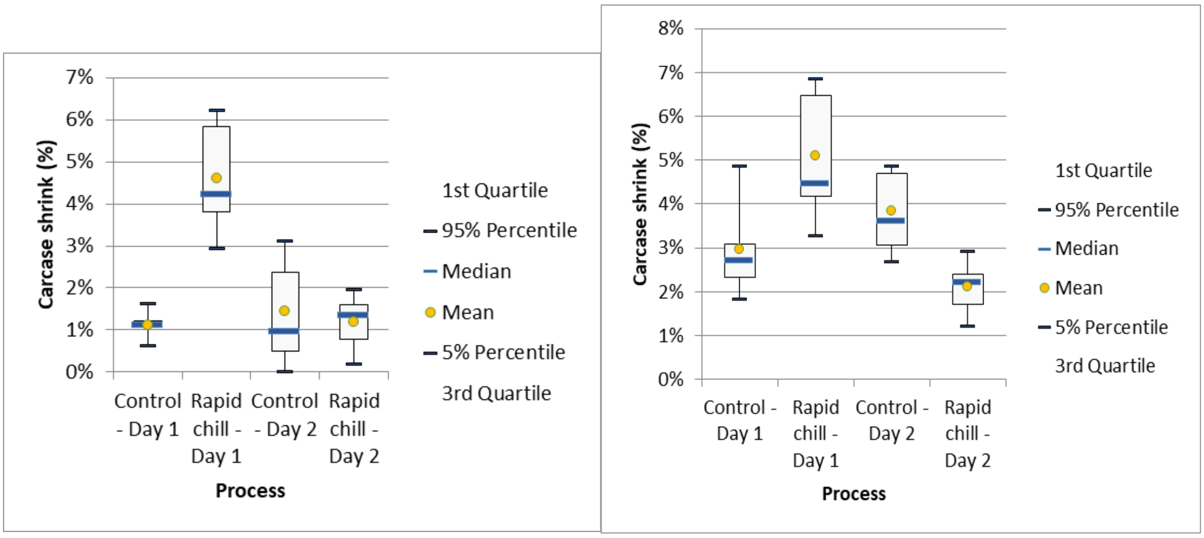



*Figure 9: Carcase shrink 5 hours Control and Rapid Chill and 24 hours post-mortem by treatment with Rapid Chill carcases in Conventional Chillers from hours 6-24*

### 6.2.2 pH and temperature declines

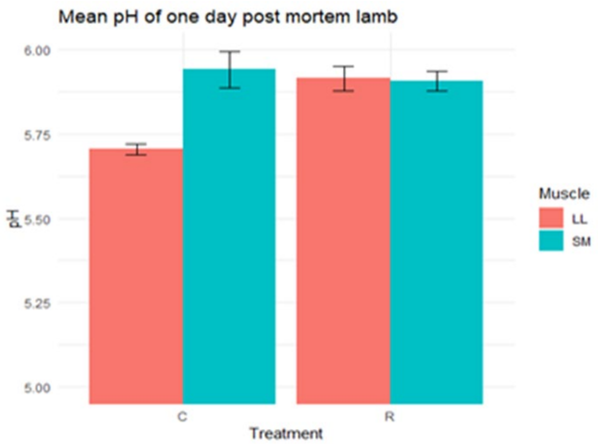
Chilling regime significantly affected pH and temperature (P<0.001), with a trend (P=0.064) in influencing the yellowness of the muscles. The pH in the Rapid Chill treatment (5.91) was significantly higher (P<0.001) than that in the conventional treatment (5.82). In contrast, the carcasses in the Rapid Chill treatment had lower temperature (-0.39°C) than those in the conventional treatment (2.46°C). The higher pH of the Rapid Chill treatment lambs is understandable because the cold temperatures reduced the speed of glycolysis and the subsequent production of lactic acid.

*Table 3: One-day post-mortem pH, temperature and colour for the conventional (Con) and Rapid Chill (Fast) lambs and the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB)*

| | Treatment | | Muscle | | | SEM | P value | Covariate P value | |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | LL | SM | TB | | T | HSCW | GR |
| pH | 5.82$^{b}$ | 5.91$^{a}$ | 5.81$^{b}$ | 5.92$^{a}$ | | 0.02 | <0.001 | 0.663 | 0.043 |
| Temp ($^{0}$C) | 2.46$^{a}$ | -0.39$^{b}$ | 1.05 | 0.95 | | 0.2 | <0.001 | 0.995 | 0.077 |
| L* | 36.8 | 35.9 | 34.2$^{b}$ | 34.3$^{b}$ | 40.6$^{a}$ | 0.32 | 0.15 | 0.864 | 0.627 |
| a* | 24.5 | 24.1 | 22.6$^{c}$ | 24.1$^{b}$ | 26.2$^{a}$ | 0.21 | 0.152 | 0.156 | 0.378 |
| b* | 11.8 | 11.7 | 10.0$^{c}$ | 11.9$^{b}$ | 13.3$^{a}$ | 0.18 | 0.064 | 0.153 | 0.209 |
| Chroma | 27.2 | 26.8 | 24.7$^{c}$ | 26.9$^{b}$ | 29.4$^{a}$ | 0.26 | 0.116 | 0.147 | 0.308 |
| hue | 25.6 | 25.7 | 23.8$^{b}$ | 26.3$^{a}$ | 26.8$^{a}$ | 0.18 | 0.058 | 0.448 | 0.219 |

T=treatment; a–c means different superscriptions within the same row in each factor (P<0.05)

L* which reports relative lightness or brightness; a* red-greenness; and b* yellow-blueness



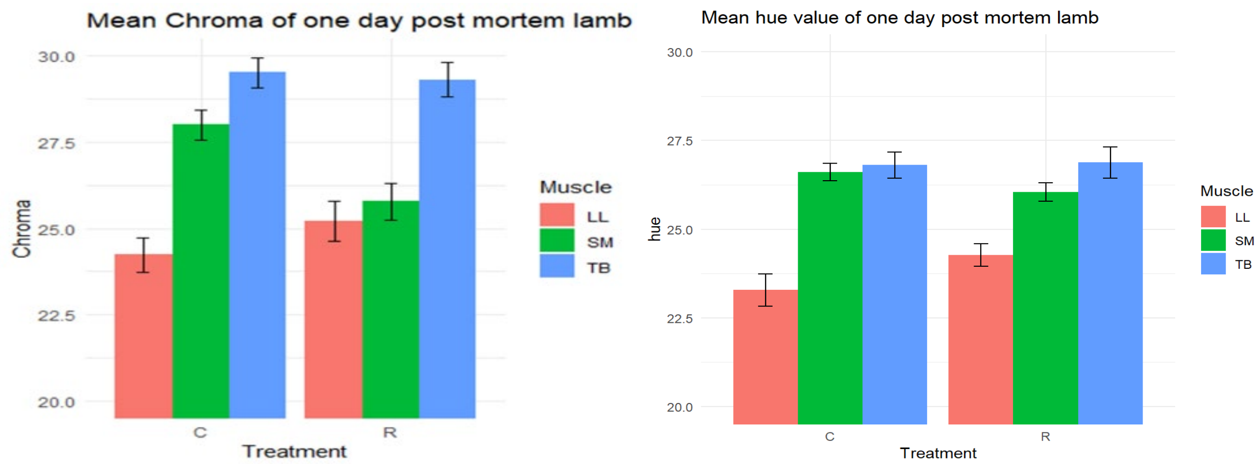



Figure 8: Treatment and muscle interaction effects on (a) pH, (b) a*, (c) b*, (d) Chroma, and (e) hue values for conventional (C) and Rapid Chill (R) lamb carcases in the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB) at one day post-mortem

### 6.2.3 Ultimate pH and colour at five days post-mortem

The ultimate pH, temperature and colorimetric parameters of muscles at five days post-mortem are shown in Table 4. The Rapid Chill system did not cause any significant differences in the measured parameters (P>0.05). Muscle type significantly affected all measured parameters (P≤0.001, Table 4). The TB recorded the highest pH (5.92) compared to the other two muscle types. Muscle type had a significant impact (P<0.001) on colour characteristics of the muscles at five days post-mortem with the TB muscle recorded the highest lightness (40.4) compared to the other muscle. There were no significant differences in lightness, redness Chroma and hue values between treatments. Covariates (HCW and GR fat depth) caused no considerable impacts on the ultimate pH, temperature and colorimetric parameters of muscles at five days post-mortem.

*Table 4: Ultimate pH, temperature and colour at five days post-mortem for the conventional (Con) and Rapid Chill (Fast) lambs and the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB)*

| | **Treatment** | | **Muscle** | | | **SEM** | **P value** | | | **Covariate P value** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | LL | SM | TB | | T | M | TxM | HSCW | GR |
| n | 69 | 72 | 47 | 47 | 47 | | | | | | |
| $pH_u$ | 5.78 | 5.79 | $5.70^{b}$ | $5.74^{b}$ | $5.92^{a}$ | 0.01 | 0.699 | **<0.001** | 0.933 | 0.320 | 0.944 |
| Temp ($^{0}$C) | 4.43 | 4.51 | $3.93^{b}$ | $5.95^{a}$ | $3.53^{c}$ | 0.12 | 0.656 | **<0.001** | 0.659 | 0.163 | 0.537 |
| L* | 37.7 | 37.4 | $36.5^{b}$ | $35.7^{c}$ | $40.4^{a}$ | 0.24 | 0.279 | **<0.001** | 0.133 | 0.159 | 0.911 |
| a* | 24.4 | 23.8 | $22.4^{c}$ | $25.5^{a}$ | $24.3^{b}$ | 0.18 | 0.869 | **<0.001** | **0.046** | 0.110 | 0.496 |
| b* | 12.1 | 11.6 | $10.7^{c}$ | $12.7^{a}$ | $12.2^{b}$ | 0.15 | 0.784 | **<0.001** | **0.015** | 0.339 | 0.392 |
| Chroma | 27.2 | 26.5 | $24.9^{c}$ | $28.5^{a}$ | $27.2^{b}$ | 0.22 | 0.836 | **<0.001** | **0.029** | 0.148 | 0.449 |
| hue | 26.3 | 25.9 | $25.4^{b}$ | $26.4^{a}$ | $26.6^{a}$ | 0.14 | 0.718 | **0.001** | **0.031** | 0.998 | 0.430 |

T=treatment; M=muscle; TxM=treatment and muscle interaction; T=treatment; M=muscle; TxM=treatment and muscle interaction; a–c means different superscriptions within the same row in each factor (P<0.05)

The SM in the conventional treatment recorded the highest redness value and was significantly higher compared to its counterpart in the Rapid Chill treatment. Conversely, the redness values of the LL were lowest and similar between the two treatments. A similar trend was found in the yellowness and Chroma values with no significant differences between the two treatments.

The chilling regime had significant influences ($P<0.05$) in purge loss and drip losses. In particular, the Rapid Chill group had higher purge (8.03%) than the conventional treatment (5.58%). Similarly, the drip losses at three and 5-day displaying in the rapid chilling group (0.93% and 1.53% respectively) were higher than those in the conventional treatment (0.69% and 1.12% respectively).

While muscle type did not influence the purge loss, the drip losses were significantly influenced ($P<0.01$, Table 5) by muscle type. The TB recorded the lowest drip losses at 3 and 5 days, displaying (0.27% and 0.43% respectively) compared to the other two muscle types, while the highest drip losses (1.38% and 2.30% respectively) were observed in the SM muscle. Kill date did not cause any considerable impacts on the purge and drip losses.

There were some significant impacts of treatment and muscle interaction on the measured losses. The effects of treatment and muscle interaction on drip loss values were demonstrated in Figure 10. From Figure 9a, it is evident that the SM in the rapid chilling treatment recorded the highest drip loss at three days of display and was significantly higher compared to its counterpart in the conventional treatment. Conversely, the three-day displaying drip loss of the TB was the lowest and similar between the two treatments. A similar trend was found in the drip loss at five days of display (Figure 10b).

Figure 11 illustrates the kill date and muscle interaction effects on purge loss and drip losses. Particularly, the purge loss values of all muscle on Kill date 1 were higher than their corresponding counterpart on Kill date 2. The different levels seemed to increase from TB, then SM and LL (Figure 11a).  The variation in drip losses at both three and five days was impacted by kill date and muscle interaction and share a similar trend (Figure 11b and 11c). The SM on Kill date 2 recorded the highest drip loss, and was significantly higher compared to its counterpart on Kill date 1. In contrast, the TB on Kill date 1 exhibited the lowest value, and was significantly lower than its counterpart on Kill date 2.

As covariates, HCW had a significant impact on purge loss and Figure 12 clearly displays the trend where HCW influences the purge loss of the muscle. GR fat depth did not considerably affect the purge and drip losses.  The negative relationship between HCW and purge loss may be associated with heavier carcases not chilling as quickly, reducing the size of the super contraction and maintaining better structural integrity of the muscle cells. This will deliver less purge loss from those heavier carcases.

*Table 5: Purge and drip losses for the conventional (Con) and Rapid Chill (Fast) muscles which were the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB)*

| | **Treatment** | | **Muscle** | | | **Kill date** | | | **P value** | | | | | **Covariate P value** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | LL | SM | TB | 1 | 2 | **SEM** | T | M | KD | TxM | MxKD | HSCW | GR |
| n | 69 | 72 | 47 | 47 | 47 | 75 | 66 | | | | | | | | |
| Purge loss (%) | $5.58^{b}$ | $8.03^{a}$ | 8.2 | 6.93 | 5.35 | 7.83 | 5.69 | 0.27 | **0.037** | 0.159 | 0.655 | 0.239 | **0.035** | **<0.001** | 0.579 |
| 3-day Drip loss (%) | $0.69^{b}$ | $0.93^{a}$ | $0.78^{b}$ | $1.38^{a}$ | $0.27^{c}$ | 0.53 | 1.13 | 0.08 | **0.002** | **<0.001** | 0.25 | **0.002** | **0.001** | 0.55 | 0.924 |
| 5-day Drip loss (%) | $1.12^{b}$ | $1.53^{a}$ | $1.25^{b}$ | $2.30^{a}$ | $0.43^{c}$ | 0.95 | 1.76 | 0.13 | **0.024** | **0.007** | 0.771 | **0.012** | **0.031** | 0.804 | 0.181 |

T=treatment; M=muscle; KD=kill date; TxM=treatment and muscle interaction; MxK= muscle and kill date interaction; HSCW=hot standard carcass weight; GR=GR fat depth; a–c means different superscriptions within the same row in each factor ($P<0.05$).

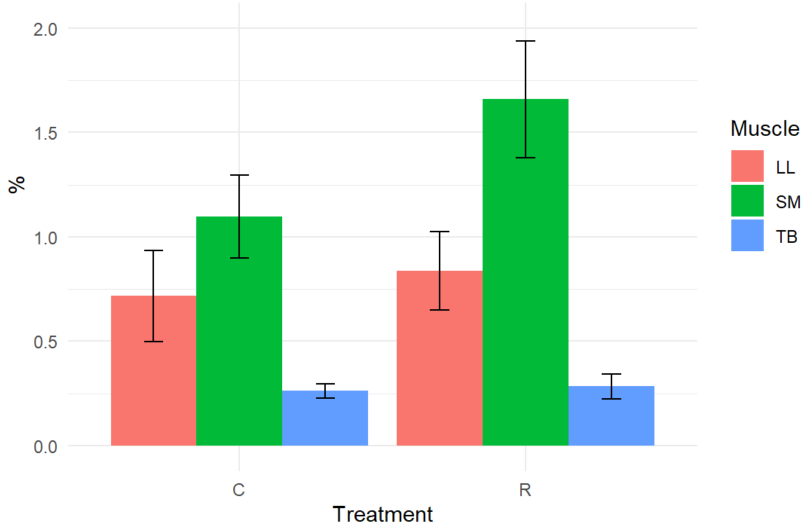



*Figure 10: Treatment and muscle interaction effects on drip loss values for conventional (C) and Rapid Chilled (R) lamb carcasses in the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB) at three days of display*

### 6.2.4 Shear force

The LL muscle from carcases that experienced cold shortening from the conventionally chilled group were removed from the shear force (SF) data set before analysing while all of the SM and TB muscles remained. The shear force (SF) of muscles across different ageing periods was summarised in Table 6. Muscle type was the main driver ($P<0.04$) influencing the changes in SF. The SF was not affected by kill date. At 3 days ageing, the SM had considerably higher SF (58.3 N) than the LL muscle (48.9 N). At 5 days ageing, there was a significant difference ($P<0.001$) in SF among the three different muscle types with the SM got the highest value (52.8 N), followed by the LL (44.4 N) while the TB recorded the lowest one (34.2 N).

Table 6: Shear force (N) of longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB) muscles from the conventional (Con) and Fast chilled lambs

| Ageing time | Treatment | | Muscle | | | Kill date | | SEM | P value | | | | Covariate P value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | LL | SM | TB | 1 | 2 | | T | M | KD | TxM | HSCW | GR |
| 3 days | 56.1 | 52.6 | 48.9$^{b}$ | 58.3$^{a}$ | | 51.1 | 58.1 | 1.65 | 0.191 | 0.001 | 0.185 | 0.101 | 0.019 | 0.313 |
| 5 days | 43.4 | 44.0 | 44.4$^{b}$ | 52.8$^{a}$ | 34.2$^{c}$ | 42.7 | 45.0 | 1.15 | 0.966 | <0.001 | 0.616 | 0.024 | 0.203 | 0.139 |

T=treatment; M=muscle; KD=kill date; TxM=treatment and muscle interaction; HSCW=hot standard carcass weight; GR=GR fat depth; a–c means different superscriptions within the same row in each factor ($P<0.05$).

A significant effect of treatment and muscle interaction ($P<0.05$) on the SF of the muscles at 5 days ageing was observed (Table 6, Figure 11). The treatment and muscle interaction effects caused a reduction of 7.1 N in the LL muscle from the Rapid Chilling (R) treatment group compared to the conventional group after 5 days of ageing.

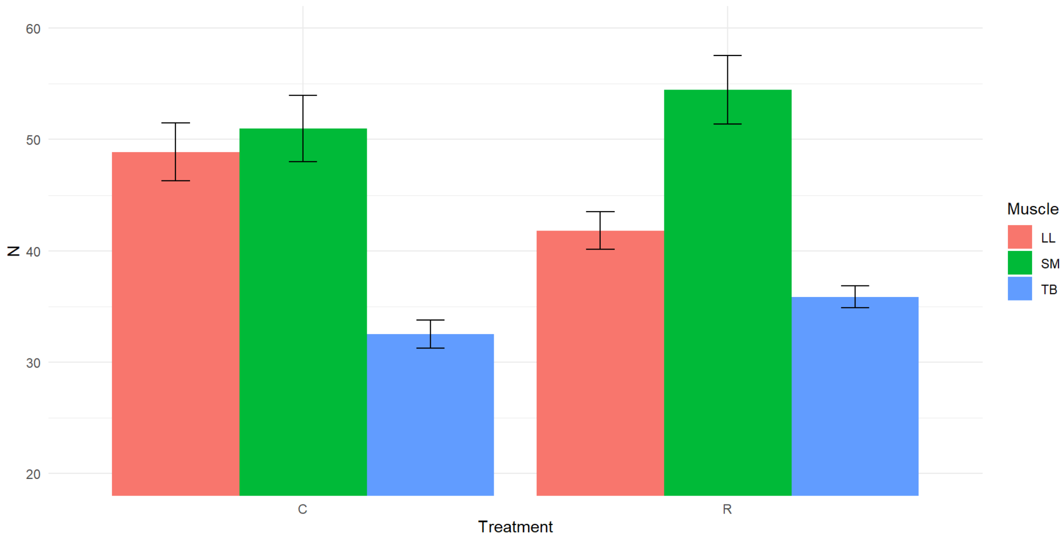



*Figure 11: Treatment and muscle interaction effects on SF of the longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB) muscles at five days post-mortem*

HCW, included as a covariate, demonstrated a significant effect on the SF of the muscles after three days of ageing. In contrast, GR fat depth did not exhibit a substantial influence on the SF. There is possibly a negative association between HCW and SF at 3 days of ageing postmortem due to the extent of cold shortening or super contraction of sarcomeres that has occurred. Heavier carcases did not chill as quickly, hence may have experienced more cold shortening than super contraction. This can be confirmed with the sarcomere length measures and myofibril fragmentation index data.

The chilling regime significantly reduced the SF of LL muscle whereas it substantially increased the SF of TB muscle ($P<0.05$). Meanwhile, the SF of SM muscle was not affected by the chilling regime ($P>0.05$).

Ageing time caused a significant decrease in the SF of LL muscle, but it had no significant impact on the SF of SM muscle.

As a covariate, HCW had a significant impact on the SF of the LL muscles. In contrast, GR fat depth did not considerably affect the SF. There is possibly a positive association between HCW and SF in the LL due to the extent of cold shortening or super contraction of sarcomeres that has occurred. Heavier carcases did not chill as quickly, hence may have experienced more cold shortening than super contraction. This can be confirmed with the sarcomere length measures and myofibril fragmentation index data from the LL.

Table 7: Shear force (N) of longissimus lumborum (LL), semimembranosus (SM) and triceps brachii (TB) muscles from the conventional (Con) and Fast chilled lambs

| Muscle | Treatment | | Ageing day | | Kill date | | SEM | P value | | | Covariate P value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | 3 | 5 | 1 | 2 | | T | A | KD | HSCW | GR |
| Longissimus Lumborum | $51.4^{a}$ | $43.9^{b}$ | $48.9^{a}$ | $44.4^{b}$ | 45.4 | 48.6 | 1.65 | <0.001 | 0.046 | 0.995 | 0.017 | 0.091 |
| Semimembranosus | 54.2 | 56.8 | 58.3 | 52.8 | 52.9 | 58.6 | 1.56 | 0.497 | 0.071 | 0.159 | 0.142 | 0.652 |
| Triceps Brachii | $32.5^{b}$ | $35.9^{a}$ | | | 33.5 | 35.0 | 0.83 | 0.049 | | 0.424 | 0.801 | 0.315 |

T=treatment; A=ageing; KD=kill date; TxM=treatment and muscle interaction; HSCW=hot standard carcass weight; GR=GR fat depth; a–c means different superscriptions within the same row in each factor ($P<0.05$).

### 6.2.5 Retail colour stability

There were no significant effects of chilling regime on colorimetric parameters ($P>0.05$). In contrast, muscle type had substantial influence on all colorimetric parameters ($P<0.01$). With the exception of hue level, the highest colorimetric values were found on the TB muscle, and they were significantly higher ($P<0.01$) compared to the other muscles. The LL and SM muscles seemed to have a similarity in redness, yellowness and chroma values.

All colorimetric parameters were considerably affected by the display time.  The lightness level was found to increase between day 0 and 1 of display and thereafter decline ($P<0.05$). The yellowness level slightly increases on the first and last days of the display period and decreases on the other days. The redness, chroma, redness ratio (630/580) and cured fade (650/570) consistently decreased, while the hue value consistently increased throughout the 5-day display period.

Some significant interaction effects were observed. The influences of treatment and muscle interaction on redness, yellowness and chroma were substantial.  Moreover, the measured colorimetric parameters were significantly affected by the display time muscle and display time interaction.

The five basic colorimetric parameters on the muscle in the two treatments across five days display are illustrated in Figure 11. The parameters exhibit similar variation trends across both treatments. Muscles in the conventional treatment generally displayed slightly higher values for lightness, redness, yellowness, and chroma, as well as slightly lower hue levels at all measurement points. However, these differences were not statistically significant $P>0.05$.

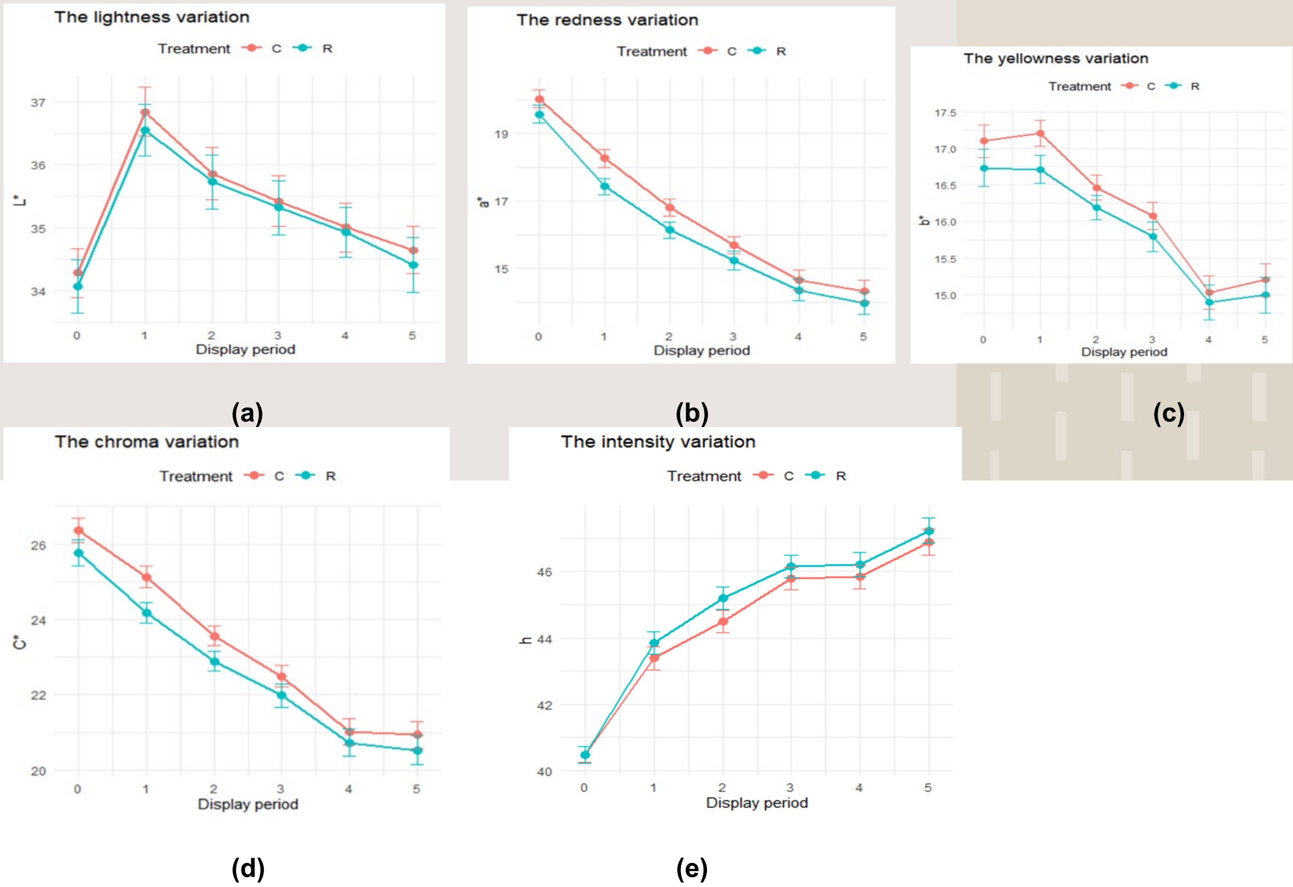



*Figure 12: The variations in (a) L* (b) a*, (c) b*, (d) Chroma and (e) hue of muscles from the conventional (C) and Rapid chilled (R) lambs*

Table 6 presents the effects of treatment, muscle, and display time on colorimetric parameters.

*Table 6: Colorimetric parameters of muscle across various display periods*

| | **Treatment** | | **Muscle** | | | **Display time** | | | | | | **SEM** | **P value** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Con | Fast | LL | SM | TB | 0 | 1 | 2 | 3 | 4 | 5 | | T | M | D | TxM | MxD |
| n | 414 | 432 | 282 | 282 | 282 | 141 | 141 | 141 | 141 | 141 | 141 | | | | | | |
| L* | 35.3 | 35.2 | 33.9 | 33.1 | 38.7 | 34.2 | 36.7 | 35.8 | 35.4 | 35 | 34.5 | 0.12 | 0.771 | **<0.001** | **0.015** | 0.214 | 0.139 |
| a* | 16.6 | 16.1 | 16 | 16 | 17.1 | 19.8 | 17.8 | 16.5 | 15.5 | 14.5 | 14.2 | 0.1 | 0.976 | **<0.001** | **<0.001** | **0.003** | **<0.001** |
| b* | 16.2 | 15.9 | 15.6 | 15.6 | 16.9 | 16.9 | 17 | 16.3 | 15.9 | 15 | 15.1 | 0.07 | 0.927 | **<0.001** | **<0.001** | **0.015** | **<0.001** |
| C* | 23.2 | 22.7 | 22.4 | 22.4 | 24.1 | 26.1 | 24.6 | 23.2 | 22.2 | 20.9 | 20.7 | 0.11 | 0.995 | **<0.001** | **<0.001** | **0.002** | **<0.001** |
| h | 44.5 | 44.8 | 44.4 | 44.8 | 44.8 | 40.5 | 43.6 | 44.9 | 46 | 46 | 47.1 | 0.12 | 0.939 | **0.003** | **<0.001** | 0.317 | **0.002** |
| Redness ratio (630/580) | 3.93 | 3.77 | 3.65 | 3.71 | 4.17 | 6.42 | 4.31 | 3.61 | 3.14 | 2.85 | 2.73 | 0.05 | 0.872 | **<0.001** | **<0.001** | 0.064 | **<0.001** |
| Cured fade (650/570) | 3.65 | 3.52 | 3.47 | 3.53 | 3.76 | 6.2 | 3.87 | 3.28 | 2.9 | 2.67 | 2.58 | 0.05 | 0.778 | **<0.001** | **<0.001** | 0.148 | **<0.001** |

## 6.3 Commercialisation strategy

A business commercialisation strategy was developed for the Fresh Xpress modular chilling system to transition from an early-stage prototype to a commercially available product. The commercialization strategy included:

(1) Preparation of Case Studies of Benefit Scenarios for Mutton and Lamb processing plants to use Rapid Chill for carcase chilling in Australia based on the findings from the research.

(2) Preparation and design of engineering plans that enable carcases to be loaded – 72 at a time automatically into the modular unit and then feed back into the chain 1-2 hours later depending on the selected chilling regime.

   a. Development of a 2 zone unit for smaller processing plants including modelling the airflow and capacity of flow and unit design

   b. Development of 7 zone unit for medium to large processing plants.

(3) Meeting with potential financiers to provide access to capital for processing plants to purchase, lease or pay a per head fee for the use of the Rapid Chill system.

### 6.3.1 Benefit Scenario – Case studies

As the system is scalable and modular, the benefit for this system could transform the entire processing industry in Australia as the systems can be scaled from a very small to very large system. This would enable processing plants no matter what their throughput volumes and speed to realise benefits. The range in opportunity benefit has been shown in the following benefit scenarios:

- System purchased outright by the processing plant:
  - Single shift lamb plant – based on 7 zone unit
  - Single shift mutton plant – based on 7 zone unit
  - Small lamb plant (40/hour) – entry level 2 zone unit
  - Small to medium lamb plant (148/hour) – Chilled airfreight carcase exports - 2 zone unit
- System leased by processing plant looking to obtain the benefits without the requirement for raising capital:
  - Single shift lamb plant – based on 7 zone unit
  - Single shift mutton plant – based on 7 zone unit
  - Small lamb plant (40/hour) – entry level 2 zone unit
  - Small to medium lamb plant (148/hour) – Chilled airfreight carcase exports - 2 zone unit

### Meat science assumptions supporting the business case

The following assumptions were made to inform the models:

- Hard fat issues impacting on immediate boning will be addressed either through adjustments to the chilling environment, or through a post-rapid chill holding stage to allow equilibration.
- Scenarios have assumed a holding period after rapid chilling. Changes in chiller configuration have assumed there will still be chiller holding space which addresses the hard fat and the possible bottle necks through downstream breakdowns that would now impact on a just-in-time chilling process.
  - Reduction in chiller space per carcase processed is 15% which still allows the current process flows to be applied in the event of downstream breakdowns.

- It has been assumed that purge can be overcome through changes in a purpose-built systems settings being optimised. If the 2.4% increase in shrink can't be overcome, it will equate to about $0.28/kg for cuts going into retail markets.
- It has also been assumed that there is no negative impact on eating quality resulting from purge if it can't be reduced through chiller setting configurations.

All the benefits included are calculated using industry standards from Greenleaf Enterprises. The benefits will vary from plant to plant with the range of benefits realisable by the processing industry shown in Table 7.

*Table 7: Average annual gross benefit and Net Present Value (NPV) for each scenario*

| Business case scenario | Average Annual Net Benefit | | Average NPV* | |
|---|---|---|---|---|
| **Company purchased system** | No Spray chilling | With spray chilling | No Spray chilling | With spray chilling |
| Single shift lamb plant – based on 7 zone unit | $ 7,198,875 | $ 4,202,122 | $ 47,644,737 | $ 26,613,708 |
| Single shift mutton plant – based on 7 zone unit | $ 3,806,840 | $ 2,669,797 | $ 23,820,499 | $ 15,851,301 |
| Small to medium lamb plant (148/hour) – 2 zone unit | $ 2,461,571 | $ 1,321,447 | $ 16,098,479 | $ 8,107,635 |
| Small lamb plant (40/hour) – Entry level 2 zone unit | $ 383,374 | $ 188,784 | $ 2,395,013 | $ 1,045,209 |
| **Leasing system** | | | | |
| Single shift lamb plant – based on 7 zone unit | $ 5,748,962 | $ 2,752,209 | $ 57,445,607 | $ 36,414,578 |
| Single shift mutton plant – based on 7 zone unit | $ 2,842,927 | $ 1,705,884 | $ 33,621,369 | $ 25,652,171 |
| Small to medium lamb plant (148/hour) – 2 zone unit | $ 2,062,371 | $ 922,247 | $ 20,098,479 | $ 12,107,635 |
| Small lamb plant (40/hour) – Entry level 2 zone unit | $ 267,374 | $ 72,784 | $ 3,395,013 | $ 2,045,209 |
| * NPV based on 10 year system life & discount rate of 7% | | | | |

## Purchased 7 zone unit - Single shift lamb plant

The scenario is based on a processor purchasing outright a 7-zone unit to process 972,000 head in a single shift. The following outlines the benefits shown in each of the tables:

- Table 8 shows a net return of between 1.07 and 1.36-years payback for plants that do not spray chill and between 1.78 and 2.01 years for a plant with spray chilling installed.
- Table 9 shows the benefit per head varies between $5.00 and $9.40/head depending on the differing shrink levels and the throughput benefits.
- Table 10 outlines the key variables.

*Table 8: Lamb plant ROI of 7 zone Rapid Chill for carcases*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 972,000 | | 972,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $9,800,870 | | $9,800,870 | |
| Gross return Per head | $7.43 | $9.40 | $5.01 | $5.66 |
| Total costs Per head | $1.01 | | $1.01 | |
| Net Benefit Per head | $6.42 | $8.39 | $4.00 | $4.65 |
| Annual Net Benefit for the plant | $ 6,240,045 | $ 8,157,706 | $ 3,884,159 | $ 4,520,085 |
| Annual Net Benefit for the ex cap | $ 7,220,132 | $ 9,137,793 | $ 4,864,246 | $ 5,500,172 |
| Pay back (years) | 1.36 | 1.07 | 2.01 | 1.78 |
| Net Present Value of investment | $40,910,312 | $54,379,162 | $24,380,468 | $28,846,948 |

*Table 9: Lamb plant business impact of installing 7 zone Rapid Chill for carcases*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.71 | $1.55 | $1.71 | $1.55 |
| | Reduced carcase shrink | $3.60 | $5.10 | $1.18 | $1.36 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **$ Benefit per head** | **$7.43** | **$9.40** | **$5.00** | **$5.66** |
| **$ Annual Benefit overall plant** | | **$7,220,132** | **$9,137,793** | **$4,864,246** | **$5,500,172** |

*Table 10: 7 zone unit processing plant assumptions*

| Plant Specifics | | |
|---|---|---|
| System Size | Large System | |
| Percentage lamb processed | 80% | |
| Current daily processing volume | 3,600 | |
| | From | To |
| Increased throughput | 10% | 15% |

## Purchased 7 zone unit – Single shift mutton plant

The scenario is based off a mutton processor purchasing a 7-zone unit to process 972,000 head per year. A different carcase pricing has been used than the lamb plant. The following outlines the benefits shown in each of the tables:

- Table 11 shows a net return of between 2.50 and 2.89-years payback for plants that do not spray chill and between 1.58 and 2.29 years for a plant with spray chilling installed or hot boning.
- Table 12 shows the variation in benefits per head which varies between $3.48 and $5.45/head depending on the differing shrink levels and the throughput benefits.
- Table 13 outlines the key variables.

*Table 11: Mutton plant ROI of 7 zone Rapid Chill for carcases*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 972,000 | | 972,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $9,800,870 | | $9,800,870 | |
| Gross return Per head | $4.40 | $5.45 | $3.49 | $4.03 |
| Total costs Per head | $1.01 | | $1.01 | |
| Net Benefit Per head | $3.40 | $4.44 | $2.48 | $3.02 |
| Annual Net Benefit for the plant | $ 3,300,888 | $ 4,312,791 | $ 2,406,687 | $ 2,932,907 |
| Annual Net Benefit for the ex cap | $ 4,280,975 | $ 5,292,878 | $ 3,386,774 | $ 3,912,994 |
| Pay back (years) | 2.29 | 1.85 | 2.89 | 2.50 |
| Net Present Value of investment | $20,266,909 | $27,374,089 | $14,003,325 | $17,699,276 |

*Table 12: Mutton plant business impact of installing 7 zone Rapid Chill for carcases*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.71 | $1.55 | $1.71 | $1.55 |
| | Reduced carcase shrink | $1.37 | $1.93 | $0.45 | $0.52 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.00 | $0.00 | $0.00 | $0.00 |
| | Market Access Price Differential | $0.00 | $0.00 | $0.00 | $0.00 |
| | Short Life Export Freezing | $0.00 | $0.00 | $0.00 | $0.00 |
| | Markdowns | $0.00 | $0.00 | $0.00 | $0.00 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **$ Benefit per head** | **$4.40** | **$5.45** | **$3.48** | **$4.03** |
| **$ Annual Benefit overall plant** | | **$4,280,975** | **$5,292,878** | **$3,386,774** | **$3,912,994** |

*Table 13: Mutton processing plant assumptions for modelling*

| Plant Specifics | | |
|---|---|---|
| System Size | Large System | |
| Percentage lamb processed | 0% | |
| Current daily processing volume | 3,600 | |
| | From | To |
| Increased throughput | 10% | 15% |

### Purchased small 2 zone unit — Small lamb plant (40/hour)

The current scenario is based off a processor utilising a small entry level 2 zone unit, chilling 40 head per hour with an estimated annual kill of 54,000 head per year based on lamb pricing. This system could also be utilised for offal with some design tweaks. The following outlines the benefits:

- With the estimated cost of $1 million for the small system, Table 14 shows a net return of between 1.85 and 2.34-years payback for plants that do not spray chill and between 3.29 and 3.65 years for plants with spray chilling installed or hot boning.
- Table 15 shows the benefits per head which varies between $5.62 and $9.99/head depending on the shrink and the throughput benefits.
- Table 16 outlines the assumptions for this scenario.

*Table 14: Smallstock two zone systems, capable of processing 40 head / hour*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 54,000 | | 54,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $1,000,000 | | $1,000,000 | |
| Gross return Per head | $7.92 | $9.99 | $5.12 | $5.66 |
| Total costs Per head | $1.85 | | $1.90 | |
| Net Benefit Per head | $6.07 | $8.13 | $3.22 | $3.77 |
| Annual Net Benefit for the plant | $ 327,527 | $ 439,220 | $ 174,069 | $ 203,499 |
| Annual Net Benefit for the ex cap | $ 427,527 | $ 539,220 | $ 274,069 | $ 303,499 |
| Pay back (years) | 2.34 | 1.85 | 3.65 | 3.29 |
| Net Present Value of investment | $2,002,769 | $2,787,258 | $941,857 | $1,148,560 |

*Table 15: Smallstock business benefit for one zone unit*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.64 | $1.34 | $1.64 | $1.34 |
| | Reduced carcase shrink | $4.16 | $5.90 | $1.36 | $1.57 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | $0.00 | $0.00 | -$0.04 | -$0.04 |
| | **$ Benefit per head** | **$7.92** | **$9.99** | **$5.08** | **$5.62** |
| **$ Annual Benefit overall plant** | | **$427,527** | **$539,220** | **$274,069** | **$303,499** |

*Table 16: Assumptions for modelling small plant annual benefit*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 100% | |
| Current daily processing volume | 200 | |
| | From | To |
| Increased throughput | 10% | 15% |

### Purchased 2 Zone unit for chilled airfreight carcase exports – Small to medium lamb plant (144/hour)

The modelling of the benefits for this scenario is based on a processor purchasing a 2 Zone unit and chilling 144 head per hour with an estimated annual kill of 54,000 head in a single shift using lamb pricing. This type of system would be ideal for plants wanting to increase capacity and test the functionality without investing in the full system. The following outlines the benefits shown in each of the tables:

- With an estimated purchase price of $4 million for the 2 Zone system, Table 17 shows a net return of between 1.25 and 1.58-years payback for plants that do not spray chill and between 2.21 and 2.45 years for a plant with spray chilling installed.
- Table 18 shows the benefits per head which varies between $5.62 and $9.99/head depending on the differing shrink levels and the throughput benefits.
- Table 19 outlines processing plant assumptions.

*Table 17: Modelling for expansion of chilled carcase sales at a small to medium plant*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 319,680 | | 319,680 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $4,000,000 | | $4,000,000 | |
| Gross return Per head | $7.92 | $9.99 | $5.12 | $5.66 |
| Total costs Per head | $1.25 | | $1.26 | |
| Net Benefit Per head | $6.67 | $8.73 | $3.86 | $4.41 |
| Annual Net Benefit for the plant | $ 2,130,958 | $ 2,792,184 | $ 1,234,335 | $ 1,408,559 |
| Annual Net Benefit for the ex cap | $ 2,530,958 | $ 3,192,184 | $ 1,634,335 | $ 1,808,559 |
| Pay back (years) | 1.58 | 1.25 | 2.45 | 2.21 |
| Net Present Value of investment | $13,776,392 | $18,420,567 | $7,495,795 | $8,719,475 |

*Table 18: Total plant benefit for expansion of chilled carcase sales*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.64 | $1.34 | $1.64 | $1.34 |
| | Reduced carcase shrink | $4.16 | $5.90 | $1.36 | $1.57 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | $0.00 | $0.00 | -$0.01 | -$0.01 |
| | **$ Benefit per head** | **$7.92** | **$9.99** | **$5.11** | **$5.66** |
| **$ Annual Benefit overall plant** | | **$2,530,958** | **$3,192,184** | **$1,634,335** | **$1,808,559** |

*Table 19: Assumptions for small to medium lamb plant*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 100% | |
| Current daily processing volume | 1,184 | |
| | From | To |
| Increased throughput | 10% | 15% |

### Leased 7 zone unit – Single shift lamb

This scenario is based off a processor utilising a 7-zone unit to process 972,000 head per year running in a single shift, with the plant paying $2.50/head as a leasing fee. The following outlines the benefits shown in each of the tables:

- Table 20 shows an annual benefit of between $4.8 and $6.7 million for plants that do not spray chill and between $2.43 and $3 million for a plant with spray chilling installed. There are no capital costs requirements for the installation of the system.
- Table 21 shows the benefits per head which vary between $2.50 and $6.90/head depending on the differing shrink levels and the throughput benefits.
- Table 22 are the processing plant assumptions used in modelling this scenario.

*Table 20: Modelling for expansion of chilled carcase sales at a large lamb plant leasing the system*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 972,000 | | 972,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $0 | | $0 | |
| Gross return Per head | $7.43 | $9.40 | $5.01 | $5.66 |
| Total costs Per head | $2.50 | | $2.50 | |
| Net Benefit Per head | $4.93 | $6.90 | $2.50 | $3.16 |
| Annual Net Benefit for the plant | $ 4,790,132 | $ 6,707,793 | $ 2,434,246 | $ 3,070,172 |
| Annual Net Benefit for the ex cap | $ 4,790,132 | $ 6,707,793 | $ 2,434,246 | $ 3,070,172 |
| Pay back (years) | 0.00 | 0.00 | 0.00 | 0.00 |
| Net Present Value of investment | $50,711,182 | $64,180,032 | $34,181,338 | $38,647,818 |

*Table 21: Total plant benefit for expansion of chilled carcase sales*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| Benefit summary | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.71 | $1.55 | $1.71 | $1.55 |
| | Reduced carcase shrink | $3.60 | $5.10 | $1.18 | $1.36 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | -$2.50 | -$2.50 | -$2.50 | -$2.50 |
| | **$ Benefit per head** | **$4.93** | **$6.90** | **$2.50** | **$3.16** |
| **$ Annual Benefit overall plant** | | **$4,790,132** | **$6,707,793** | **$2,434,246** | **$3,070,172** |

*Table 22: Assumptions for large processing plant leasing the system*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 80% | |
| Current daily processing volume | 3,600 | |
| | From | To |
| Increased throughput | 10% | 15% |

| | |
|---|---|
| Cost per head | $ 2.50 |

### Leased 7 zone unit – Single shift mutton plant

A mutton processor with a 7-zone unit processing 972,000 head per year in a single shift and paying $2.00/head as a leasing fee has benefits as shown in the tables below. The fee has been reduced from $2.50 per head in the lamb plant to $2.00 per head in the mutton plant, enabling the plant to remain profitable on a per head basis.

- Table 23 shows an annual benefit of between $2.3 and $3.45 million for plants that do not spray chill and between $1.4 and $1.97million for a plant with spray chilling installed, with no capital costs requirements for the installation of the system.
- Table 24 shows the variation in benefits per head which varies between $1.48 and $3.45/head depending on the differing shrink levels and the throughput benefits.
- Table 25 provides an outline of the processing plant assumptions for this scenario.

*Table 23: Modelling for expansion of a large mutton processing plant leasing the system*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 972,000 | | 972,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $0 | | $0 | |
| Gross return Per head | $4.40 | $5.45 | $3.49 | $4.03 |
| Total costs Per head | $2.00 | | $2.00 | |
| Net Benefit Per head | $2.40 | $3.45 | $1.48 | $2.03 |
| Annual Net Benefit for the plant | $ 2,336,975 | $ 3,348,878 | $ 1,442,774 | $ 1,968,994 |
| Annual Net Benefit for the ex cap | $ 2,336,975 | $ 3,348,878 | $ 1,442,774 | $ 1,968,994 |
| Pay back (years) | 0.00 | 0.00 | 0.00 | 0.00 |
| Net Present Value of investment | $30,067,779 | $37,174,959 | $23,804,195 | $27,500,146 |

*Table 24: Total plant benefit for expansion of processing*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd<br>From | $/hd<br>To | $/hd<br>From | $/hd<br>To |
| Processing benefits | Reduced Electricity cost | $1.71 | $1.55 | $1.71 | $1.55 |
| | Reduced carcase shrink | $1.37 | $1.93 | $0.45 | $0.52 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.00 | $0.00 | $0.00 | $0.00 |
| | Market Access Price Differential | $0.00 | $0.00 | $0.00 | $0.00 |
| | Short Life Export Freezing | $0.00 | $0.00 | $0.00 | $0.00 |
| | Markdowns | $0.00 | $0.00 | $0.00 | $0.00 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | -$2.00 | -$2.00 | -$2.00 | -$2.00 |
| | **$ Benefit per head** | **$2.40** | **$3.45** | **$1.48** | **$2.03** |
| **$ Annual Benefit overall plant** | | **$2,336,975** | **$3,348,878** | **$1,442,774** | **$1,968,994** |

*Table 25: Assumptions for large processing plant leasing the system*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 0% | |
| Current daily processing volume | 3,600 | |
| | From | To |
| Increased throughput | 10% | 15% |
| | | |
| Cost per head | $ 2.00 | |

### Leased 2 Zone unit – Small to medium lamb plant (144/hour)

The following tables model the benefits for a lamb processor utilising a 2-zone unit to process 319,680 head per year in a single shift, based on the plant paying $2.50/head as a leasing fee.

- Table 26 shows an annual benefit of between $1.7 and $2.4 million for plants that do not spray chill and between $835,000 and $1million for a plant with spray chilling installed, with no capital costs requirements for the installation of the system.
- Table 27 shows the benefits per head which varies between $2.61 and $7.49/head depending on the differing shrink levels and the throughput benefits.
- Table 28 outlines the assumptions for the modelling of the benefits for the small to medium lamb plant.

*Table 26: Modelling for expansion of chilled carcase sales at a small to medium plant*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 319,680 | | 319,680 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $0 | | $0 | |
| Gross return Per head | $7.92 | $9.99 | $5.12 | $5.66 |
| Total costs Per head | $2.50 | | $2.51 | |
| Net Benefit Per head | $5.42 | $7.49 | $2.61 | $3.16 |
| Annual Net Benefit for the plant | $ 1,731,758 | $ 2,392,984 | $ 835,135 | $ 1,009,359 |
| Annual Net Benefit for the ex cap | $ 1,731,758 | $ 2,392,984 | $ 835,135 | $ 1,009,359 |
| Pay back (years) | 0.00 | 0.00 | 0.00 | 0.00 |
| Net Present Value of investment | $17,776,392 | $22,420,567 | $11,495,795 | $12,719,475 |

*Table 27: Total plant benefit for expansion of chilled carcase sales*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd From | $/hd To | $/hd From | $/hd To |
| Processing benefits | Reduced Electricity cost | $1.64 | $1.34 | $1.64 | $1.34 |
| | Reduced carcase shrink | $4.16 | $5.90 | $1.36 | $1.57 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | -$2.50 | -$2.50 | -$2.51 | -$2.51 |
| | **$ Benefit per head** | **$5.42** | **$7.49** | **$2.61** | **$3.16** |
| **$ Annual Benefit overall plant** | | **$1,731,758** | **$2,392,984** | **$835,135** | **$1,009,359** |

*Table 28: Assumptions for the small to medium lamb plant*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 100% | |
| Current daily processing volume | 1,184 | |
| | From | To |
| Increased throughput | 10% | 15% |

### Leased Entry level 2 zone unit – Small lamb plant (40/hour)

A lamb processor with a small entry 2 zone unit chilling 40 head per hour with an estimated annual kill of 54,000 head, with a leased system at $4 per head has potential benefits to the business shown in the Tables below. This system could also be utilised for offal. The following outlines the benefits shown in each of the tables:

- With the estimated $4/head to lease the system, Table 29 shows an annual benefit of between $211,000 and $323,200/year for plants that do not spray chill and between $58,000 and $87,499 for a plant with spray chilling installed or that is hot boning.
- The variation in benefits per head ranges from between $1.62 and $5.99/head depending on the differing shrink levels and the throughput benefits.
- Table 16 outlines the plant process assumptions.

*Table 29: Smallstock entry level unit ROI*

| SUMMARY PERFORMANCE MEASURES | | | | |
|---|---|---|---|---|
| | No-Spray chilling | | Spray chilling | |
| Hd / annum | 54,000 | | 54,000 | |
| | From | To | From | To |
| Capital cost (pmt option, upfront) | $0 | | $0 | |
| Gross return Per head | $7.92 | $9.99 | $5.12 | $5.66 |
| Total costs Per head | $4.00 | | $4.04 | |
| Net Benefit Per head | $3.92 | $5.99 | $1.08 | $1.62 |
| Annual Net Benefit for the plant | $ 211,527 | $ 323,220 | $ 58,069 | $ 87,499 |
| Annual Net Benefit for the ex cap | $ 211,527 | $ 323,220 | $ 58,069 | $ 87,499 |
| Pay back (years) | 0.00 | 0.00 | 0.00 | 0.00 |
| Net Present Value of investment | $3,002,769 | $3,787,258 | $1,941,857 | $2,148,560 |

*Table 30: Smallstock business benefit for entry level unit*

| TOTAL BENEFIT | | | | | |
|---|---|---|---|---|---|
| | | No-Spray chilling | | Spray chilling | |
| **Benefit summary** | | $/hd<br>From | $/hd<br>To | $/hd<br>From | $/hd<br>To |
| Processing benefits | Reduced Electricity cost | $1.64 | $1.34 | $1.64 | $1.34 |
| | Reduced carcase shrink | $4.16 | $5.90 | $1.36 | $1.57 |
| | Gross margin on additional livestock | $0.45 | $0.65 | $0.45 | $0.65 |
| | Reduced overhead costs per head | $0.87 | $1.31 | $0.87 | $1.31 |
| | Airfreight $/kg Differential | $0.02 | $0.02 | $0.02 | $0.02 |
| | Market Access Price Differential | $0.28 | $0.28 | $0.28 | $0.28 |
| | Short Life Export Freezing | $0.45 | $0.45 | $0.45 | $0.45 |
| | Markdowns | $0.04 | $0.04 | $0.04 | $0.04 |
| **Throughput costs - Chiller costs only** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **OH&S costs** | | $0.00 | $0.00 | $0.00 | $0.00 |
| **Labour costs** | **Chiller Automation** | $0.00 | $0.00 | $0.00 | $0.00 |
| **Equipment costs** | **Maintenance** | $0.00 | $0.00 | $0.00 | $0.00 |
| | **Operation** | -$4.00 | -$4.00 | -$4.04 | -$4.04 |
| | **$ Benefit per head** | **$3.92** | **$5.99** | **$1.08** | **$1.62** |
| **$ Annual Benefit overall plant** | | **$211,527** | **$323,220** | **$58,069** | **$87,499** |

*Table 31: Assumptions for modelling the small plant benefits scenario*

| Plant Specifics | | |
|---|---|---|
| System Size | Small System | |
| Percentage lamb processed | 100% | |
| Current daily processing volume | 200 | |
| | From | To |
| Increased throughput | 10% | 15% |
| | | |
| Cost per head | $ 4.00 | |

## Benefit calculations

The benefits included for the above rapid chilling scenarios are based on the calculations outlined in this section.

Table 32 shows the baseline price for mutton and lamb carcases, utilised within the model. The following outlines the benefits included in the benefit scenario calculations:

- Reduction in electricity consumed within the plant through more controlled chilling and processing of carcases.
- Reduced carcase shrink through optimisation of the rapid chilling system (down from 2%).
- In Australia, carcase chilling capacity is a limiting factor to increase throughput. The Rapid Chill system could increase processing plant capacity due to removal of the chilling bottle neck. The following outlines the benefits associated with this area:
  - Increased gross margin on carcases currently processed due to a reduction in fixed costs allocation.
  - The gross margin on the additional animals processed, this is based on a 10 to 15% increase in processing capacity.
- It is anticipated that the rapid chilling of carcases should increase shelf-life of products. The following outline benefits attributed to increase shelf-life:
  - Reduction in airfreight from extending the shelf-life of product and reducing chiller airfreight requirements.
  - Market access price differential through selling higher volumes of chilled cuts.
  - Reduction in product being frozen due to limited shelf-life remaining.
  - Reduction in markdowns of product resulting from an increase in shelf-life for domestic product.

*Table 32: Whole carcase price utilised by the model for lamb and mutton*

| **Model Template** | | |
|---|---|---|
| Average discount level | | 20% |
| Cut | $/kg | Discount Value |
| Whole Carcass - Lamb | $11.41 | $9.13 |
| Whole Carcass - Mutton | $3.74 | |

### Electricity Benefits

The electricity benefits for processing plants with the installation of a Rapid Chill tunnel are expected to be sizable. Figure 12 shows the estimated increase in electricity and gas costs as the cost of power increases. Utilising plant processing data for carcase chilling and storage, which is shown in Table 33, the current cost to chill and store carcases is calculated at $1.81/head for lamb processing. The 7 zone system is expected to draw 561KW with a cost between $0.10 and $0.39/head to chill carcases with an optimised system costing as low as $0.10/head cost to chill. Using these assumptions equates to the following benefits:

- Kill and bone same day benefit between $1.42 and 1.71/head benefit
- Kill and bone the following day would benefit a business between $1.00 and $1.29/head.

The benefits within the scenarios are based off the system having the capacity to process carcases within an hour. The cost of electricity has been based off $0.15/kWh which is conservative in the current market.

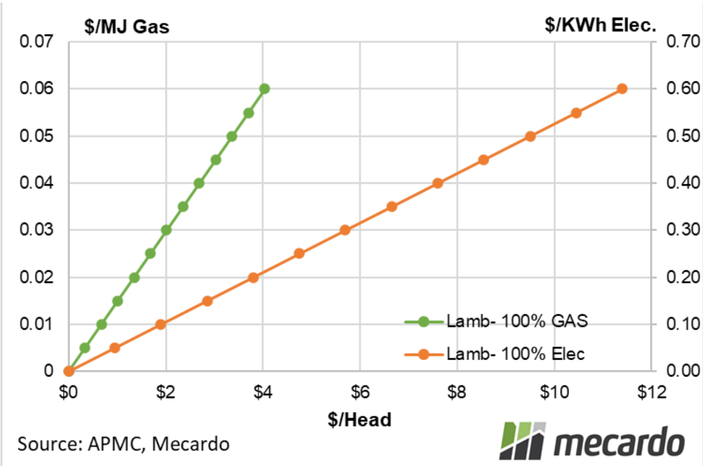



*Figure 13: Australian lamb processing cost per head for energy usage*

*Table 33: Electricity usage benefits associated with the adoption of the Rapid Chilling tunnel*

| **Conventional chilling** | | | | | | |
|---|---|---|---|---|---|---|
| Cost per kWh | $ 0.15 | | | | | |
| | Hourly | Daily | Daily cost | Daily KG's | Cost per KG | Sheep costs |
| Carcase storage kWh (hourly) | 525 | 6,299 | $ 945 | 48,436 | $ 0.02 | $ 0.42 |
| Carcase chilling + storage (hourly usa | 580 | 20,890 | $ 3,133 | 48,436 | $ 0.06 | $ 1.39 |
| Total | | 27,189 | $ 4,078 | 48,436 | 0.08 | $ 1.81 |

| Rapid chilling system - 7 or 9 zone unit | | | | | | |
|---|---|---|---|---|---|---|
| System Details | Chilling time 0.75 (hrs) - Number of zones 7 | Chilling time 1 (hrs) - Number of zones 9 | Chilling time 1.5 (hrs) - Number of zones 9 | Chilling time 2 (hrs) - Number of zones 9 | Chilling time 2.5 (hrs) - Number of zones 9 | Chilling time 3 (hrs) - Number of zones 9 |
| Hours chilling time | 0.75 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| Carcases per zone | 72.00 | 72.00 | 72.00 | 72.00 | 72.00 | 72.00 |
| Number of zones | 7.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Carcase per minute | 11.20 | 10.80 | 7.20 | 5.40 | 4.32 | 3.60 |
| Carcase per hour | 672 | 648 | 432 | 324 | 259 | 216 |
| Carcase per shift (8 hours production | 5,376 | 5,184 | 3,456 | 2,592 | 2,074 | 1,728 |

| **Rapid chill power usage** | | | | | | |
|---|---|---|---|---|---|---|
| kWh draw | 441 | 561 | 561 | 561 | 561 | 561 |
| kWh draw per carcase - Rapid chill | 0.66 | 0.87 | 1.30 | 1.73 | 2.16 | 2.60 |
| Cost per carcase | $ 0.10 | $ 0.13 | $ 0.19 | $ 0.26 | $ 0.32 | $ 0.39 |

| **Conventional** | | | | | | |
|---|---|---|---|---|---|---|
| kWh draw per carcase - Chilling | 9.28 | 9.28 | 9.28 | 9.28 | 9.28 | 9.28 |
| kWh draw per carcase - Storage | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 |
| Total | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Power cost per head - Chill | $ 1.39 | $ 1.39 | $ 1.39 | $ 1.39 | $ 1.39 | $ 1.39 |
| Power cost per head - Carcase storag | $ 0.42 | $ 0.42 | $ 0.42 | $ 0.42 | $ 0.42 | $ 0.42 |
| Total | $ 1.81 | $ 1.81 | $ 1.81 | $ 1.81 | $ 1.81 | $ 1.81 |

| **Benefit per head** | | | | | | |
|---|---|---|---|---|---|---|
| | Chilling time 0.75 (hrs) - Number of zones 7 | Chilling time 1 (hrs) - Number of zones 9 | Chilling time 1.5 (hrs) - Number of zones 9 | Chilling time 2 (hrs) - Number of zones 9 | Chilling time 2.5 (hrs) - Number of zones 9 | Chilling time 3 (hrs) - Number of zones 9 |
| Benefit - Kill and bone same day | $ 1.71 | $ 1.68 | $ 1.62 | $ 1.55 | $ 1.49 | $ 1.42 |
| Benefit - Kill and bone next day | $ 1.29 | $ 1.26 | $ 1.20 | $ 1.13 | $ 1.07 | $ 1.00 |

# 7.0 Discussion

## Eating Quality Traits

To mitigate cold shortening, carcases need to be at or below 0°C within 5 hours (Jacob et al. 2012). From measurements taken during the research trials at Mildura, the researchers hypothesised based on the existing published literature that the loin won't cold shorten because of the rapid drop in its temperature; however, the bolar blade and topside might cold shorten. As the loin is a grilling cut and the topside and bolar blade are generally slow roasting cuts this shouldn't be a major issue for the consumer. Further research is required once the first purpose-built carcase chilling system has been installed as the compressors will be 5⁺ times more powerful than the retro-fitted fruit chilling system. Jacob et al. (2012) identified low shear force was recorded in loins when cooled to less than 0° at 1.5 hours postmortem which aligns with the findings from the UNE meat science analysis undertaken in this project.

The research at Mildura in the retro-fitted tunnel aligns with other fast chilling research undertaken by Yan et al. (2022) where there were no significant differences or negative impact in shear force in the very fast chilled muscles at the 24-hour mark.

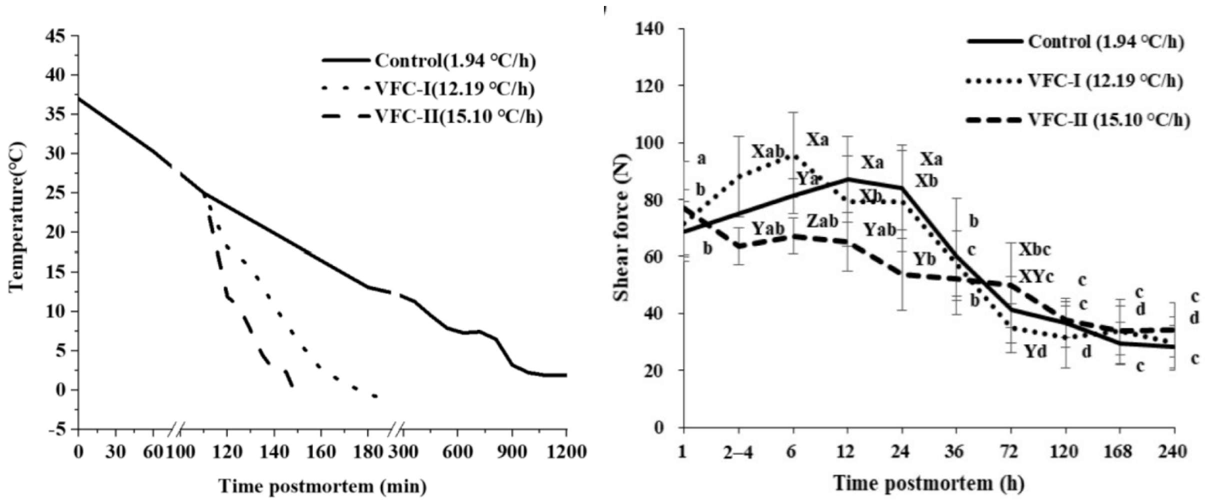



*Figure 14: Temperature decline and shear forces results from Yan et al. (2022) for testing completed in silverside muscles*

In the Mildura research trial the conventionally chilled control had a higher shear force than the Rapid Chilled treatment carcases for the *longissimus lumborum* (LL) – loin muscle which had been aged for 5 days. Thus, the rapid chilling process improved eating quality through lowering the shear force.

The results of the trial at Mildura showed that the Rapid Chilling system can chill carcases to 0°C within 5 hours meaning the meat wasn't cold shortened. The size of the carcase and fat depth of the carcase impacts the rate of chilling. The design of the commercial system for carcases will need to include adjustments for time and temperature based on carcase characteristics to ensure that carcases are not cold shortened if they are large, very fat carcases.

## Impact of trial results on commercial adoption

1. During the Mildura trial the carcases remained in the Rapid Chill system for 5 hours. This created a hard external fat layer resulted which would prevent carcases being boned out immediately after chilling if processing plants chilled under the same conditions as in the trials. It is assumed the hard set fat could be alleviated with some of the following interventions:
    - The purpose-built system for carcases could chill faster initially to achieve the rapid chill improvements in tenderness, then slow the rate of cooling to just below freezing allowing the external to equilibrate with internal temperature
    - Adjusting the chilling environment had a significant impact between day 1 to day 2 on carcase shrink. The refinement of settings in a purpose-built system will allow for more flexibility of adjustment of the chiller settings without negatively impacting cold shortening of muscles.
2. A 2.4% increase in vacuum bag purge will impact negatively on retail cut yields.
    - Adjustment to chiller settings could also help reduce purge.
    - However, it should be noted that a driver of purge is the potential disruption of the sarcomeres resulting from the Rapid Chill system. The extent to which purge is impacted by external chilling environment is yet to be proven.

It should also be noted there is a large variation in shrink between plants, cuts of meat and chilling formats from plant to plant.

Further to this, neither the controls nor the treatment had electrical stimulation which will have some impact on purge as well. The main point being that further testing is required across all the factors positive and negative that have been reported in this project. The negative impact from this small trial may not be a big factor relative to the benefits.

3. A positive impact on extending shelf life is likely. Reduction in bacterial surface load is expected due to the extremely cold conditions. Extended shelf life is a significant financial benefit to companies as international freight times extend. Testing is required to validate the length of extension expected.
4. Although tenderness (SF) significantly improved in loins there may be a reduction in juiciness and mouthfeel because of the slightly higher purge, but this has not been tested. Anecdotal evidence based on taste tests conducted during the research trial suggests there is not a reduction in juiciness.
5. Significantly reduced chilling time could enable conventional chiller holding space to be removed or re-purposed. Downstream breakdowns could result in carcase backup. A chilled carcase buffer would be recommended to avoid slaughter floor stoppages resulting from boning room breakdowns. Depending on post-rapid chill holding times and shift schedules, it may be that carcases do not need to be held over a weekend in future. The benefits of this have not been modelled at this stage.
6. Carcase sortation post hot carcase grading to align to boning runs will require some carcase chiller space.
7. Coordination of kill agendas into groupings of livestock to boning runs is done well at a lot of plants, but if done poorly will impact on the amount of carcase holding chillers required post-rapid chill tunnel to sort into boning runs and required cut plans.

## Business case value propositions

The value proposition for the FreshXpress tunnel has been quantified by Greenleaf Enterprises. The business case for the installation of the FreshXpress Rapid Chill tunnel is influenced by each processing plants current operational constraints and chilling technology. The following outlines the list of value propositions with some operational constraints noted for each value proposition.

- **Reduction in carcase shrink**. If spray chilling is being used it is assumed there will be no gain from change in carcase shrink due to the use of Rapid Chill. If spray chilling is not installed or being used carcase shrink will be reduced. The location and configuration of the tunnel will also impact if there is a reduction in carcase shrink.
- **Reduced energy usage** when compared to conventional chilling of carcases. The following operational implications need to be tested:
    - Rapid chilling of carcases and boning the following day in alignment with the conventional process flows.
    - Rapid chilling of carcases in a two-shift operation, slaughtering in the morning and boning during night shift, reducing chiller space requirements and enabling carcases chillers to be turned off over-night.
    - Rapid chilling carcases with an offset time period between slaughter and boning 3 to 4 hours after carcases enter the chilling unit to enable carcases to be slaughtered and boned on the same day. This will reduce the carcases chilling capacity required.
- **Reduced labour** required in the processing plant through the automation of the carcase chilling process. This will be impacted by the different process flows utilised in plant.
- **Throughput increase** by increasing carcase chilling capacity at plants will result in the following benefits:
    - Reduction in fixed cost per head allocation due to increase processing capacity.
    - Increasing plant profits through the increase in carcases processed.
    - Labour and throughput requirements by the plant will need to be considered as part of a future commercial installation.
- **Quicker time to freeze** carcases or cartons particularly if previously processing hot or on the curve.
- **Offal temperature reduction:** by designing the tunnel to enable offal chilling simultaneously with carcase chilling:
    - Improved offal quality.
    - Reduced overall freezing capacity requirements as offal temperature is reduced prior to plate or blast freezing – reducing the need for capital investment to cope with additional offal and product volumes packed and frozen.
- **Reduced days aging** - Depending on the 3- and 5-days aging impact on the shear force results, there may also be a benefit of reduced aging requirements for aged frozen products. In that, if there is no difference in the quality of the product between 3 and 5 days (based on the MSA aging requirements), the product could be frozen 2 days earlier, reducing the capacity required in carton chillers.
- **Longer shelf life** - Increase in chilled product shelf-life resulting in:
    - an increased percentage of products being sold as chilled with an increased price,

    - reduced necessity in the use of airfreight for some products.
- **Carton rapid chill benefits not directly costed** – Although rapid chilling of cartons provides additional advantages, they have in some ways already been captured in the Throughput and Shelf-life benefit areas. Given there are still some points like purge and juiciness to be confirmed, carton rapid chill benefits have not been modelled.

### Carcase shrink benefits

The Rapid Chilling technology can reduce carcase shrink to a negligible level. Table 34 shows the expected benefits from a reduction in carcase shrink when compared to the systems with and without Rapid Chilling systems for lambs and mutton. The value opportunity needs to be verified throughout future stages of development to optimise the temperature and humidity of the Rapid Chilling tunnel to minimise the carcase shrink.

*Table 34: Benefit calculations associated with a reduction in carcases shrink through an optimised system*

| Lambs | | | | |
|---|---|---|---|---|
| | No Spray chilling | | With Spray chilling | |
| | From | To | From | To |
| Average carcase weight | 23.00 | 23.00 | 23.00 | 23.00 |
| Conventional shrink | 2.1% | 3.1% | 0.8% | 1.0% |
| Rapid chill shrink | 0.1% | 0.3% | 0.1% | 0.3% |
| Weight gain/loss on the carcase | 0.46 | 0.65 | 0.15 | 0.17 |
| Value ($/kg) | $ 11.41 | $ 11.41 | $ 11.41 | $ 11.41 |
| | | | | |
| Benefit per head ($/head) | $ 5.20 | $ 7.37 | $ 1.71 | $ 1.97 |

| Mutton | | | | |
|---|---|---|---|---|
| | No Spray chilling | | With Spray chilling | |
| | From | To | From | To |
| Average carcase weight | 23.00 | 23.00 | 23.00 | 23.00 |
| Conventional shrink | 2.1% | 3.1% | 0.8% | 1.0% |
| Rapid chill shrink | 0.1% | 0.3% | 0.1% | 0.3% |
| Weight gain/loss on the carcase | 0.46 | 0.65 | 0.15 | 0.17 |
| Value ($/kg) | $ 3.74 | $ 3.74 | $ 3.74 | $ 3.74 |
| | | | | |
| Benefit per head ($/head) | $ 1.71 | $ 2.42 | $ 0.56 | $ 0.65 |

## Increased throughput benefits

There is an anticipated increase in processing capacity for plants which install a Rapid Chill system due to carcase chillers being a bottleneck in many plants. The benefits related to an increase in processing capacity are listed in Table 35. The assumptions applied in the model are a 10 to 15% increase in capacity due to the use of a Rapid Chill system.

- Reduction in **fixed cost allocation** per head. The figures are based on the last cost of industry report commissioned by AMPC showing that as the processor increases production, the cost per head of fixed costs is decreased per head due to the higher numbers being processed, see Table 35 for details.
- The **gross margin** on the increased volume processed can be seen in Table 36. The benefit is based on a $5/head gross margin which will vary depending on market dynamics. Each individual processor undertaking a BCA to understand the benefits of technology will need to adjust the benefit based on their gross margin per head.

*Table 35: Fixed cost variation*

Overhead cost allocation per head reduction - From

| Industry average cost components | Amount per head | Cost allocation |
|---|---|---|
| **Labour costs** | | |
| Processing Wages | $ 16.89 | Variable |
| Salaries | $ 2.37 | Fixed |
| Payroll tax | $ 0.83 | Variable |
| Workers compensation | $ 0.97 | Variable |
| Retirement Benefits | $ 1.39 | Variable |
| **Utility related costs** | | |
| Electricity | $ 0.81 | Fixed |
| Other Fuel | $ 0.57 | Fixed |
| Water & Sewerage | $ 0.28 | Fixed |
| Waste disposal | $ 0.74 | Fixed |
| **Additional costs to the business** | | |
| Certification/audit costs | $ 1.26 | Fixed |
| Packaging | $ 3.66 | Variable |
| Transport | $ 6.10 | Variable |
| Repairs & Mainenance | $ 1.91 | Fixed |
| Processing consumables | $ 1.71 | Variable |
| Other costs | $ 1.18 | Fixed |

| | |
|---|---|
| Average weight per head | 23 |
| Increase in throughput | 10.00% |

| | Cost per head | Cost per KG |
|---|---|---|
| Variable | $ 31.55 | $ 1.37 |
| Fixed | $ 9.12 | $ 0.40 |

| Variable | Lamb | Hogget | Mutton | Overall benefit |
|---|---|---|---|---|
| HSCW | 22.00 | 22.00 | 22.00 | |
| System Accuracy | 100% | 100% | 100% | |
| Percentage of population | 0% | 0% | 100% | |
| | | | | |
| Current costs | $ 38.90 | $ 38.90 | $ 38.90 | |
| Variable | $ 30.18 | $ 30.18 | $ 30.18 | |
| Fixed | $ 8.72 | $ 8.72 | $ 8.72 | |
| | | | | |
| New costs per head | $ 38.03 | $ 38.03 | $ 38.03 | |
| Variable | $ 30.18 | $ 30.18 | $ 30.18 | |
| Fixed | $ 7.85 | $ 7.85 | $ 7.85 | |
| | | | | |
| Benefit per head | $ 0.87 | $ 0.87 | $ 0.87 | $ - |
| Variable | $ - | $ - | $ - | $ - |
| Fixed | $ 0.87 | $ 0.87 | $ 0.87 | $ 0.87 |

*Table 36: Gross margin on additional head processed*

| | From | To |
|---|---|---|
| Gross Margin per head | $5.00 | $5.00 |
| Increased throughput | 10% | 15% |
| Current Number of head | 3,600 | 3,600 |
| Number of head | 3,960 | 4,140 |
| | | |
| Benefit per head processed | $ 0.45 | $ 0.65 |

### Shelf-life related product benefits

Most of the product value benefits are due to increased product shelf life which impacts market access, customer mix and product price differentials. All these factors vary widely between processors. The assumptions in the following scenarios should be used as an indication only and should be adapted to each specific processor supply chain. Table 37 provides alternative scenario models where some of the following value propositions will apply to only some supply chains. This sensitivity gives a clear understanding of the impact that each area of benefit will have on the overall investment in Rapid Chilling technology. In future research, shelf-life trials need to be completed to verify the impact of the Rapid Chilling system on product shelf-life.

The next sections explain the assumptions underpinning each benefit area.

#### Extension of shelf life – Converting a portion of airfreight to sea freight

A portion of chilled product for a selection of customers requires air freight shipment to provide the minimum shelf life required. If shelf life was extended, some customers would be able to accept sea freight shipments which would reduce the supply chain cost. The following assumptions have been made when estimating the value of extending shelf life:

- Freight differential between sea and air freight has been estimated at $1.73/kg.
- Chilled products comprise of 46% of total product sales.
- Export equates to 75% of product sales.
- Of the export chilled product sales, 10% is air freight.
- Of air freight sales, 20% could be converted to sea freight if shelf life was extended by 20 days.

#### Extension of shelf life – Reduced risk of freezing due to longer shipping times

Length of shipping transit times has always been a juggle for certain products and some international destinations. With the recent freight logistic challenges this has had a negative impact on processors with accounts of boats being cancelled and transit times to the USA increasing from 50 days to 75 days as examples.

Processors have had to freeze chilled containers of product due to limited remaining shelf life. This has been an increase in processing and storage costs and a reduction in product value.

This benefit area has not included any additional processing costs. Reduced product sales value assumptions include:

- Chilled products comprise of 46% of total product sales.
- Export equates to 75% of product sales.
- Of the export chilled product sales, 5% is converted from chilled to frozen on arrival at destination.
- Overall impact on carcase value is $1.81 or 0.7% of total carcase value.

### Extension of shelf life – Reduced markdowns and dumps for retail product

Retailers' markdown product when it comes close to end of shelf life to try and sell it before it needs to be dumped (disposed of). This process varies between retailers but it can be 6-9% of sales. Markdowns range from 5-50% depending on the days of shelf life remaining.

The financial benefit is received by the retailer, not the processor. However, it does reflect on the processor brand and does contribute to the effectiveness of the whole value chain. The assumptions used to estimate the benefit to the supply chain include:

- Application for chilled products (46% of carcase mix).
- Retail portion of chilled products this benefit is applied to is 25%. Note some companies with retail contracts will have a significantly higher share of production this will apply to.
- Markdown value by 25%. No dumping or complete loss in value has been assumed.
- Incidence of markdowns is 7% as the baseline with a reduction in markdowns of 25%.

*Table 37: Increase in sale value of cuts due to the installation of the Rapid Chilling systems*

| Item | HAM Code | Yield (Indicative % of sales mix) | Kg's/CCW (Indicative % of sales mix) | Export Share % | Domestic Share | Portion of Export Markets Lost | Predominantly Chilled | $/kg Export Market (Chilled) | $/kg Export Market (Frozen) | Domestic Market $/kg | Market Access Price Differential | Current Shelf Life | Potential Shelf Life | Risk of Freezing Export Chilled (Short Shelf Life) | Frozen Price Differential | Client Markdown $/kg | Client % Markdown | Reduced Markdowns | Reduced Markdown Value ($/kg) (Retail % of chilled) | Pdct % Airfreight (% decrease w/ shelf life increase) | Airfreight $/kg Differential |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Assumptions** | | | | 75% | | 25% | | | 70% | 90% | | | | 5% | | 25% | 7% | 25% | 25% | 10% | $ 1.73 |
| | | | | | | | | | | | | | | | | | | | | 20% | |
| Neck | | 2.3% | 0.50 | 75.0% | 25.0% | 25.0% | | $ 7.19 | $ 7.19 | $ 6.47 | $ 0.07 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | $ 0.02 |
| Neck Bone | | 2.0% | 0.43 | 75.0% | 25.0% | 25.0% | | $ 7.39 | $ 7.39 | $ 6.65 | $ 0.06 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Neck Fillet Roast | | 1.5% | 0.32 | 75.0% | 25.0% | 25.0% | | $ 20.26 | $ 20.26 | $ 18.23 | $ 0.12 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| B/L Square Cut Shoulder | | 6.6% | 1.44 | 75.0% | 25.0% | 25.0% | Y | $ 15.13 | $ 10.59 | $ 13.62 | $ 0.41 | | | 5% | $ 4.54 | $ 3.78 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.05 |
| Shoulder Square Cut B/IN | | 12.5% | 2.75 | 75.0% | 25.0% | 25.0% | | $ 8.53 | $ 8.53 | $ 7.68 | $ 0.44 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| B/L Shoulder Oyster cut | | 0.7% | 0.15 | 75.0% | 25.0% | 25.0% | Y | $ 13.39 | $ 9.37 | $ 12.05 | $ 0.04 | | | 5% | $ 4.02 | $ 3.35 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.01 |
| B/L Shoulder Rolled | | 0.1% | 0.01 | 75.0% | 25.0% | 25.0% | | $ 14.93 | $ 14.93 | $ 13.44 | $ 0.00 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Shoulder Meat Pieces | | 2.7% | 0.60 | 75.0% | 25.0% | 25.0% | | $ 8.97 | $ 8.97 | $ 8.07 | $ 0.10 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Foreshank | | 3.7% | 0.81 | 75.0% | 25.0% | 25.0% | Y | $ 10.13 | $ 7.09 | $ 9.12 | $ 0.15 | 75 | 95 | 5% | $ 3.04 | $ 2.53 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.03 |
| Breast and Flap | | 0.2% | 0.04 | 75.0% | 25.0% | 25.0% | | $ 6.99 | $ 6.99 | $ 6.29 | $ 0.00 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Breast and Flap Pieces | | 8.8% | 1.94 | 75.0% | 25.0% | 25.0% | | $ 10.41 | $ 10.41 | $ 9.36 | $ 0.38 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Flap - 8 Rib | | 4.3% | 0.94 | 75.0% | 25.0% | 25.0% | | $ 11.56 | $ 11.56 | $ 10.41 | $ 0.20 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Rib Set | | 0.7% | 0.16 | 75.0% | 25.0% | 25.0% | | $ 7.96 | $ 7.96 | $ 7.16 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Thick Skirt & Thin Skirt | | 0.6% | 0.12 | 75.0% | 25.0% | 25.0% | | $ 8.55 | $ 8.55 | $ 7.69 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Spare Ribs 8 Rib | | 0.2% | 0.05 | 75.0% | 25.0% | 25.0% | | $ 15.01 | $ 15.01 | $ 13.51 | $ 0.01 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Rack Cap On - Frenched 8 Rib | | 5.9% | 1.30 | 75.0% | 25.0% | 25.0% | Y | $ 32.08 | $ 22.46 | $ 28.87 | $ 0.78 | | | 5% | $ 9.62 | $ 8.02 | 7.0% | 25.0% | $ 0.04 | 20% | $ 0.04 |
| Rack Cap On 8 Rib | | 0.4% | 0.09 | 75.0% | 25.0% | 25.0% | Y | $ 27.07 | $ 18.95 | $ 24.36 | $ 0.05 | | | 5% | $ 8.12 | $ 6.77 | 7.0% | 25.0% | $ 0.03 | 20% | $ 0.00 |
| B/L Rack Cap | | 0.9% | 0.20 | 75.0% | 25.0% | 25.0% | | $ 4.78 | $ 4.78 | $ 4.31 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Back Bone | | 1.4% | 0.30 | 75.0% | 25.0% | 25.0% | | $ 3.66 | $ 3.66 | $ 3.30 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| B/L Short Loin | | 1.5% | 0.33 | 75.0% | 25.0% | 25.0% | Y | $ 32.12 | $ 22.48 | $ 28.91 | $ 0.20 | | | 5% | $ 9.64 | $ 8.03 | 7.0% | 25.0% | $ 0.04 | 20% | $ 0.01 |
| Short Loin - 1 Rib | | 1.1% | 0.24 | 75.0% | 25.0% | 25.0% | Y | $ 16.50 | $ 11.55 | $ 14.85 | $ 0.07 | | | 5% | $ 4.95 | $ 4.13 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.01 |
| Short Loin Pair | | 0.3% | 0.07 | 75.0% | 25.0% | 25.0% | Y | $ 16.24 | $ 11.37 | $ 14.61 | $ 0.02 | | | 5% | $ 4.87 | $ 4.06 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.00 |
| Short Loin Pair - 1 Rib | | 0.9% | 0.21 | 75.0% | 25.0% | 25.0% | Y | $ 13.47 | $ 9.43 | $ 12.12 | $ 0.05 | | | 5% | $ 4.04 | $ 3.37 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.01 |
| Backstrap Membrane | | 0.1% | 0.02 | 75.0% | 25.0% | 25.0% | | $ 5.57 | $ 5.57 | $ 5.01 | $ 0.00 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Tenderloin | | 0.5% | 0.10 | 75.0% | 25.0% | 25.0% | Y | $ 21.90 | $ 15.33 | $ 19.71 | $ 0.04 | | | 5% | $ 6.57 | $ 5.47 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.00 |
| Rump | | 1.2% | 0.27 | 75.0% | 25.0% | 25.0% | Y | $ 18.23 | $ 12.76 | $ 16.41 | $ 0.09 | | | 5% | $ 5.47 | $ 4.56 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.01 |
| Chump B/In | | 2.2% | 0.49 | 75.0% | 25.0% | 25.0% | | $ 6.78 | $ 6.78 | $ 6.10 | $ 0.06 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Leg Femur Bone Chump Off | | 2.0% | 0.44 | 75.0% | 25.0% | 25.0% | Y | $ 12.58 | $ 8.80 | $ 11.32 | $ 0.10 | | | 5% | $ 3.77 | $ 3.14 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.02 |
| Leg Chump Off ABO | | 1.6% | 0.35 | 75.0% | 25.0% | 25.0% | Y | $ 11.82 | $ 8.28 | $ 10.64 | $ 0.08 | | | 5% | $ 3.55 | $ 2.96 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.01 |
| Leg Chump Off | | 8.3% | 1.83 | 75.0% | 25.0% | 25.0% | Y | $ 9.45 | $ 6.61 | $ 8.50 | $ 0.32 | | | 5% | $ 2.83 | $ 2.36 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.06 |
| B/L Leg Chump Off Shank Off | | 7.9% | 1.73 | 75.0% | 25.0% | 25.0% | Y | $ 13.93 | $ 9.75 | $ 12.54 | $ 0.45 | | | 5% | $ 4.18 | $ 3.48 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.06 |
| B/L Leg Chump On | | 0.3% | 0.06 | 75.0% | 25.0% | 25.0% | Y | $ 17.79 | $ 12.45 | $ 16.01 | $ 0.02 | | | 5% | $ 5.34 | $ 4.45 | 7.0% | 25.0% | $ 0.02 | 20% | $ 0.00 |
| Leg Chump On ABO | | 0.5% | 0.12 | 75.0% | 25.0% | 25.0% | Y | $ 11.41 | $ 7.99 | $ 10.27 | $ 0.03 | | | 5% | $ 3.42 | $ 2.85 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.00 |
| Leg Mixed Cuts | | 0.6% | 0.14 | 75.0% | 25.0% | 25.0% | | $ 7.32 | $ 7.32 | $ 6.59 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Leg Shank Bone | | 0.2% | 0.05 | 75.0% | 25.0% | 25.0% | | $ 9.86 | $ 9.86 | $ 8.88 | $ 0.01 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Leg Bones | | 3.4% | 0.75 | 75.0% | 25.0% | 25.0% | | $ 3.62 | $ 3.62 | $ 3.26 | $ 0.05 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Leg Tip | | 0.9% | 0.20 | 75.0% | 25.0% | 25.0% | | $ 6.36 | $ 6.36 | $ 5.72 | $ 0.02 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Hindshank | | 2.4% | 0.52 | 75.0% | 25.0% | 25.0% | Y | $ 10.54 | $ 7.38 | $ 9.49 | $ 0.10 | | | 5% | $ 3.16 | $ 2.64 | 7.0% | 25.0% | $ 0.01 | 20% | $ 0.02 |
| Carcase 6 Way | | 0.2% | 0.04 | 75.0% | 25.0% | 25.0% | | $ 9.40 | $ 9.40 | $ 8.46 | $ 0.01 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Assorted Cuts | | 0.0% | 0.01 | 75.0% | 25.0% | 25.0% | | $ - | $ - | $ - | $ - | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Bone | | 2.8% | 0.62 | 75.0% | 25.0% | 25.0% | | $ 5.81 | $ 5.81 | $ 5.22 | $ 0.07 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Trimmings | | 3.9% | 0.86 | 75.0% | 25.0% | 25.0% | | $ 6.12 | $ 6.12 | $ 5.51 | $ 0.10 | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Render | | | | 75.0% | 25.0% | 25.0% | | $ - | $ - | $ - | $ - | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| Commercial value of Defect Trim | | | | 75.0% | 25.0% | 25.0% | | $ - | $ - | $ - | $ - | | | - | $ - | - | 7.0% | 25.0% | $ - | - | - |
| **Value Created / Head** | | **98%** | **21.58** | | | | **10.05** | **$193.09** | | **$ 57.93** | **$ 1.10** | | | | **$ 1.81** | **$ 40.15** | | | **$ 0.18** | | **$ 0.06** |

## System Adoption forecasts

The size and type of system is influenced by the size of the processing plant and if the system is being used for cartons and/or carcases. Processing plants have identified the adoption will be influenced by:

- Existing plant bottlenecks,
- Target markets and
- New product and business development.

The focus of the commercialisation research has been smallstock plants in Australia, particularly with the impending shift from live export to processing in Australia. In plants with existing bottlenecks around carcase and carton chilling, this will prevent expanding production to incorporate a second shift if the chilling and cold rooms are already at capacity.

Processing plants have indicated an increase in chilled carcase trade with this trend anticipated to continue as a result of diminished live trade. Processing plants have indicated they are looking to install Rapid Chill to take advantage of the increase in demand for chilled carcases however, they are restricted by available chiller space inside the processing plant. The ability to install a modular Rapid Chill system on the side of the plant from where chilled carcases can be directly loaded out from provides a solution to the space and logistical bottlenecks.

It is conservatively estimated that by the end of 2030 there will be 4 small modules installed and operational at small to medium sized processing plants to chill cartons and/or carcases. Based on discussions with processing plants by the end of 2030 it is estimated there will be 1 carton chilling unit and 4 large units for carcase chilling. A total of 9 units will be installed and operational by the end of 2030 as a conservative estimate based on current discussions.

There are an additional 5 processing plants in Australia where chilling carcases, cartons and offal has been identified as a bottleneck. However these processing plants have not stated their interest or commitment to invest in a Rapid Chill system. One processing plant is considering a nitrogen tunnel while another is looking at hiring mobile cold rooms and chillers – both of which are higher cost per unit chilled compared to a Rapid Chill unit.

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | Total |
|---|---|---|---|---|---|---|---|
| Small | 1 | | 1 | | 1 | 1 | **4** |
| Med/Large | 1 | 1 | 1 | 2 | | | **5** |

*Figure 15: Conservative sales of Rapid Chill carcase and carton modular units*

Small plants are classified as processing 300-800 smallstock per day while plants are regarded as medium if processing 1800 to 4000 per day and larger plants 4000+ per day.

The installation of a carcase and carton chilling system provides opportunities for processing plants which are primarily focused on frozen products. Improved shelf life due to rapid chilling could enable processing plants to export chilled products and switch products from frozen to chilled. This requires research to confirm shelf-life impacts of different cuts.

## Business Models

Lease of units to processing plants:

The modular units which are self-contained and external to the processing plant enables processing plants to expand as required. The impact on reducing energy usage and improving business efficiencies has been identified by potential agricultural investors as of interest to purchase the units and lease the facilities to the processing plants. A capital firm has expressed interest in buying the units and leasing to processing plants who have limited capital expenditure budget. Using the Rapid Chill system, the business expansion in chilled carcases and chilled product sales will provide revenue to pay the equipment lease.

Lease to buy:

A lease to buy arrangement with 8% interest rate applied has been offered by capital investment firms to facilitate purchase by processing plants and provide access to capital based on the modular Rapid Chill unit as collateral.

Outright purchase:

Based on the increase in throughput depending on the individual plant, product profit margins and bottlenecks, the payback period is 1.5-3 years, which is standard payback period for investment by smallstock processors.

## Business development and commercialisation plan for smallstock

The proposed business development and commercialisation plan is to have a 4 to 7-unit system prototype built and installed at a commercial plant as a demonstration unit which undertakes further scientific testing. The demonstration unit will allow onsite demonstration and further research and development on shelf life, eating quality and system optimisation for carcase, carton and offal chilling. External funding will be sought to provide co-funding to demonstrate the Rapid Chill technology in reducing processing plant chiller bottlenecks to help improve manufacturing competitiveness and reduce energy consumption.

FreshXpress are aware that there are capital constraints by many processing plants and have sought out agricultural capital providers to enable the Rapid Chill units to be leased or have a special loan at approximately 6% interest to enable processing plants to install and utilise the units.

The market consists of:

1. Large processing plants who have capital to purchase the system, but require 1-3 years to include the system in their capital investment planning.
2. Medium sized processing plants who often don’t have ready access to capital for investments, which would benefit from improved and expanded chiller and freezer capacity.
3. Small processing plants looking to grow, develop and diversity and require a multi-functional facility that can chill both cartons and carcases.

A 7-zone unit is required for chilling lamb carcases with a chain speed of 8/minute or an estimated 3500 to 3700 per day. The cost currently for a unit installed and commissioned is estimated at $10 million. This cost doesn’t include connection to the processing plant chain and chillers.

A 2-zone unit installed and commissioned has a cost estimated at $4.5 million. Additional refinement of system design, PLC units and automation could result in the cost being under $4 million which is the target to enable suitable ROI for processing plants.

A small entry level 2-zone multi-functional unit purpose built and designed for small processing plants is estimated to cost $1 million with minimal onsite installation and setup required.

Research and development in refinement of the system for meat processing plants is required post installation of the first unit. This R&D will need to include verification of:

1. Carcase shrink and yield for different types of carcases including goat, mutton and lamb
2. Shelf life implications
3. Meat colour
4. Drip loss
5. pH temperature decline

## Benefit for Industry

Rapid Chill provides a lower cost alternative solution for carcase chilling compared to existing technology, with the added benefits of multi-directional circulation of >-15°C air in closed modular units which greatly improves cooling efficiencies in processing plants, chilling carcases to 0°C in less than 3 hours.

Rapid Chill provides the opportunity for industry to:

- Reduce carcase shrinkage in processing plants where spray chilling hasn't been installed (increased saleable meat yield by 2% per animal chilled using the Rapid Chill instead of using conventional chillers). It is anticipated that conventional chillers will be used to hold carcases at 0-2°C, rather than needing to chill carcases from 36°C to 2°C.
- Reduce energy usage, water for cleaning and carbon footprint for chilling carcases.
- Rapid Chill has no requirement for liquid nitrogen, liquid carbon dioxide or ammonia glycol.
- Processing plants can turn chillers off on weekends.
- Increase throughput of processing plants which have bottlenecks in chillers, carcase cold rooms and freezing capacity – to expand capacity using external module units. Increase in profitability for processing plants based on increased throughput achieved.
- Processing plants which are space constrained have mentioned they would expand boning and value adding into existing chiller space that would no longer be needed.
- Reduction in capital expenditure required to improve throughput based on installation of new cold rooms and chillers using the existing technology.
- Increased shift flexibility as processing plants are not waiting for carcases in chillers to reach temperature to start boning.
- Increase in sales of chilled carcases rather than frozen carcases due to ability to load from end of the 7-zone unit directly into shipping containers and trucks for airfreight and delivery to customers.
- The modular units allow expansion and adjustment and can be used for cartons or carcases depending on system design. They can be retrofitted for carcase or carton as the processing plant changes and invests in different technologies. The use of the units for chilling of meat and offal hasn't been tested, although the unit was originally built for horticultural products packed in cartons and trays.

Rapid Chill provides a lower cost alternative solution for carcase chilling as the technology of multi-directional >-15°C air circulation in closed modular units greatly improves cooling efficiencies for processing plants.

# Future Projects

### Use of Rapid Chill Technology for Carton Chilling

This project conducted research on the impact of Rapid Chill on lamb carcases including temperature decline and meat quality traits. Processing plants have identified they are struggling to chill offal, particularly livers, and are looking for alternatives to investing in additional plate and blast freezers. Further testing is required on chilling cartons of product including primals, trim and offal to investigate the impact on (1) shelf life and (2) eating quality.

Research and development is required to design a system which loads cartons from conveyors into a shelf system to then enter the modular system. Testing is required on different box sized and shapes as elongated boxes could be chilled with the lids on. Research is required to see if hearts and liver can be chilled sufficiently in the large square boxes with the lids on. Open cartons mean the temperature can decline quicker as the airflow is maximised around the product. However, this means the cartons need to be sealed upon exit which adds further complications on labelling and food safety requirements.

In summary, research is required for:

- Lid on versus lid off cooling,
- Shelf life and quality impact on primals, 6-way, offal, trim,
- Analysing reductions in time required for product to be in the plate and blast freezers if product enters the freezer already chilled by the Rapid Chill system.

Development is required to:

- Build conveyor systems for different sized cartons to travel through the modular unit and exit the unit chilled at or below 2°C.
- Internal system engineering for inflows, outflows and sorting post cooling.

### Design and build of a commercial chilling system for a small processing plant

Small processing facilities, particularly those doing custom kills are interested in having a facility which rapidly chills carcases enabling smallstock to be processed in the morning and loaded out as carcases in the afternoon. The ability to have the same day turnover is beneficial for businesses with minimal chilling space and who want to provide a fresh product to the domestic market. This provides a service to butcher shops and for custom kills who then have their product processed at butcher shops, as is the case for producer marketed products where the supply chain is producer direct to customer. For part of the week, the smaller processors undertake custom kills and then the rest of the week they undertake their own kills which then are chilled and sometimes broken down.

The smaller unit needs research and design to be multi-purpose and multi-functional. The larger units have different airflow and temperature settings in each sealed modular unit. The smaller unit will be designed to be multi-functional in that it can chill carcases and cartons, and it can provide multi-directional air flow.

Research and development will be required to test if it’s possible to have multi-directional air flow in a small two-unit system. Systems and structures will need to be designed to enable cartons and carcases to be loaded.

### Design and build of a commercial carcase chilling system for a medium small stock processing plant

A unit designed to chill fruit was retrofitted to chill carcases in this project. The retrofitted unit demonstrated proof of concept to chill carcases without cold shortening the product. The proof of concept provided insights into what was possible to reduce carcase shrinkage with system adjustments.

Research and development required includes:

- Building and testing commercial viability of a 7-zone unit to chill carcases in an hour to allow chilling of 3500-4,000 head per at 8 per minute chain speed.
- Development of a system which allows maximum use of the 7 zones. The concept is that carcases are loaded onto a holding area and then the entire holding area zone when full is automatically rolled into the first zone. Each zone then automatically opens and closes to keep the racks moving through. At the other side there is an unloading to optimise throughput and minimise manual handling.
- Trials and development of protocols and chilling parameters to ensure negligible carcase shrinkage during chilling.
- Eating quality was tested on a range of carcase sizes in lamb, to see the impact on carcase size and fat coverage on chilling times and cold shortening (eating quality). Similar tests are required for mutton carcases and goat carcases as well as during commissioning phase of the 7-zone purpose-built unit to ensure eating quality is optimised.
- Shelf-life and micro testing are required on carcases and on saleable products.

### Prototype design and testing for beef carcases and cartons

No formal R&D has been undertaken on beef carcases. The R&D for meat science will need to be undertaken as per the work undertaken with lamb at a test facility across several research trials including:

1. pH temperature decline
2. Shear force (cold shortening)
3. Carcase shrink / yield loss
4. Time for different parts of the carcase to reach 0°C over a range of carcase sizes and fat depth
5. Drip loss
6. Shelf life
7. Meat colour, fat colour etc
8. Impact on visual appearance of marbling
9. Ease of boning larger carcases

# 8.0 Conclusions

## Processing implications

The development and installation of a rapid chill tunnel within a lamb processing facility will impact current process flows. Plants currently processing mutton either hot or on the curve will have less of an impact as they are already killing and boning on the same day. The following outlines some alternative shift structures which could be implemented due to the installation on the rapid chilling tunnel:

- Utilise current shift configuration of boning product the day after it has been slaughtered.
- Plant operating 2 shifts, kill morning shift bone night shift, next shift kills night shift boning day shift.
- Delayed boning, single shift operation, start slaughter at 6am and start boning at 9 am boning all carcases same day of production.

The key consideration with the above will come down to the ability of plants to operate each of the systems within their unique circumstances and process flow bottlenecks.

## International market development

Middle and high-end retail and food service establishments in the Middle East prefer chilled products. The cessation of live export to the Middle East provides an opportunity to further develop the mutton and chilled lamb and goat markets. The growing urban population in countries like Qatar and Saudi Arabia, especially those who have travelled are becoming increasingly discerning in their dining habits resulting in the opportunity to market premium Australian chilled lamb. There are considerable benefits for carcase-based processors in Australia and the Middle East enabling processors to kill, chill and airfreight, with the carcase landed in importing country within 24 hours of killing.

## System capacities and Chilling rates

The research trials were undertaken in a retrofitted fruit tunnel with chilling time being over an hour for some parts of the carcase. The system when optimised should be able to chill a lamb carcase with medium fat coverage to 1 degree in an hour. Depending on the processing plants requirements, the air temperature can be altered to speed up or slow down the carcase chilling as required depending on average carcase size and type. Future research and development are needed to optimise the system and the chilling time for the different smallstock carcase types.

*Table 38: Capacity requirements of the 7 and 9 zone systems depending on the final chilling times with 72 carcases per zone*

| Rapid chilling system - 7 or 9 zone unit | | | | | | |
|---|---|---|---|---|---|---|
| System Details | Chilling time 0.75 (hrs) - Number of zones 7 | Chilling time 1 (hrs) - Number of zones 9 | Chilling time 1.5 (hrs) - Number of zones 9 | Chilling time 2 (hrs) - Number of zones 9 | Chilling time 2.5 (hrs) - Number of zones 9 | Chilling time 3 (hrs) - Number of zones 9 |
| Hours chilling time | 0.75 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| Carcases per zone | 72.00 | 72.00 | 72.00 | 72.00 | 72.00 | 72.00 |
| Number of zones | 7.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Carcase per minute | 11.20 | 10.80 | 7.20 | 5.40 | 4.32 | 3.60 |
| Carcase per hour | 672 | 648 | 432 | 324 | 259 | 216 |
| Carcase per shift (8 hours production | 5,376 | 5,184 | 3,456 | 2,592 | 2,074 | 1,728 |

The aim is to design the small system to chill offal and byproducts, cartons and carcases as a multi-species and multi-use facility with the option of chilling and freezing carcases and cartons.

*Table 39: Capacity requirements of small system depending on the final chilling times with 40 carcases per zone*

| Rapid chilling system - Small unit chilling capacity | | | | | | |
|---|---|---|---|---|---|---|
| System Details | Chilling time 0.75 (hrs) - Number of zones 2 | Chilling time 1 (hrs) - Number of zones 2 | Chilling time 1.5 (hrs) - Number of zones 2 | Chilling time 2 (hrs) - Number of zones 2 | Chilling time 2.5 (hrs) - Number of zones 2 | Chilling time 3 (hrs) - Number of zones 2 |
| Hours chilling time | 0.75 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| Carcases per zone | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| Number of zones | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Carcase per minute | 1.78 | 1.33 | 0.89 | 0.67 | 0.53 | 0.44 |
| Carcase per hour | 107 | 80 | 53 | 40 | 32 | 27 |
| Carcase per shift (8 hours production | 853 | 640 | 427 | 320 | 256 | 213 |

## Industry adoption

The adoption of this technology will enable small stock abattoirs to increase the rate at which carcases can be chilled without compromising eating quality. As seen in Figure 15, the different sizes and types of systems will provide solutions to the breadth of the red meat processing and value adding sectors. The following outlines factors which will support adoption of this technology:

- **Reducing carcase and or carton chilling constraints**: Enables small and large processors to increase their carcase and carton chilling capacity with a self-contained external unit that does not need nitrogen or glycol to operate – only electricity.
- **Increase in chilled carcase sales** as modular units can be built on the side of an existing plant and chilled carcases loaded directly onto trucks from the end of the Rapid Chill system.
- **Reduce carcase shrink** if spray chilling isn't installed in the existing chillers.
- **Reduce electricity usage** by turning off carcase chillers overnight and weekends if processed and packed on the same day.
- **Help eliminate bottlenecks with freezing capacity.** Reduce time in freezing units for carcases and cartons as products can enter plate or blast freezers at or close to 0°C.
- **Improved eating quality**: VFC (very fast chilling) where carcases are less than 0 °C at 1.5 h postmortem has challenged the traditional concept of cold shortening with studies confirming that VFC has the potential to result in less tough meat (lower SF) (Chen et al., 2022 & Jacob et al., 2012).
- **Improved shelf life**: Meat spoilage is a complex phenomenon with limited studies on shelf life for VFC being undertaken as most of the research has been focused on weight loss, tenderness and meat colour (Chen et al. 2022). In theory, there could be improved shelf life although this needs to be validated.
- **System modularity** enables processing plants to add chilling capacity as required.
- **Leasing options** are available requiring limited capital expenditure to enable the benefit to be realised for the processing plant. The modular unit is collateral for the leasing agent and the Rapid Chill system provides a return on investment for both the processing plant and the leasing agent.
- **External self-contained system** that is outside the current plants' footprint**.** This will enable a minimal disruption for the internal plant operations during installation. There is no need for nitrogen, ammonia or glycol – thus no connections other than a chain and to electricity.

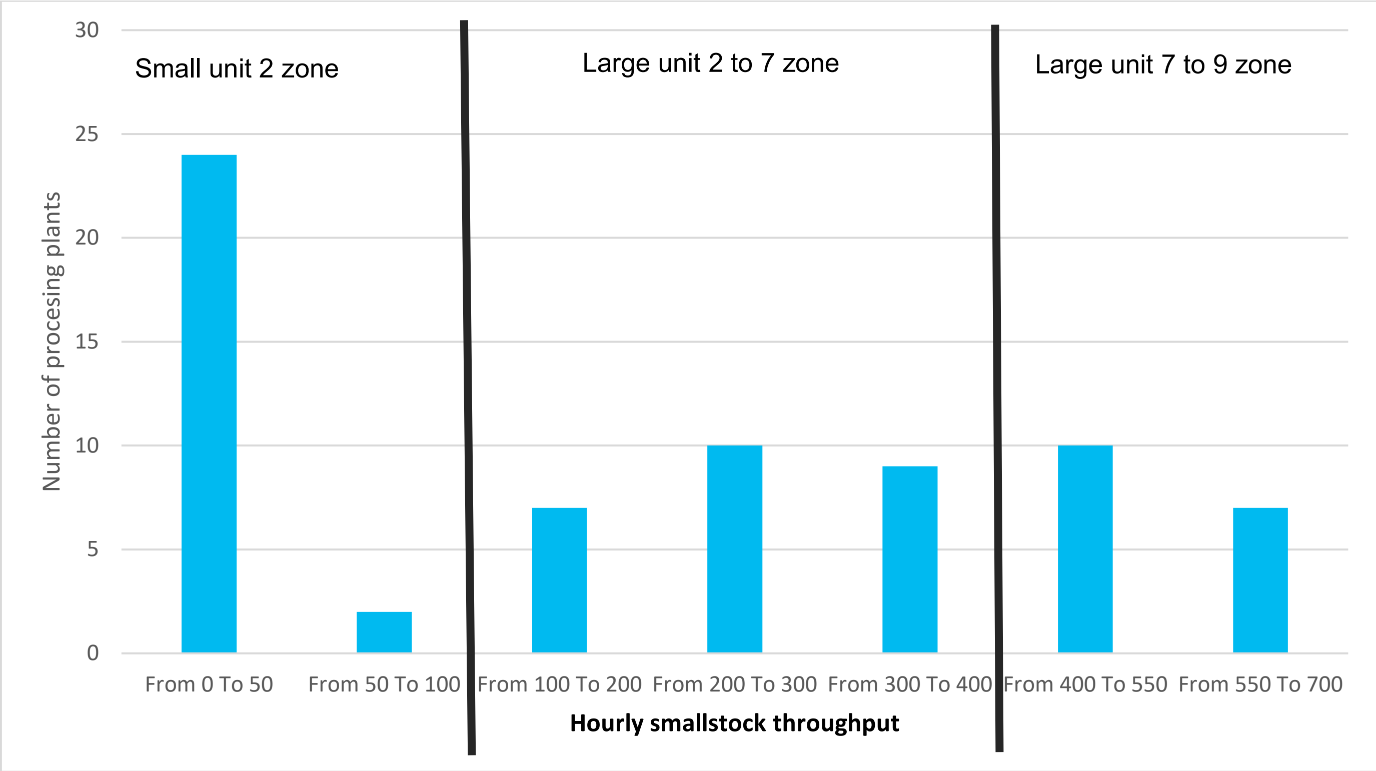



*Figure 16: Distribution of hourly processing volumes in Australia for small stock processing plants*

The potential market for the different zones units based on the number of processing plants in Australia and their throughput is shown in the above graph. Each processing plant tends to have different bottlenecks from offal freezing to carcase chilling or chilling product post boning room. The versatility of the Rapid Chill system as well as the design where it is a stand-alone unit provides an opportunity for industry wide adoption. The ability to lease the system removes the capital expenditure limitation that many plants have.

## Issues solved by the Rapid Chill system

The Rapid Chill system provides solutions to the following issues identified by processors:

- Plate freezers struggling to reduce temperature of 20-25kg cartons of livers quick enough to maintain quality.
- Cartons sitting in cold rooms for 1-2 days waiting for products to reach temperatures which meet product specifications, effectively taking up cold room space for no reason other than needing to ‘chill’ product down.
- Processing plants which don’t have enough carcase chiller space meaning the processing plant have a maximum number of lambs it can process and chill per day and then they to processing hot mutton carcases.
- There is growing demand for chilled carcases particularly in the current environment of live export trade phasing out. With limited chiller space in processing plants and carcases taking 18-24 hours to chill prior to being loaded out, processors cannot increase throughput which is required to satisfy the increasing demand for chilled carcases.

## Future opportunities for the system

The current research project focused on lambs with standard weight ranges and fat depths. The Rapid Chilling unit could be applied to offal cartons and beef carcases, however extensive R&D would be required to ensure the beef carcases did not cold shorten. The following summarises data collected over the last 12 months to further validate the capabilities of this technology for use on beef carcases and cartons.

Figure 16 shows the temperature decline of a beef carcase between 200 and 250kg's, utilising the horticulture tunnel. The temperature decline shows potential but will need to be tested and further validated once a red meat system built for carcases is operational.

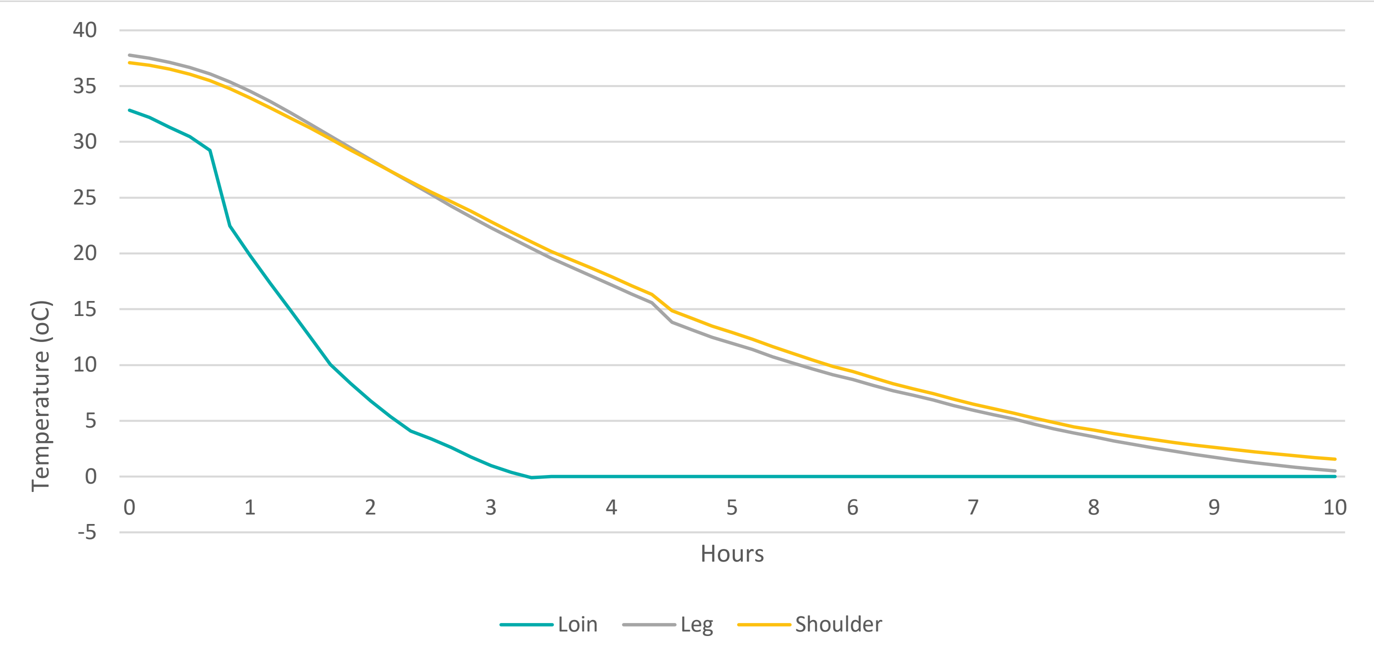



*Figure 17: Temperature decline of a test beef carcase*

# 9.0 Recommendations

The Rapid Chill system enabled very fast chilling of carcases, defined as reaching a temperature between -5°C to 0°C in the centre of muscle in <5 h post-mortem (Warner et al. 2015). Very fast chilling goes outside of the temperature pH decline curve which is used to identify eating quality traits, for example optimal chilling verses cold shortening which results in a poor eating experience (tough meat).

**Processor needs -** Australian meat processors are looking for solutions to (1) reduce electricity usage, (2) increase chilled carcase throughput, (3) reduce pressure on existing carcase chiller space, (4) chill offal cartons prior to freezing and (5) reduce the temperature of primals post vacuum sealing and prior to boxing. The Rapid Chill system removes these bottlenecks without needing nitrogen, ammonia glycol or liquid carbon dioxide as the modular system is a stand-alone unit that can be added to the side of an existing processing plant facility.

**Trials achieved rapid chilling targets** - This research trial was undertaken in a retro-fitted fruit system enabling extensive and detailed meat science data to be collected and analysed on lamb carcases. The temperature decline showed that smaller carcases reached 0$^{o}$C within an hour. The heavier fatter carcases took longer than 1 hour.

**Preliminary meat science results are positive** - The Rapid Chill system has demonstrated that it does not cold shorten lamb carcases and in fact could improve meat tenderness. Detailed analysis and results from UNE indicate a reduction in shear force, an increase in purge and a minimal difference in meat colour. Adjustment to system settings like zone temperature and air speed produced a variation in results that indicate a meat specific multi zone system could be optimised to achieve optimal meat quality results.

**Return on investment of $6.42/hd** – depending on the size of plant and mix of business and financing options to determine the payback period. For lamb with a capital outlay there was less than an 18-month payback period.

**Modular design applies to 100% of industry** – Given the system design concept enables modular configuration a commercial system can be designed and sized for any size meat processing plant.

**Development of a commercial prototype is required** - A commercial installation is required at a meat processing facility to test and validate shelf life and additional meat quality parameters such as drip loss. The installation would also enable R&D to be undertaken on offal, boned product, mutton carcases, cartons of hot 6-way mutton and goat.

**Commercialisation pathways are developing** - The commercialisation strategy has identified investors that are willing to lease the modular system to processing plants minimising capital expenditure requirements and allowing adoption to be expedited. Several smallstock processors have expressed interest in being involved in carton and carcase trials if a modular / portable Rapid Chill unit was available with the view to invest in a 7 to 9 zone unit or a 2-zone unit for increasing chilled carcase sales.

# 10.0 Project outputs

- Carcase chilling demonstration, open taste and taste test held at the Mildura retro-fitted Rapid Chill System on the 19th of August 2024.

# 11.0 Bibliography

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