Final Report

Shelf-life models for beef and lamb

Project code: V.MFS.0453

Prepared by: Dr. Laura Rood, Prof Tom Ross, Prof John Bowman, and
Dr Chawalit ('Jay') Kocharunchitt
Tasmanian Institute of Agriculture, University of Tasmania

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PO Box 1961
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Executive summary

The overall aim of this project was to develop a scientifically rigorous decision-support tool that will enable the Australian red meat industry to optimise and manage the quality of various product types in diverse cold chains. This was achieved by exploiting the science underpinning red meat shelf-life and the well-validated predictive models for shelf-life of vacuum-packed (VP) red meat in supply chains to develop additional models for retail-ready products. These included vacuum skin packs (VSP), modified atmosphere packs (MAP, 20% CO_2 and 80% O_2) and overwrapped (OW) packs. The decision-support tool will offer a cost-effective approach to the industry for better management of supply chains, assuring customer/consumer trust in product quality, while increasing its profitability through a reduction in wastage and markdowns.

Over the course of this project (from January 2021 to April 2024), a series of trials were conducted to evaluate the shelf-life of VSP, MAP, and OW products after reprocessing from VP primals with different wet aging durations. The data of those trials was used to either evaluate the applicability of the existing models, or (if not performed well) develop new models for shelf-life prediction for other product/packaging types. In this report, the key achievements of this project are summarised and described below.

The results confirmed that the shelf-life of VSP products (*i.e.*, beef and lamb products previously wet aged at 0-4°C for up to 35 days and 20 days, respectively) were predicted well by the existing models, but not for any MAP and OW red meat products. Accordingly, new mathematical models for shelf-life prediction of beef and lamb products in OW (*i.e*., steak and mince) and MAP (*i.e*., mince) previously wet aged for up to 35 days for beef and 14 days for lamb were successfully developed. These models were incorporated into the tool known as 'the Shelf-life Calculator for Red Meat' (available as an MS ®Excel version and a more user-friendly online version). The new/existing models within the Calculator were successfully validated using independent data for commercially available products in simulated supply chains. The results indicated that the Calculator provided an accurate prediction of the shelf-life for all VSP, OW and MAP products with and without wet aging, with a deviation ranging between 4 – 13%. Furthermore, thermoform packs (TP) were included as another retail-ready VP format to further explore the performance of the Calculator. It was found that the Calculator accurately predicts their shelf-life with a deviation of up to 17%, indicating its applicability for TP products. Despite the successful validation, it is worthwhile noting that further research is still required to evaluate the performance of the Calculator in real supply chains, ensuring its usability and effectiveness in industrial settings. The Calculator, however, can be readily adopted by the industry as a decision-support tool for supply chain management.

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1. Publications (preparation, submitted or published)

1.1 Manuscripts in preparation

- Rood, L., Bowman, J., Ross, T., Pagnon, J., Yang, S., and Kocharunchitt, C. (2023). The effects of wet aging on the secondary shelf-life of retail ready beef and lamb products – intended to be submitted to a peer-reviewed journal (*i.e., Meat Science* or *International Journal of Food Microbiology*).

- Rood, L., Bowman, J.P., Ross, T., and Kocharunchitt, C. (2024). Shelf-life predictive models for Australian beef and lamb products in overwrap trays and modified atmosphere packs: development and evaluation – intended to be submitted to a peer-reviewed journal (*i.e., Food Microbiology* or *Frontiers in Food Microbiology*)

1.2 Submitted manuscripts

None

1.3 Published manuscripts

None

2. Report and theses

- Kocharunchitt, C., Bowman, J., and Ross, T. (2021). Shelf-life models for beef and lamb: Milestone 2 report (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.
- Rood, L., Bowman, J., Ross, T., and Kocharunchitt, C. (2021). Shelf-life models for beef and lamb: Milestones 3 and 4 report (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.
- Rood, L., Bowman, J., Ross, T., and Kocharunchitt, C. (2022). Shelf-life models for beef and lamb: Milestone 5 report (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.
- Rood, L., Bowman, J., Ross, T., and Kocharunchitt, C. (2023). Shelf-life models for beef and lamb: Milestone 6 report (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.
- Rood, L., Bowman, J., Ross, T., and Kocharunchitt, C. (2023). Shelf-life models for beef and lamb: Milestone 7 report (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.
- Rood, L., Bowman, J., Ross, T., and Kocharunchitt, C. (2024). Shelf-life models for beef and lamb: Report for Milestones 8 and 9 (V.MFS.0453). Meat and Livestock Australia, North Sydney, Australia.

3. Where we were in 2021

The Australian red meat industry has a reputation for producing meat with excellent shelf-life, which services both domestic and export markets in the retail and further processing sectors (contributing $18.5 billion to Gross Domestic Product in 2017/2018). This reputation is constantly challenged by the need to minimise the loss of product shelf-life along different supply chains and to meet a wide range of shelf life-related specifications imposed by intended international markets. For example, China specifies a shelf life of 120 and 80 days from slaughter for vacuum packed (VP) beef and lamb/mutton cuts, respectively (DAFF, 2015), while some Middle East countries require at least 50% shelf-life to remain when the consignment has landed (Huynh et al., 2016). Therefore, being able to assure required quality remaining for products in supply chains is critical for the success of the Australian red meat industry.

Through our previous MLA-funded projects (G.MFS.0.289 and V.MFS.0402), the unusually long shelf-life of Australian VP red meats was confirmed. It was demonstrated that both rates of total viable count (TVC) increase and off-odour development of meat were amongst the most suitable indicators of the end of quality shelf-life of VP beef and lamb regardless of their sources and storage temperatures (Kaur et al., 2021). From the results of these novel experiments, shelf-life predictive models for VP beef and lamb were successfully developed based on the growth rate of microorganism`s present and processes of spoilage (based on odour) as a function of temperature (Huynh et al., 2016). The models were then validated using independent data from commercially available products in both simulated and commercial cold chains, both within Australia and internationally, and are being adopted as a decision-support tool. This tool offers a cost-effective approach for the industry to better manage its supply chains, *i.e.,* to optimise product quality, to avoid unexpected loss of quality (at each stage of cold chain), and to reduce wastage, markdowns, and customer complaints. Indeed, a cost *vs.* benefit analysis has estimated that the utilisation of the existing shelf-life predictive tool provides a benefit of $9.1 million per annum for a domestic retail beef supply chain alone, with 99.5% of this benefit from reduced waste and markdowns (Kaur et al., 2018; Ross et al., 2019). The benefits of demonstrably longer shelf-life of Australian red meats also led to a successful negotiation with export markets to modify existing, potentially irrelevant, microbiological criteria. Specifically, some Middle Eastern countries have now changed their shelf-life regulations from ~70 days or less to 90 days for Australian VP lamb. This provides further financial benefit/productivity gain to the Australian red meat industry (*i.e.,* receiving in excess of $100 million in additional returns) (MLA, 2020).

Due to the enormous benefits of the developed tool to the industry (as discussed above), its utilisation for meat in other packaging formats is being sought. Our preliminary trials to evaluate the performance of the tool for various red meat products in a simulated domestic supply chain suggested the potential to predict the shelf-life of VP beef primal reprocessed to steaks in other packaging systems such as vacuum skin packs (VSP), but *not* modified atmosphere packs (MAP, 20% CO_2 and 80% O_2) and overwrap (OW) trays (Kaur et al., 2018). These results are expected given the unique selection pressures created by the different gaseous atmospheres between VP, MAP and OW packaging formats (Kameník et al., 2014; Kiermeier et al., 2013; Taylor et al., 1990). Further development and modifications to the tool are, therefore, required for accurate and reliable predictions of shelf-life of these products in cold chains.

The aim of this project was to develop a scientifically rigorous decision-support tool that will enable the Australian red meat industry to optimise and manage the quality shelf-life of various retail-ready products in diverse supply chains. The following objectives were given to achieve the stated aim:

- determine the shelf-life of beef and lamb in retail-ready packaging types including VSP, MAP (20% CO_2 and 80% O_2) and OW trays under different storage temperatures;
- evaluate the applicability of the existing red meat shelf-life predictive models to quantify the shelf-life of beef and lamb in both primary (*i.e.,* processed into OW trays from carcases) and secondary packaging formats (*i.e.*, primals wet aged in VP followed by reprocessing into VSP, MAP, or OW trays);
- develop new mathematical models for shelf-life prediction of products if not predicted well by the existing models;
- validate the new shelf-life predictive models in simulated supply chains; and
- incorporate the models into a user-friendly web-based tool.

4. Where we are in 2024

To achieve the proposed objectives of this project, a series of trials were conducted to determine the shelf-life of various red meat products when stored at both constant and dynamic temperatures as occur in commercial supply chains. The data generated was then used to evaluate the applicability of the existing shelf-life predictive tool for VP primals or (if not performed well) to develop new predictive models. Detailed description of those trials (including the development and validation of new shelf-life predictive models), and results and interpretations obtained are presented in their corresponding milestone reports (*see* below). Appendix A describes specifications for each packaging type considered in this project. Key findings and outputs are presented below:

4.1 Outputs

- Laboratory trials confirmed that the existing shelf-life predictive tool for VP primals can be used to predict the shelf-life of VSP beef and lamb steaks (based on off-odour development) that were reprocessed from VP primals previously wet aged at 0-4°C for up to 35 and 20 days, respectively (Milestone Reports 5 and 6).
- It was, however, evident that the existing tool did not perform well for MAP and OW products with and without prior wet aging. The data also showed that off-colour (rather than off-odour as in the case of VP/VSP products) was the most appropriate parameter indicative of spoilage (Milestone Reports 4, 5 and 6). These agree well with previous studies indicating the differences in the microbiology of spoilage between these packaging types (Kameník et al., 2014; Kiermeier et al., 2013; Taylor et al., 1990).
- The data for OW red meat products (*i.e.,* steak and mince) agrees well with previous observations indicating that *Pseudomonas* spp. are the specific spoilage organism for chilled foods stored under aerobic conditions (Gill et al., 1977). It was found that the growth rates of *Pseudomonas* spp. corresponded to the rates of quality loss of the products (based on colour attribute). The rates of quality loss were also not affected by a wet aging process (VP primals stored at 0-4°C for durations up to 35 days for beef and 14 days for lamb prior to further processing). Accordingly, the shelf-life of OW beef and lamb products could be modelled and predicted as a function of temperature based on the growth of *Pseudomonas* spp. and the time taken for *Pseudomonas spp.* to reach a certain population level that corresponded to spoilage (*i.e.,* at 7.6 ± 0.8 and 7.8 ± 0.7 log units for beef and lamb, respectively) (Milestone Reports 4, 5, and 6).
- The shelf-life data for MAP beef and lamb steak revealed that TVC and colour sensory score were amongst the most appropriate parameters to estimate shelf-life. Aging of primals in VP for different durations (up to 35 days for beef and 14 days for lamb) did not have any effects on the rates of TVC increase and quality loss of MAP products. Both rates of TVC increase and quality loss were also found to be strongly temperature dependent (R^2= 0.96 to 0.99). These indicate that the shelf-life of MAP products can be predicted based on the initial TVC and the rate of quality loss as a function of temperature (Milestone reports 6 and 8).
- Based on the shelf-life data described above, new mathematical models for shelf-life prediction of beef and lamb products in OW (*i.e*., steak and mince) and MAP (*i.e*., mince)

were successfully developed. These new models together with the existing models for shelf-life prediction of VP red meat were incorporated into the tool (known as 'Shelf-life Calculator for Red Meat') in MS 365 ®Excel (Milestone Report 7).

- The new/existing models within the Shelf-life Calculator for Red Meat were successfully validated using independent data for commercially available products in simulated supply chains. Overall, a good agreement was observed between the observed and predicted shelf-lives for all VSP, OW and MAP products with and without wet aging, and with a deviation ranging between 4 and 13%. This indicates that the Calculator provides an accurate and reliable prediction of the shelf-life of these retail-ready products (Milestone Report 8).
- To further explore the performance of the Calculator, thermoform packs (TP) were included as another retail-ready VP format. It was found that the Calculator accurately predicts their shelf-life with a deviation of up to 17%, indicating its applicability for TP products (Milestone Report 8).
- A user-friendly online interface of the Shelf-life Calculator for Red Meat was developed (*see* Appendix B for a user guide for web-based tool)

4.2 Outcomes

The Shelf-life Calculator for Red Meat (both as an MS ®Excel version and a more user-friendly online version) was successfully developed and validated for VP primals and various retail-ready products (mince and/or steak) in VSP, TP, MAP and OW packs. This Calculator can be readily adopted by the Australian red meat industry as a reliable decision-making tool for supply chain management both within Australia and internationally. The Calculator once adopted will offer a cost-effective approach for better and more flexible management of any given supply chain (*e.g.*, helping to decide on product movement and quality in a supply chain), reducing customer complaints and waste, and increasing business profitability.

This project has also provided scientific information about the shelf-life of beef and lamb products in various retail-ready packaging types (with and without prior wet aging) stored at different temperatures. Such knowledge, along with documentation of the model validation within supply chains, can be used to develop science-based shelf-life criteria and support negotiations with relevant markets where non-science based and outdated, or irrelevant regulations are currently imposed. This will lead to long-term benefits for the Australian meat industry, such as reduced economic losses and food wastage through premature termination of shelf-life.

In addition to the above, a significant outcome of this project is the increased scientific capabilities in the Australian red meat industry. This has been achieved through training of a post-doctoral expert for red meat microbial quality and predictive microbiology who can support the industry to respond to market challenges and continue to develop innovative tools based on its needs. This expert can also provide other training opportunities for young scientists whose research would be relevant to the Australian red meat industry.

5. Where to from here

As described above, this project has extended the applicability of the existing Shelf-life Calculator for VP beef and lamb primals to predict the shelf-life of common retail ready products, including VSP, TP, MAP and OW products with and without prior wet aging. The Calculator has been developed as an MS ®Excel version and a user-friendly online version, and can be readily used by the Australian red meat industry as a decision-making tool in commercial supply chains. However, it is important to note that despite this project successfully validating the Calculator, the data used was generated from trials involving simulated supply chains. Further validation within industry settings is, therefore, recommended prior to industry adoption. This would involve collaboration with industry partners to evaluate its performance (including limitations) in real supply chains to ensure its usability and effectiveness in commercial supply chains. Furthermore, a cost-benefit analysis should be conducted to clearly demonstrate the expected benefits of the Calculator against any associated costs to the industry, *i.e.,* the cost of the tool development and its adoption.

The results of this project have also successfully demonstrated that the end of shelf-life of different red meat products can be predicted as a function of temperature, enabling the development of shelf-life predictive models. This highlights the potential for future studies to further extend the applicability of the Calculator for shelf-life prediction of more product types. For instance, the Calculator could be extended to include shelf-life predictive model for VP Wagyu beef primals, which is known to have a shorter shelf-life compared to regular beef due to a higher intramuscular fat content. Further development of the Calculator would provide more financial benefit/productivity gain to the Australian red meat industry.

Further to the above, the Calculator can be further modified/refined over time in response to changing industry practices. This is to ensure that its usability and effectiveness continue to meet industry needs. For instance, future studies may consider evaluating the performance of the Calculator for shelf-life prediction of products in new, more sustainable packaging materials and innovative packaging technologies.

6. References

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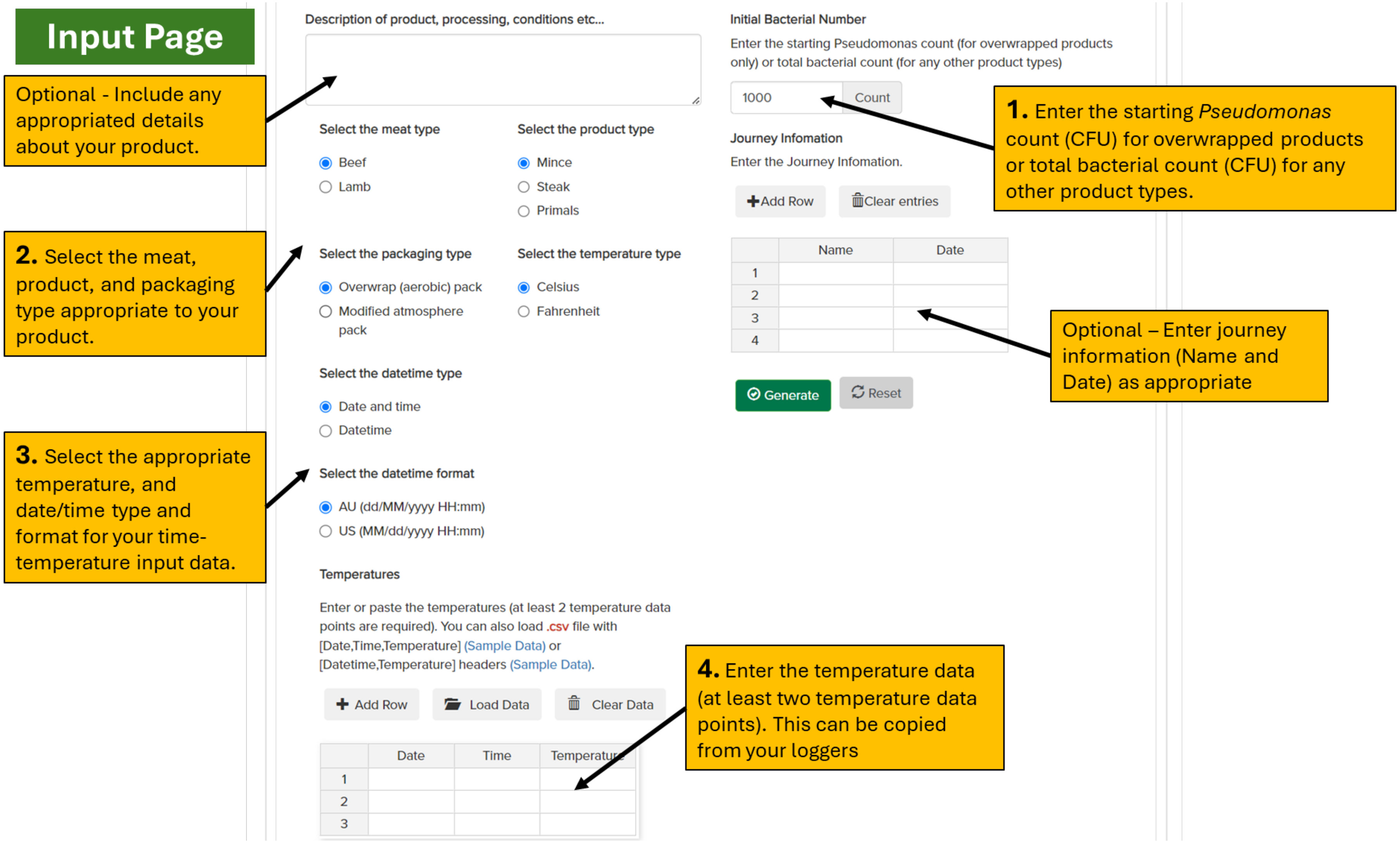
7. Appendices

7.1 Appendix A: Specification for retail-ready packaging formats used for the development of shelf-life predictive models

Packaging format		Specifications	
Type	**Trial**	**Tray**	**Film**
Vacuum-skin pack	**Development**	*Mondini Tray Thermoformed Tray Plantic Technologies* Polyethylene terephthalate Oxygen transmission: <1 cc/m2/ day at 23deg C at 0% RH Barrier layer material: Ethylene Vinyl Alcohol laminated Gauge: 8 um Sealant layer material: Low density polyethylene laminated Gauge: 142 um	*Cryovac DARFRESH TH 300 top web* Low density polyethylene (soft) Gauge: 150 um Oxygen transmission: 2 cc/m2/ day at 23deg C at 0% RH
	Validation	*Klöckner Pentaplast VSP (Product: 1030933L)* rPETPE: recycled polyethylene terephthalate Gauge: - Oxygen transmission: -	*FLEXO-FRESH PHB-B 3000* Gauge: 120 um Oxygen transmission: -
Thermoform	**Validation**	*FLEXO-FRESH PHB-B 3000* Polyhydroxybutyrate Gauge: 300um Oxygen transmission: 1.5cc/m2/day at 23deg C at 0% RH	Flexo-Fresh Top Web Gauge: 120 um Oxygen transmission: -
Modified Atmosphere packs*	**Development**	*PLANTIC™ R+ (Product: PLA2283)* Polyethylene terephthalate (7.7% PE/ Hot Melt/ 35% RPET/ 22% Plantic Starch/ 35% RPET) Gauge: 450 um Oxygen transmission: <0.5 cc/m2/ day at 23deg C at 0% RH	*LINTOP STAR PE SXI very high barrier shrink film* Polyethylene Gauge: 33+/- 10% um Oxygen transmission: <8 cc/m2/ day at 23deg C at 0% RH
	Development	*Sealed Air Clear Tray (Product: 100799183)* Polypropylene Gauge: 820 um Oxygen barrier: 4 cc/m2/day	*Sealed Air LID1050-High Abuse, Anti-Fog Barrier Shrink Film* Gauge: 25 um Oxygen transmission: 32 cc/m2/ day at 23deg C at 0% RH
	Validation	Klöckner Pentaplast (Product: 1035870L) PET ELITE rPET Mono: recycled polyethylene terephthalate Gauge: - Oxygen transmission: -	Klöckner Pentaplast FLEXILID EH 240 OPP/PE-EVOH-PE LAMIN Gauge: 40um Oxygen transmission: 5 cc/m2/ day at 23deg C at 0% RH
Overwrap trays*	**Development/Validation**	Standard compact foam polystyrene	Standard commercial cling wrap

7.2 Appendix B: A quick user guide for web-based shelf-life predictive tool



Output Page

The Calculator provides a summary of your input data including product type, its microbiological quality and storage conditions.

Meat Shelf Life Calculator

Beef - Mince - Modified atmosphere pack

Logger summary	
Start Date/Time:	2018-10-25 00:00
End Date/Time:	2018-11-03 00:00
Recording Interval (min):	1440 Mins

Storage Summary	
Storage Duration:	9 Days
Average Temp:	2 °C
Min Temp:	2 °C
Max Temp:	2 °C

Product	Bacterial numbers (TVC)	
Mince	(cfu)	(log cfu)
Initial	1,000	3.00
Increase	X 19	1.28
Final	18,902	4.28

	Temperature	Time(d) remaining to spoilage at nominated storage temperature based on colour ?
Nominated remaining storage temperature	0 °C ?	5 days

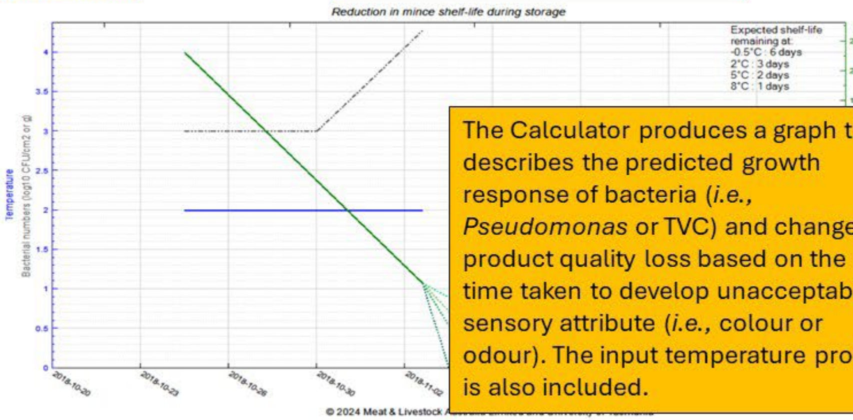
Optional – enter a nominated remaining storage temperature to estimate the shelf-life remaining of your product.

You can print, edit data or create a new graph

Print | Edit Data | New Graph

Optional - click this button to show/hide prediction on a graph, *i.e.*, the expected shelf-life remaining at different storage temperatures.

Hide Prediction



The Calculator produces a graph that describes the predicted growth response of bacteria (*i.e.*, *Pseudomonas* or TVC) and changes in product quality loss based on the time taken to develop unacceptable sensory attribute (*i.e.*, colour or odour). The input temperature profile is also included.

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