Final report

Project code:	**P.PIP.0563**
Prepared by:	**Chawalit ('Jay') Kocharunchitt, Tom Ross, Long Huynh** **University of Tasmania**
Date submitted:	**12 April 2019**
Date published:	**[April 2019]**

Predictive Modelling pilot trial on vacuum skin-packed beef through a retail supply chain

Table of Contents

Executive Summary

Longer shelf life of fresh meat is a desirable attribute to optimise productivity of the supply chain. This report examines the shelf lives of vacuum-skin-packed (VSP) products in a simulated domestic supply chain. The shelf life of these products was compared with that predicted by a UTas/MLA vacuum packed (VP) beef shelf life model to evaluate the reliability of the model.

Trials were conducted on VSP steak produced from beef rump primal after aging (in VP at approximately 0°C) for different durations (*i.e.,* 0, 30 and 57 days). These VSP samples were then subjected to different processes for different durations and at different temperatures representative of retail domestic supply chains (*e.g.,* vacuum skin packaging, distribution centre storage and retail storage/display) to storage in a consumer's fridge. Microbiological analyses (standard plate counts) and sensory evaluations (odour characteristics) were also carried out periodically throughout the trials. Product temperature was continuously logged. The acceptable shelf life of the VSP products was determined based on odour characteristics and compared with that predicted by the model.

All VSP steaks (with or without aging) had a shelf life from 37 to 41 days. These shelf lives were much longer than the shelf lives (between 22 and 27 days) based on the microbiological criteria (SPCs of ≥100 million CFU/cm^2). This reinforces that microbiological criteria for shelf life determination are not appropriate as an indicator of product quality. However, aging of rump primals for up to 56 days had only marginal effects on the shelf life of VSP products based on both microbiological quality or odour attributes. This offers some flexibility in the process of producing VSP products to meet customer's expectations without significant effects on their shelf life.

A good agreement was observed between the observed and predicted shelf lives of all VSP products with a deviation of up to 8%. This indicates that the model provides an accurate prediction of the shelf life of VSP steaks (with or without aging). The model can therefore be adopted as a reliable decision-making tool in commercial supply chains for VSP beef in addition to VP beef cuts. This tool offers 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, reducing waste and increasing business profitability. A secondary cost benefit analysis conducted by Greenleaf has estimated that utilisation of the shelf life prediction model has a benefit of $7.8 million per annum for the Australian domestic retail beef supply chain, with 99.5% of this benefit from reduced waste and markdowns.

Introduction

Shelf life of fresh red meat can be affected by many factors, such as plant hygiene, processing protocols, packaging conditions and supply chain temperatures. Good plant hygiene minimises the initial level of microbial inoculum and storing meat at low temperature subsequently reduces the rate of growth of microbes thereby extending its shelf life. A broad variety of bacteria; *Acinetobacter*, *Brochothrix*, *Clostridium*, *Flavobacterium*, *Micrococcus*, *Moraxella*, *Pseudomonas*, *Psychrobacter*, *Staphylococcus*, lactic acid bacteria (LAB) and members of *Enterobacteriaceae* family have been reported to be associated with chilled meat (Casaburi et al., 2015). However, the extent to which temperature influences the microbial growth and thus shelf life is dependent on the type of microorganisms present on the meat and the atmosphere under which it is stored. Furthermore, storage temperature and atmosphere themselves play an important role in the selection of the microorganisms present, their growth rate and production of metabolites that manifest as spoilage odour and flavour. Vacuum packaging of meat gives a much-extended shelf life at low temperature. The shelf life achieved for fresh meat under vacuum packaging (VP) is now much longer than earlier perceived by the industry, which to a degree is based on historic practices rather than fundamental science. Under VP, Australian beef and lamb primals can have shelf lives of up to 182 days and 124 days at -0.5°C and -1.2°C, respectively (Kaur et al., 2017; Small et al. 2012).

Although meat spoilage is a complex phenomenon involving interactions among growing microorganisms, various endogenous biochemical reactions and storage environment, the growth of microorganisms and processes of spoilage are predictable in a well-defined ecosystem, which serves as the foundation of a field of food microbiology called 'Predictive Microbiology'. Predictive microbiology measures the change in growth rate of microorganisms and accompanying biochemical reactions responsible for sensory characteristics as a function of temperature and other parameters. Observations on the influence of physico-chemical factors on the shelf life of the product are converted into mathematical equations (predictive models), which are then translated into software tools that help food companies to better manage their product quality through supply chains. The University of Tasmania (UTas) has a strong and established reputation for developing industry-relevant predictive models and decision support software[1] including the Refrigeration Index, *E. coli* inactivation in fermented meats, and "Risk Ranger". Most of these models have been developed for the prediction of growth of bacterial pathogens rather than 'Specific Spoilage Organisms' and prediction of the shelf life of foods. A current long-term study at UTas, funded by Meat & Livestock Australia (MLA) and Australian Meat Processor Corporation (AMPC), aims to develop mathematical models to predict the effect of storage temperature on the shelf life of vacuum packed (VP) beef and lamb primals and has led to the development of the current shelf life prediction models (MLA, 2017).

The shelf life prediction models are available for meat processors and exporters to use to predict the shelf life of chilled vacuum-packed beef and lamb in general with the additional ability of being tailored to specific supply chains. The current project, P.PIP.0563 – Predictive modelling pilot trial on vacuum skin-packed (VSP) beef through a retail supply chain, aimed to validate the UTas/MLA beef model with three different VSP products, through a simulated domestic supply chain, with a view to extending the utilisation of the models to other beef and lamb products.

[1] **These software tools can be accessed at the University of Tasmania Food Safety Centre web-site at: http://www.foodsafetycentre.com.au/predictive-models.php**

Objectives

- Product shelf life validation throughout supply chain by microbial and organoleptic (odour) assessment
- Evaluation of the UTas/MLA beef shelf life model in a simulated domestic supply chain
- Evaluation of current processes and nominal shelf life restrictions on product

Methodology

Shelf life trial

All trials were conducted at a beef processing plant between August and December 2018 for product intended for the domestic market.

Figure 1 summarises the life cycle of vacuum skin-packed (VSP) steak produced from beef rump primal. Briefly, rump primal was freshly obtained and aged (in vacuum packs, VP at approximately 0°C) for different durations (*i.e.,* 0, 30 and 57 days). All samples (with or without aging) were cut into steaks and vacuum-skin-packed (Figure 2). These VSP samples were then subjected to different processes for different durations and at different temperatures as experienced in a domestic supply chain. In addition, conditions that simulate consumer's practices (*i.e.,* consumers returning home and storing in their fridge) were included.

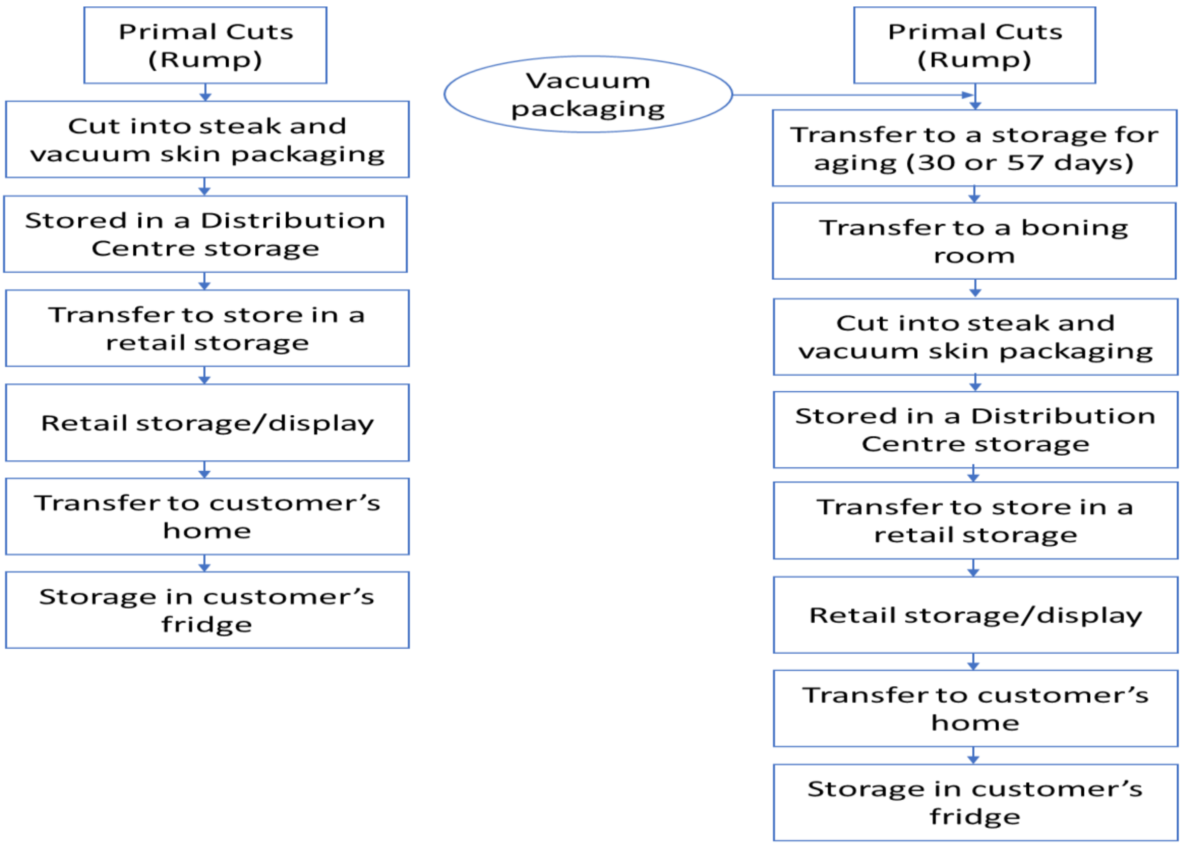

Figure 1. Life cycle of non-aged vacuum-skin packed beef steak (left) and vacuum-skin packed steak previously aged for either 30 or 57 days (right).

a)

b)

c)

Figure 2. Non-aged vacuum-skin packed beef steak (a), and vacuum-skin packed steak after aging for either 30 (b) or 57 days (c).

Samples (VP primal or VSP steaks) were taken periodically throughout the trials for microbiological analysis (standard plate counts, "SPC") and sensory evaluation (uncooked smell or 'persistent' odour assessed by a semi-trained panel comprising of 5 people) as described previously (Kaur et al. 2019).

In each trial, the temperature of the samples was continuously logged using 5 data loggers.

Determination of the shelf life of VSP steaks and its comparison with the UTas/MLA model

The shelf life of VSP steaks was determined from odour assessment using a semi-trained panel. Specifically, the products that were rated as 'marginal – smell off' were considered as commercially unacceptable*, i.e.,* beyond the acceptable quality endpoint. The time taken to reach that endpoint was recorded as the shelf life of the products. Due to the variability of the product characteristics even within the same trial, the shelf life was determined only when all products were rated as commercially unacceptable at any given time point and subsequent time points.

The observed shelf lives of VSP samples were compared directly with the shelf life predicted by the UTas/MLA VP beef shelf life prediction model. The model predicted the shelf life of any given product based on initial standard plate counts and time: temperature history that the product experienced in the supply chain.

Results and Discussion

Temperature profile

Table 1 describes the average temperatures of each step throughout the life cycle of three different vacuum skin-packed (VSP) products (*i.e.,* non-aged products and the products aged for 30 and 57 days before distribution). Generally, the temperatures experienced by 30-day aged and 56-day aged products were similar (within ± 0.5°C) but different to those experienced by non-aged products (at least by 1°C). Non-aged products were exposed to higher temperatures compared to other two types of products, especially during simulated distribution centre storage and transfer to a retail storage.

Table 1. Average temperature (± standard deviation) of each step throughout the life cycle of different vacuum skin-packed steaks.

Step	No aging (°C)	30-days aging (°C)	57-days aging (°C)
Aging process	NA[a]	0.12 ± 0.04	0.08 ± 0.08
Transfer to boning room	NA	1.39 ± 0.08	1.40 ± 0.07
Vacuum skin packaging	10.15 ± 0.92	5.39 ± 0.24	3.85 ± 0.42
Distribution Centre storage	3.56 ± 0.41	2.32 ± 0.22	1.77 ± 0.36
Transfer to a retail storage	1.87 ± 0.22	0.16 ± 1.15	0.78 ± 0.94
Retail storage/display	1.25 ± 0.18	1.69 ± 0.07	1.79 ± 0.06
Transfer to consumer’s home	8.08 ± 0.62	11.82 ± 0.88	12.20 ± 1.63
Storage in consumer’s fridge	3.29 ± 0.14	3.26 ± 0.08	3.21 ± 0.16
Average temperature throughout the trials	3.25 ± 0.11	1.78 ± 0.04	1.31 ± 0.07

a. NA = not applicable

Microbiological quality

Major retailers have their own microbiological criteria for the shelf life of any given meat product. For instance, product is typically considered as commercially unacceptable when those products contain SPC of ≥100 million CFU/cm^2 (≥8 Log CFU/cm^2).

It was evident in all cases that the initial SPCs of rump primal (before commencing the trials) were similar (Table 2). This ranged between 2.30 and 2.93 Log CFU/cm^2. After aging in a vacuum pack at approximately 0°C for 30 and 57 days, SPC increased to 3.23 and 4.00 Log CFU/cm^2, respectively. These aged products still satisfied *microbiological* shelf life criteria.

Table 2. Microbial counts of different vacuum skin-packed steaks before and after aging process and their shelf life based on microbiological criteria.

	Non-aged VSP steaks	30-day aged VSP steaks	57-day aged VSP steaks
Average initial SPC (Log CFU/cm^2)	2.30	2.93 ± 0.42	2.40 ± 0.35
Average SPC after aging process (Log CFU/cm^2)	NA[a]	3.23 ± 0.34	4.00 ± 0.97
Observed shelf life after aging (days) based on SPC (≥100 million CFU/cm^2)[b]	27	27	22

a. NA = not applicable

b. The time taken for VSP steaks to reach its end of shelf life based on microbiological criteria (SPCs of ≥100 million CFU/cm^2).

The time taken for each type of VSP products (non-aged, 30-day aged and 57-day aged products) to reach "end of shelf life" based on microbiological criteria was 27, 27 and 22 days, respectively. These observations indicate that primal aging for up to 30 days did not have any effect on the microbiological quality of VSP steaks (compared to non-aged products). However, aging under similar conditions but for more than 30 days and up to 56 days appeared to marginally reduce the microbiological quality of VP steaks (5 days shorter than the microbiological shelf life of non-aged and 30-day aged products).

Observed shelf life based on odour attribute and its comparison with the shelf life model

In this study, the odour characteristics of VSP steaks was used as an indicator for the first signs of loss of quality based carefully controlled studies at the University of Tasmania and that underpin the beef shelf life model used and being evaluated in this study. Table 3 describes the shelf life observed for non-aged VSP products (41 days) and VSP products previously aged for 30 and 56 days (38 and 37 days, respectively). These data suggest that aging under anaerobic conditions at approximately 0°C for up to 57 days had little impact on the quality of VSP products when compared to the products without aging. Furthermore, it is noteworthy that the shelf life of each type of product was much longer than that when the microbiological criteria (SPC of ≥100 million CFU/cm^2) was applied (*see* above). This reinforces that determination of shelf life of VSP products based on microbiological quality is inappropriate and unreliable.

Table 3. The UTas/MLA shelf life model predictions for different vacuum skin-packed steaks compared to observed data

	Non-aged VSP steaks	30-day aged VSP steaks	57-day aged VSP steaks
Based on the trial data			
Average initial SPCs (Log CFU/cm^2)	2.30	2.93 ± 0.42	2.40 ± 0.35
Average temperature throughout the trials (°C)	3.25 ± 0.11	1.78 ± 0.04	1.31 ± 0.07
Observed shelf life (days) based on odour attribute[a]	41	38	37
Based on the shelf life model			
Expected shelf life (days)[b]	43 ± 1	35 ± 1	22 ± 2
Deviation	5%	8%	41%

a. The time taken for VSP steaks to reach its end of shelf life based on odour attribute.

b. Predicted shelf life was determined for VSP products (not for primals)

The UTas/MLA model for VP beef and lamb shelf life predictions was used to predict the shelf life of different VSP steaks based on their time:temperature history and initial microbial counts, with emphasis on the development of persistent odour in their packs (Table 3). A good agreement was observed between the observed and predicted shelf lives in all cases, except for 57-day aged products. The observed and predicted shelf lives of non-aged products and products previously aged for 30 days were similar with a deviation of ≤8%, whereas for 57-day aged products, the model underpredicted the shelf life (22 days) compared to that observed (37 days) (*i.e.,* a deviation of 41%, *i.e.,* between predicted and observed growth). This suggests that the model might be able to provide an accurate prediction of the shelf life of VSP products previously aged for up to 30 days only. However, this conclusion is discussed further below.

To further explore the performance of the model for aged VSP steaks, their temperature profile and microbial counts after aging were used for shelf life prediction (Table 4). It was found that the model could predict the shelf life of both 30-day and 57-day aged products with a deviation of ≤5% (when compared to their observed shelf life). This also agrees well with the predicted shelf life of 30-day aged products when the model used the time:temperature history and microbial counts before aging process (Tables 3 and 4). The basis of the apparent differences in the predicted shelf life of 56-day aged products between different inputs for the model (*i.e.,* using the time:temperature history and microbial counts before and after aging process) remains to be elucidated. However, it is worthwhile noting that primal rump and steak can be considered as different products, especially in term of microbial counts. The process of producing steaks involves cutting rump into smaller pieces. This would result in a dilution/reduction of microbial counts on steaks compared to its respective rump (*i.e.,* by having more surface area and creating more sterile surface that can be contaminated). Therefore, it is more appropriate to use the model to predict the shelf life of VSP products after aging (*i.e.,* using the time:temperature history and microbial counts after aging process).

Table 4. The UTas/MLA shelf life prediction model for different vacuum skin-packed steaks after aging.

	30-day aged VSP steaks	57-day aged VSP steaks
Based on the trial data		
Average SPCs at the end of aging process (Log CFU/cm^2)	3.23 ± 0.34	4.00 ± 0.97
Average temperature after aging process (°C)	3.21 ± 0.04	3.16 ± 0.11
Observed shelf life (days) based on odour attribute[a]	38	37
Based on the shelf life model		
Expected shelf life (days)[b]	40 ± 1	38 ± 1
Deviation	5%	3%

a. The time taken for VSP steaks to reach "end of shelf life" based on odour.

b. Predicted shelf life was determined for VSP products (not for primals)

From the above, the model previously developed for VP beef and lamb shelf life predictions could be used to accurately predict the shelf life of VSP beef steaks through a domestic supply chain. The model also performed well for VSP products previously produced from rump primal that had been aged under anaerobic conditions at approximately 0°C for up to 56 days. It is also worthwhile noting that the model generally provided a shelf life prediction for all types of VSP products with a deviation of ≤8%. This agrees well with previous validation trials for the model that reported an average deviation of 11% when compared between the observed and predicted shelf lives of different VP beef and lamb cuts (Ross et al., 2019). Taken together, the data presented here provide further validation of the model for shelf life prediction of not only VP beef and lamb cuts but also for VSP beef.

Conclusions

This study examined the shelf lives of VSP beef products (non-aged VSP steaks, and the same products aged for 30 and 56 days) in a simulated domestic supply chain. The observed shelf life of these products was compared with those predicted by the UTas/MLA VP beef shelf life model for model validation purposes.

The data indicate that determination of the shelf life of VSP products (with or without aging process) should be based on their odour characteristics and not on microbiological quality (i.e., SPCs of ≥100 million CFU/cm^2). Aging beef rump primal under anaerobic conditions at approximately 0°C for up to 56 days before being reprocessed and packed as VSP steaks also did not have significant effects on the shelf life of VSP products (based on both microbiological quality and odour attribute). This offers some flexibility in the process of producing any particular VSP products to meet up customer's demand without significant effects of their shelf life.

The validation trials to date (including the data of this study) revealed that the UTas/MLA shelf life prediction model can provide an accurate prediction of the shelf life (deviation of up to 11%). It is, therefore, valid for the model to be adopted as a reliable decision-making tool in a commercial supply chain for beef in different packaging systems (*i.e.,* VP and VSP). Such a tool will offer a cost-effective approach for better management of any given supply chain (*e.g.,* helping to decide on product movement in a supply chain), reducing customer dissatisfaction and increasing business profitability. Furthermore, a cost *vs.* benefit analysis conducted by Greenleaf has estimated that utilisation of the shelf life prediction model has a benefit of $7.8 million per annum for the Australian domestic retail beef supply chain, with 99.5% of this benefit from reduced waste and markdowns.

References

Casaburi, A., Piombino, P., Nychas, G.J, Villani, F. and Ercolini, D. (2015) Bacterial populations and the volatilome associated to meat spoilage. Food Microbiology. 45, 83-102.

Kaur, M., Ross, T., Bowman, J.P. and Huynh, L. (2018) Predictive modelling pilot trial on beef products through a retail supply chain (P.PIP.0543), Meat & Livestock Australia, North Sydney, NSW.

Kaur, M., Shang, H., Tamplin, M., Ross, T. and Bowman, J.P. (2017) Culture-dependent and culture-independent assessment of spoilage community growth on VP lamb meat from packaging to past end of shelf life. Food Microbiology. 68, 71-80.

MLA (2017) Processor's guide to improving microbiological quality and shelf life of meat – 3rd Edition, Meat & Livestock Australia, North Sydney, NSW.

Ross, T., Bowman, J.P., Kocharunchitt, C. and Mellefont, L. (2019). Microbial ecology and physiology (V.MFS.0402) – Milestone 6 Report. Meat and Livestock Australia, North Sydney, Australia.

Small, J.H., Jenson, I., Kiermeier, A. and Sumner, J. (2012) Vacuum-packed beef primals with extremely long shelf life have unusual microbial counts. Journal of Food Protection. 75, 1524-1527.