Final report

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Predictive modelling pilot trial on beef products through a retail supply chain

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Executive Summary

Longer shelf life of fresh meat is a desirable attribute to effectively control the supply chain. This report examined the shelf lives of three retail beef products in a domestic supply chain. Besides evaluating the performance of supply chain and shelf lives of the products the data were also used for the validation of UTas/MLA vacuum packaged (VP) beef shelf life model. The trials also provided a basis for a cost benefit analysis in shelf life extension.

Trials were conducted on, VP beef rump roast, rump steaks in modified atmosphere packed (MAP, 80:20 O_2:CO_2) and rump steaks in over wrapped (OW) trays. As a requirement various ageing regimes at the cold storage were evaluated as well during the trial. After packing, VP rump roast were aged for 5, 20 and 69 days and then moved to a distribution centre (simulated in house) followed by retail display and consumer's fridge storage. MAP steaks followed a different part and required VP rump primals to be aged for 28, 34 and 69 days before being processed into steaks and moved to retail and consumer fridges. For OW steaks, VP primals used ageing regimes of 40, 61 and 90 days followed by retail display and consumer's fridge storage. Product temperature was continuously logged throughout the trials and microbiological and organoleptic criteria were tested along the trial.

For model validation direct comparison of shelf life observed in these trials for beef products based on sensory evaluation (odour) and the shelf life predicted by the model using initial standard plate counts and time: temperature history the products experienced in the supply chain was performed, as this is the main basis of the shelf life model.

The VP rump roast can achieve 64 days shelf life when aged for 20 days at a cold store (~0.6°C) followed by low temperature storage in distribution centre (~0.6°C) for another 30 days and 14 days in retail display and consumer fridges (both operating at ~4°C). This is almost double the currently (35 days) restriction.

Longer ageing time of 69 days marginally changed the aroma and flavour of cooked beef without any noticeable change in odour. Further, longer ageing of VP rumps reduced the retail life of MAP steaks by half (4 days as compared to 8 days). Similar to OW steaks prepared from 90 days old primals had 4 days with some marginal changes in odour and flavour. Compared to 61days old VP rump which were acceptable for 7 days at retail.

A good agreement was observed between the predicted and observed shelf lives for VP beef rump roast with average deviation of around 5%. Further, the model accurately predicted the end/near end (marginal) of shelf life for VP beef.

Validation results confirmed that model is safe for use for accurately predicting the shelf life of VP beef for this supply chain. For reprocessed MAP steaks, there was a lower correlation of 0.93 (compared to 0.98 for VP rump roast) between observed and predicted shelf lives. However, correlation was poor (0.45) for OW steaks. This is expected, as model has been developed for VP product.

Greenleaf estimates, that by using the shelf life model to extend the current shelf life in the domestic market leading to reduced wastage and product testing, this will return benefits of $16.3 million for industry.

Introduction

Shelf life of fresh red meat can be affected by several factors, such as plant hygiene, processing protocols, packaging atmosphere and supply chain temperature. Good plant hygiene restricts the initial level of microbial inoculum and then storing meat at low temperature reduces the rate of growth of these 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 2014). 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. Further, 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 can give a much-extended shelf life at low temperature. The shelf life observed for fresh meat is now much longer than earlier perceived by the industry, which to a degree is based on historic practices rather than fundamental science. Under vacuum packaging conditions, 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 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/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 has a long reputation of developing industry-relevant predictive models and decision support software[1] including the Refrigeration Index, *E. coli* inactivation in fermented meats, and Risk Ranger. The majority 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 the University of Tasmania (UTas), funded by Meat & Livestock Australia (MLA), aimed 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 capability of being tailored to specific supply chains. The current project, P.PIP.0543 – Predictive modelling pilot trial on beef products through a retail supply chain, aimed to validate the UTas/MLA shelf life model with three different products, through a 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**

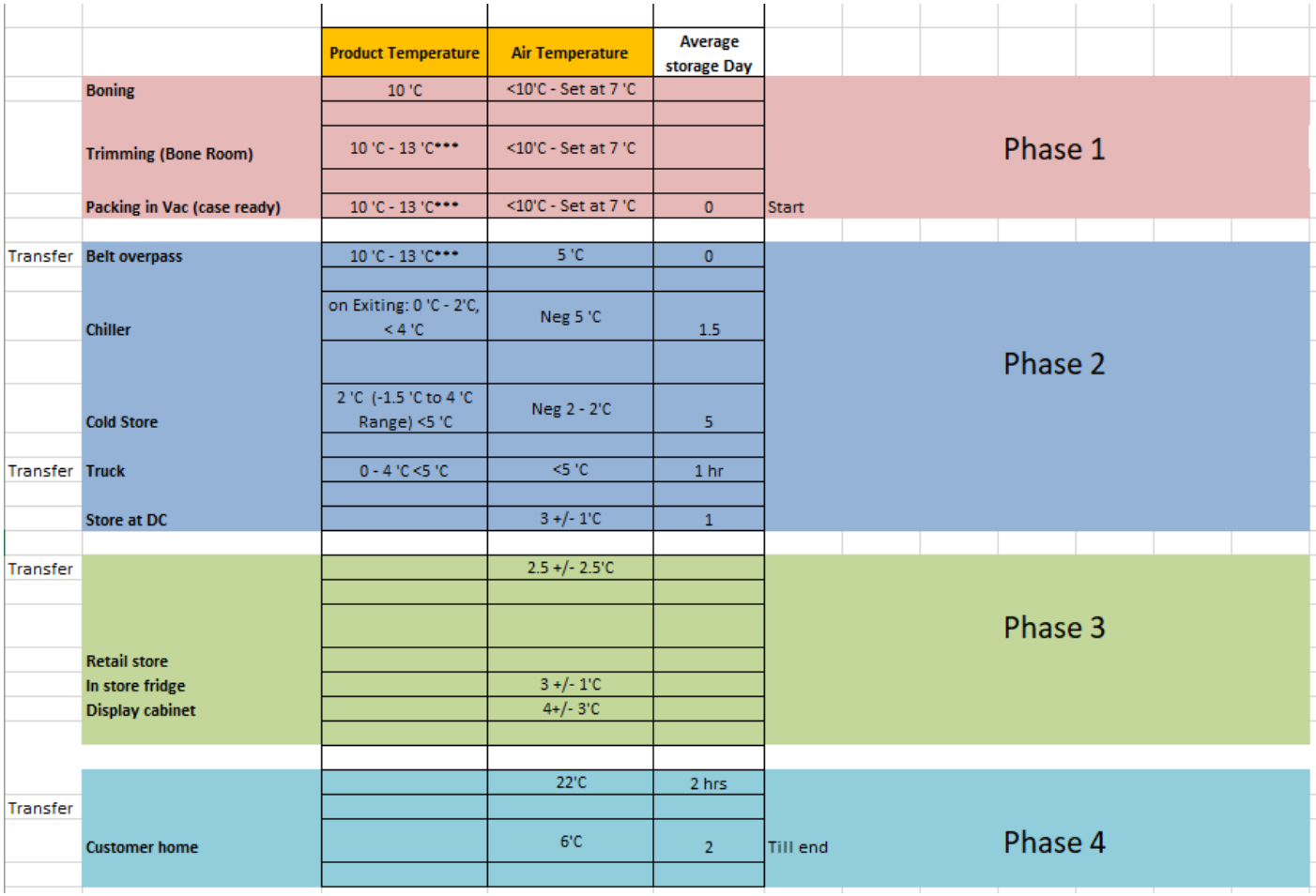
Objectives

- Establish a template for a trial design that can be used for data collection, resourcing accountability and trial budgeting across all shelf life prediction validation trials
- Product shelf life validation throughout supply chain by microbial and organoleptic assessment
- Decision making on product movement to maximise shelf life cost effectively
- Simplify the complexity of product life cycle to one final use by date
- Validate current imposed processes, and shelf life restriction on product
- Validation of beef shelf life model in a domestic supply chain
- Develop a case study for cost: benefit analysis of the shelf life models
- The significance of microbiology and its ability to accurately determine and dictate end of shelf life

Methodology

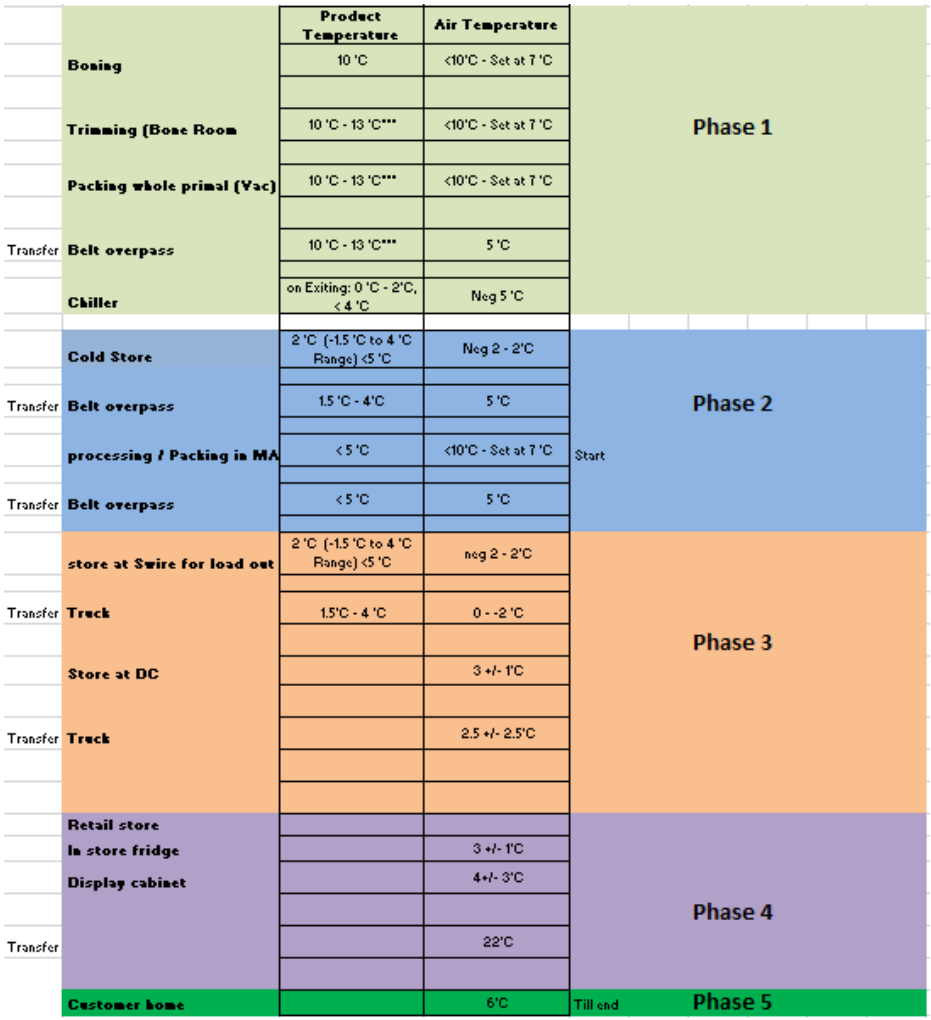
Product life cycle mapping

The life cycles for vacuum packed (VP) beef rump roast, beef rump steak Modified Atmosphere Pack (MAP, 18-25% CO_2 and 75-82% O_2) and beef rump steak Over Wrap (OW) pack were mapped. The current proposed guidelines consider 35 days shelf life for VP rump roast, 70 days including 9 days after reprocessing of VP beef rump primals to MAP steaks and 70 days including 4 days after reprocessing of VP beef rump primals to OW steaks (Figures 1 – 3)



		Product Temperature	Air Temperature	Average storage Day		
	Boning	10 'C	<10'C - Set at 7 'C			Phase 1
	Trimming (Bone Room)	10 'C - 13 'C***	<10'C - Set at 7 'C			
	Packing in Vac (case ready)	10 'C - 13 'C***	<10'C - Set at 7 'C	0	Start	
Transfer	Belt overpass	10 'C - 13 'C***	5 'C	0		Phase 2
	Chiller	on Exiting: 0 'C - 2'C, < 4 'C	Neg 5 'C	1.5		
	Cold Store	2 'C (-1.5 'C to 4 'C Range) <5 'C	Neg 2 - 2'C	5		
Transfer	Truck	0 - 4 'C <5 'C	<5 'C	1 hr		
	Store at DC		3 +/- 1'C	1		
Transfer	Retail store		2.5 +/- 2.5'C			Phase 3
	In store fridge		3 +/- 1'C			
	Display cabinet		4+/- 3'C			
Transfer	Customer home		22'C	2 hrs		Phase 4
			6'C	2	Till end	

Figure 1. Life cycle of vacuum packed beef rump roast – trial 1



		Product Temperature	Air Temperature		
	Boning	10 'C	<10'C - Set at 7 'C		Phase 1
	Trimming (Bone Room	10 'C - 13 'C***	<10'C - Set at 7 'C		
	Packing whole primal (Vac)	10 'C - 13 'C***	<10'C - Set at 7 'C		
Transfer	Belt overpass	10 'C - 13 'C***	5 'C		
	Chiller	on Exiting: 0 'C - 2'C, < 4 'C	Neg 5 'C		
	Cold Store	2 'C (-1.5 'C to 4 'C Range) <5 'C	Neg 2 - 2'C		Phase 2
Transfer	Belt overpass	1.5 'C - 4'C	5 'C		
	processing / Packing in MA	< 5 'C	<10'C - Set at 7 'C	Start	
Transfer	Belt overpass	< 5 'C	5 'C		
	store at Swire for load out	2 'C (-1.5 'C to 4 'C Range) <5 'C	neg 2 - 2'C		Phase 3
Transfer	Truck	1.5'C - 4 'C	0 - -2 'C		
	Store at DC		3 +/- 1'C		
Transfer	Truck		2.5 +/- 2.5'C		
	Retail store				Phase 4
	In store fridge		3 +/- 1'C		
	Display cabinet		4+/- 3'C		
Transfer			22'C		
	Customer home		6'C	Till end	Phase 5

Figure 2. Life cycle of vacuum packed beef rump reprocessed in MAP steaks – trial 2

		Product Temperature	Air Temperature		
	Boning	10 'C	<10'C - Set at 7 'C		Phase 1
	Trimming (Boning Room)	10 'C - 13 'C***	<10'C - Set at 7 'C	Start	
	Packing whole primal (Vac)	10 'C - 13 'C***	<10'C - Set at 7 'C		
Transfer	Belt Overpass	10 'C - 13 'C***	5 'C		
	Chiller	on Exiting: 0 'C - 2'C, < 4 'C	Neg 5 'C		
	Cold storage	2 'C (-1.5 'C to 4 'C Range) <5 'C	Neg 2 - 2'C		
Transfer	Truck	1.5'C - 4 'C	0 - -2 'C		Phase 2
	Store at DC		3 +/- 1'C		
Transfer	Truck		2.5 +/- 2.5'C		
	Retail store			Must be used by day 69 from slaughter	
	In store fridge		3 +/- 1'C		Phase 3
	In store processing		Room temp		Phase 4
	Display cabinet		4 +/- 3'C		
Transfer			22'C		
	Customer home		6'C	Till end	Phase 5

Figure 3. Life cycle of vacuum packed beef rump reprocessed in OW steaks –trial 3

Trials' design

Based on UTas beef shelf life model three trials were designed using rump as the primal due to its poor colour retention. One for VP beef rump roast, beef rump MAP steaks and OW steaks.

In these trials after vacuum primals were aged for various durations and passed through the supply chain spending variable times at each location under different temperature conditions experienced the supply chain.

A detailed description of trials' pathways is provided in Appendices 1-3. In summery VP rump roast was aged for 5, 20 and 69 days at cold storage and moved to distribution centre (simulated in house) followed by retail display and consumer's fridge storage constituting 40 different pathways grouped into nine streams.

VP rump primals were aged for 28, 34 and 69 days at Cold storage before being reprocessed to MAP steaks and moved to retail display and simulated consumer fridges in 51 pathways (9 streams).

OW steaks VP primals followed 36 pathways (18 streams) inclusive of three ageing regimes of 40, 61 and 90 days at the cold store followed by retail display and consumer's fridge.

In addition, all products spent around 2 h in refrigerated trucks and a minimum 1.5 h at ambient temperature challenge to simulate consumers returning home from the shops.

Sampling

Vacuum packed primals for the three trials were collected from a single kill. These primals were then packed in cartons along with calibrated temperature data loggers and taken for cold storage.

pH

The pH was recorded (Labchem-Cond/pH, TPS) at the time of primal packaging and thereafter at regular intervals as per trial schedule.

Microbiological analysis

Data on standard plate counts, LAB, *Enterobacteriaceae* and *Pseudomonas* spp. were collected on the day of primal packing and thereafter at designated time intervals. All analyses were done in triplicates. For microbial analyses, the outer surface of the package (primals and steaks) was disinfected with isopropyl alcohol wipes and then, using a sterile scalpel blade, packaging was cut open exposing the meat surface. Using a new sterile scalpel blade and sterile forceps, strings surrounding the beef rump roast were removed followed by aseptically sampling five pieces of ~5g portions of the meat each. The five sampled cuts were combined in a sterile stomacher bag to achieve a total sample mass of 25 ± 2.5 g. For steak a surface section from the longest length available to a mass of ~25g was sampled (Figure 4). Aseptically 1:10 w/w amount of Buffered Peptone Water (BPW) was added to each sample and stomached in the stomacher for 1 minute. Ten-fold serial dilutions were prepared as required.

Figure 4. Microbiological sampling of VP beef rump roast and steak

A 100 µL of the initial suspension and dilutions was transferred onto pre- labelled, pre-poured tryptone soy agar, de Man, Rogosa and Sharpe (MRS) agar at pH 5.7, Cetrimide, Fucidin and Cephaloridine (CFC) agar and Violet Red Bile Glucose agar (VRBG) plates for standard plate count, lactic acid bacteria, *Pseudomonas* spp and *Enterobacteriaceae* counts, respectively. Using a sterile spreader bar inoculum was evenly spread over the entire surface of the agar plate. Plates were incubated at 20 ± 1°C for 5 days aerobically and anaerobically for standard plate count and LAB, respectively and colonies were counted thereafter and expressed as log cfu/g. For *Pseudomonas* spp and *Enterobacteriaceae* plates were stored at 25 °C ± 1 °C for 48 h ± 2 h and 37 ±1°C for 24 h ± 2 h, respectively. Only standard plate count data were used for model validation.

Organoleptic analysis

At regular intervals, three packs were taken out and evaluated for their sensory attributes by a five membered semi trained sensory panel.

The Organoleptic criteria assessed were:

Visual evaluation:

Criteria: colour, purge, packaging and overall appearance.

Frequency: evaluation was conducted daily on product in the retail display cabinet and consumer fridge.

Cooking Evaluation:

Criteria - Uncooked: colour, smell (odour) – initial smell (odour) – persistent smell (odour) texture/appearance, purge.

Criteria - Cooked: appearance, aroma, flavour, mouthfeel, tenderness, juiciness, overall and packaging condition.

Assessment criteria for organoleptic evaluation: Product was rated as acceptable, marginal or not acceptable. Commentary and photos were taken to document reason.

For the shelf life model evaluation, uncooked smell (persistent odour) was the measurement used to define as end of shelf life.

Validation of UTas/MLA VP beef shelf life model

Validation of model was done by direct comparison of shelf life observed in these trials for beef products based on sensory evaluation (odour) and the shelf life predicted by the model using initial standard plate counts and time: temperature history the products experienced in the supply chain, as these are the main bases of the shelf life model. Further, standard plate counts observed in the trial were compared with predicted counts and accuracy and bias factors (Ross 1996) for the model were calculated. Comparisons between shelf life predicted by the model and that observed for MAP and OW rump steaks prepared from VP rump aged for various durations were also computed.

Results and Discussion

Temperature profile during the study

The temperature profiles for each trial including streams within it are presented in Tables 1 - 3. Due to challenges in setting up the trial, storage, and logistics into the retail supply chain and retrieving the product, the project team agreed the best approach was to replicate the temperatures using commercially available retail display fridge for the trial.

In trial 1, the average temperature of cold storage, refrigerated truck, distribution centre, retail display and consumer fridge was 0.32, 1.75, -0.06, 4.25 and 4.17 °C, respectively. Low temperature was experienced in the retail display fridge for streams 7, 8 and 9 as compared to 1 - 6 (Table 1).

Table 1. Temperature profile of VP beef rump roast during storage at different locations within each stream

	Average temperature (°C)								
Stream	1	2	3	4	5	6	7	8	9
Cold Storage	-0.10	-0.56	-0.56	0.52	0.58	0.58	0.78	0.82	0.82
Truck	-0.03	1.01	1.01	2.31	2.21	2.21	2.37	2.34	2.34
DC storage (Simulated)	-1.50	0.20	0.58	-0.89	0.40	0.59	-0.43	-0.05	0.55
Retail display storage	6.73	6.36	4.91	6.25	5.91	4.09	1.44	2.08	0.47
Temperature challenge	12.63	12.63	12.11	12.11	15.18	7.00	8.85		11.90
Consumer Fridge (Simulated)	4.19	4.42	4.33	4.11	4.33	3.12	4.53	4.14	4.37

In trial 2, the average temperature of cold storage and consumer fridge was 0.89 and 4.01°C, respectively. Low temperature was also observed here for retail display fridge for streams 4 – 9 (Table 2).

Table 2. Temperature profile of beef rump MAP steaks during storage at different locations within each stream

	Average temperature (°C)								
Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Cold Storage	0.82	0.89	0.89	0.94	1.04	1.04	0.79	0.83	0.83
Processing and MAP packing	2.91	1.87	1.87	3.40	3.41	3.41	2.72	2.35	2.35
DC storage (Simulated)	0.85	0.64	0.64	1.32	1.37	1.37	1.82	2.34	2.34
Truck	1.26	1.36	1.36	1.69	2.78	2.78	0.52	1.07	1.07
Retail display storage	6.63	7.05	6.79	-1.58	-1.54	-1.62	-1.45	1.24	1.00
Temperature challenge	11.47	15.86	15.86	16.22	8.16	8.16	10.34	10.34	11.66
Consumer Fridge (Simulated)	4.33	4.11	4.19	4.77	5.20	2.53	3.67	3.38	3.89

During trial 3, the average temperature of cold storage, distribution centre, retail fridge and customer fridge was 0.85, 0.66, 2.57 and 4.59°C respectively (Table 3).

Table 3. Temperature profile of beef rump OW steaks during storage at different locations within each stream

	Average temperature (°C)																	
Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Cold Storage	0.98	0.98	0.98	0.98	0.98	0.98	0.84	0.98	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.75	0.76	0.78
Truck	2.15	2.15	2.15	2.15	2.15	2.15	2.59	2.15	1.02	1.02	1.02	1.02	1.02	1.02	1.02	2.54	1.02	2.59
DC storage (Simulated)	0.54	0.54	0.54	0.54	0.54	0.54	0.44	0.54	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.67	0.71	1.34
Processing and OW packing	4.82	4.82	4.82	4.82	4.82	4.82	3.58	4.82	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.26	4.16	1.41
Retail display storage	3.77	3.12	3.45	2.12	3.16	3.45	4.71	3.12	2.20	1.37	2.67	2.20	1.27	1.37	2.67	1.64	1.37	
Temperature challenge		14.53	14.53	14.53	14.53	14.53	14.53	14.53		13.57	13.57	13.57	13.57	13.57	13.57	13.57	13.57	
Consumer Fridge (Simulated)	3.86	4.13	4.17	4.21	4.12	4.15	4.51	4.14		3.84	5.61	5.54	4.60	4.88	5.51	5.54	5.45	3.79

Overall, there was good temperature control during cold storage (~0.8°C), however, the temperature of distribution centre which was simulated was lower (~0.6°C) than what the product would have experienced under real supply chain (~4°C). Temperature of retail fridge was towards the lower end. However, most of the time was within the range (4±3°C) experienced in the commercial supply chain.

pH

At the time of packing the mean pH of VP beef rump roast was 5.47 that increased slightly during storage (5.69 at 114 days). For VP beef rump primals the pH was around 5.41 at the time of packing which increased to 5.60 by day 92. The pH data suggested that samples included in this study were within a pH range considered normal for vacuum packaged beef regardless of storage time.

Observed shelf life

Trial 1 – VP beef rump roast

In trial 1, the VP rump roast experienced three ageing regimes (5, 20 and 69 days) at cold storage. The average standard plate counts, LAB and *Enterobacteriaceae* counts at the time of primal packing were log 1.03, <-0.60 and <-0.60 log cfu/g, respectively. The microbial counts increased and sensory score dropped in magnitude during storage (Tables 4 - 8). Retailers have microbiological and sensory criteria for shelf life of those products

Results from this trial showed that VP rump roast can achieve 64 days shelf life when aged for 20 days at cold storage followed by low temperature storage in distribution centre (both operating at ~0.6°C) for up to 30 days and 7 days each in retail display and consumer fridges (both operating at ~4°C), easily meeting micro and sensory criteria (Table 7 and Figure 5). Further, it is possible to extend the shelf life to 100 plus days with longer ageing at cold storage (69 days) while having marginal effect on sensory attributes of the product (Table 8). For VP rump roast odour (uncooked), flavour and aroma (cooked) seemed to be the important sensory attributes for shelf life determination. At present, major retailers consider the product has reached its end of shelf life if standard plate counts are ≥100,000,000 cfu/cm^2; counts for *Enterobacteriaceae* are ≥100,000 cfu/cm^2 or if it failed organoleptically. Currently, the shelf life of VP rump roast is considered to be 35 days, including 5 – 21 days ageing at cold storage (at -1.5 - 4°C) and ~1 day at distribution centre where temperature is usually higher (around 4°C) as compared to what was observed in this trial. Results from this trial show that VP rump roast can be aged for longer at low temperature either at cold storage or distribution centre thereby achieving a shelf life >35 days without negatively effecting its microbiological and sensory qualities.

Figure 5. Appearance of 64 days old VP beef rump roast

Table 4. Microbial and sensory profile of 5 days aged VP beef rump roast stored at distribution centre for 4 days along with retail and consumer fridge storage

Stream	1	2	3	4	5	6	7	8	9A	9B
Storage (days)										
Cold storage	Day 0	5 days ageing								
DC storage (Simulated)		0	3	4	4	4	4	4	4	4
Retail display storage		0	0	6	7	7	7	7	7	7
Consumer Fridge (Simulated)		0	0	0	0	11	18	25	49	56
Total		**5**	**8**	**15**	**16**	**27**	**34**	**41**	**65**	**72**
SPC (Log cfu/g)	1.03	<2	2.37		2.94	6.77	7.25	7.81	7.72	8.39
LAB (log cfu/g)	<-0.60	<2	<2		2.37	5.67	6.61	7.08	7.74	8.14
Entro (log cfu/g)	<-0.60	<2	<2		<2	3.96	4.54	5.17	5.67	6.21
Sensory (uncooked)	**Purge**	Minor - bright red	NIL		Moderate - red	Moderate - red	Moderate - red	Moderate - red	High	High - foul brown colour
	Colour	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable - corner browning	Acceptable	Unacceptable - heavily browned
	Texture/Appearance	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
	Odour- initial	Acceptable	Acceptable		Acceptable - slightly aged	Acceptable	Acceptable	Acceptable	Marginal - sulfury/aged	Unacceptable - foul/putrid
	Odour - persistant	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Marginal - sulfury/aged	Unacceptable - foul/putrid
Sensory (cooked)	**Appearance**	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
	Aroma	Acceptable	Acceptable	No sensory	Acceptable	Acceptable	Acceptable	Acceptable	Marginal - sulfury/aged	NOT COOKED
	Flavour	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Marginal - aged/bland	NOT COOKED
	Mouthfeel	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	NOT COOKED
	Tenderness	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable - extremely tender	NOT COOKED
	Juiciness	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	NOT COOKED
	Packaging Condition	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable - slight air bubbles	Acceptable	Acceptable - loose	Unacceptable - loose
Sensory (overall)		Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable	Marginal	Unacceptable

*Green – acceptable, yellow – marginal and red - unacceptable

Table 5. Microbial and sensory profile of 5 days aged VP beef rump roast stored at distribution centre for 15 days along with retail and consumer fridge storage

Stream	1	10	11	12
Storage (days)				
Cold storage	Day 0	5 days ageing		
DC storage (Simulated)		15	15	15
Retail display storage		3	3	3
Consumer Fridge (Simulated)		4	11	18
Total		27	34	41
SPC (Log cfu/g)	1.03	5.89	7.09	7.38
LAB (log cfu/g)	<-0.60	4.43	6.19	6.78
Entro (log cfu/g)	<-0.60	2.73	2.43	4.53
Sensory (uncooked)	**Purge**	Moderate - red	Moderate - dark red	Minor
	Colour	Acceptable	Acceptable	Acceptable
	Texture/Appearance	Acceptable	Acceptable	Acceptable
	Odour- initial	Acceptable	Acceptable	Acceptable
	Odour - persistant	Acceptable	Acceptable	Acceptable
Sensory (cooked)	**Appearance**	Acceptable	Acceptable	Acceptable
	Aroma	Acceptable	Acceptable	Acceptable
	Flavour	Acceptable	Acceptable	Acceptable
	Mouthfeel	Acceptable	Acceptable	Acceptable
	Tenderness	Acceptable	Acceptable	Acceptable
	Juiciness	Acceptable	Acceptable	Acceptable
	Packaging Condition	Acceptable	Acceptable - slight loose	Acceptable
Sensory (overall)		Acceptable	Acceptable	Acceptable

Table 6. Microbial and sensory profile of 5 days aged VP beef rump roast stored at distribution centre for 25 days along with retail and consumer fridge storage

Stream	1	13	14	15	16	17	18A	18B	18C	18D
Storage (days)										
Cold storage	Day 0	5 days ageing								
DC storage (Simulated)		24	25	25	25	25	25	25	25	25
Retail display storage		0	2	3	3	3	3	3	3	3
Consumer Fridge (Simulated)		0	0	0	1	8	32	39	46	53
Total		**29**	**32**	**33**	**34**	**41**	**65**	**72**	**79**	**86**
SPC (Log cfu/g)	1.03			5.98	5.36	7.26	8.13	8.14	8.12	8.11
LAB (log cfu/g)	<-0.60			3.58	3.09	6.17	7.63	7.79	7.88	8.26
Entro (log cfu/g)	<-0.60			<2	<2	2.72	5.81	5.28	4.75	5.58
Sensory (uncooked)	**Purge**	No sensory	No sensory	No sensory	Moderate - red	Minor	Moderate	No sensory	High	No sensory
	Colour				Acceptable	Acceptable	Acceptable		Acceptable	
	Texture/Appearance				Acceptable	Acceptable	Acceptable		Acceptable	
	Odour- initial				Acceptable	Acceptable	Marginal - sulfury/aged		Marginal - sulfury/aged	
	Odour - persistant				Acceptable	Acceptable	Marginal - sulfury/aged		Marginal - sulfury/aged	
Sensory (cooked)	**Appearance**				Acceptable	Acceptable	Acceptable		Acceptable	
	Aroma				Acceptable	Acceptable	Marginal - sulfury/aged		Unacceptable - sulfury/aged	
	Flavour				Acceptable	Acceptable	Marginal - aged/bland/acidic		Unacceptable - aged/sour	
	Mouthfeel				Acceptable	Acceptable	Acceptable		Acceptable	
	Tenderness				Acceptable	Acceptable	Acceptable - extremely tender		Acceptable	
	Juiciness				Acceptable	Acceptable	Acceptable		Acceptable	
	Packaging Condition				Acceptable	Acceptable	Acceptable - loose		Unacceptable - loose bag, air bubbles	
Sensory (overall)					Acceptable	Acceptable	Marginal		Unacceptable	

Table 7. Microbial and sensory profile of 20 days aged VP beef rump roast stored along with distribution centre, retail and consumer fridge storage

Stream	1	19	20	21	22	23	24	25	26	27A	27B
Storage (days)											
Cold storage	Day 0	20 days ageing									
DC storage (Simulated)		0	4	4	14	15	15	30	30	30	30
Retail display storage		0	7	7	0	6	7	7	7	7	7
Consumer Fridge (Simulated)		0	0	7	0	0	7	7	10	15	22
Total		**19**	**31**	**38**	**34**	**41**	**49**	**64**	**67**	**72**	79
SPC (Log cfu/g)	1.03	2.6	5.78	6.72				7.54	7.67	8.15	8.01
LAB (log cfu/g)	<-0.60	<2	5.59	5.86				7.28	6.91	7.76	7.73
Entro (log cfu/g)	<-0.60	<2	3.12	3.54				3.1	3.55	5.44	5.37
Sensory (uncooked)	**Purge**	Moderate - r	Moderate - red	Minor - red			Moderate to high	Minor	High	High	High
	Colour	Acceptable	Acceptable	Acceptable			Acceptable - slight browning discoloration	Acceptable	Acceptable	Acceptable	Acceptable
	Texture/Appearance	Acceptable	Acceptable	Acceptable			Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
	Odour- initial	Acceptable	Acceptable	Acceptable			Marginal - Sulfury/aged scent	Acceptable	Acceptable	Acceptable	Marginal - sulfury/aged
	Odour - persistant	Acceptable	Acceptable	Acceptable			Acceptable - slight aged/sulfury	Acceptable	Acceptable	Acceptable	Marginal - sulfury/aged
Sensory (cooked)	**Appearance**	Acceptable	Acceptable	Acceptable			Acceptable	Acceptable	Marginal - blood in fat	Marginal - blood in fat	Acceptable
	Aroma	Acceptable	Acceptable	Acceptable	No sensory	No sensory	Acceptable - slightly aged	Acceptable	Acceptable	Marginal - sulfury/aged	Unacceptable - sulfury/aged
	Flavour	Acceptable	Acceptable	Acceptable			Acceptable - slightly aged	Acceptable	Acceptable	Marginal - sulfury/aged	Unacceptable - aged/sour
	Mouthfeel	Acceptable	Acceptable	Acceptable			Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
	Tenderness	Acceptable	Acceptable	Acceptable			Acceptable - extremely tender	Acceptable - extremely tender	Acceptable - very tender	Acceptable	Acceptable
	Juiciness	Acceptable	Acceptable	Acceptable			Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
		Acceptable	Acceptable	Acceptable			Acceptable - loose	Acceptable - loose	Marginal - loose with air bubbles	Marginal - loose with air bubbles	Unacceptable - bag loose with air bubbles
Sensory (overall)		Acceptable	Acceptable	Acceptable			Acceptable	Acceptable	Acceptable	Marginal	Unacceptable

Table 8. Microbial and sensory profile of 69 days aged VP beef rump roast stored along with distribution centre, retail and consumer fridge storage

Stream	1	28	29	30	31	32	33	34A	34B
Storage (days)									
Cold storage	Day 0	69 days ageing							
DC storage (Simulated)		1	8	8	16	31	31	31	31
Retail display storage		0	4	5	7	6	6	6	6
Consumer Fridge (Simulated)		0	0	6	7	0	8	11	15
Total		**70**	**81**	**88**	**99**	**106**	**114**	**117**	**121**
SPC (Log cfu/g)	1.03	5.71	7.15	7.18	7.99		7.61	7.49	7.08
LAB (log cfu/g)	<-0.60	4.81	6.12	6.85	7.61		7.33	7.59	6.79
Entro (log cfu/g)	<-0.60	<2	3.86	3.99	3.6		2.64	3.98	2.78
Sensory (uncooked)	**Purge**	Moderate	Moderate	Moderate	Moderate	No sensory	High	High	High
	Colour	Acceptable	Acceptable	Acceptable	Acceptable		Accept	Acceptable	Acceptable
	Texture/Appearance	Acceptable	Acceptable	Acceptable	Acceptable		Accept	Acceptable	Acceptable
	Odour- initial	Marginal - slightly sulfury	Marginal - sulfury	Marginal - sulfury	Marginal - aged		Accept	Marginal - Strong meaty	Acceptable
	Odour - persistant	Marginal - slightly sulfury	Acceptable	Marginal - sulfury	Marginal - aged		Accept	Not assessed	Acceptable
Sensory (cooked)	**Appearance**	Acceptable	Acceptable	Acceptable	Acceptable		Accept	Acceptable	Acceptable
	Aroma	Marginal - aged/sulfury smell	Acceptable	Marginal - aged/sulfury	Marginal - aged smell		Marginal - strong meaty	Acceptable	Acceptable
	Flavour	Marginal - aged	Marginal - watery/bland	Marginal - aged/slight sour	Marginal - aged taste		Not assessed	Marginal - bland, slight old	Marginal - bland, unpleasant aftertaste
	Mouthfeel	Acceptable	Acceptable	Acceptable	Acceptable		Not assessed	Marginal - powdery, dry	Powdery
	Tenderness	Acceptable - very tender	Acceptable - very tender	Acceptable - very tender	Acceptable		Not assessed	Very	Acceptable
	Juiciness	Acceptable	Acceptable	Acceptable	Acceptable		Not assessed	Marginal - dry	Marginal - dry
		Acceptable	Acceptable	Acceptable	Marginal - air in package		Acceptable - slight loose	Acceptable	Acceptable
Sensory (overall)		Marginal	Acceptable	Marginal	Marginal		Not acceptable	Marginal	Marginal

Trial 2 – Beef rump steak MAP pack

In this trial, the beef rump was aged under vacuum packaged conditions for three durations (28, 34 and 69 days) at cold storage before being reprocessed and packed into MAP conditions as steaks. As with rump roast the starting microbial counts were low; standard plate counts log 1.95 cfu/g, LAB log <-0.60 cfu/g and *Enterobacteriaceae* log 0.1 cfu/g. During storage, standard plate and LAB counts increased. The number of *Pseudomonas* spp. did not increase much. This might be due to the lack of oxygen under vacuum packaging and presence of high CO_2 (~20%) under MAP conditions which inhibit the growth of these aerobes (Tables 9 – 11).

Results showed that VP rump primals were able to meet micro shelf life criteria (standard plate counts ≥100,000cfu/cm^2; *Enterobacteriaceae* counts ≥100 cfu/cm^2) easily after 28 and 34 days ageing and sensory were well acceptable (Tables 9 – 10). For 69 days ageing, there was marginal change in aroma and flavour while odour was still acceptable. In addition, the standard plate and *Enterobacteriaceae* counts marginally reached the micro limits (Table 11) after 69 days ageing. After processing 28 and 34 days old primals MAP packed steaks were marginally acceptable up to 8 days (Tables 9 -10, Figure 6). However, ageing of primals for 69 days under VP conditions reduced the shelf life of MAP retail steaks (4 days). Both colour and eating sensory attributes seemed important in the shelf life determination of MAP steaks.

A shorter retail display shelf life with increasing primal ageing, mainly because of discolouration, which has also been reported previously (Anonymous 2002). However, the difference (4 as compared to 9 days shelf life) in the shelf life of MAP steaks from 69 days aged primals observed here (4 days) and those observed in a Danish study (9 days) with Australian 75 days aged primals needs further investigation (Tørngren and Darré 2016), especially the effect on small difference of gas composition 80:20 O_2:CO_2 in this trial as compared to 70:30 O_2:CO_2 in the Danish study has on the shelf life. Currently there is 7 – 29 days ageing regime with 9 days MAP pack steak shelf life and this trial showed that product tested here was able to meet that criterion in its supply chain with the possibility of extending the ageing of VP primals. Future more targeted work on MAP will benefit in extending the shelf life of MAP product.

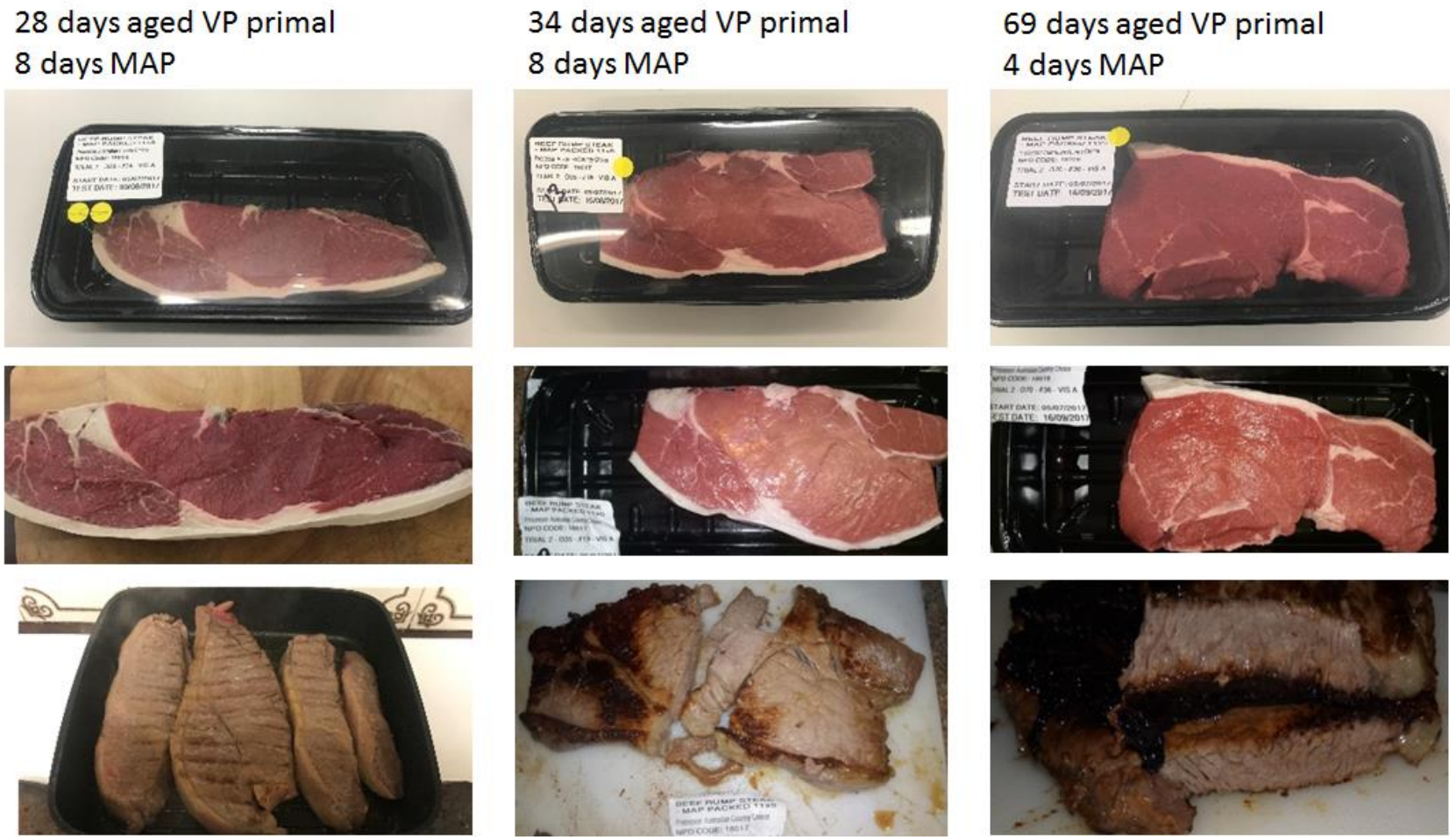


Figure 6. Appearance of MAP steaks from VP aged beef rump

Table 9. Microbial and sensory profile of 28 days aged VP beef rump processed and MAP packed steaks

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Day 0	**28 - as primal**	**28 days aged primals MAP pacakging**	**28 - as primal**												
	0		1	1	1	1	1	1	1	1	1	1	1	1	1
	0		1	1	1	1	5	5	5	5	7	7	7	7	7
	0		5	6	8	10	1	2	3	6	0	1	2	4	4
	28	**28**	**35**	**36**	**38**	**40**	**35**	**36**	**37**	**40**	**36**	**37**	**38**	**40**	**40**
1.95	4.01	3.5	5.69	5.9	6.72	7.26	6.76	6.86	6.06	7.18		6.46	7.18	7.49	
<-0.60	2.6	<2													
0.1	<2	<2													
	<2	<2	<2	<2	2.22	2.22	<2	<2	<2	2.22		2.37	<2	2.22	
Colour		Acceptable	Marginal - edges discolouration	Unacceptable - green patches	Unacceptable - discolouration	Marginal some slight browning	Marginal - discolouration on edges of steak	Marginal - browned and pale	Unacceptable - discolouration	Unacceptable - discolouration	No sensory	Unacceptable - discolouration	Unacceptable - discolouration	Unacceptable - discolouration	No sensory
Odour		Acceptable	Acceptable	Acceptable - No scent	Acceptable	Unacceptable - offensive odour persistent	Marginal - Slight odour	Acceptable - No scent	Acceptable	Unacceptable - offensive odour		Acceptable	Acceptable	Unacceptable - offensive odour	
Texture		Acceptable	Acceptable	Acceptable	Marginal	Acceptable	Acceptable	Acceptable	Marginal	Acceptable		Marginal	Marginal	Acceptable	
Purge		NIL	Some	Moderate	Moderate	Some	Some	High	Moderate	Some		Moderate	Moderate	Some	
Appearance		Accpetable	Accpetable	Accpetable	Acceptable	Not Cooked	Accpetable	Marginal	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Aroma		Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Acceptable	Marginal - slightly acidic taste	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Flavour		Acceptable	Acceptable - slightly old tasting	Acceptable	Acceptable	Not Cooked	Marginal - old tasting	Acceptable	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Mouthfeel		Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Tenderness		Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Juiciness		Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
Cooked overall		Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Acceptable	Marginal	Acceptable	Not Cooked		Acceptable	Acceptable	Not Cooked	
		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	
		Acceptable	Marginal	Unacceptable	Unacceptable	Unacceptable	Marginal	Marginal	Unacceptable	Unacceptable		Uncooked	Uncooked	Uncooked	

Table 10. Microbial and sensory profile of 34 days aged VP beef rump processed and MAP packed steaks

1	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Day 0	34 - as primal	34 days aged primals MAP pacakging	34													
	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	0	1	1	1	1	5	5	5	5	5	7	7	7	7	7
	0	0	5	6	8	10	0	1	2	3	6	0	1	2	4	
	34	**34**	**41**	**42**	**44**	**46**	**40**	**41**	**42**	**43**	**46**	**42**	**43**	**44**	**46**	No testing
1.95	4.46	5.22	6.24	6.43	7.35	7.63	4.44	5.44	6.19	6.15	7.66		5.89	6.18	7.29	
<-0.60	3.07	3.08														
0.1	<2	<2														
	<2	<2	2.7	2.85	2.64	2.3	2.43	<2	2.6	2.73	2.78		2.85	<2	2.48	
Colour	Acceptable	Acceptable	Acceptable - slightly pale	Acceptable - slightly pale	Unacceptable - browned/green	Marginal - pale with some dark patches	Acceptable	Acceptable	Marginal - browning	Acceptable - slightly pale	Unacceptable - browned/slightly green	No sensory	Acceptable - slightly pale	Unacceptable - browned heavily	Unacceptable - very dark and browned	No sensory
Odour	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable - foul smelling	Unacceptable - foul smelling	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable - foul smelling		Acceptable	Unacceptable - foul smelling	Unacceptable - foul smelling	
Texture	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable		Acceptable	Unacceptable	Unacceptable	
Purge	NIL	NIL	Acceptable	Acceptable	Minor	Moderate	Minor	Acceptable	Acceptable	Acceptable	Minor		Acceptable	Minor	Moderate	
Appearance	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Aroma	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Flavour	Acceptable	Acceptable	Marginal - bland taste	Marginal - bland/acidic taste	Not Cooked	Not Cooked	Acceptable	Marginal - bland taste	Marginal - bland taste	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Mouthfeel	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Tenderness	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Juiciness	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked		Acceptable	Not Cooked	Not Cooked	
Cooked overall	Acceptable	Acceptable	Marginal	Marginal	Unacceptable	Unacceptable	Acceptable	Marginal	Marginal	Acceptable	Unacceptable		Acceptable	Unacceptable	Unacceptable	
	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	
	Acceptable	Acceptable	Marginal	Marginal	Unacceptable	Unacceptable	Acceptable	Marginal	Marginal	Acceptable	Unacceptable		Acceptable	Unacceptable	Unacceptable	

Table 11. Microbial and sensory profile of 69 days aged VP beef rump processed and MAP packed steaks

1	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Day 0	69 - as primal	69 days aged primals MAP pacakging									69								
	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	0	1	1	1	1	1	1	1	5	5	5	5	5	7	7	7	7	7
	0	0	0	2	5	6	8	10	21	0	1	2	3	6		1	2	4	15
	69	**69**	**71**	**73**	**76**	**77**	**79**	**81**	**92**	**75**	**76**	**77**	**78**	**81**	**77**	**78**	**79**	**81**	**92**
1.95	6.34	5.49	5.79	5.88	7.16	7.27	7.41	7.69	8.66	5.24	6.04	6.03	7.01	7.54		6.65	6.84	7.54	8.36
<-0.60	5.53	4.17																	
0.1	2.8	2.87																	
	<2	<2	2.67	3.45	2.12	2	2.12	2.12	<2	2.22	2.64	3.43	2	<2		2	<2	<2	<2
Colour	Acceptable	Acceptable	Acceptable	Acceptable	Marginal - browning	Acceptable - slightly yellowed	Unacceptable - heavily browned	Unacceptable - heavily browned	Unacceptable - heavily grey/green/brown	Marginal - yellowing	Marginal - browning	Unacceptable - heavily browned/greenish	Unacceptable - heavily browned	Unacceptable - heavily browned		Marginal - fading/pale/yellowed	Marginal - fading/pale	Unacceptable - heavily browned	Unacceptable - heavily grey/green/brown
Odour	Acceptable	Acceptable	Marginal - light aged/off smell	Marginal - foul smelling on opening, but dissapated after a	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - extremely putrid	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell		Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - persistant foul smell	Unacceptable - extremely putrid
Texture	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable
Purge	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate		Moderate	Moderate	Moderate	Moderate
Appearance	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked		Not Cooked	Not Cooked	Not Cooked	Not Cooked
Aroma	Marginal - aged/sulfury	Marginal - aged/sulfury	Marginal - aged/sulfury	Acceptable	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked		Not Cooked	Not Cooked	Not Cooked	Not Cooked
Flavour	Marginal - aged/off	Marginal - aged/off	Marginal - aged/off	Marginal - bland	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	No sensory	Not Cooked	Not Cooked	Not Cooked	Not Cooked
Mouthfeel	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked		Not Cooked	Not Cooked	Not Cooked	Not Cooked
Tenderness	Acceptable	Acceptable	Acceptable	Marginal - tough	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked		Not Cooked	Not Cooked	Not Cooked	Not Cooked
Juiciness	Acceptable	Acceptable	Acceptable	Acceptable	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked	Not Cooked		Not Cooked	Not Cooked	Not Cooked	Not Cooked
Cooked overall	Marginal	Marginal	Marginal	Marginal	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable		Unacceptable	Unacceptable	Unacceptable	Unacceptable
	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable		Acceptable	Acceptable	Acceptable	Acceptable
	Marginal	Marginal	Marginal	Marginal	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable		Unacceptable	Unacceptable	Unacceptable	Unacceptable

Trial 3 – Beef rump steak OW pack

In this trial, the beef rump was aged under vacuum packaged conditions for three durations 40, 61 and 90 days at cold storage before being reprocessed and packed under OW conditions as steaks. The starting microbial counts were low; standard plate counts log 1.45 cfu/g, LAB log <-0.60 cfu/g and *Enterobacteriaceae* log -0.3 cfu/g. During storage, standard plate counts and LAB counts increased. Further, as expected the number of *Pseudomonas* spp. increased from <2 log to log 8 cfu/g under OW conditions because of the availability of O_2 and the absence of high CO_2 (Tables 12 – 14).

Results showed that VP rump primals were able to meet the micro shelf life criteria (standard plate counts ≥100,000cfu/cm^2; *Enterobacteriaceae* counts ≥100 cfu/cm^2 for primals for further processing) easily after 40 days ageing and sensory wise were well acceptable (Tables 12). For 61 and 90 days ageing, there was marginal increase in standard plate counts however sensory wise primals were acceptable (Tables 13 – 14). After processing 40 and 61 days old primals OW packed steaks were acceptable for up to 7 days and marginally acceptable by 9 days (Tables 12 – 13, Figure 7). A similar shelf life of 7 days has been reported for OW steaks prepared from 75 days aged VP primals in a previous study (Tørngren and Darré 2016). The shelf life of OW retail packs from 90 days old primals was 4 days with some marginal changes in odour and flavour. Cooked sensory attributes seemed more important in determining the shelf life of OW packs. Results showed that product is able to meet and exceed the shelf life requirement for OW pack that allows 7 – 35 days ageing at cold storage plus 4 days for OW retail steaks if cold temperature conditions are maintained as observed in this trial.

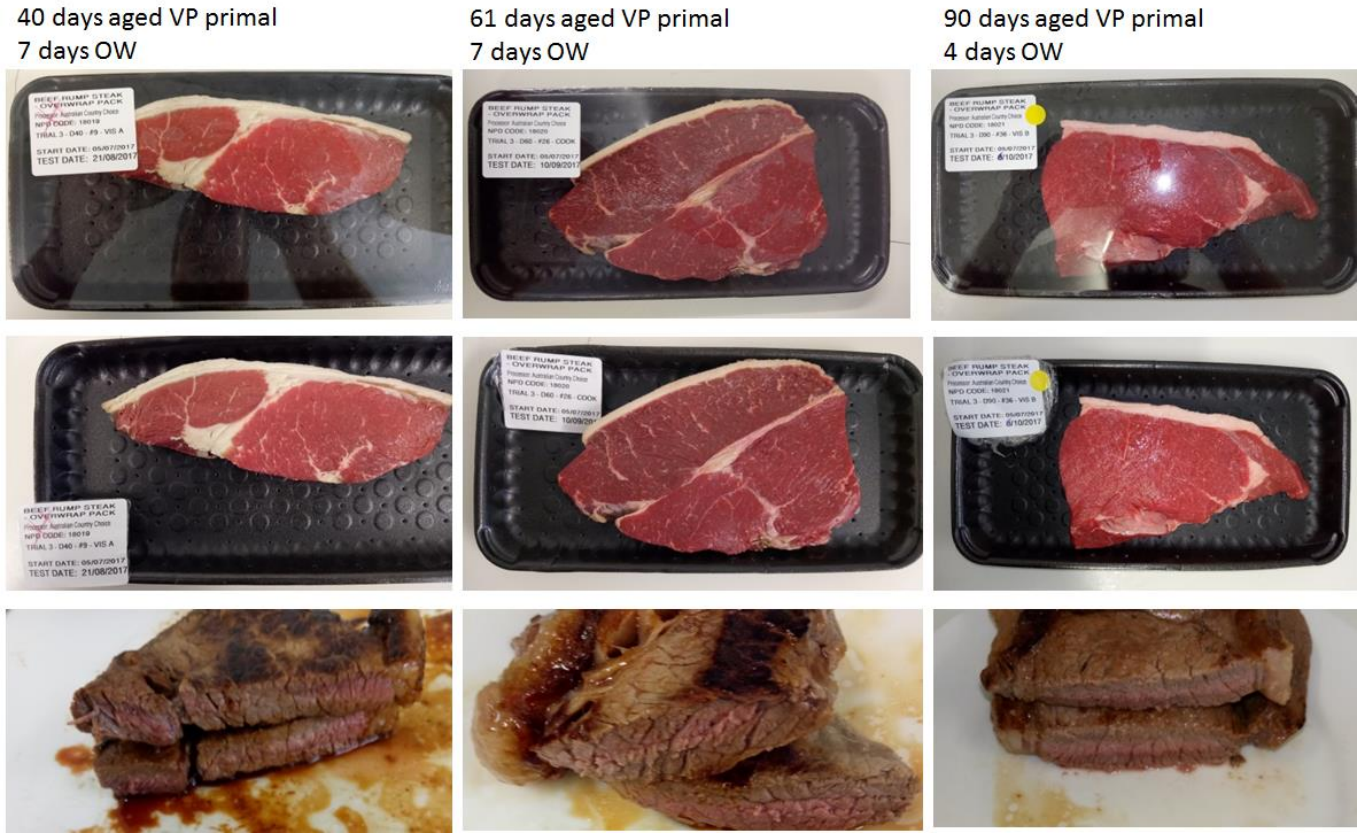


Figure 7. Appearance of OW steaks from VP aged beef rump

Table 12. Microbial and sensory profile of 40 days aged VP beef rump processed and OW packed as steaks

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Day 0	40 -as primal	**40 - as primal**												
		3 - as primal	3	3	3	3	3	3	3	3	3	3	3	3
			OW	2	3	4	1	2	4	1	2	3	4	2
			0	0	0	0	2	2	1	3	2	2	1	4
	40	**43**	**43**	**45**	**46**	**47**	**46**	**47**	**48**	**47**	**47**	**48**	**48**	**49**
1.45	5.11	4.81	5.09	5.18	6.03	6.53	6.21	6.21	6.58	6.33	7.29	7.29	7.45	7.11
<-0.602	3.36	3.54	3.08	-	-	-	-	-	-	-	-	-	-	-
-0.301	<2	<2	<2	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	2.22	2	2	2.12	3.64	3.29	<2	<2	4.4	4.47	4.38
Colour		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable - slight discolouration	Acceptable	Acceptable - slight	Unacceptable- heavily browned	Acceptable	Acceptable	Marginal - yellowed	Marginal - yellowed	Marginal - yellowed
Odour		Acceptable	Acceptable	Acceptable	Acceptable	Marginal - aged scent	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Texture		Acceptable	Acceptable	Acceptable	Acceptable	Marginal - aged scent	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Purge		NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Appearance		Acceptable	Acceptable	Acceptable	Accpetable	Accpetable	Accpetable	Accpetable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Aroma		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Flavour		Acceptable	Acceptable	Acceptable	Acceptable	Marginal - watery & bland	Acceptable	Acceptable	Marginal - bland	Acceptable	Acceptable	Marginal - bland	Marginal - bland	Marginal - bland
Mouthfeel		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Tenderness		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Juiciness		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Cooked overall		Acceptable	Acceptable	Acceptable	Acceptable	Marginal	Acceptable	Acceptable	Marginal	Acceptable	Acceptable	Marginal	Marginal	Marginal
		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
		Acceptable	Acceptable	Acceptable	Acceptable	Marginal	Acceptable	Acceptable	Marginal	Acceptable	Acceptable	Marginal	Marginal	Marginal

Table 13. Microbial and sensory profile of 61 days aged VP beef rump processed and packed as OW steaks

1	18	19	20	21	22	23	24	25	26	27	28	29	30
Day 0	**61 - as primal**	**61 - as primal**											
	2 - as primal	2	2	2	2	2	2	2	2	2	2	2	2
	0	2	3	4	2	3	4	1	2	3	4	2	2
	0	0			1	1	1	3	2	2	1	4	7
	63	**65**	**66**	**67**	**66**	**67**	**68**	**67**	**67**	**68**	**68**	**69**	**72**
1.45		5.93	6.58	6.65	6.78	6.96	6.79	7.11	7.64	7.78	7.26	7.56	8.97
<-0.602		-	-	-	-	-	-	-	-	-	-	-	-
-0.301		-	-	-	-	-	-	-	-	-	-	-	-
-		2.37	4.01	3.55	2.3	3.48	3.32	4.28	3.92	4.89	4.35	4.74	8.19
Colour		Acceptable	Acceptable	Acceptable	Slightly dark / brown	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Discoloured	No sensory
Odour		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Old, sour foul odour	
Texture		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	
Purge		NIL	Nil	NIL	Nil	NIL	Minor	NIL	NIL	Minor	Minor	Nil	
Appearance		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Not cooked	
Aroma		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Not cooked	
Flavour		Acceptable	Marginal/sour	Acceptable	Acceptable	Acceptable	Sour - not pleasant to eat	Acceptable	Acceptable	Marginal	Marginal	Not cooked	
Mouthfeel		Acceptable	Accept	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Not cooked	
Tenderness		Acceptable	Very tender	Acceptable	Very tender	Acceptable	Very tender	Acceptable	Acceptable	Very tender	Very tender	Not cooked	
Juiciness		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Very tender	Acceptable	Acceptable	Very tender	Very tender	Not cooked	
Cooked overall		Acceptable	Marginal	Acceptable	Acceptable	Acceptable	Unacceptable	Acceptable	Acceptable	Marginal	Marginal	Not cooked	
		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	
		Acceptable	Marginal	Acceptable	Acceptable	Acceptable	Unacceptable	Acceptable	Acceptable	Marginal	Marginal	Unacceptable	

Table 14. Microbial and sensory profile of 90 days aged VP beef rump processed and packed as OW steaks

1	31	32	33	34	35	36
Day 0	**90 - as primal**	**90 - as primal**				
		2 - as primal	2	2	2	2
		OW				
			2	3	4	1
	90	**92**	**94**	**95**	**96**	**93**
1.45	6.74	5.64	6.29	6.74	6.81	5.19
<-0.602	-	-	-	-	-	-
-0.301	-	-	-	-	-	-
-	<2	<2	<2	<2	<2	<2
Colour		Acceptable	Acceptable	Accept	Acceptable	Acceptable
Odour		Marginal - sulfury	Acceptable	Mild odour	Marginal - fatty scent	Acceptable
Texture		Acceptable	Acceptable	Accept	Acceptable	Acceptable
Purge		Moderate	Acceptable	Accept	Acceptable	Acceptable
Appearance		Acceptable	Acceptable	Accept	Acceptable	Acceptable
Aroma		Marginal - aged/livery	Acceptable	Accept	Acceptable	Acceptable
Flavour		Marginal - aged/livery/sulfury	Marginal - bland	Marginal - not flavoursome	Marginal - bland	Marginal - bland
Mouthfeel		Marginal - powdery	Marginal - powdery	Marginal - powdery	Marginal - powdery	Marginal - powdery
Tenderness		Acceptable	Acceptable	Accept	Acceptable	Acceptable
Juiciness		Acceptable	Acceptable	Accept	Acceptable	Acceptable
Cooked overall		Marginal	Marginal	Marginal	Marginal	Marginal
		Acceptable	Acceptable	Accept	Acceptable	Acceptable
		Marginal	Marginal	Marginal	Marginal	Marginal

VP beef shelf life model validation – comparison between observed and predicted shelf lives

The UTas/MLA model is developed for VP beef and shelf life predictions are based on the time: temperature history of the product and initial microbial counts, with emphasis on the development of persistent odour in the vacuum pack. For validation of the model, comparison was made between the observed shelf life of VP rump roast, VP beef rump reprocessed as MAP and OW steaks and the shelf life predicted by the model. There were some excess VP primals from trials 2 and 3, tested for sensory characteristics and these were also included in this model validation process. For this analysis, only those streams were considered where end of the shelf life was observed by sensory analysis, thereby reducing the number of observations/data. A good agreement was observed between the predicted and observed shelf lives for VP beef with average deviation of around 5% (Figure 8). Further, the model accurately predicted the end/near end (marginal) of shelf life for VP beef.

Despite some over prediction, a good correlation between predicted and observed shelf lives was also observed for VP rump reprocessed as MAP steaks (Figure 9). A poor correlation between observed and predicted shelf lives was observed for OW steaks (Figure 10), this might partially be because of low number of observations, hence data for rigorous analysis in this instance. The relatively low predictability especially for OW product is understandable as model was developed for VP product.

A good agreement was reported for the observed standard plate counts and counts predicted by the model (Figure 11) with bias 1.1, i.e. on average the model predicts 10% more log cfu/g than observed making it 'fail safe'. The accuracy, i.e., how close the predicted microbial growth is to the observed growth on average is 0.6 log cfu/g, which is not much different than the widely accepted limit of accuracy of any plate count, i.e., log ±0.5 cfu. The correlation co-efficient between observed and predicted counts was 0.8 indicating a relatively good description of the observed data by the model.

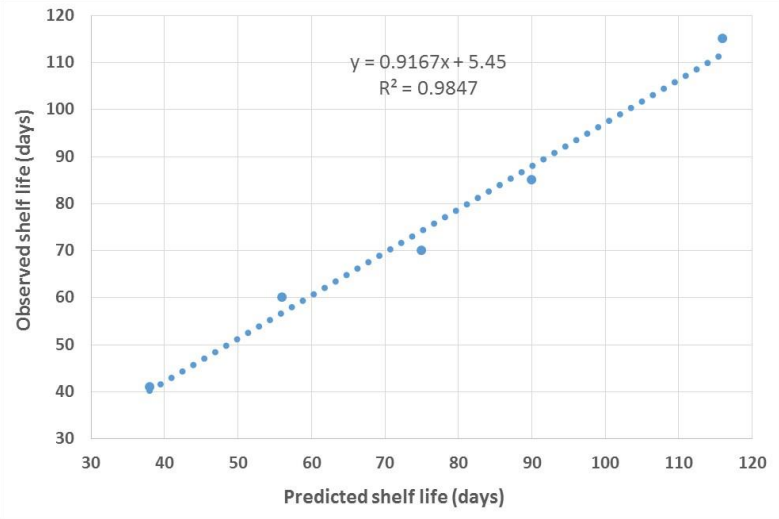


Figure 8. Comparison between observed and predicted shelf lives of VP beef primals

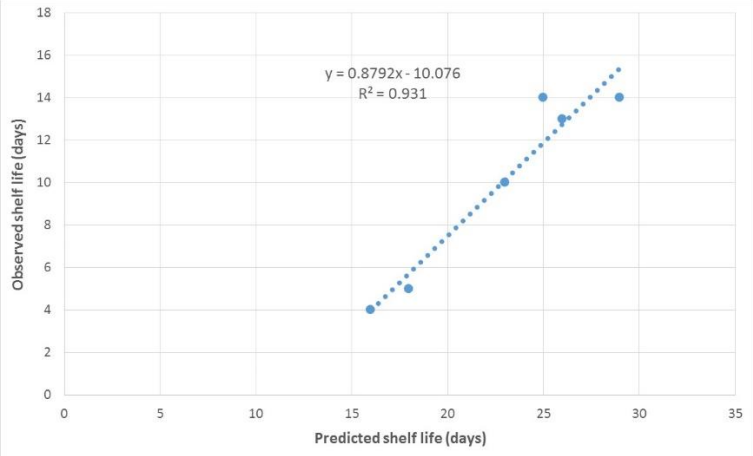


Figure 9. Comparison between observed and predicted shelf lives of VP beef primals reprocessed and packed as MAP

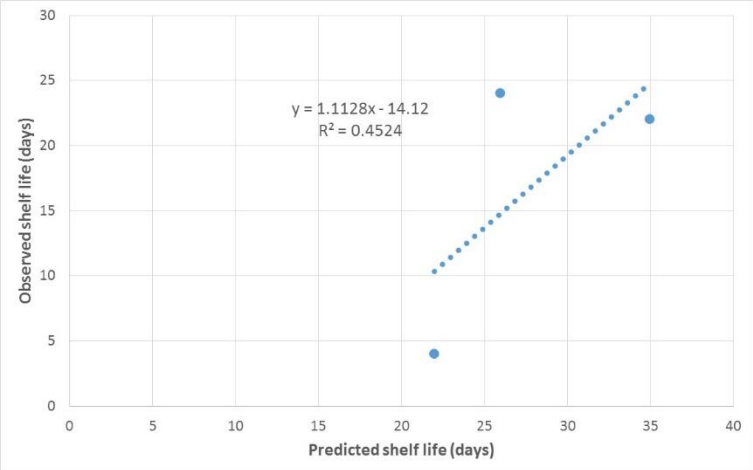


Figure 10. Comparison between observed and predicted shelf lives of VP beef primals reprocessed and packed as OW

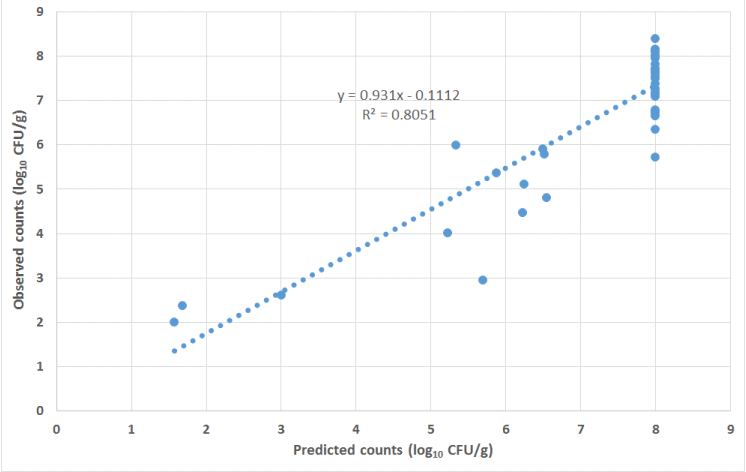


Figure 11. Comparison between observed and predicted standard plate counts of VP beef primals

Conclusions

This report examined the shelf lives of three retail beef products (VP beef roast, VP beef rump followed by MAP steaks and VP beef rump followed by OW steaks) in a domestic supply chain. The trials showed that the products have longer shelf life than what is currently imposed in the specifications.

The VP rump roast can achieve 64 days shelf life after packing (currently restricted to 35 days) when aged for 20 days at storage followed by low temperature storage in the distribution centre (both operating at ~0.6°C) for up to 30 days and 7 days each in retail display and consumer fridges (both operating at ~4°C). Further, it is possible to extend the shelf life to 100 plus days with longer ageing at cold storage (69 days) while having marginal effect on sensory attributes of the product. The VP rump primals can be aged twice as long (60 days) compared to the current practice (around 30 days) before being reprocessed and packed as MAP and OW steaks for retail without having any negative effect on their retail shelf life.

The data gathered in this trial were used for UTas/MLA beef shelf life model validation. A good agreement was observed between the predicted and observed shelf lives of VP beef rump roast and rump. Further, the model accurately predicted the end/near end (marginal) of shelf life of these products. Analysis showed that it is valid to use the model in this supply chain for VP beef.

The MLA/UTas shelf life model for VP beef has been validated for a domestic supply chain. The model is safe to be implemented to accurately predict the shelf life of VP beef in this supply chain. As a reliable decision making tool the model can help product movement in this supply chain in a cost efficient way, reduce customer dissatisfaction and increase business profitability. As observed and accurately predicted by the model here VP beef has much longer shelf life and can be stored for longer avoiding unnecessary product mark down/wastage.

Recommendations

Naturally, implementation of the tool into a commercial supply chain would be the next logical phase to ensure the supply chain can utilise the validated tool. Further work is required for developing new/tailoring the current available models specific for packaging other especially OW or MAP and other emerging new packaging technology.

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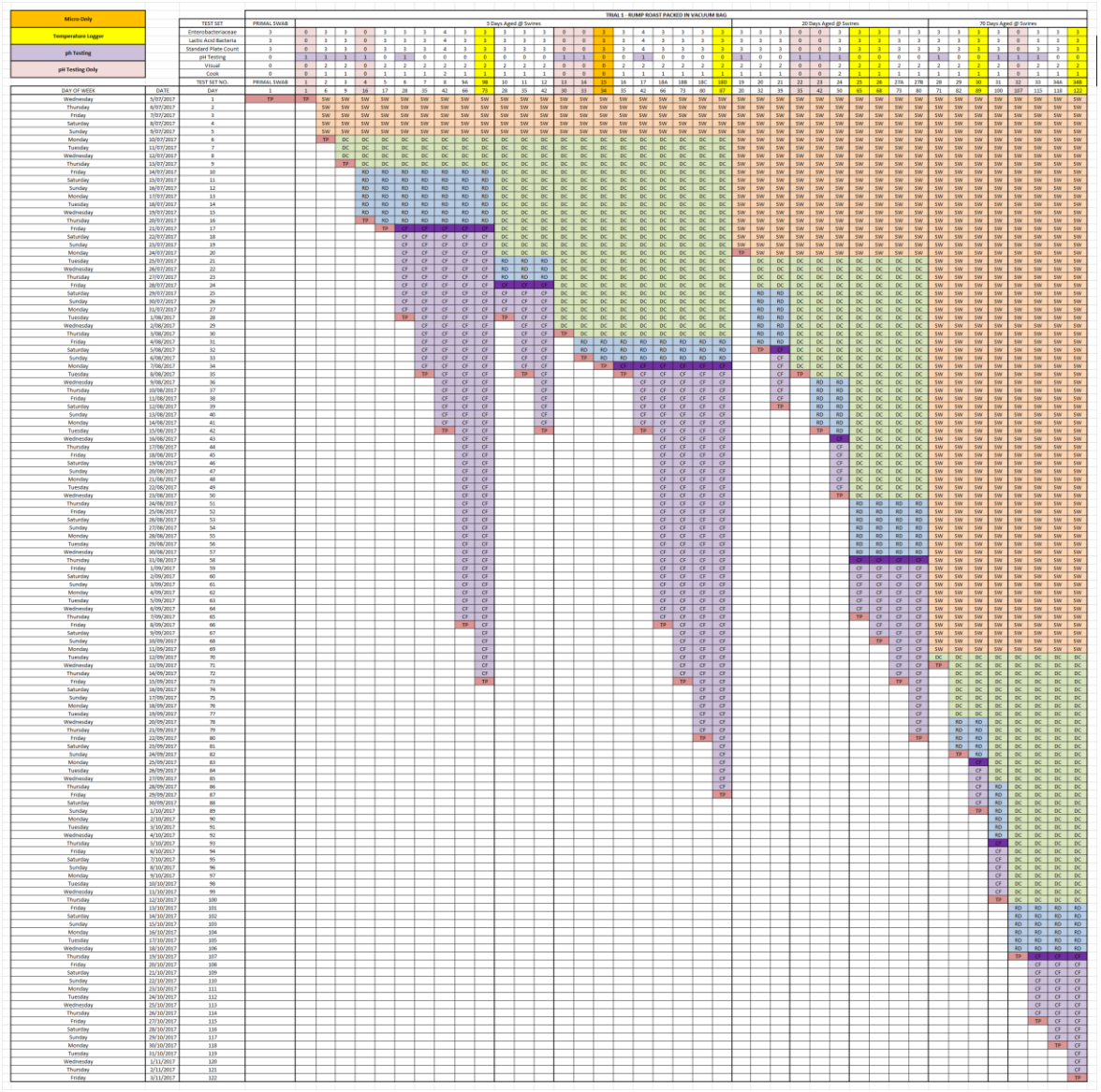
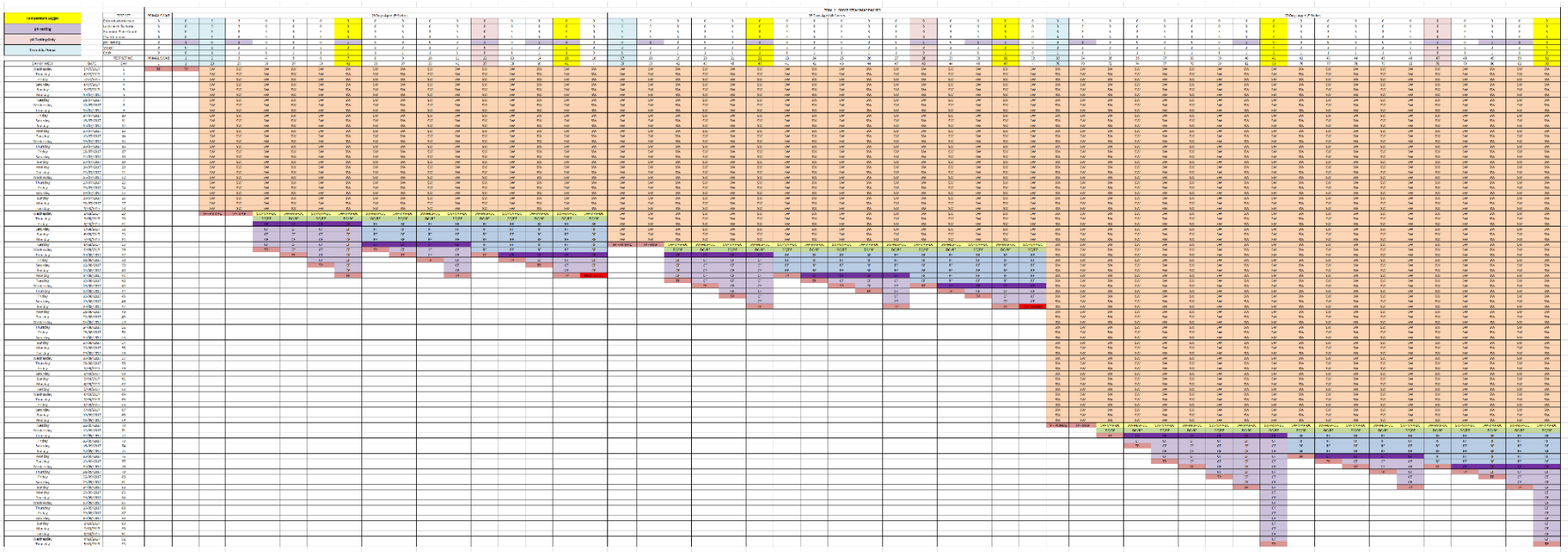
Appendices

Appendix 1. Trail 1 – VP beef rump roast pathway



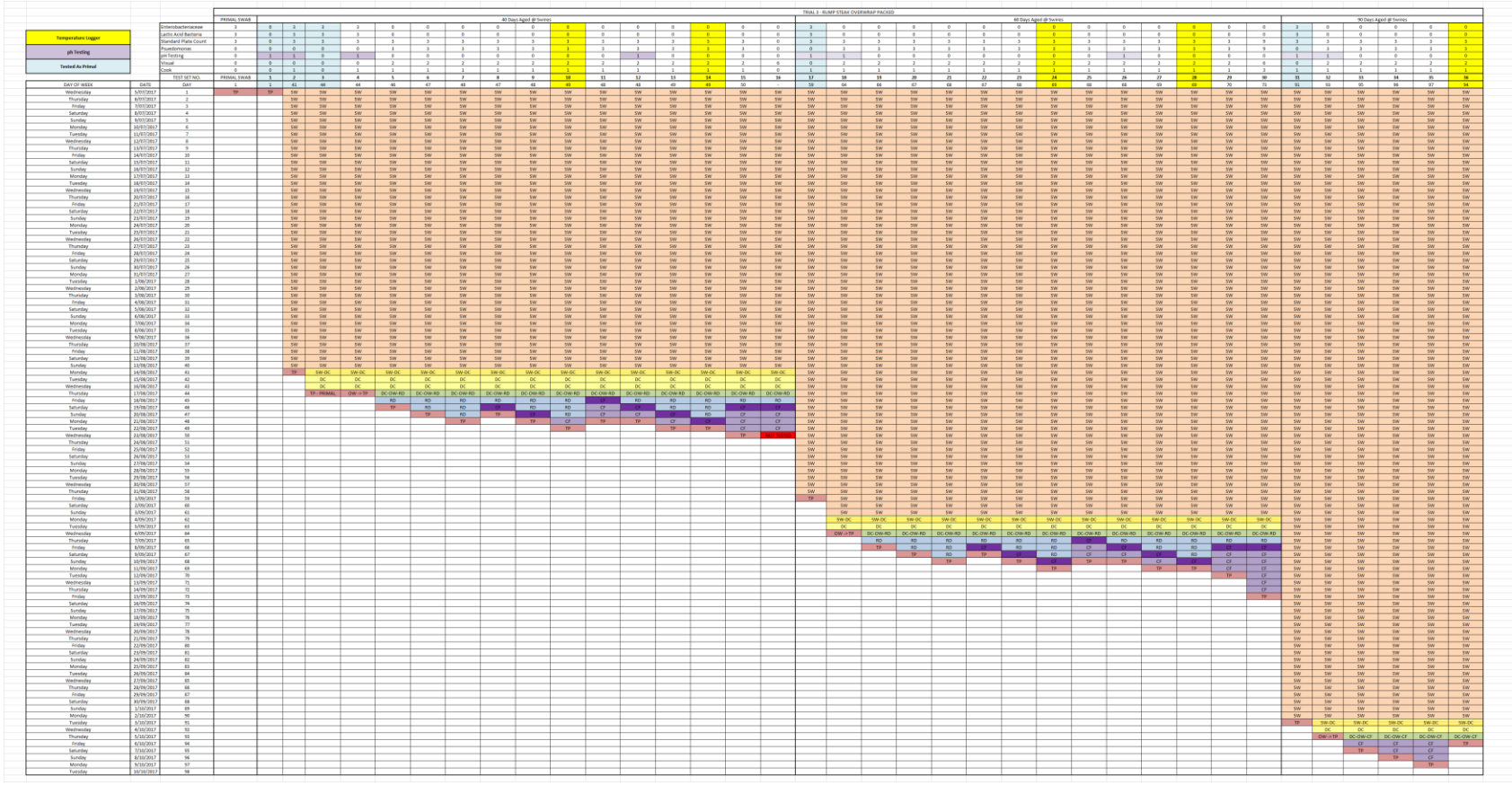
SW	Cold Storage
DC	DC storage (Simulated)
RD	Retail display storage
CF	Temperature challenge
CF	Consumer Fridge (Simulated)
TP	Test point

Appendix 2. Trail 2 – Beef rump steak MAP pack pathway



SW	Cold Storage
SW-MAP-DC	Cold storage to MAP pack
DC	DC storage (Simulated)
RD	Retail display storage
CF	Temperature challenge
CF	Consumer Fridge (Simulated)
TP	Test point

Appendix 3. Trail 3 – Beef rump steak OW pack pathway



SW	Cold Storage
SW-DC	Cold storage to DC
DC	DC storage (Simulated)
DC-OW-RD	DC to OW pack into RD
RD	Retail display storage
CF	Temperature challenge
CF	Consumer Fridge (Simulated)
TP	Test point