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Prepared by: Alison Small

CSIRO

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Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Investigation of the storage life of vacuum packaged beef

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EXECUTIVE SUMMARY

Despite the industry's continued use of vacuum-packaging as a mechanism for extending shelf-life there has been little recent emphasis on determining factors affecting the storage life of vacuum-packaged beef and lamb and the retail life of meat cuts prepared from the vacuum packs. Consequently current practices are based on data generated up to 2 decades ago. Improvements in processing technologies, transport and refrigeration systems, and packaging technologies during that time highlights a need for a review of this area. Furthermore, there is opportunity to generate data that is suitable for incorporation into predictive models which would assist the Australian industry.

Four export establishments supplied vacuum-packed striploins and cube rolls for the project. Product was supplied to FSA for storage in Australia, while a parallel shipment was sent to the US for analysis. Samples were taken where possible on days 3, 7, 10 and 14 of storage, and subsequently fortnightly from 6 weeks of storage in Australia, while product was sampled fortnightly from week 10 in the US. All samples were analysed for Total Viable Count (TVC), Enterobacteriaceae, *Brochothrix thermospacta* and Lactic Acid Bacteria (LAB) counts, and samples taken from week 6 of storage underwent sensory panel assessment and lipid oxidation analysis by TBARS.

In the Australian component of the project, there was a slight deterioration in visual appearance of the intact pack and the post-bloom primal, a slight increase in confinement odour, and a slight deterioration in visual appearance (greying of fat) of 3-day displayed steaks as the vacuum storage period increased. Concurrently, there was a slight increase in lipid oxidation over 3 days retail display, and a slight overall increase in mean LAB count, although microbial counts were very variable between cuts and processors. Low detections of Enterobacteriaceae and *Brochothrix thermospacta* indicated that processor hygiene and packaging integrity were very good. It is possible that the highly variable counts observed in the Australian component are a result of the small sample size in each sampling point, leading to data belonging to outliers or limit-of-range product. However, it is also possible, given the low initial microbial load at packaging suggested by the results of the day 14 samples, and the strict temperature control during storage, that such variability, and the presence of surprisingly low counts later in storage are in fact a feature of current commercially produced vacuum packed chilled beef.

In the US component, the product was considered good on arrival at week 10 of storage, and, in the case of Processor A, had surprisingly low microbial counts. However, the acceptability of the product rapidly deteriorated as storage duration extended, and microbial counts rapidly increased to the expected plateau at 6-7 $\log_{10}$cfu/cm. It is possible that the

difference in storage temperature between the US component (3°C) and the Australian component (-1°C) may have contributed to the observed increase in microbial numbers in the US component, as the rate of growth of psychrotrophic organisms such as *Lactobacillus* spp is expected to be greater at temperatures above 0°C than below (Tsigarida and Nychas, 2006). However, the question also remains as to whether the increases in counts and deterioration of product acceptability observed subsequent to the initial sampling on week 10 are true representations of the storage life of vacuum packed beef, or are affected by the repeated exposure and repackaging resulting from the methodologies used.

It was impossible to draw firm conclusions regarding the storage life of vacuum packed beef produced in Australia. However, the data gathered in Australia suggests that storage lives may well be substantially in excess of the currently recommended 10-12 weeks, assuming that appropriate production and storage conditions are met. Further work is required to ascertain whether this data set represents a true picture of the storage life of vacuum packaged beef produced within the Australian industry, and to identify processing practices and conditions that lead to such extended storage lives.

INVESTIGATION OF THE STORAGE LIFE OF VACUUM PACKAGED BEEF

INTRODUCTION

Vacuum packaging of beef and lamb under chilled conditions remains an effective measure for extending the shelf life of such products and for the control of foodborne pathogens. The low oxygen concentration involved in vacuum-packaging has a selective effect on the microbial population and generally results in the proliferation of lactic acid bacteria (LAB). The predominant organisms include *Carnobacterium divergens*, *Carnobacterium piscicola*, *Lactobacillus sakei*, *Lactobacillus curvatus*, *Leuconostoc gelidum*, *Leuconostoc carnosum* and *Brochothrix thermosphacta* (Fontana et al., 2006, Sakala et al., 2002, Jones, 2004, Ercolini et al., 2006, Nissen and Sorheim, 1996). Under good processing and packaging conditions, the counts of LAB on the surfaces of primals at the time of packaging are very low (<100/cm^2), however the numbers of LAB increase during storage and can be expected to exceed 10^6/cm^2 after 2 to 3 weeks (Leisner et al., 1995, Blixt and Borch, 2002). The presence of high numbers of LAB may result in the presence of unacceptable odours and meat flavours in products stored for prolonged periods of time (Leisner et al., 1995, Borch et al., 1996). Similarly the presence of LAB and other contaminating bacteria such as *Enterobacteriaceae* may subsequently cause spoilage, odour and flavour issues in retail packs prepared from vacuum-packaged meat.

Despite the industry's continued use of vacuum-packaging as a mechanism for extending shelf-life there has been little recent emphasis on determining factors affecting the storage life of vacuum-packaged beef and lamb and the retail life of meat cuts prepared from the vacuum packs. Consequently current practices are based on data generated up to 2 decades ago. Improvements in processing technologies, transport and refrigeration systems, and packaging technologies during that time highlights a need for a review of this area. Furthermore, there is opportunity to generate data that is suitable for incorporation into predictive models which would assist the Australian industry.

PROJECT AIMS

- To determine the shelf-life of vacuum packs of beef, as determined by sensory evaluation of typical products exported to the USA.
- To collect microbiological and chemical data that may assist in the development of a predictive model for the shelf-life of vacuum packed beef primals.

METHODS

The project had two major components:

- A vacuum packed beef storage trial in Australia
- A vacuum packed beef storage trial in the US.

Five export establishments were invited to, and indicated that they were willing to, participate in the project by Fiona Sparke of MLA. These processors were subsequently contacted by the project team, and asked to supply vacuum packed striploin and cube roll to the project, in accordance with the procedure detailed in Appendix 1. It was hoped that all product could be supplied within a short window of approximately 2 weeks, so that the majority of the analyses could be carried out simultaneously. Unfortunately, due to the logistics of supplying matching product to Food Science Australia (FSA), Cannon Hill, and to Texas Tech University (TT), USA, product was supplied at different times. As such the day zeros for the processors occurred over a seven week period between February 1st and March 21st 2008. One processor did not supply product. As a result, four processors, designated A, B, C and Z were involved in the project, of which A, B and C supplied product to both FSA and TT, while Z only supplied product to FSA.

Attempts were made to communicate analysis methodologies between FSA and TT during the project planning stage, but ultimately, although the evaluations carried out in Australia and the US had similar objectives, the methodologies used differed substantially, as detailed below.

Methodologies used at FSA

It was hoped that product could be supplied to FSA shortly after packaging, so that the primals could be sampled on days 3, 7, 10 and 14 of vacuum storage as per the project design. Again, however, the logistics of supplying the cartons to Cannon Hill proved to be a problem. Only one processor succeeded in supplying product in time for sampling on day 3, one provided product prior to day 10 and the other two provided product prior to day 14.

On arrival, product was immediately transferred to chill storage at 0°C ± 1°C. In the first two weeks of storage, primals were subjected to microbiological evaluation only, on days 3, 7, 10 and 14. Subsequent sampling occasions were fortnightly from week 6 to week 20, at which the primals were subject to sensory evaluation, microbiological evaluation, MINOLTA colourimetry and lipid oxidation by TBARS assay.

Sampling procedure

On each designated sampling occasion, one pack of striploin and one of cube roll was removed from storage. Packs were assessed by a 6-member informal sensory panel, using a 9-point scale (Appendix 2), for vacuum integrity; appearance of the intact pack; presence of confinement odour; and post-bloom appearance, 30 minutes after the pack was opened. Packs were opened carefully, and the drip measured. Using aseptic technique three excision samples were taken from the lean meat surface. Each excision sample was 10cm² in area, and each was processed separately.

Following post-bloom assessment, each cut was sliced into 1.5cm thick steaks and packaged in overwrap trays. The resulting retail packs were assessed using MINOLTA colourimetry, and the meat pH measured. They were then displayed in a retail cabinet at 3°C, under fluorescent light for three days. At the end of the three day display, the packs were again assessed by MINOLTA colourimetry, and by a 6-member panel for visual appearance. Samples were taken for lipid oxidation analysis, pH measurement and the volume of drip present in the retail tray measured.

Microbiological analysis

A 50 ml aliquot of 0.85% saline was added to each stomacher bag and stomached for 30s. A decimal dilution series was prepared in 0.85% saline, and these plated onto Petrifilm Aerobic®, Petrifilm Enterobacteriaceae® and STAA plates for TVC, Enterobacteriaceae count and *Brochothrix thermospacta* count respectively. The dilutions were also prepared in MRS broth and plated onto Petrifilm Aerobic® according to the Petrifilm method for enumeration of Lactic Acid Bacteria. Plates were prepared and incubated as detailed in the Milestone 1 report. Microbial counts were converted to log_{10}cfu/cm², and the mean log of the three samples calculated using an Excel spreadsheet (Microsoft).

Lipid Oxidation

Lipid oxidation was assessed by the thiobarbituric acid-reactive substances (TBARS) method of Witte *et al.* (1970). All meat samples (2 g) were heated at 75°C for 20 minutes in a water bath and then cooled in ice prior to determination. TBARS were calculated from a standard curve of malondialdehyde (MDA), freshly prepared by acidification of TEP (1,1,3,3-tetraethoxypropane), and calculated as mg MDA per kg sample.

Methodologies used at TT

Procurement of samples

Vacuum packaged striploins and cube rolls were received at “Gordon Davis” Meat Lab of Texas Tech University from three Australian processing companies 9 weeks after having been packaged. The primal cuts (15 striploins and 15 cube rolls from each processor) were stored under refrigeration (3 °C) and tested on the week following their arrival (at 10 weeks) and subsequently at two week intervals (weeks 12, 14, 16, 18 and 20). All packs were opened on each sampling occasion.

The first time that the packages were opened (week 10) they were assessed for off-odor. On each designated sampling occasion, tables and knives were disinfected between each primal cut package to maintain aseptic conditions. Before opening, an area for sampling (avg. 302cm^2) was measured out on each pack. This area would be swabbed (micro analysis) and sliced to obtain steaks for TBARS and colour evaluation; thus, the primal cut was not exposed in its totality, rather only the packaging was peeled off this area of the package in order to not contaminate the rest of the primal surface. Once samples were taken (swabbed and sliced), the remnant portion of the primal was immediately repackaged under vacuum for storage until the next evaluation (every two weeks).

After having swabbed the exposed surface of the primal, three steaks were sliced from the exposed area, one 0.5 cm-thick steak for TBARS analysis and two 1.5cm-thick steaks for colour evaluation. The steaks for TBARS analysis were flushed with nitrogen and frozen immediately (-20°C), for subsequent analysis; steaks assigned to colour evaluation (by panelist and colourimeter) were overwrapped in white foam trays and placed in retail cabinets (single and multi-deck) at 3°C, under fluorescent light for three days.

Once the trays were prepared for retail display, and the steaks bloomed, colour evaluation was carried out by trained panelist and Hunter colourimeter. The colour evaluation was repeated every 24 hours for 3 days. At the end of the display period, the steaks were removed from retail cabinets and frozen at -20°C for subsequent TBARS analysis.

Microbiological analysis

The samples were taken from the surface of each primal, using a sponge moistened with 10 ml of buffered peptone water (BPW). After taking the sample an additional 10 ml of BPW was added to give a final volume of 20 ml. These samples were then stomached for 2 min to obtain a homogenised sample.

From each sample a serial dilution was prepared by using dilution blanks with 9 ml of sterile phosphate buffer and 1 ml aliquots. Each sample was diluted serially to 10^{-7}. Each sample was plated in duplicate.

Culture media used were for APC (mesophiles) and psychrotrophic counts: aerobic plate count agar (Difco), and for LAB: MRS agar (Difco) (deMan, Rogosa and Sharp).

For aerobic plate count (APC), psychrotrophic count and lactic acid bacteria (LAB) counts, the spiral plate method was used as described in the USFDA CFSAN Bacteriological Analytical Manual (USFDA/CFSAN, 2001). In this method, a mechanical plater inoculates a rotating agar plate with liquid sample. The sample volume dispensed decreases as the dispensing stylus moves from the center to the edge of the rotating plate. The microbial concentration was determined by counting the colonies on a part of the petri dish where they were easily countable and dividing this count by the appropriate volume.

After inoculation of the Petri dishes, they were placed in incubators at appropriate times and temperatures as follows: Aerobic plate count (Mesophiles): 48 h at 37 °C; Aerobic Plate count for psychrotrophic organisms: 7 days at 5°C; LAB (MRS agar): 48 h at 37 °C. After the incubation time, the plates for each sample were counted using a Q-counter.

Instrumental colour

Instrumental colour was determined using a Hunter Lab Miniscan XE Plus using illuminant D65 and 10 standard observer angles. Meat colour was measured at the surface of steaks, 1 hour post-bloom and every 24 hours for 3 days. CIE L* (lightness), a* (redness) and b* (yellowness) values were measured and hue angle and chroma were calculated.

Sensory assessment of odour and colour

The sensory panel (for odour and colour evaluation) was composed of 6 trained panellists from the Animal and Food Science department at Texas Tech University. Off-odour evaluation was conducted the first time that packages were opened (at 10 weeks). Scores for ‘‘off-odour’’ referred to the intensity of off-odours associated with meat deterioration: 1 = none, 2 = slight, 3 = small, 4 = moderate and 5 = extreme.

The colour evaluation was conducted at 1hour post-bloom and every 24 hours for 3 days. The trained panellists scored the samples through descriptive scale from 1 to 9 (1=very bright red; 9=tan to brown).

Cold chain verification

Thermologgers were placed in cartons at the point of production to track the temperature profile during both components of the project. All product was handled appropriately, maintaining a shipping temperature of -1±1°C. Example temperature traces are shown for FSA (figure 1) and TT (figure 2) product. Small peaks in temperature can be seen at around day 3-4 (load-out from processing plant) on both traces, and on the US trace at days 11 (loading onto the ship), 45 (arrival in the US) and 50 (loading onto road transport). Product was then stored at +3°C at TT.

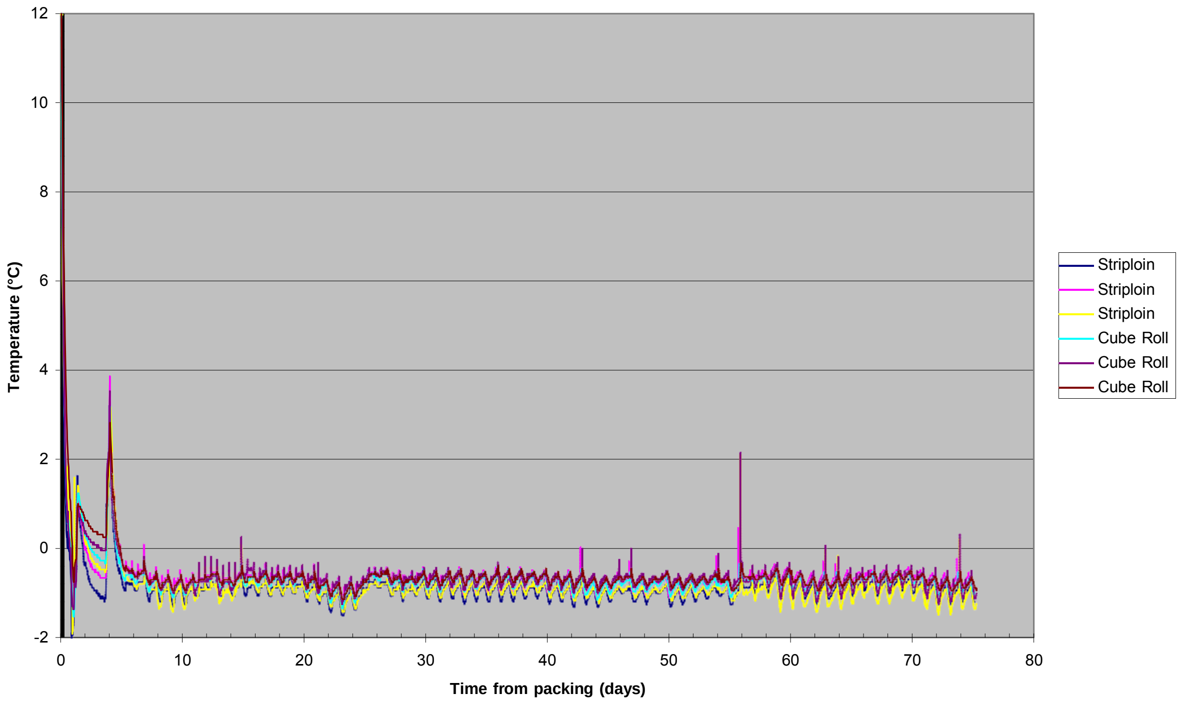

Figure 1: Temperature profile for product supplied to the Australian component of the project

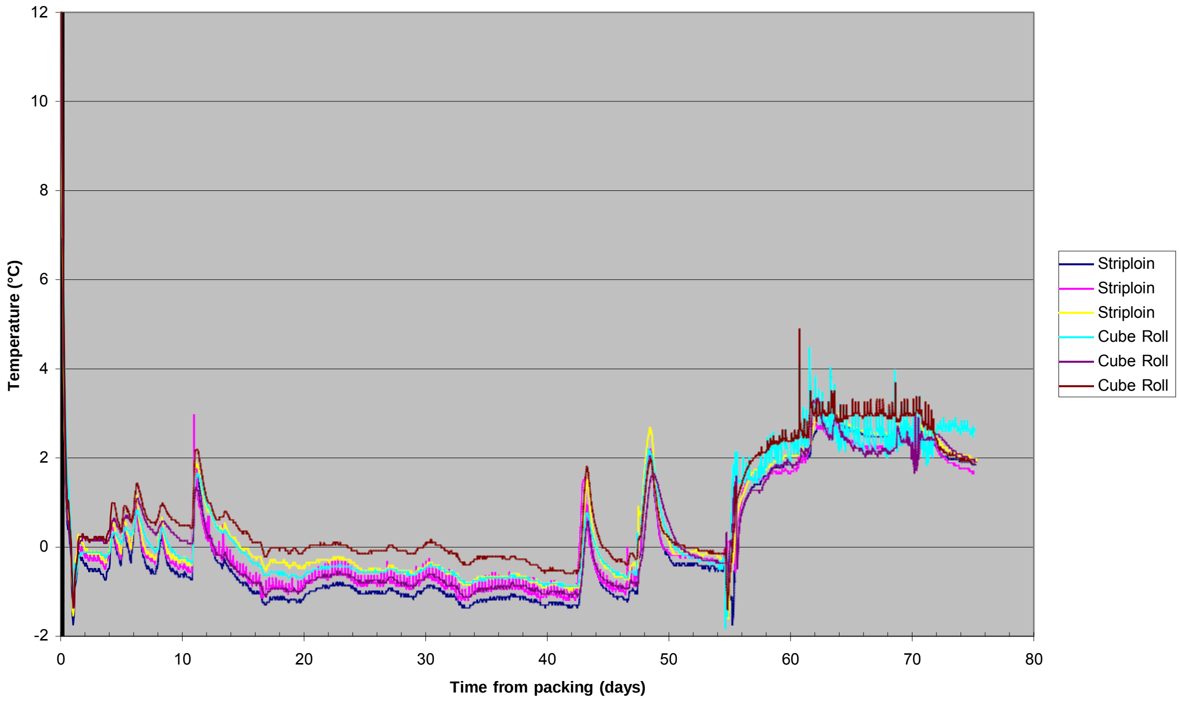

Figure 2: Temperature profile for product supplied to the US component of the project

RESULTS and DISCUSSION

A full data set is presented in Appendix 3. Where data was not collected for a particular evaluation at either research facility, the table cells are filled red. To allow comparison of the sensory evaluations, a simple correlation equation was generated to convert TT results to their FSA equivalent value. For example, for odour evaluation FSA used 0 to indicate extreme off odour, and 8 none, whereas TT used 5 to indicate extreme, and 1 none. The resultant conversion equation was *FSA = -1.6*TT + 8*. Similarly for visual assessment, FSA used 0 to indicate extremely unacceptable, and 8 excellent, whereas TT used 9 to indicate extremely unacceptable and 1 excellent. The resultant conversion equation in this instance was *FSA = -TT + 9*.

Due to the differences in methodologies used at each research establishment, it is very difficult to fully compare the data sets, so each is presented individually.

FSA recorded vacuum integrity, drip loss and pH of product; these measurements were not made at TT. Vacuum integrity of all packs was considered normal to excellent, the pH of the product ranged between 5.44 and 6.07, and drip losses in the order of 0.64% to 13.48% throughout storage and retail display (Appendix 3, Tables A3.7 to A3.9).

Sensory Panel Assessment (Appendix 3, Tables A3.1 to A3.6)

Visual assessment of intact pack

This was carried out at FSA only. All cuts scored highly (above mean score 5) at all time points.

Confinement odour

At FSA, at each sampling point, a single striploin and a single cube roll was opened for sampling. Thus, confinement odour was evaluated at each time point. At TT, however, all packs were opened at week 10, the first sampling point, and then repacked each time following sample collection. Therefore, confinement odour was only evaluated at week 10 (table 1). At FSA, product scored above 4 (acceptable) on all but three occasions: Processor Z striploin, week 10 (2.00); Processor Z cube roll, week 10 (3.80) and Processor A striploin, week 16 (3.43). The scores assigned to product received in the US, after 10 weeks of vacuum storage life were similarly good (TT scores 1.00-1.66, equivalent to FSA scores 6.40-5.34).

Table 1: Confinement odour assessment – mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT*	FSA	TT	FSA	TT	FSA
Striploin	6	7.60	Not done	6.00	Not done	5.80	Not done	6.83
	8	4.50		7.00		5.50		5.40
	10	5.40	6.40 (1.00)	4.40	5.6 (1.50)	6.00	5.79 (1.38)	2.00
	12	7.00		5.17		6.00		4.67
	14	6.14		5.80		5.50		5.17
	16	3.43		4.80		6.00		5.00
	18	5.60		6.33		6.00		5.33
	20	4.83		6.14		6.33		6.17
Cube Roll	6	7.80		6.17		4.80		5.50
	8	6.67		6.60		5.33		6.00
	10	6.00	6.40 (1.00)	5.40	5.63 (1.48)	6.00	5.34 (1.66)	3.80
	12	5.80		5.50		7.00		4.83
	14	6.57		6.80		5.83		6.57
	16	4.86		5.20		6.17		5.83
	18	5.40		6.16		5.33		5.67
	20	4.83		6.29		5.33		5.33

*TT scores converted to FSA equivalent, original score in brackets

Post bloom visual assessment

All cuts evaluated at FSA scored good to excellent (mean score greater than 5), except Processor A striploin, week 16 (4.14, acceptable). A slight decrease in score over time was evident, but this was not marked (table 2). Product at TT, however, scored more poorly, and the deterioration was more marked. Processor A striploin and cube roll scored most highly (FSA equivalent score 6.95 and 6.27 respectively at week 10), followed by Processor B (5.16 and 4.52), then Processor C (4.51 and 4.14). Scores dropped below 4 (acceptable) in processor C cube roll, weeks 12, 18 and 20. All other scores remained above 4. The difference in testing methodologies may account for the difference in extent of deterioration in this evaluation between the two research establishments. At FSA, only a single pack of each was opened on a single occasion, so a small sample size could be held responsible for generating data that may lie at the edges of the normal range. However, at TT, all packs were repeatedly opened and sampled, and it is possible that there was sufficient exposure to air at each sampling occasion to lead to greater discolouration of the product.

Table 2: Post bloom visual assessment, mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT*	FSA	TT	FSA	TT	FSA
Striploin	6	7.80	Not done	7.17	Not done	7.60	Not done	7.50
	8	6.00		6.20		6.83		8.00
	10	8.00	6.95 (2.05)	6.60	5.16 (3.84)	5.67	4.51 (4.49)	6.20
	12	6.80	6.80 (2.20)	5.50	5.05 (3.95)	7.00	4.38 (4.62)	6.00
	14	7.00	5.93 (3.07)	5.80	4.93 (4.07)	6.33	4.44 (4.56)	7.17
	16	4.14	6.43 (2.57)	7.00	4.80 (4.20)	5.00	4.49 (4.51)	7.33
	18	6.20		6.00	4.57 (4.43)	5.17		6.83
	20	7.00		6.57	4.52 (4.48)	6.83		6.50
Cube Roll	6	8.00		7.67		7.20		7.83
	8	6.00		7.20		7.50		7.20
	10	7.20	6.27 (2.73)	7.00	4.52 (4.48)	5.83	4.14 (4.86)	6.40
	12	6.20	6.19 (2.81)	6.17	4.43 (4.57)	6.67	3.94 (5.06)	7.83
	14	7.14	5.46 (3.54)	6.60	4.36 (4.64)	6.67	4.27 (4.73)	7.00
	16	6.57	5.53 (3.47)	7.00	4.54 (4.46)	6.17	4.19 (4.81)	7.33
	18	6.20	4.85 (4.15)	6.50	4.43 (4.57)	5.50	3.77 (5.23)	6.67
	20	5.17	4.01 (4.99)	6.00	4.39 (4.61)	6.67	3.70 (5.30)	7.50

*TT scores converted to FSA equivalent, original score in brackets

Retail pack visual assessment

Retail packs were evaluated every day for three days at TT, while at FSA, they were evaluated only on the third day (table 3). Once again, product from processor A scored more highly than product from the other processors, at both establishments. TT also recorded a greater deterioration in visual acceptance of product as vacuum shelf-life extended than that recorded at FSA. Once again this could be an artefact of small sample size at each time point at FSA, or an effect of repeated repackaging at TT.

At FSA, retail packs scored highly (above 5) at all time points except Processor B cube roll, week 18 (4.90) and Processor A cube roll, week 20 (4.60). At TT, however, only product from processor A scored highly (above FSA equivalent score 5) on day 1 at weeks 10, 12 (striploin and cube roll) and 14 (striploin), and on day 2 at weeks 10 (striploin and cube roll) and 12 (striploin). Product from processor C was not considered acceptable (FSA equivalent score of below 4) on any retail pack assessment. For all processors, TT recorded a progressive deterioration in appearance of retail packed product over three days display.

Table 3: Retail pack visual assessment

Cut	Weeks of vacuum storage	Processor												
		A				B				C				Z
		Day 1 TT*	Day 2 TT	Day 3 TT	Day 3 FSA	Day 1 TT*	Day 2 TT	Day 3 TT	Day 3 FSA	Day 1 TT*	Day 2 TT	Day 3 TT	Day 3 FSA	Day 3 FSA
Striploin	**6**				8.00				7.30				7.50	6.67
	8				8.00				7.33				6.08	8.00
	10	6.16 (2.84)	5.56 (3.44)	4.58 (4.42)	6.25	4.40 (4.60)	3.76 (5.24)	2.99 (6.01)	5.83	3.55 (5.45)	2.91 (6.09)	2.95 (6.05)	6.63	7.75
	12	6.05 (2.95)	5.34 (3.66)	4.58 (4.42)	7.17	4.28 (4.72)	3.47 (5.53)	3.41 (5.59)	6.50	3.79 (5.21)	2.55 (6.45)	2.12 (6.88)	7.17	6.83
	14	5.17 (3.83)	4.11 (4.89)	3.74 (5.26)	6.00	4.21 (4.79)	3.06 (5.94)	2.59 (6.41)	5.90	3.69 (5.31)	2.61 (6.39)	2.31 (6.69)	6.92	6.20
	16	4.25 (4.75)	2.90 (6.10)	2.10 (6.90)	6.83	3.83 (5.17)	2.82 (6.18)	2.39 (6.61)	5.58	2.69 (6.31)	1.99 (7.01)	1.48 (7.52)	5.25	6.92
	18				7.30	2.80 (6.20)	2.09 (6.91)	1.65 (7.35)	5.70				5.33	7.25
	20				7.00	2.60 (6.40)	1.90 (7.10)	0.77 (8.23)	6.00				3.70	6.42
Cube Roll	**6**				8.00				6.70				6.25	6.67
	8				8.00				6.83				6.5	7.67
	10	5.80 (3.20)	5.21 (3.79)	4.35 (4.65)	6.42	3.55 (5.45)	2.85 (6.15)	2.46 (6.54)	5.67	3.38 (5.62)	2.99 (6.01)	2.81 (6.19)	6.38	7.00
	12	5.63 (3.37)	4.86 (4.14)	4.28 (4.72)	6.00	3.47 (5.53)	2.82 (6.18)	2.78 (6.22)	5.20	3.21 (5.79)	2.49 (6.51)	2.12 (6.88)	4.92	6.17
	14	4.79 (4.21)	3.96 (5.04)	3.31 (5.69)	6.20	3.46 (5.54)	2.30 (6.70)	1.72 (7.28)	6.20	3.54 (5.46)	2.83 (6.17)	2.58 (6.42)	5.67	5.10
	16	4.15 (4.85)	3.29 (5.71)	2.60 (6.40)	7.00	3.44 (5.56)	2.21 (6.79)	1.65 (7.28)	5.17	2.65 (6.35)	1.95 (7.05)	1.49 (7.51)	5.92	6.08
	18	3.34 (5.66)	2.43 (6.57)	2.04 (6.96)	5.80	2.86 (6.14)	1.65 (7.35)	1.13 (7.87)	4.90	2.47 (6.53)	1.93 (7.07)	1.18 (7.82)	6.42	6.83
	20	2.68 (6.32)	1.66 (7.34)	1.23 (7.77)	4.60	2.39 (6.61)	1.46 (7.54)	0.93 (8.07)	5.10	1.67 (7.33)	1.29 (7.71)	1.12 (7.88)	5.20	5.92

*TT scores converted to FSA equivalent, original score in brackets

Lipid Oxidation (Appendix 3, Tables A3.10 to A3.11)

At FSA, in general, TBARS values increased between weeks 6 and 20 for both cooked and raw product (table 4). TBARS values for striploin tended to be greater than those from cube roll from the same processor at any time point. Greene and Cumuze (1981) identified that untrained taste panellists began to detect off-flavours in cooked beef in the TBARS range 0.6 - 2.0. In the current project, the highest TBARS values in cooked beef at FSA were 1.714 (Processor A striploin, week 14) and 1.153 (Processor C striploin week 18). Values above 0.6 were also detected from Processor A striploin week 18 (0.793); Processor A cube roll weeks 18 and 20 (0.645 and 0.949); Processor B striploin weeks 10 and 20 (0.710 and 0.605); Processor B cube roll week 20 (0.621); Processor C striploin week 20 (0.679); Processor C cube roll weeks 12 and 14 (0.642 and 0.663); Processor Z striploin weeks 18 and 20 (0.670 and 0.756); and Processor Z cube roll weeks 18 and 20 (0.732 and 0.869).

Product shipped to TT also gave very low TBARS values at day three of retail display, but as expected, the TBARS value increased as storage time increased.

TBARS are a measure of secondary oxidation products, mainly aldehydes, carbonyls or hydrocarbons, which contribute to off-aromas and flavours in meat (Igene et al., 1985). Their concentration in the product may also begin to decrease over time. The rate of decrease varies with storage conditions, packaging, and fat content. The consequence of all of these changing concentrations is that any attempt to evaluate the rancidity of a product will be difficult Low aldehyde concentrations may be the result of limited oxidation or the aldehydes may have volatilized. In consequence, a low TBARS value is not an absolute indicator of fat quality. Aldehydes may have not yet formed or volatile aldehydes may have been lost during processing and storage. In these cases, sensory evaluations may be the key to understanding the data (NPAL, 2008).

Studies have shown that TBARS values increase up to a certain point during the storage period, after which there is a decrease in these values (Gokalp et al., 1983, Babji et al., 1998). Igene and Pearson (1979) stated that, during the evaluation of lipid oxidation in stored foods, decreases in TBARS values are probably due to interactions between malonaldehyde and proteins.

Table 4: Mean TBARS (mg/kg) – raw steaks, day 3 of retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	0.101		0.063		0.257		0.193
	8	0.016		0.231		0.438		0.178
	10	0.341	0.338	0.619	0.313	0.213	0.302	0.418
	12	0.110		0.376		0.410		0.528
	14	1.676		0.470		0.347		0.775
	16	0.410	0.274	0.141	0.350	0.129	0.313	0.556
	18	0.834		0.347		1.042		0.690
	20	0.621		0.605	0.308	0.632		0.756
Cube Roll	6	0.082		0.201		0.076		0.135
	8	0.149		0.084		0.190		0.140
	10	0.522	0.317	0.190	0.260	0.101	0.294	0.382
	12	0.269		0.281		0.711		0.290
	14	0.356		0.267		0.672		0.245
	16	0.382	0.304	0.357	0.273	0.399	0.305	0.499
	18	0.726		0.126		0.461		0.739
	20	1.136	0.248	0.374	0.261	0.248	0.187	0.831

Colourimetry (Appendix 3, Tables A3.12 to A3.34)

It is very difficult to compare the two data sets from FSA and TT, as different colourimetry methods were used. TT used a Hunter Lab Miniscan unit, while FSA used a MINOLTA portable device, and using different devices will give different values because of the wide range in translucency of meat (MacDougall, 1994). In the FSA data set, there were no consistent changes in colour measurements over three days retail display in the product (tables 5-7), which is broadly in accordance with the sensory panel assessment scores assigned to displayed packs. In contrast, the retail display packs prepared and evaluated at TT showed a consistent deterioration, particularly in terms of change in hue: as vacuum storage life increased, the degree of change in hue increased (table 6). This also correlates with the deterioration in sensory evaluation scores assigned to the retail packs evaluated at TT.

Table 5: Change in L value over 3 days retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	-2.40		-0.49		+0.89		+1.46
	8	-1.31		+2.43		+1.52		-0.48
	10	-2.98	-0.04	-0.73	-0.78	-1.06	-1.13	+4.11
	12	+3.59	-1.59	-4.95	-1.38	+3.55	-1.79	-1.01
	14	-0.08	-1.12	-1.37	-1.19	+4.42	-1.12	-2.16
	16	+2.89	-2.08	+0.72	-1.47	-0.99	-3.19	-0.25
	18	-0.01		+0.73	-2.62	-6.94		-0.33
	20	-0.15		-0.37	-1.22	-0.75		-0.38
Cube Roll	**6**	+1.74		+1.10		+3.82		+0.06
	8	+7.19		+4.92		+3.46		-2.51
	10	-1.50	-0.51	-0.15	-0.73	-1.86	-0.70	+1.47
	12	+1.48	-1.77	-8.10	-1.08	+0.96	-0.51	-1.88
	14	-1.68	-1.43	-1.22	-0.96	+1.36	-1.98	-0.86
	16	+6.55	-1.50	-0.70	-2.47	-2.79	-2.98	-1.06
	18	-1.16	-1.74	+2.46	-3.63	-2.94	-0.70	-1.47
	20	-5.53	-1.34	+0.67	-1.51	+1.53		+2.44

Table 6: Change in hue over 3 days retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6	-0.030		-0.111		-0.226		-0.040
	8	-0.127		-0.442		-0.047		-0.074
	10	-0.217	+0.06	-0.053	+2.30	-0.022	+2.85	-0.346
	12	-0.356	+2.45	-0.076	+3.30	-0.035	+4.44	+0.0001
	14	-0.017	+3.36	-0.097	+5.85	0.039	+7.32	-0.021
	16	-0.102	+5.15	-0.058	+10.17	+0.087	+8.63	-0.029
	18	-0.100		-0.083	+10.13	-0.049		+0.036
	20	-0.087		-0.039	+15.08	-0.007		+0.11
Cube Roll	6	-0.050		-0.088		-0.308		-0.016
	8	-0.507		-0.398		-0.111		-0.065
	10	-0.147	-0.94	-0.055	+2.89	-0.023	+2.08	-0.304
	12	-0.370	+1.87	-0.059	+3.24	-0.027	+2.72	+0.240
	14	-0.025	+2.46	-0.057	+6.52	-0.121	+5.77	+0.071
	16	-0.075	+6.13	-0.011	+12.37	-0.021	+7.81	-0.024
	18	-0.128	+5.61	-0.126	+13.00	-0.0824	+7.96	+0.062
	20	+0.089	+7.67	-0.037	+15.44	-0.029		+0.088

Table 7: Change in chroma over 3 days retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	+2.16		+2.82		+3.75		-1.03
	8	+0.43		+3.54		+1.17		+3.05
	10	+1.20	-8.40	-0.02	-6.07	-1.20	-6.62	+3.43
	12	+0.09	-6.20	+3.17	-7.95	+0.04	-9.52	-2.73
	14	-2.41	-6.46	-0.57	-9.18	-1.74	-9.75	+2.72
	16	-13.62	-8.37	-2.30	-10.32	+0.06	-7.96	-2.44
	18	+0.14		-2.83	-9.12	-0.73		-0.05
	20	-1.35		-3.35	-12.29	-3.27		-2.11
Cube Roll	**6**	+1.94		+0.93		+3.83		-1.96
	8	+1.07		+3.82		+2.00		+3.96
	10	+1.38	-7.11	+2.96	-7.36	+0.27	-5.20	+2.23
	12	+1.97	-5.35	+3.57	-7.42	-2.91	-7.62	-9.41
	14	+0.41	-7.72	+1.37	-10.69	-3.43	-7.70	-0.23
	16	-3.99	-9.49	-1.88	-12.41	-0.09	-7.81	-2.76
	18	+0.04	-8.75	-0.31	-9.71	+4.51	-11.73	-2.12
	20	-3.39	-7.64	-3.64	-11.62	-4.36		-2.11

Microbiology (Appendix 3, Tables A3.35 to A3.43)

First two weeks of storage

In the Australian component of the project, packs were opened, where possible, on days 3, 7, 10 and 14, in order to determine the microbiological status of the product. However, only Processor A supplied product in time for the day 3 evaluation, Processor Z achieved the day 10 evaluation, while Processors B and C only met the day 14 evaluation (table 8). TVC and LAB counts were surprisingly low on day 14 (mean 0.5-2.53 $\log_{10}$cfu/cm²). From published literature, TVC and LAB counts in vacuum packaged beef aged for 2 weeks would be expected to reach levels of around 6 $\log_{10}$cfu/cm². Blixt and Borch (2002) recorded increases in Aerobic bacteria from 3 $\log_{10}$cfu/cm² to 6 $\log_{10}$cfu/cm² and LAB from 1 $\log_{10}$cfu/cm² to 6 $\log_{10}$cfu/cm² in the first two weeks of storage of vacuum packed beef loin; while Sakala *et al.* (2002) recorded increases from 3-3.5 $\log_{10}$cfu/cm² to 5.5-7 $\log_{10}$cfu/cm² over 2 weeks vacuum storage for a number of LAB species on beef; and Leisner *et al.* (1995) recorded increases in inoculated *Carnobacterium maltaromicus* from 3 $\log_{10}$cfu/cm² to 5 $\log_{10}$cfu/cm², *Lactobacillus sake* from 2 $\log_{10}$cfu/cm² to 6.5 $\log_{10}$cfu/cm², and *Leuconostoc gelidum* from 3 $\log_{10}$cfu/cm² to 4.5 $\log_{10}$cfu/cm² on beef slices stored under vacuum for 2 weeks. It is interesting to note, however, that none of the samples collected in the current project yielded microbial levels as high as those cited in the literature on day 14. It may be that limited flora on the current project's product at day zero contributed to the low counts observed at day 14.

Enterobacteriaceae were detected only on Processor A cube roll on day 10 and Processor Z striploin, day 10, at the detection limit (0.5 $\log_{10}$cfu/cm²), suggesting that hygienic conditions of production were good at all participants' premises. *Brochothrix thermospacta* were not detected in any sample.

Table 8: Microbiology in first two weeks of storage (mean $log_{10}cfu/cm^2$) (FSA only)

Cut	Days of vacuum storage	Processor							
		A		B		C		Z	
		TVC	LAB	TVC	LAB	TVC	LAB	TVC	LAB
Striploin	**3**	2.02	1.40						
	7	2.92	2.57						
	10	1.93	1.30					3.71	3.00
	14	2.00	1.64	1.52	1.30	1.22	0.80	2.53	0.90
Cube Roll	**3**	1.50	0.80						
	7	0.86	0.96						
	10	1.03	0.80					1.80	1.30
	14	0.50	1.00	1.59	1.10	0.96	0.80	2.05	1.49

Weeks 6 onwards

Again, in the Australian (FSA) component of the project, some startling results were obtained. Total Viable Counts (TVCs) were highly variable, between 0.40 and 7.04 log_{10}cfu/cm² (table 9), and there was no obvious consistent trend over time or across processors and primals (figure 3). Processor A cube roll TVCs were particularly low (range 0.40 to 2.73 log_{10}cfu/cm²). Similarly, LAB counts in the Australian component were highly variable ranging from 1.00 to 6.76 log_{10}cfu/cm², and again surprisingly low, particularly in the case of Processor A (table 10). LAB were not detected in all samples, nor from all packs (table 11) (Detection limit: 1.00 log_{10}cfu/cm²). In general, however, the frequency of detection and the mean count detected increased over storage time. LAB were not detected from processor A striploin in week 20, from Processor A cube roll in weeks 8, 16, 18 and 20, from Processor B striploin in weeks 12 and 16, and from Processor Z striploin in weeks 8 and 12. From published literature (Sakala et al., 2002, Blixt and Borch, 2002, Leisner et al., 1995), total counts and LAB counts on beef would be expected to plateau at around 6-7 log_{10}cfu/cm² after three weeks of vacuum storage, and be maintained at that level. It is possible that the highly variable counts observed in this project are a result of the small sample size in each sampling point, leading to data belonging to outliers or limit-of-range product. However, it is also possible, given the low initial microbial load at packaging suggested by the results of the day 14 samples, and the strict temperature control during storage, that such variability, and the presence of surprisingly low counts later in storage are in fact a feature of current commercially produced vacuum packed chilled beef.

Table 9: Mean TVC ($log_{10}cfu/cm^2$)

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**	1.77		2.22		4.39		4.05
	8	4.74		1.51		0.50		1.06
	10	2.47	1.48	2.73	6.93	4.06	4.73	5.72
	12	1.19	4.45	1.06	6.85	6.97	6.60	3.97
	14	2.14	6.15	3.75	6.65	2.26	6.31	6.40
	16	1.92	5.18	5.02	6.05	5.52	6.76	3.78
	18	1.65		0.40	6.30	2.29		3.70
	20	0.60		0.70	5.50	5.74		4.90
Cube Roll	**6**	2.14		2.08		2.05		5.20
	8	0.60		5.50		4.82		1.90
	10	1.06	0.65	5.49	7.01	5.32	4.82	4.78
	12	2.73	2.76	2.72	7.19	4.68	6.73	4.12
	14	0.40	5.69	3.12	6.94	4.24	6.35	3.21
	16	1.38	5.93	1.98	6.59	3.91	6.66	4.39
	18	0.83	5.98	4.86	6.61	4.97	6.22	2.76
	20	0.50	5.77	2.99	5.65	6.40	6.43	7.04

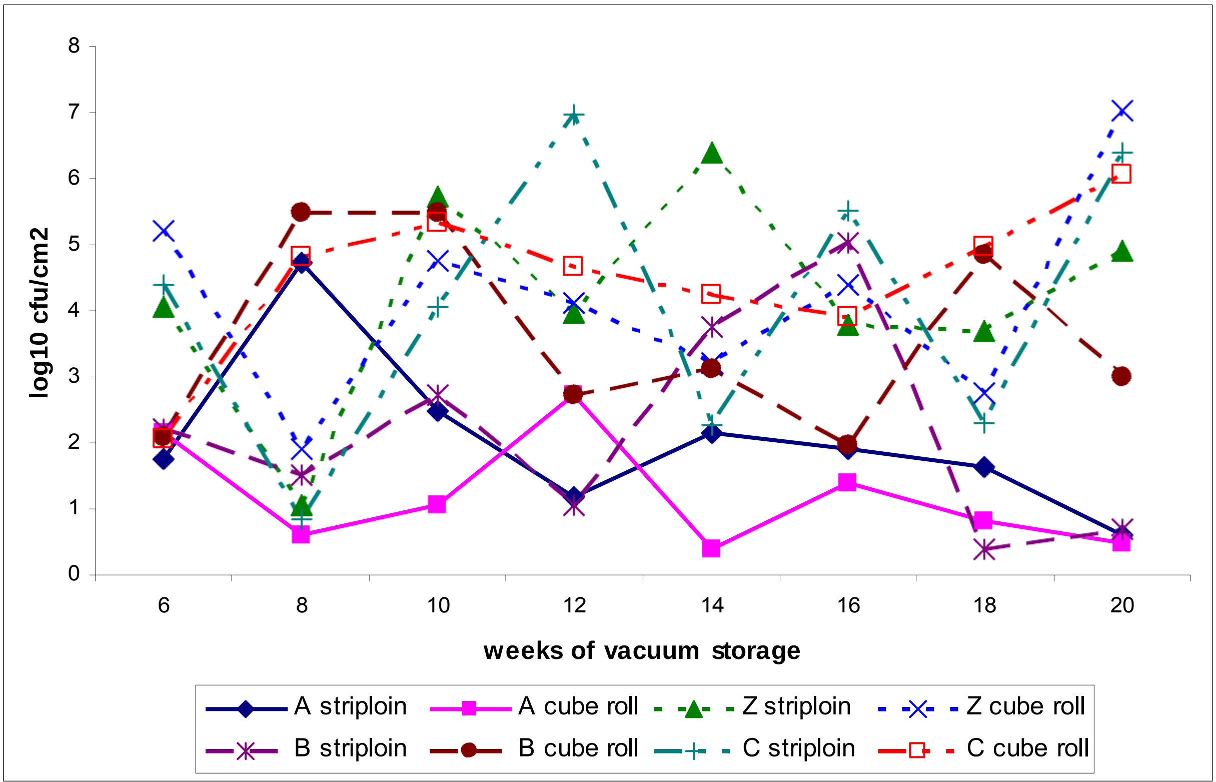

Figure 3: Mean TVC, FSA product

Processor A product shipped to the US (tables 8 and 9) also showed surprisingly low counts in week 10 (striploin 1.48 log_{10}cfu/cm² TVC, 0.55 log_{10}cfu/cm² LAB; cube roll 0.65 log_{10}cfu/cm² TVC, 0.08 log_{10}cfu/cm² LAB), but these quickly reached expected levels (above 5 log_{10}cfu/cm² by week 14). Product from Processor B was at expected levels (above 6 log_{10}cfu/cm²), while product from Processor C had TVCs and LAB counts in the region of 4.18-4.82 log_{10}cfu/cm² at week 10, and above 5 log_{10}cfu/cm² by week 12 (figure 4).

Total psychrotroph counts were carried out at TT only (table 12). Numbers were in the expected region (5-7 log_{10}cfu/cm²) for processors B and C, however, at week 10, psychrotroph counts for Processor A striploin and cube roll were very low (0.64 and 0.36 log_{10}cfu/cm² respectively). These increased rapidly reaching 6.46 and 2.99 log_{10}cfu/cm² in week 12 and above 5 log_{10}cfu/cm² thereafter.

It was interesting to note that microbial levels in product shipped to the US had not reached the expected plateaus by week 10, and numbers only levelled off at weeks 12 to

14, particularly for Processor A. It is possible that the difference in storage temperature between TT (3°C) and FSA (-1°C) may have contributed to the observed increase in microbial numbers at TT, as the rate of growth of psychrotrophic organisms such as *Lactobacillus* spp is expected to be greater at temperatures above 0°C than below (Tsigarida and Nychas, 2006). However, the question also remains as to whether the increases in counts observed subsequent to the initial sampling on week 10 are true representations of the microbiological status of vacuum stored beef, or are affected by the repeated exposure and repackaging resulting from the methodologies used.

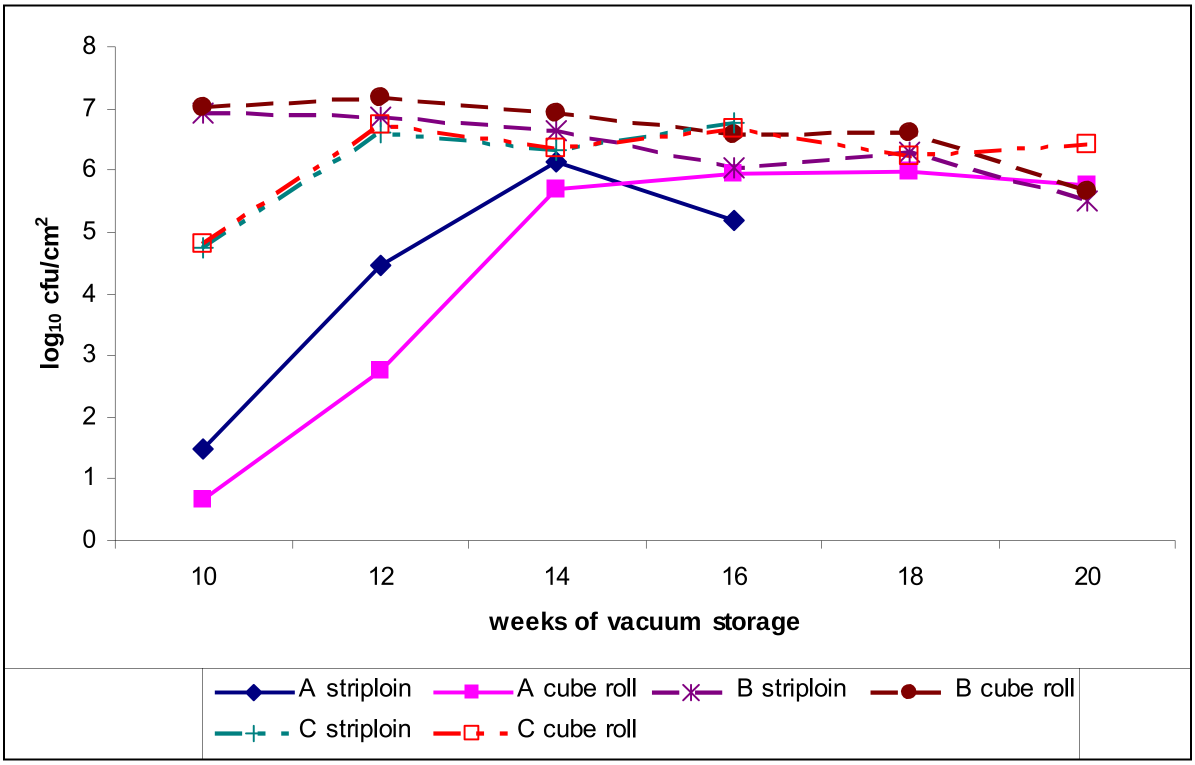

Figure 4: Mean TVC, TT product

Table 10: Mean lactic acid bacteria (LAB) count ($log_{10}cfu/cm^2$)

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	1.00		2.06		3.30		4.11
	8	4.18		1.35		2.24		Not detected
	10	1.30	0.55	1.69	6.99	4.91	4.18	6.34
	12	2.07	3.84	Not detected	6.34	6.96	4.63	Not detected
	14	3.76	5.73	3.19	6.89	5.69	5.85	6.36
	16	1.91	5.00	Not detected	6.37	4.65	5.52	3.76
	18	6.10		2.70	6.46	1.65		3.67
	20	Not detected		6.55	5.71	6.08		4.38
Cube Roll	6	1.62		1.00		1.79		2.92
	8	Not detected		4.61		2.55		2.12
	10	3.18	0.08	4.10	6.97	4.49	4.68	2.49
	12	1.83	3.58	2.54	6.94	5.00	5.29	2.23
	14	6.76	5.83	3.60	6.93	5.54	5.78	3.04
	16	Not detected	5.58	4.13	6.48	4.65	6.26	1.70
	18	Not detected	5.28	6.35	6.63	2.00	5.84	2.81
	20	Not detected	4.64	4.88	6.06	5.64	5.85	6.81

Detection limit: 1.00 $log_{10}cfu/cm^2$

Table 11: FSA only: Total lactic acid bacteria (LAB) (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $\log_{10}$cfu/cm^2 of positive samples below). Detection limit: 1.00 $\log_{10}$cfu/cm^2

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	1/3 1.00	3/3 2.06	3/3 3.30	3/3 4.11
	8	2/3 4.18	2/3 1.35	3/3 2.24	Not detected
	10	1/3 1.30	3/3 1.69	3/3 4.91	3/3 6.34
	12	2/3 2.07	Not detected	3/3 6.96	Not detected
	14	3/3 3.76	3/3 3.19	3/3 5.69	3/3 6.36
	16	3/3 1.91	Not detected	3/3 4.65	3/3 3.76
	18	3/3 6.10	1/3 2.70	2/3 1.65	3/3 3.67
	20	Not detected	3/3 6.54	3/3 6.08	3/3 4.63
Cube Roll	6	3/3 1.62	1/3 1.00	2/3 1.79	3/3 2.92
	8	Not detected	3/3 4.61	3/3 2.55	2/3 2.12
	10	3/3 3.18	3/3 4.10	3/3 4.49	3/3 2.49
	12	2/3 1.83	3/3 2.54	3/3 5.00	1/3 2.23
	14	3/3 6.76	3/3 3.60	3/3 5.54	3/3 3.04
	16	Not detected	3/3 4.13	3/3 4.65	1/3 1.70
	18	Not detected	3/3 6.35	1/3 2.00	2/3 2.81
	20	Not detected	3/3 4.88	3/3 5.64	3/3 6.81

Table 12: TT only: Total psychrotroph count (log_{10} cfu/cm²)

Cut	Weeks of vacuum storage	Processor		
		A	B	C
Striploin	**10**	0.64	7.05	5.20
	12	6.46	7.22	6.90
	14	6.49	7.16	6.58
	16	7.00	6.79	7.11
	18		6.98	
	20		6.82	
Cube Roll	**10**	0.38	7.04	5.88
	12	2.99	6.41	7.63
	14	5.54	7.26	6.72
	16	7.08	6.82	7.12
	18	7.05	7.05	6.60
	20	6.58	6.57	6.60

Enterobacteriaceae and *Brochothrix thermospacta* enumerations were carried out at FSA only. Enterobacteriaceae were detected more often from processor Z than from other processors, particularly in cube roll (table 13). Enterobacteriaceae were not detected from processor A cube roll at any time point, and from processor C cube roll from a single sample out of three on a single sampling occasion. Mean counts when detected were in the order of 0.70 to 2.85 log_{10}cfu/cm². *Brochothrix thermospacta* were recovered in week 6 from processor A striploin (1.70 log_{10}cfu/cm²) and cube roll (2.95 log_{10}cfu/cm²), from processor B cube roll in weeks 8 and 10 (2.02 and 4.25 log_{10}cfu/cm² respectively), from processor C striploin in week 10 (2.79 log_{10}cfu/cm²) and from processor C cube roll, in weeks 6, 14, 18 and 20 (2.95, 1.94, 1.70 and 6.37 log_{10}cfu/cm² respectively) (table 14). The low detection rate for Enterobacteriaceae suggests that hygiene during production was good, while low detections of *Brochothrix thermospacta* are consistent with beef of normal pH, packaged in films of low Oxygen Transmission Rate (OTR). The pH of the product was determined at FSA on each sampling occasion, and found to be consistently in the range of pH 5.5 to 5.7.

Table 13: FSA only: Enterobacteriaceae detections (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $log_{10}cfu/cm^2$ of positive samples below). Detection limit: 0.70 $log_{10}cfu/cm^2$

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	**6**	Not detected	1/3 1.70	Not detected	1/3 0.70
	8	Not detected	Not detected	Not detected	Not detected
	10	1/3 1.54	Not detected	1/3 0.70	3/3 1.62
	12	1/3 1.54	Not detected	3/3 3.04	Not detected
	14	Not detected	Not detected	Not detected	2/3 0.70
	16	Not detected	1/3 0.70	2/3 1.54	3/3 2.04
	18	Not detected	Not detected	Not detected	1/3 0.70
	20	Not detected	Not detected	Not detected	2/3 5.32
Cube Roll	**6**	Not detected	2/3 1.27	Not detected	1/3 1.00
	8	Not detected	2/3 1.00	Not detected	1/3 1.40
	10	Not detected	Not detected	Not detected	3/3 1.17
	12	Not detected	Not detected	Not detected	2/3 2.85
	14	Not detected	Not detected	Not detected	1/3 0.70
	16	Not detected	1/3 1.18	1/3 1.54	1/3 0.70
	18	Not detected	Not detected	Not detected	Not detected
	20	Not detected	Not detected	Not detected	3/3 0.90

Table 14: FSA only: *Brochothrix thermospacta* detections (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $\log_{10}$cfu/cm^2 of positive samples below). Detection limit: 1.70 $\log_{10}$cfu/cm^2

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	1/3 1.70	Not detected	Not detected	Not detected
	8	Not detected	Not detected	Not detected	Not detected
	10	Not detected	Not detected	2/3 2.79	Not detected
	12	Not detected	Not detected	Not detected	Not detected
	14	Not detected	Not detected	Not detected	Not detected
	16	Not detected	Not detected	Not detected	Not detected
	18	Not detected	Not detected	Not detected	Not detected
	20	Not detected	Not detected	Not detected	Not detected
Cube Roll	6	1/3 2.95	Not detected	1/3 2.95	Not detected
	8	Not detected	3/3 2.02	Not detected	Not detected
	10	Not detected	3/3 4.25	Not detected	Not detected
	12	Not detected	Not detected	Not detected	Not detected
	14	Not detected	Not detected	2/3 1.94	Not detected
	16	Not detected	Not detected	Not detected	Not detected
	18	Not detected	3/3 4.78	1/3 1.70	Not detected
	20	Not detected	Not detected	3/3 6.37	Not detected

Possible correlations

The data set from TT showed a distinct deterioration with storage time for all observations. Good scores on sensory evaluations were given to product from processor A in weeks 10 and 12, and this correlated with low microbial counts for the same product at the same time points, as compared with product from Processors B and C. The data set from FSA, however, showed few trends, other than that product from Processor A tended to score better in general than that from Processors B, C or Z. Attempts were made to correlate particular observations within the FSA data set, but it was difficult to draw firm conclusions. For example:

- Processor A striploin at week 16 scored just below acceptable (3.43) for confinement odour, and only just above acceptable (4.14) for post bloom visual appearance. However, retail pack score at day three was good (6.83), TBARS value was good (0.410 raw and 0.386 cooked), and microbiology was good (TVC 1.92 log_{10}cfu/cm²; LAB 1.91 log_{10}cfu/cm)
- Processor A cube roll at week 20 had a high TBARS value (1.676 raw, 1.714 cooked), but sensory scores were good (confinement odour 4.83; post bloom visual appearance 5.17; retail pack at day three 4.60), and microbiology good (TVC 0.50 log_{10}cfu/cm²; LAB not detected)

SUMMARY

In the Australian component of the project, there was a slight deterioration in visual appearance of the intact pack and the post-bloom primal, a slight increase in confinement odour, and a slight deterioration in visual appearance (greying of fat) of 3-day displayed steaks as the vacuum storage period increased. Concurrently, there was a slight increase in lipid oxidation over 3 days retail display as indicated by increasing TBARS values, and a slight overall increase in mean LAB count. Low detections of Enterobacteriaceae and *Brochothrix thermospacta* indicated that processor hygiene and packaging integrity were very good. It is possible that the highly variable counts observed in the Australian component are a result of the small sample size in each sampling point, leading to data belonging to outliers or limit-of-range product. However, it is also possible, given the low initial microbial load at packaging suggested by the results of the day 14 samples, and the strict temperature control during storage, that such variability, and the presence of surprisingly low counts later in storage are in fact a feature of current commercially produced vacuum packed chilled beef.

In the US component, the product was considered good on arrival at week 10 of storage, and, in the case of Processor A, had surprisingly low microbial counts. However, the acceptability of the product rapidly deteriorated as storage duration extended, and microbial counts rapidly increased to the expected plateau at 6-7 $\log_{10}$cfu/cm. It is possible that the difference in storage temperature between the US component (3°C) and the Australian component (-1°C) may have contributed to the observed increase in microbial numbers at TT, as the rate of growth of psychrotrophic organisms such as *Lactobacillus* spp is expected to be greater at temperatures above 0°C than below (Tsigarida and Nychas, 2006). However, the question also remains as to whether the increases in counts and deterioration of product acceptability observed subsequent to the initial sampling on week 10 are true representations of the storage life of vacuum packed beef, or are affected by the repeated exposure and repackaging resulting from the methodologies used.

FUTURE WORK

In light of the stark differences between the data gathered in Australia and those gathered in the US, the differing methodologies used, and the small numbers of processors and product involved, it is impossible from this project to draw firm conclusions regarding the storage life of vacuum packed beef produced in Australia. However, the data gathered in Australia suggests that storage lives may well be substantially in excess of the currently recommended 10-12 weeks, assuming that appropriate production and storage conditions are met.

In order to further explore the potential storage life of Australian vacuum packaged beef, two options should be considered:

- Repeat the Australian component of this project, involving the same processors, but using a larger number of product samples at each time point, in order to obtain a result carrying more statistical confidence than that gained from sampling a single pack at each time point.
- Carry out a larger survey of processors and products in order to obtain a more industry-wide picture of the current storage life of vacuum packaged beef.

With either option, it would be important to gather information on the production practices and conditions of the product sampled, in order to identify ‘good’ practices that could lead to an extended storage life.

Alison Small

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APPENDIX 1: PARTICIPATING PROCESSORS' PROCEDURE

Processor's Instructions

Introduction

Food Science Australia is coordinating a research project funded by MLA to investigate the development of lactic acid bacteria (LAB) in chilled vacuum-packed primals, and their impact on shelf-life.

The industry relies on the use of vacuum-packaging as a mechanism for extending shelf-life but there has been little recent emphasis on the storage life of vacuum-packaged beef and lamb and the retail life of meat cuts prepared from the vacuum packs. Consequently current practices are based on data generated up to 2 decades ago. Improvements in processing technologies, transport and refrigeration systems, and packaging technologies during that time highlights a need for a review of this area. Several requests have come from the USA regarding data to support shelf life claims, and thus a need to investigate exactly how our product performs once it reaches the US.

The purpose of this project is to investigate the shelf life claims of vacuum-packaged primals exported to the USA, and the factors affecting the storage life. To investigate sufficiently, there is a requirement to carry out microbiological testing and sensory evaluation of product. The project also presents an opportunity to generate data suitable for incorporation into a predictive model to assist the entire industry in setting realistic shelf life claims.

Outcomes

A consolidated report combining all data gathered will be produced for MLA by Food Science Australia. This will be made available to the Australian meat industry through normal MLA channels.

Supplementary to the general report, each participating processor will receive an individual report, detailing their own product data and analysis.

Details of individual participants and individual results will be kept strictly confidential through a system of randomisation of sample numbers.

Product needs

The project involves two parallel shipments, one to Texas Tech University, Texas, USA, and one to Food Science Australia, Cannon Hill, QLD.

Each recipient will need 15 pieces of striploin and 15 cube rolls.

Please cut striploins into halves and vacuum pack each piece separately.

Primal	Piece size	Texas	Food Science	Total
Striploin	half	15 pieces	15 pieces	30 pieces = 15 striploins
Cube Roll	entire	15 pieces	15 pieces	30 cube rolls

Package the pieces in fibreboard cartons as normal for shipment to the US as chilled product, incorporating temperature loggers into each carton as detailed below. Stickers will be supplied to aid in labelling the cartons.

Ship one set of cartons to the US (destination Texas Tech University – details below), and simultaneously ship the matching set to Food Science Australia (details below).

Placing the temperature loggers into the cartons

Thermocron button temperature loggers in labelled clip seal plastic bags and corresponding carton labels have been supplied along with a recording sheet. After packing the test vacuum packed cuts in the cartons, place one temperature logger into a space in each carton and tape the plastic bag to the surface of a cut so that the logger is resting against the product. Attach the corresponding numbered labels to the top, side and end panel of each carton.

Record the logger number, product details and packing date and time on the sheet supplied and return the sheet and any remaining loggers to Food Science Australia.

Documentation

The shipment to the US will require the standard health certificate for export of fresh beef.

Information to accompany product to Food Science Australia

Please supply the following information pertaining to the product:

- Kill date
- Bone date
- Hot boned/cold boned
- Grass fed/grain fed
- Final pH
- Final temp
- RI (as of vacuum packaging)

If you would like the plant-specific report to include a relationship with the initial TPC, this can be included as an optional extra.

A proforma record sheet will be supplied with the temperature loggers to aid collating of this information.

Dispatch of Product

The cartons and documentation are to be delivered to:

Attn: Alison Small Food Science Australia Cnr Creek and Wynnum Roads Cannon Hill QLD 4170 Telephone: +61-7-3214-2109	Dr. Mark Miller Gordon W Davis Meat Science Laboratory Texas Tech University Indiana and Main Streets Lubbock Texas USA 79409-2141 USDA license: 236 Telephone: +1- 806-742-2805

Product Details

(Return this form to FSA with the product)

Cattle type: Brahman Cross European

Cattle age (months):

Kill date:

Bone Date:

Boned: Cold Warm Hot

Feeding: Grass Grain

Duration of grain feed:

Final pH:

Final temperature:

RI at vacuum packaging:

Comments:

Temperature Loggers (Return this form to FSA with the product)

Carton ID	Thermologger ID code	Product	Date and Time of packing

APPENDIX 2 – SENSORY EVALUATION

2.1: FSA sensory evaluation form

Date:

Sample number	**Attribute**					**Comments**
	Vacuum 8 = complete vacuum, tight package adhesion 6 = good vacuum 4 = moderate vacuum 2 = poor vacuum 0 = no vacuum, probable leaker	**Appearance** 8 = very fresh, no discolouration 6 = fresh, slight discolouration 4 = good, acceptable 2 = poor 0 = severe discolouration		**Odour** 8 = fresh, no off / confinement odour 6 = slight confinement / off odour 4 = typical confinement odour 2 = strong confinement / off odour 0 = extreme off odour	**Minolta Colour Reading**	
		Intact pack	**After Bloom**	**On opening**		

2.2: TT Odour evaluation form

TEXAS TECH UNIVERSITY

AUSTRALIAN SHELF LIFE

Trained Odor Evaluation

NAME____________________DATE ________

Presence of Off-odor	Odor characterization
1= No Off-odor	1= No Off-odor
2= Slight Off-odor	2= Rancid
3= Small Off-odor	3= Sweet
4= Moderate Off-odor	4= Sour
5= Extreme Off-odor	5= Acidic
	6= Putrid
	7= None of the above

Striploin			Ribeye Roll		
No.	Off	Odor	No.	Off	Odor
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		
11			11		
12			12		
13			13		
14			14		

2.3: TT Colour evaluation form

TEXAS TECH UNIVERSITY

AUSTRALIAN PROJECT

Trained Colour Evaluation

NAME: ______________________________ DATE: ______

Muscle Color Score Scale (Oxy)

1. Very bright red
2. Bright red
3. Dull red
4. Slightly dark red
5. Moderately dark red
6. Dark red or dark reddish tan or
7. Dark pinkish red or dark pinkish tan
8. Tannish red or tannish pink
9. Tan to brown

*****Score to half-point increments*****

Discoloration Scale
Surface % MetMb

1. None (0%)
2. Slight discoloration (1-19%)
3. Small discoloration (20-39%)
4. Modest discoloration (40-59%)
5. Moderate discoloration (60-79%)
6. Extensive discoloration (80-99%)
7. Total discoloration (100%)

*****Whole point increments only*****

Sample ID	Color Score	Discoloration Score
1 a		
2 a		
3 a		
4 a		
5 a		
6 a		
7 a		
8 a		
9 a		
10 a		
11 a		

APPENDIX 3 – DATA

SENSORY PANEL ASSESSMENT

Table A3.1: Visual assessment of intact packs, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	7.40	Not done	6.83	Not done	5.60	Not done	6.17
	8	6.83		6.00		5.83		7.20
	10	7.20		5.00		6.83		5.80
	12	6.00		6.00		6.00		5.83
	14	5.43		5.40		6.50		6.83
	16	5.71		5.60		5.17		6.33
	18	6.00		6.33		6.00		7.00
	20	6.30		5.86		6.83		5.83
Cube Roll	6	8.00		6.50		6.00		6.83
	8	6.50		6.20		6.00		7.20
	10	7.20		5.60		5.83		5.60
	12	6.20		5.83		6.50		6.17
	14	6.29		5.60		7.00		5.83
	16	5.71		5.80		6.00		6.67
	18	6.00		6.17		6.33		6.67
	20	5.83		6.14		6.17		6.17

Table A3.2: Confinement odour assessment, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	7.60	Not done	6.00	Not done	5.80	Not done	6.83
	8	4.50		7.00		5.50		5.40
	10	5.40	6.40 (1.00)	4.40	5.6 (1.50)	6.00	5.79 (1.38)	2.00
	12	7.00		5.17		6.00		4.67
	14	6.14		5.80		5.50		5.17
	16	3.43		4.80		6.00		5.00
	18	5.60		6.33		6.00		5.33
	20	4.83		6.14		6.33		6.17
Cube Roll	6	7.80		6.17		4.80		5.50
	8	6.67		6.60		5.33		6.00
	10	6.00	6.40 (1.00)	5.40	5.63 (1.48)	6.00	5.34 (1.66)	3.80
	12	5.80		5.50		7.00		4.83
	14	6.57		6.80		5.83		6.57
	16	4.86		5.20		6.17		5.83
	18	5.40		6.16		5.33		5.67
	20	4.83		6.29		5.33		5.33

*TT scores converted to FSA equivalent, original score in brackets

Table A3.3: Post bloom visual appearance assessment, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	7.80		7.17		7.60		7.50
	8	6.00		6.20		6.83		8.00
	10	8.00	6.95 (2.05)	6.60	5.16 (3.84)	5.67	4.51 (4.49)	6.20
	12	6.80	6.80 (2.20)	5.50	5.05 (3.95)	7.00	4.38 (4.62)	6.00
	14	7.00	5.93 (3.07)	5.80	4.93 (4.07)	6.33	4.44 (4.56)	7.17
	16	4.14	6.43 (2.57)	7.00	4.80 (4.20)	5.00	4.49 (4.51)	7.33
	18	6.20		6.00	4.57 (4.43)	5.17		6.83
	20	7.00		6.57	4.52 (4.48)	6.83		6.50
Cube Roll	6	8.00		7.67		7.20		7.83
	8	6.00		7.20		7.50		7.20
	10	7.20	6.27 (2.73)	7.00	4.52 (4.48)	5.83	4.14 (4.86)	6.40
	12	6.20	6.19 (2.81)	6.17	4.43 (4.57)	6.67	3.94 (5.06)	7.83
	14	7.14	5.46 (3.54)	6.60	4.36 (4.64)	6.67	4.27 (4.73)	7.00
	16	6.57	5.53 (3.47)	7.00	4.54 (4.46)	6.17	4.19 (4.81)	7.33
	18	6.20	4.85 (4.15)	6.50	4.43 (4.57)	5.50	3.77 (5.23)	6.67
	20	5.17	4.01 (4.99)	6.00	4.39 (4.61)	6.67	3.70 (5.30)	7.50

*TT scores converted to FSA equivalent, original score in brackets

Table A3.4: Retail pack visual assessment, day 1, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**							
	8							
	10		6.16 (2.84)		4.40 (4.60)		3.55 (5.45)	
	12		6.05 (2.95)		4.28 (4.72)		3.79 (5.21)	
	14		5.17 (3.83)		4.21 (4.79)		3.69 (5.31)	
	16		4.25 (4.75)		3.83 (5.17)		2.69 (6.31)	
	18				2.80 (6.20)			
	20				2.60 (6.40)			
Cube Roll	**6**							
	8							
	10		5.80 (3.20)		3.55 (5.45)		3.38 (5.62)	
	12		5.63 (3.37)		3.47 (5.53)		3.21 (5.79)	
	14		4.79 (4.21)		3.46 (5.54)		3.54 (5.46)	
	16		4.15 (4.85)		3.44 (5.56)		2.65 (6.35)	
	18		3.34 (5.66)		2.86 (6.14)		2.47 (6.53)	
	20		2.68 (6.32)		2.39 (6.61)		1.67 (7.33)	

*TT scores converted to FSA equivalent, original score in brackets

Table A3.5: Retail pack visual assessment, day 2, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6							
	8							
	10		5.56 (3.44)		3.76 (5.24)		2.91 (6.09)	
	12		5.34 (3.66)		3.47 (5.53)		2.55 (6.45)	
	14		4.11 (4.89)		3.06 (5.94)		2.61 (6.39)	
	16		2.90 (6.10)		2.82 (6.18)		1.99 (7.01)	
	18				2.09 (6.91)			
	20				1.90 (7.10)			
Cube Roll	6							
	8							
	10		5.21 (3.79)		2.85 (6.15)		2.99 (6.01)	
	12		4.86 (4.14)		2.82 (6.18)		2.49 (6.51)	
	14		3.96 (5.04)		2.30 (6.70)		2.83 (6.17)	
	16		3.29 (5.71)		2.21 (6.79)		1.95 (7.05)	
	18		2.43 (6.57)		1.65 (7.35)		1.93 (7.07)	
	20		1.66 (7.34)		1.46 (7.54)		1.29 (7.71)	

*TT scores converted to FSA equivalent, original score in brackets

Table A3.6: Retail pack visual assessment, day 3, Mean panel scores

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	8.00		7.30		7.50		6.67
	8	8.00		7.33		6.08		8.00
	10	6.25	4.58 (4.42)	5.83	2.99 (6.01)	6.63	2.95 (6.05)	7.75
	12	7.17	4.58 (4.42)	6.50	3.41 (5.59)	7.17	2.12 (6.88)	6.83
	14	6.00	3.74 (5.26)	5.90	2.59 (6.41)	6.92	2.31 (6.69)	6.20
	16	6.83	2.10 (6.90)	5.58	2.39 (6.61)	5.25	1.48 (7.52)	6.92
	18	7.30		5.70	1.65 (7.35)	5.33		7.25
	20	7.00		6.00	0.77 (8.23)	3.70		6.42
Cube Roll	6	8.00		6.70		6.25		6.67
	8	8.00		6.83		6.5		7.67
	10	6.42	4.35 (4.65)	5.67	2.46 (6.54)	6.38	2.81 (6.19)	7.00
	12	6.00	4.28 (4.72)	5.20	2.78 (6.22)	4.92	2.12 (6.88)	6.17
	14	6.20	3.31 (5.69)	6.20	1.72 (7.28)	5.67	2.58 (6.42)	5.10
	16	7.00	2.60 (6.40)	5.17	1.65 (7.28)	5.92	1.49 (7.51)	6.08
	18	5.80	2.04 (6.96)	4.90	1.13 (7.87)	6.42	1.18 (7.82)	6.83
	20	4.60	1.23 (7.77)	5.10	0.93 (8.07)	5.20	1.12 (7.88)	5.92

*TT scores converted to FSA equivalent, original score in brackets

DRIP LOSS

Table A3.7: Mean percentage drip loss during vacuum storage

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**	2.11		5.72		1.18		0.67
	8	4.09		2.72		0.81		3.47
	10	3.19		8.68		0.72		1.26
	12	0.00		5.22		1.60		3.20
	14	3.08		6.70		4.06		2.74
	16	4.42		8.39		2.23		1.88
	18	4.05		7.37		2.63		2.48
	20	3.46		7.80		1.74		1.92
Cube Roll	**6**	1.21		1.58		1.33		1.13
	8	3.33		0.93		2.27		1.36
	10	4.18		2.28		1.95		1.25
	12	1.68		2.42		1.22		1.10
	14	2.00		2.61		0.75		2.67
	16	3.14		3.82		0.64		0.85
	18	2.01		3.43		1.58		2.43
	20	3.71		3.77		0.88		3.71

Table A3.8: Mean percentage drip loss during retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**	2.75		3.93		0.63		3.55
	8	0.39		0.46		2.88		2.92
	10	0.77		2.19		3.83		0.37
	12	0.64		4.41		3.59		3.47
	14	4.09		3.17		3.33		4.22
	16	3.65		5.07		3.09		2.81
	18	3.96		4.05		4.40		3.90
	20	4.20		4.82		0.44		3.35
Cube Roll	**6**	4.17		3.75		1.16		2.66
	8	0.50		0.27		4.08		2.55
	10	0.79		3.94		3.78		0.71
	12	0.22		3.74		3.71		3.22
	14	5.62		2.49		4.79		3.99
	16	4.97		3.32		5.00		3.77
	18	2.77		3.50		4.04		4.51
	20	6.12		3.67		0.40		4.00

Table A3.9: Mean overall percentage drip loss

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**	4.86		9.65		1.81		4.22
	8	4.48		3.18		3.69		6.39
	10	3.97		10.87		4.54		1.63
	12	0.64		9.63		5.19		6.67
	14	7.17		9.87		7.38		6.96
	16	8.07		13.46		5.32		4.69
	18	8.00		11.43		7.03		6.38
	20	7.66		12.62		2.14		5.27
Cube Roll	**6**	5.38		5.34		2.50		3.79
	8	3.84		1.20		6.35		3.91
	10	4.97		6.22		5.73		1.96
	12	1.90		6.16		4.93		4.32
	14	7.62		5.10		5.54		6.66
	16	8.11		7.14		5.64		4.62
	18	4.78		6.93		5.62		6.95
	20	9.83		7.44		1.28		5.18

LIPID OXIDATION (TBARS)

Table A3.10: Mean TBARS (mg/kg) – raw steaks, day 3 of retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	0.101		0.063		0.257		0.193
	8	0.016		0.231		0.438		0.178
	10	0.341	0.338	0.619	0.313	0.213	0.302	0.418
	12	0.110		0.376		0.410		0.528
	14	1.676		0.470		0.347		0.775
	16	0.410	0.274	0.141	0.350	0.129	0.313	0.556
	18	0.834		0.347		1.042		0.690
	20	0.621		0.605	0.308	0.632		0.756
Cube Roll	6	0.082		0.201		0.076		0.135
	8	0.149		0.084		0.190		0.140
	10	0.522	0.317	0.190	0.260	0.101	0.294	0.382
	12	0.269		0.281		0.711		0.290
	14	0.356		0.267		0.672		0.245
	16	0.382	0.304	0.357	0.273	0.399	0.305	0.499
	18	0.726		0.126		0.461		0.739
	20	1.136	0.248	0.374	0.261	0.248	0.187	0.831

Table A3.11: Mean TBARS (mg/kg) – cooked steaks, day 3 of retail display

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	**6**	0.079	0.018	0.528	0.217
	8	0.355	0.203	0.473	0.196
	10	0.342	0.710	0.300	0.378
	12	0.193	0.370	0.436	0.502
	14	1.714	0.456	0.354	0.810
	16	0.386	0.177	0.453	0.581
	18	0.793	0.298	1.153	0.670
	20	0.347	0.605	0.679	0.756
Cube Roll	**6**	0.038	0.117	0.072	0.220
	8	0.198	0.128	0.244	0.145
	10	0.517	0.204	0.214	0.345
	12	0.264	0.300	0.642	0.564
	14	0.336	0.248	0.663	0.299
	16	0.288	0.414	0.453	0.498
	18	0.645	0.161	0.587	0.732
	20	0.949	0.621	0.382	0.869

COLOURIMETRY

Table A3.12: Day 0 L value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6	43.96		40.94		36.71		40.29
	8	39.47		41.26		34.93		43.32
	10	39.75	37.58	39.10	35.43	36.97	32.47	36.60
	12	36.20	37.13	39.55	34.69	40.16	33.56	40.38
	14	39.37	37.48	39.50	35.12	44.40	33.70	44.96
	16	43.62	39.62	40.59	36.44	42.24	37.88	43.86
	18	43.01		40.27	38.35	44.13		44.26
	20	39.86		39.52	37.63	41.01		42.64
Cube Roll	6	42.92		39.86		33.99		40.67
	8	36.73		33.55		39.38		44.96
	10	41.02	35.34	38.08	34.19	39.86	32.18	37.59
	12	39.87	36.56	43.64	33.78	36.83	31.81	42.90
	14	43.78	36.96	39.15	33.86	41.52	33.95	41.27
	16	41.11	38.07	42.69	36.47	43.91	36.35	44.48
	18	42.06	37.73	39.50	39.26	40.57	34.74	46.41
	20	48.66	37.08	40.94	37.58	38.16		41.02

Table A3.13: Day 0 a value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	16.29		17.71		15.21		20.30
	8	16.63		15.16		22.17		16.47
	10	16.28	24.33	17.68	23.11	13.99	23.73	15.40
	12	15.85	23.56	15.92	23.64	18.48	23.09	21.59
	14	18.95	21.75	16.06	22.67	17.81	22.77	14.46
	16	28.59	20.11	15.13	22.80	15.17	18.52	18.56
	18	14.60		16.99	18.70	17.84		16.65
	20	15.63		18.50	19.45	16.27		16.58
Cube Roll	**6**	15.89		18.82		16.18		21.98
	8	15.31		13.68		21.58		15.30
	10	15.13	24.23	16.92	23.96	16.65	23.57	15.63
	12	14.59	22.86	16.71	23.94	20.10	22.84	23.38
	14	16.54	23.10	16.31	23.09	19.06	23.02	17.59
	16	16.26	21.41	18.75	23.85	16.56	19.84	20.14
	18	15.85	20.47	17.20	20.39	12.30	20.93	17.37
	20	16.17	18.28	20.66	19.68	16.93		19.14

Table A3.14: Day 0 b value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	3.19		2.89		0.83		6.51
	8	0.86		-0.20		4.62		3.77
	10	0.85	22.84	2.65	19.50	1.46	19.21	-0.19
	12	-0.65	20.16	1.92	19.86	4.61	18.99	5.79
	14	5.08	20.62	0.38	19.53	4.81	18.81	2.64
	16	6.36	18.87	2.92	19.42	4.06	15.06	4.65
	18	0.34		3.85	16.19	3.85		4.40
	20	2.45		2.85	19.02	3.34		4.96
Cube Roll	**6**	2.14		2.00		-0.20		7.50
	8	-3.60		-0.50		5.76		2.11
	10	1.12	22.48	3.04	19.59	3.58	18.97	-0.33
	12	0.26	19.23	3.02	20.21	4.18	19.26	7.58
	14	4.85	21.72	2.75	19.54	4.83	18.87	4.86
	16	2.61	19.18	6.00	20.42	5.20	15.05	5.57
	18	0.30	18.83	3.37	16.59	1.16	18.27	4.99
	20	6.70	17.60	4.21	18.69	3.29		5.71

Table A3.15: Day 0 hue

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	1.38		1.41		1.52		1.26
	8	1.52		1.58		1.37		1.35
	10	1.52	43.19	1.42	40.15	1.47	38.99	1.58
	12	1.61	40.55	1.45	40.04	1.33	39.44	1.31
	14	1.31	43.48	1.55	40.74	1.31	39.56	1.39
	16	1.35	43.18	1.38	40.41	1.31	39.13	1.33
	18	1.55		1.35	40.89	1.36		1.31
	20	1.42		1.42	44.37	1.37		1.28
Cube Roll	**6**	1.44		1.46		1.58		1.24
	8	1.80		1.61		1.31		1.43
	10	1.50	42.86	1.39	39.27	1.36	38.83	1.59
	12	1.55	40.07	1.39	40.17	1.37	40.14	1.26
	14	1.29	43.24	1.40	40.25	1.32	39.34	1.30
	16	1.41	41.85	1.26	40.56	1.27	37.19	1.30
	18	1.55	42.61	1.38	39.14	1.48	41.11	1.29
	20	1.18	43.91	1.37	43.52	1.38		1.28

Table A3.16: Day 0 chroma

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6	16.60		17.94		15.23		21.31
	8	16.65		15.16		22.65		16.90
	10	16.30	33.36	17.88	30.25	14.07	30.53	15.40
	12	15.86	31.01	16.04	30.88	19.05	29.90	22.35
	14	19.62	29.97	16.06	29.92	18.45	29.54	14.70
	16	29.29	27.58	15.41	29.95	15.70	23.87	19.13
	18	14.60		17.42	24.74	18.25		17.22
	20	15.82		18.72	27.21	16.61		17.31
Cube Roll	6	16.03		18.93		16.18		23.22
	8	15.73		13.69		22.34		15.44
	10	15.17	33.05	17.19	30.95	17.03	30.25	15.63
	12	14.59	29.87	16.98	31.33	20.53	29.88	24.58
	14	17.24	31.70	16.54	30.25	19.66	29.77	18.25
	16	16.47	28.75	19.69	31.40	17.36	24.90	20.90
	18	15.85	27.81	17.53	26.29	12.35	27.79	18.07
	20	17.50	25.37	21.08	27.14	17.25		19.97

Table A3.17: Day 1 L value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6							
	8							
	10		36.74		34.39		32.70	
	12		36.18		33.84		32.35	
	14		37.26		34.20		32.24	
	16		38.68		34.40		34.71	
	18				35.67			
	20				38.07			
Cube Roll	6							
	8							
	10		35.34		33.16		33.24	
	12		35.88		33.07		32.07	
	14		36.63		32.96		31.56	
	16		36.11		33.50		32.23	
	18		36.00		35.65		33.17	
	20		35.90		38.01			

Table A3.18: Day 1 a value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		20.46		21.87		20.49	
	12		21.29		20.04		18.85	
	14		19.15		18.38		17.08	
	16		16.55		15.03		14.15	
	18				13.92			
	20				11.40			
Cube Roll	**6**							
	8							
	10		22.26		21.87		20.71	
	12		21.34		20.26		19.08	
	14		20.33		18.65		18.80	
	16		18.42		15.54		16.72	
	18		16.18		15.66		13.72	
	20		13.92		10.89			

Table A3.19: Day 1 b value

Cut	Weeks of vacuum storage	Processor A FSA (MINOLTA)	Processor A TT (Hunter)	Processor B FSA (MINOLTA)	Processor B TT (Hunter)	Processor C FSA (MINOLTA)	Processor C TT (Hunter)	Processor Z FSA (MINOLTA)
Striploin	6							
	8							
	10		17.62		18.57		16.96	
	12		19.00		17.22		16.28	
	14		18.63		16.65		16.04	
	16		17.01		15.41		13.95	
	18				14.31			
	20				14.49			
Cube Roll	6							
	8							
	10		18.94		18.87		16.89	
	12		18.47		17.67		16.44	
	14		19.11		16.46		17.12	
	16		17.20		16.54		15.00	
	18		15.96		15.14		12.95	
	20		14.91		13.56			

Table A3.20: Day 1 hue

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		40.73		41.39		39.61	
	12		41.74		40.67		40.80	
	14		44.21		42.18		43.20	
	16		45.79		45.72		44.59	
	18				45.80			
	20				51.80			
Cube Roll	**6**							
	8							
	10		40.39		40.79		39.20	
	12		40.87		41.10		40.76	
	14		43.23		41.43		42.33	
	16		43.04		46.79		41.89	
	18		44.61		44.03		43.33	
	20		46.97		51.22			

Table A3.21: Day 1 chroma

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		27.00		28.89		26.60	
	12		28.53		26.43		24.91	
	14		26.71		24.80		23.43	
	16		23.73		21.52		19.87	
	18				19.97			
	20				18.44			
Cube Roll	**6**							
	8							
	10		29.23		28.89		26.72	
	12		28.22		26.88		25.19	
	14		27.90		24.88		25.43	
	16		25.20		22.70		22.46	
	18		22.73		21.79		18.87	
	20		20.40		17.39			

Table A3.22: Day 2 L value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		36.71		34.01		31.47	
	12		35.46		33.53		30.99	
	14		36.41		33.54		32.34	
	16		37.29		34.97		34.67	
	18				35.33			
	20				37.61			
Cube Roll	**6**							
	8							
	10		35.46		32.56		31.76	
	12		34.88		32.39		31.25	
	14		35.71		32.21		32.44	
	16		35.74		33.15		33.51	
	18		35.35		34.62		34.52	
	20		35.40		37.36			

Table A3.23: Day 2 a value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		18.96		19.57		18.72	
	12		19.39		17.71		16.62	
	14		17.69		15.91		15.23	
	16		14.17		13.53		12.37	
	18				12.35			
	20				8.73			
Cube Roll	**6**							
	8							
	10		19.66		19.48		19.50	
	12		19.60		18.08		17.42	
	14		18.37		16.05		17.19	
	16		16.25		13.52		14.09	
	18		13.42		13.09		11.18	
	20		12.10		8.93			

Table A3.24: Day 2 b value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		17.23		17.50		15.73	
	12		17.94		15.54		15.51	
	14		18.11		16.21		15.01	
	16		15.74		15.06		13.00	
	18				14.02			
	20				13.60			
Cube Roll	**6**							
	8							
	10		17.08		17.22		15.63	
	12		17.39		15.84		15.99	
	14		18.50		16.20		16.45	
	16		15.92		15.99		13.55	
	18		14.16		14.77		11.55	
	20		14.50		12.96			

Table A3.25: Day 2 hue

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**							
	8							
	10		42.26		41.80		40.04	
	12		42.78		41.28		43.02	
	14		45.67		45.54		44.58	
	16		48.01		48.06		46.44	
	18				48.63			
	20				57.29			
Cube Roll	**6**							
	8							
	10		40.98		41.47		38.72	
	12		41.58		41.23		42.56	
	14		45.21		45.27		43.75	
	16		44.41		49.77		43.87	
	18		46.55		48.45		45.94	
	20		50.16		55.43			

Table A3.26: Day 2 chroma

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6							
	8							
	10		25.62		26.26		24.45	
	12		26.42		23.56		22.73	
	14		25.32		22.71		21.38	
	16		21.18		20.25		17.95	
	18				18.68			
	20				16.16			
Cube Roll	6							
	8							
	10		26.04		26.00		24.99	
	12		26.20		24.03		23.64	
	14		26.07		22.80		23.79	
	16		22.75		20.94		19.55	
	18		19.51		19.74		16.08	
	20		18.88		15.73			

Table A3.27: Day 3 L value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	41.56		40.45		37.60		41.93
	8	38.16		43.69		36.45		42.84
	10	36.77	35.54	38.37	34.65	35.91	31.34	40.17
	12	39.79	35.54	34.60	33.31	43.71	31.77	39.37
	14	39.29	36.36	38.13	33.93	48.82	32.58	42.80
	16	46.51	37.54	41.31	34.97	41.25	34.69	43.61
	18	43.00		41.00	35.73	37.19		43.93
	20	39.71		39.15	36.41	40.26		42.26
Cube Roll	**6**	44.66		40.96		37.81		40.73
	8	43.92		38.47		42.84		42.45
	10	39.52	34.83	37.94	33.46	38.00	31.48	39.06
	12	41.35	34.79	35.54	32.70	37.79	31.30	41.02
	14	42.10	35.53	37.93	32.90	42.88	31.97	40.41
	16	47.66	36.57	41.99	34.00	41.12	33.37	43.42
	18	40.90	35.99	41.96	35.63	37.63	34.04	44.94
	20	43.13	35.74	41.61	36.07	39.69		43.46

Table A3.28: Day 3 a value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6	18.29		20.00		18.24		19.06
	8	16.81		17.01		23.06		19.06
	10	16.87	18.18	17.50	17.84	12.76	17.81	17.80
	12	15.17	18.15	18.84	16.68	18.34	14.69	18.95
	14	16.54	16.08	15.38	14.25	16.29	13.52	17.07
	16	14.87	12.77	12.70	11.83	15.53	10.69	16.07
	18	14.63		13.91	9.82	16.93		16.75
	20	14.05		15.09	7.59	13.05		14.96
Cube Roll	6	17.76		19.49		19.14		20.01
	8	16.16		16.38		22.67		19.01
	10	16.15	19.31	19.61	17.49	16.82	18.93	17.15
	12	15.33	18.24	19.97	16.85	17.15	16.32	15.13
	14	16.80	16.75	17.46	13.39	15.14	15.57	17.66
	16	12.14	12.89	16.90	11.45	16.36	12.53	17.36
	18	15.72	12.69	16.34	10.18	16.60	10.52	15.57
	20	13.47	11.02	16.25	8.00	14.77		16.00

Table A3.29: Day 3 b value

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	4.15		5.60		5.26		6.96
	8	3.04		7.77		5.94		5.88
	10	4.66	17.11	3.58	16.32	1.62	15.95	6.16
	12	4.95	16.92	3.75	15.74	5.27	14.12	5.08
	14	4.74	17.15	1.87	15.07	3.72	14.44	3.49
	16	4.95	14.35	3.23	14.40	2.73	11.78	4.53
	18	1.82		4.39	12.14	4.53		3.79
	20	3.48		2.93	12.85	2.78		2.68
Cube Roll	**6**	3.28		3.82		5.83		7.19
	8	4.58		6.19		8.85		3.89
	10	3.62	17.34	4.66	15.84	4.03	16.40	4.99
	12	6.26	16.39	4.83	15.94	4.05	15.14	1.12
	14	5.39	17.16	3.98	14.25	5.86	15.63	3.56
	16	2.90	14.31	5.62	15.15	5.52	12.53	5.26
	18	2.33	14.21	5.41	13.09	2.96	12.14	3.45
	20	4.22	13.90	3.94	13.29	3.31		3.27

Table A3.30: Day 3 hue

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	6	0.22		0.27		0.28		0.35
	8	0.18		0.43		0.25		0.30
	10	0.27	43.25	0.20	42.45	0.13	41.84	0.33
	12	0.32	43.00	0.20	43.34	0.28	43.88	0.26
	14	0.28	46.84	0.12	46.59	0.22	46.88	0.20
	16	0.32	48.33	0.25	50.58	0.17	47.76	0.27
	18	0.12		0.31	51.02	0.26		0.22
	20	0.24		0.19	59.45	0.21		0.18
Cube Roll	6	0.18		0.19		0.30		0.34
	8	0.28		0.36		0.37		0.20
	10	0.22	41.92	0.23	42.16	0.24	40.91	0.28
	12	0.39	41.94	0.24	43.41	0.23	42.86	0.07
	14	0.31	45.70	0.22	46.77	0.37	45.11	0.20
	16	0.23	47.98	0.32	52.93	0.33	45.00	0.29
	18	0.15	48.22	0.32	52.14	0.18	49.07	0.22
	20	0.30	51.58	0.24	58.96	0.22		0.20

Table A3.31: Day 3 chroma

Cut	Weeks of vacuum storage	Processor A FSA (MINOLTA)	Processor A TT (Hunter)	Processor B FSA (MINOLTA)	Processor B TT (Hunter)	Processor C FSA (MINOLTA)	Processor C TT (Hunter)	Processor Z FSA (MINOLTA)
Striploin	**6**	18.75		20.77		18.98		20.29
	8	17.08		18.70		23.81		19.95
	10	17.50	24.96	17.86	24.18	12.86	23.91	18.84
	12	15.96	24.81	19.21	22.93	19.08	20.38	19.62
	14	17.21	23.51	15.49	20.74	16.71	19.79	17.42
	16	15.67	19.21	13.10	18.63	15.77	15.91	16.70
	18	14.74		14.59	15.62	17.53		17.17
	20	14.47		15.37	14.92	13.34		15.20
Cube Roll	**6**	17.97		21.26		19.86		20.01
	8	16.80		17.51		24.33		19.40
	10	16.55	25.94	20.15	23.59	17.30	25.05	17.86
	12	16.56	24.52	20.55	23.19	17.62	22.26	15.17
	14	17.64	23.98	17.91	19.56	16.23	22.07	18.02
	16	12.48	19.26	17.81	18.99	17.27	17.72	18.14
	18	15.89	19.06	17.21	16.58	16.86	16.06	15.95
	20	14.12	17.73	16.72	15.52	15.14		16.33

Table A3. 32: Change in L value over 3 days retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	-2.40		-0.49		+0.89		+1.46
	8	-1.31		+2.43		+1.52		-0.48
	10	-2.98	-0.04	-0.73	-0.78	-1.06	-1.13	+4.11
	12	+3.59	-1.59	-4.95	-1.38	+3.55	-1.79	-1.01
	14	-0.08	-1.12	-1.37	-1.19	+4.42	-1.12	-2.16
	16	+2.89	-2.08	+0.72	-1.47	-0.99	-3.19	-0.25
	18	-0.01		+0.73	-2.62	-6.94		-0.33
	20	-0.15		-0.37	-1.22	-0.75		-0.38
Cube Roll	**6**	+1.74		+1.10		+3.82		+0.06
	8	+7.19		+4.92		+3.46		-2.51
	10	-1.50	-0.51	-0.15	-0.73	-1.86	-0.70	+1.47
	12	+1.48	-1.77	-8.10	-1.08	+0.96	-0.51	-1.88
	14	-1.68	-1.43	-1.22	-0.96	+1.36	-1.98	-0.86
	16	+6.55	-1.50	-0.70	-2.47	-2.79	-2.98	-1.06
	18	-1.16	-1.74	+2.46	-3.63	-2.94	-0.70	-1.47
	20	-5.53	-1.34	+0.67	-1.51	+1.53		+2.44

Table A3.33: Change in hue over 3 days retail display

Cut	Weeks of vacuum storage	Processor A FSA (MINOLTA)	Processor A TT (Hunter)	Processor B FSA (MINOLTA)	Processor B TT (Hunter)	Processor C FSA (MINOLTA)	Processor C TT (Hunter)	Processor Z FSA (MINOLTA)
Striploin	**6**	-0.030		-0.111		-0.226		-0.040
	8	-0.127		-0.442		-0.047		-0.074
	10	-0.217	+0.06	-0.053	+2.30	-0.022	+2.85	-0.346
	12	-0.356	+2.45	-0.076	+3.30	-0.035	+4.44	+0.0001
	14	-0.017	+3.36	-0.097	+5.85	0.039	+7.32	-0.021
	16	-0.102	+5.15	-0.058	+10.17	+0.087	+8.63	-0.029
	18	-0.100		-0.083	+10.13	-0.049		+0.036
	20	-0.087		-0.039	+15.08	-0.007		+0.11
Cube Roll	**6**	-0.050		-0.088		-0.308		-0.016
	8	-0.507		-0.398		-0.111		-0.065
	10	-0.147	-0.94	-0.055	+2.89	-0.023	+2.08	-0.304
	12	-0.370	+1.87	-0.059	+3.24	-0.027	+2.72	+0.240
	14	-0.025	+2.46	-0.057	+6.52	-0.121	+5.77	+0.071
	16	-0.075	+6.13	-0.011	+12.37	-0.021	+7.81	-0.024
	18	-0.128	+5.61	-0.126	+13.00	-0.0824	+7.96	+0.062
	20	+0.089	+7.67	-0.037	+15.44	-0.029		+0.088

Table A3.34: Change in chroma over 3 days retail display

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)	TT (Hunter)	FSA (MINOLTA)
Striploin	**6**	+2.16		+2.82		+3.75		-1.03
	8	+0.43		+3.54		+1.17		+3.05
	10	+1.20	-8.40	-0.02	-6.07	-1.20	-6.62	+3.43
	12	+0.09	-6.20	+3.17	-7.95	+0.04	-9.52	-2.73
	14	-2.41	-6.46	-0.57	-9.18	-1.74	-9.75	+2.72
	16	-13.62	-8.37	-2.30	-10.32	+0.06	-7.96	-2.44
	18	+0.14		-2.83	-9.12	-0.73		-0.05
	20	-1.35		-3.35	-12.29	-3.27		-2.11
Cube Roll	**6**	+1.94		+0.93		+3.83		-1.96
	8	+1.07		+3.82		+2.00		+3.96
	10	+1.38	-7.11	+2.96	-7.36	+0.27	-5.20	+2.23
	12	+1.97	-5.35	+3.57	-7.42	-2.91	-7.62	-9.41
	14	+0.41	-7.72	+1.37	-10.69	-3.43	-7.70	-0.23
	16	-3.99	-9.49	-1.88	-12.41	-0.09	-7.81	-2.76
	18	+0.04	-8.75	-0.31	-9.71	+4.51	-11.73	-2.12
	20	-3.39	-7.64	-3.64	-11.62	-4.36		-2.11

MICROBIOLOGY

Table A3.35: Microbiology in first two weeks of storage (mean log_{10}cfu/cm²) (FSA only)

Cut	Days of vacuum storage	Processor							
		A		B		C		Z	
		TVC	LAB	TVC	LAB	TVC	LAB	TVC	LAB
Striploin	**3**	2.02	1.40						
	7	2.92	2.57						
	10	1.93	1.30					3.71	3.00
	14	2.00	1.64	1.52	1.30	1.22	0.80	2.53	0.90
Cube Roll	**3**	1.50	0.80						
	7	0.86	0.96						
	10	1.03	0.80					1.80	1.30
	14	0.50	1.00	1.59	1.10	0.96	0.80	2.05	1.49

Enterobacteriaceae detected on Processor A cube roll on day 10 and Processor Z striploin, day 10, at the detection limit (0.5 log_{10}cfu/cm²).

Brochothrix thermospacta were not detected in any sample.

Table A3.36: Mean TVC ($log_{10}cfu/cm^2$)

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	6	1.77		2.22		4.39		4.05
	8	4.74		1.51		0.50		1.06
	10	2.47	1.48	2.73	6.93	4.06	4.73	5.72
	12	1.19	4.45	1.06	6.85	6.97	6.60	3.97
	14	2.14	6.15	3.75	6.65	2.26	6.31	6.40
	16	1.92	5.18	5.02	6.05	5.52	6.76	3.78
	18	1.65		0.40	6.30	2.29		3.70
	20	0.60		0.70	5.50	5.74		4.90
Cube Roll	6	2.14		2.08		2.05		5.20
	8	0.60		5.50		4.82		1.90
	10	1.06	0.65	5.49	7.01	5.32	4.82	4.78
	12	2.73	2.76	2.72	7.19	4.68	6.73	4.12
	14	0.40	5.69	3.12	6.94	4.24	6.35	3.21
	16	1.38	5.93	1.98	6.59	3.91	6.66	4.39
	18	0.83	5.98	4.86	6.61	4.97	6.22	2.76
	20	0.50	5.77	2.99	5.65	6.40	6.43	7.04

Table A3.37: Total lactic acid bacteria (LAB) ($log_{10}cfu/cm^2$)

Cut	Weeks of vacuum storage	Processor						
		A		B		C		Z
		FSA	TT	FSA	TT	FSA	TT	FSA
Striploin	**6**	1.00		2.06		3.30		4.11
	8	4.18		1.35		2.24		Not detected
	10	1.30	0.55	1.69	6.99	4.91	4.18	6.34
	12	2.07	3.84	Not detected	6.34	6.96	4.63	Not detected
	14	3.76	5.73	3.19	6.89	5.69	5.85	6.36
	16	1.91	5.00	Not detected	6.37	4.65	5.52	3.76
	18	6.10		2.70	6.46	1.65		3.67
	20	Not detected		6.55	5.71	6.08		4.38
Cube Roll	**6**	1.62		1.00		1.79		2.92
	8	Not detected		4.61		2.55		2.12
	10	3.18	0.08	4.10	6.97	4.49	4.68	2.49
	12	1.83	3.58	2.54	6.94	5.00	5.29	2.23
	14	6.76	5.83	3.60	6.93	5.54	5.78	3.04
	16	Not detected	5.58	4.13	6.48	4.65	6.26	1.70
	18	Not detected	5.28	6.35	6.63	2.00	5.84	2.81
	20	Not detected	4.64	4.88	6.06	5.64	5.85	6.81

Table A3.38: TT only: Total psychrotroph count ($\log_{10}$ cfu/cm²)

Cut	Weeks of vacuum storage	Processor		
		A	B	C
Striploin	**10**	0.64	7.05	5.20
	12	6.46	7.22	6.90
	14	6.49	7.16	6.58
	16	7.00	6.79	7.11
	18		6.98	
	20		6.82	
Cube Roll	**10**	0.38	7.04	5.88
	12	2.99	6.41	7.63
	14	5.54	7.26	6.72
	16	7.08	6.82	7.12
	18	7.05	7.05	6.60
	20	6.58	6.57	6.60

Table A3.39: FSA only: Enterobacteriaceae detections (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $log_{10}cfu/cm^2$ of positive samples below). Detection limit: 0.70 $log_{10}cfu/cm^2$

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	Not detected	1/3 1.70	Not detected	1/3 0.70
	8	Not detected	Not detected	Not detected	Not detected
	10	1/3 1.54	Not detected	1/3 0.70	3/3 1.62
	12	1/3 1.54	Not detected	3/3 3.04	Not detected
	14	Not detected	Not detected	Not detected	2/3 0.70
	16	Not detected	1/3 0.70	2/3 1.54	3/3 2.04
	18	Not detected	Not detected	Not detected	1/3 0.70
	20	Not detected	Not detected	Not detected	2/3 5.32
Cube Roll	6	Not detected	2/3 1.27	Not detected	1/3 1.00
	8	Not detected	2/3 1.00	Not detected	1/3 1.40
	10	Not detected	Not detected	Not detected	3/3 1.17
	12	Not detected	Not detected	Not detected	2/3 2.85
	14	Not detected	Not detected	Not detected	1/3 0.70
	16	Not detected	1/3 1.18	1/3 1.54	1/3 0.70
	18	Not detected	Not detected	Not detected	Not detected
	20	Not detected	Not detected	Not detected	3/3 0.90

Table A3.40: FSA only: Brochothrix thermospacta detections (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $log_{10}cfu/cm^2$ of positive samples below). Detection limit: 1.70 $log_{10}cfu/cm^2$

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	1/3 1.70	Not detected	Not detected	Not detected
	8	Not detected	Not detected	Not detected	Not detected
	10	Not detected	Not detected	2/3 2.79	Not detected
	12	Not detected	Not detected	Not detected	Not detected
	14	Not detected	Not detected	Not detected	Not detected
	16	Not detected	Not detected	Not detected	Not detected
	18	Not detected	Not detected	Not detected	Not detected
	20	Not detected	Not detected	Not detected	Not detected
Cube Roll	6	1/3 2.95	Not detected	1/3 2.95	Not detected
	8	Not detected	3/3 2.02	Not detected	Not detected
	10	Not detected	3/3 4.25	Not detected	Not detected
	12	Not detected	Not detected	Not detected	Not detected
	14	Not detected	Not detected	2/3 1.94	Not detected
	16	Not detected	Not detected	Not detected	Not detected
	18	Not detected	3/3 4.78	1/3 1.70	Not detected
	20	Not detected	Not detected	3/3 6.37	Not detected

Table A3.41: FSA only: Total lactic acid bacteria (LAB) (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $log_{10}cfu/cm^2$ of positive samples below). Detection limit: 1.00 $log_{10}cfu/cm^2$

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	1/3 1.00	3/3 2.06	3/3 3.30	3/3 4.11
	8	2/3 4.18	2/3 1.35	3/3 2.24	Not detected
	10	1/3 1.30	3/3 1.69	3/3 4.91	3/3 6.34
	12	2/3 2.07	Not detected	3/3 6.96	Not detected
	14	3/3 3.76	3/3 3.19	3/3 5.69	3/3 6.36
	16	3/3 1.91	Not detected	3/3 4.65	3/3 3.76
	18	3/3 6.10	1/3 2.70	2/3 1.65	3/3 3.67
	20	Not detected	3/3 6.54	3/3 6.08	3/3 4.63
Cube Roll	6	3/3 1.62	1/3 1.00	2/3 1.79	3/3 2.92
	8	Not detected	3/3 4.61	3/3 2.55	2/3 2.12
	10	3/3 3.18	3/3 4.10	3/3 4.49	3/3 2.49
	12	2/3 1.83	3/3 2.54	3/3 5.00	1/3 2.23
	14	3/3 6.76	3/3 3.60	3/3 5.54	3/3 3.04
	16	Not detected	3/3 4.13	3/3 4.65	1/3 1.70
	18	Not detected	3/3 6.35	1/3 2.00	2/3 2.81
	20	Not detected	3/3 4.88	3/3 5.64	3/3 6.81

Table A3.42: FSA only: Homofermentative LAB (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $\log_{10}$cfu/cm² of positive samples below). Detection limit: 1.00 $\log_{10}$cfu/cm²

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	**6**	Not detected	2/3 1.90	3/3 3.20	1/3 2.31
	8	2/3 3.60	1/3 1.30	3/3 2.24	Not detected
	10	Not detected	1/3 3.68	3/3 4.75	2/3 5.48
	12	2/3 1.89	Not detected	3/3 6.49	Not detected
	14	1/3 2.602	3/3 2.64	3/3 5.54	3/3 5.94
	16	1/3 1.85	Not detected	3/3 5.61	3/3 3.37
	18	3/3 5.34	1/3 1.70	2/3 1.5	3/3 3.31
	20	Not detected	3/3 5.95	3/3 5.56	3/3 4.38
Cube Roll	**6**	1/3 2.08	Not detected	1/3 1.90	3/3 2.31
	8	Not detected	3/3 4.55	3/3 2.55	1/3 1.95
	10	3/3 2.29	3/3 4.03	3/3 4.45	3/3 2.23
	12	1/3 1.70	3/3 2.76	3/3 4.59	1/3 2.23
	14	3/3 6.27	3/3 3.35	3/3 5.54	3/3 2.83
	16	Not detected	3/3 3.77	3/3 4.31	1/3 1.30
	18	Not detected	3/3 5.81	1/3 2.00	1/3 1.85
	20	Not detected	3/3 3.77	3/3 4.84	3/3 6.46

Table A3.43: FSA only: Heterofermentative LAB (number of samples testing positive out of 3 samples per primal, with counts expressed as mean $log_{10}cfu/cm^2$ of positive samples below). Detection limit: 1.00 $log_{10}cfu/cm^2$

Cut	Weeks of vacuum storage	Processor			
		A	B	C	Z
Striploin	6	1/3 1.00	3/3 1.64	3/3 2.47	3/3 4.10
	8	2/3 4.00	2/3 1.24	Not detected	Not detected
	10	1/3 1.30	Not detected	3/3 4.38	2/3 5.81
	12	2/3 1.50	Not detected	3/3 6.74	Not detected
	14	3/3 3.74	3/3 3.07	3/3 5.28	3/3 6.14
	16	3/3 1.89	Not detected	3/3 5.55	3/3 3.51
	18	3/3 6.01	1/3 2.70	1/3 2.00	3/3 3.42
	20	Not detected	3/3 6.41	3/3 5.92	3/3 4.26
Cube Roll	6	3/3 1.59	1/3 1.00	2/3 1.67	3/3 2.76
	8	Not detected	2/3 3.98	Not detected	2/3 2.04
	10	3/3 3.11	1/3 3.45	3/3 3.13	3/3 2.14
	12	2/3 1.80	1/3 3.36	3/3 4.75	Not detected
	14	3/3 6.39	3/3 3.12	3/3 3.37	3/3 2.59
	16	Not detected	3/3 3.87	3/3 4.39	1/3 1.48
	18	Not detected	3/3 6.19	1/3 1.70	1/3 1.00
	20	Not detected	3/3 4.84	3/3 5.56	3/3 6.47