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Greening of vacuum-packaged lamb – causative factors

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Abstract

Australian vacuum-packaged lamb has at times been rejected for greening of packs after storage times as short as 6 weeks. Greening of beef was in the past associated with high-pH meat, so a multi-pronged program was developed to determine the main factors involved in the greening of lamb.

1. A survey was conducted to determine the incidence of high-pH lamb;
2. A storage trial was undertaken using lamb cuts of different pH ranges, and
3. Lamb cuts from carcases of different pH ranges were inoculated with a micro-organism expected to cause greening and packed in films of different oxygen transmission rate and stored at -1 and 2°C for up to 12 weeks.

Lamb knuckles and blades have a higher pH than the rack and also higher incidence of high pH. Over 97% of knuckles and blades had a pH above 5.7, whereas 64% of racks were above pH 5.7. Breed was the major factor influencing ultimate pH with full-blood Merinos being higher than mixed and other breeds.

The results of both the storage trial and the inoculation trial indicated that the main determining factor in preventing greening is temperature control. Storage of chilled vacuum-packed lamb at a temperature of -1°C or below will prevent greening and enable a storage life of 9 weeks or more.

Executive Summary

Australian vacuum-packaged lamb has been rejected by some export markets for occurrence of greening in the pack after storage times as short as 6 weeks. The appearance of greening with vacuum-packaged beef has in the past been associated with high-pH muscles but it is unclear whether this is also the case with lamb. In order to determine the main factors that cause greening in lamb vacuum packs this project was conducted in three phases:

1. A survey of the pH of three cuts in four abattoirs during autumn and spring;
2. A study of the shelf life of vacuum-packed cuts from carcases of different pH ranges, and
3. An inoculation trial to assess the storage life of lamb racks inoculated with organisms expected to cause greening and packed in films of low and high oxygen transmission rate and stored at -1 and +2°C.

During the survey conducted at four lamb processing plants in Victoria and New South Wales, the pH of the knuckle (*m. rectus femoris*), rack (*m. longissimus dorsi*) and blade (*m. infraspinatus*) of a total of 1614 carcases was measured during autumn (April 2013) and spring (October 2013). The mean pH of the rack was 5.79 which was lower than that of the knuckle (6.08) and blade (6.12). Approximately 64% of lamb racks had a pH above 5.7 while 97% of knuckles and 99% of blades were above 5.7. Analysis of the results indicated that there was no influence on pH of method of sourcing (direct consignment or saleyards), transport distance, season, and whether the lambs were new season or old season during spring ($P > 0.05$). Breed did have an effect, with Merino lambs having a higher pH than cross-bred and other lambs ($P < 0.05$).

During the storage trial, vacuum-packaged lamb knuckles, racks and boneless shoulders from carcases of normal (≤5.7), intermediate (5.71 – 5.99) and high (≥6.0) pH measured in the rack were stored at -1°C for up to 12 weeks. When opened after 6 week's storage, all packs were considered acceptable based on assessment of the odour on opening the packs. At 9 weeks, the majority were still acceptable but by 12 weeks very few were acceptable. Acceptability bore little relationship to meat pH and there was no evidence of greening except for two packs of racks at 12 weeks which were both from the high-pH group.

Some high-pH packs assessed after 6 weeks storage at -1°C were re-packed and then stored in a chiller operating at +2.5°C and inspected regularly. Approximately 50% were green after 2 weeks and all were green after 5 weeks at +2.5°C indicating that temperature has a major influence on incidence of greening.

In the third phase of the project, lamb racks (frenched and cap off) from the three different pH ranges above were inoculated with a cocktail of organisms expected to cause greening and then packed in vacuum films of low oxygen transmission rate (9.9 $cm^3/m^2/day$) and high OTR (36 $cm^3/m^2/day$). They were then stored at either -1°C or +2°C and inspected for indications of greening for up to 12 weeks. Greening appeared first in the group stored at 2°C in the high OTR film after 4 weeks, then in the low OTR group at 2°C after 5 weeks. The samples packed in the low OTR film and stored at -1°C were the last to show greening with the first indications at 6 weeks but the low-pH range not greening until 9 weeks.

Despite the low OTR, low temperature and low pH samples being the last to show greening, there was little indication in the groups that pH had a major influence on tendency to green. Un-inoculated control cuts also showed greening. Samples in the high-OTR film stored at 2°C showed greening after only 5 weeks but in low-OTR film and both films at -1°C lasted for 10 to 12 weeks.

These results indicate that the major factor influencing tendency of vacuum-packed lamb to green is the storage temperature. Storage at a temperature of -1°C or below should ensure that storage life is maximised. A vacuum bag from a film of low oxygen transmission rate is also of benefit but muscle pH appeared to be of less influence.

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1 Background

Australian vacuum-packaged lamb has at times been rejected by export markets due to greening of the product after storage times as short as 6 weeks. Vacuum-packed lamb would normally be expected to have a chilled storage life of at least 8 weeks when stored at -1°C (Egan & Shay 1988). A shorter shelf life could restrict marketing opportunities and harm the reputation of the Australian product. There has been very little research reported into the causes of greening of lamb but there was a considerable amount of work done with beef when this problem was an issue during the early years of the chilled beef trade.

Greening of vacuum-packaged beef was a major storage life issue when chilled beef was first exported from Australia. Nicol *et al* (1970) determined that the green pigment was sulphmyoglobin formed from the attachment of hydrogen sulphide (H_2S) to the myoglobin molecule. The H_2S-producing bacteria were tentatively identified as *Pseudomonas mephitica* (now reclassified as *Janthinobacterium lividum*). The organism only produced H_2S when the oxygen tension was about 1% and the pH of the meat was 6.0 and above. The effect of the packaging oxygen permeability was further investigated by Taylow & Shaw (1977) who showed that greening could occur with high-pH beef (6.2 – 6.7) stored at 1°C in all packaging materials and in packaging with a relatively high permeability (73 and 92 cm^3 O_2/m^2-day-atm at 90% RH) with beef in the pH range 5.9 – 6.1. Greening did not occur with low oxygen permeability of 23 and 25 cm^3 O_2/m^2-day-atm and meat pH below 6.2 or with any packs of normal pH.

Due to the potential loss of storage life and other undesirable qualities, darker-coloured beef which normally has a high pH (>5.9) is not normally vacuum-packed for export and long-term storage. Dark-coloured beef is normally detected during chiller assessment but no such assessment colour of pH is made of lamb carcases. Therefore it is likely that high-pH lamb is vacuum-packaged for export and this could lead to the occurrence of greening.

The incidence of high-pH beef (>5.7) in Australia is around 4.3% (MSA 2013) but there is little information on the occurrence of high-pH lamb in Australia. This project, funded through the Australian Meat Processor Corporation and Meat & Livestock Australia, aimed to determine this incidence and investigate the influence of pH, packaging material permeability and storage temperature on greening.

2 Project objectives

The objectives of the project were to determine and report:

1. Quantification of the incidence of high-pH lamb in Australia at different seasons and for various supply chains.

2. Identification of the effect of pH and packaging material on the incidence of greening in vacuum-packed lamb loins.

3. Recommendations on how processors can avoid greening in vacuum-packed lamb including pH cutoffs and recommended packaging materials.

3 Methodology

3.1 pH survey

Following discussions with MLA and with plant management four plants were selected for the survey:

Plant A – VIC

Plant B – NSW

Plant C – VIC

Plant D – VIC

Two visits were made to each plant – one in Autumn (April 2013) and one in Spring (October 2013). During each visit the aim was to sample at least 20 carcases from as many different lots as possible over two days covering both direct consigned lots and lots that had been sourced through saleyards. Where available the breed of lamb and distance travelled would also be recorded for each lot.

The pH was measured in the chiller prior to boning and at least 20 hours after slaughter to ensure the pH was near to the ultimate pH for the cases where electrical stimulation was not applied.

The pH was measured in the knuckle (*m. rectus femoris*), the eye of the rack (*m. longissimus dorsi*) and the blade (*m. infraspinatus*). A small incision was made to the edge of the muscle with a knife and the electrode and temperature sensor of a TPS WP80 pH meter inserted into the muscle until a stable reading was achieved. The pH meter was calibrated at pH 7 and pH 4 between each lot.

3.2 Storage trial

Samples were collected for chilled shelf life assessment during the Autumn survey visits to plants C and D. When the pH was being measured and recorded in the chillers, carcases were tagged with a colour-coded label when the LD muscle was within the following pH ranges:

Normal (green tag):	≤5.7
Intermediate (blue tag):	5.71 – 5.99
High (purple tag)	≥6.0

Nine carcases of each pH range were selected. These were then boned in groups and one knuckle, rack (frenched, cap on) and boneless shoulder were removed from each carcase, vacuum packed and cartoned (total 162 samples). Temperature loggers were placed into the cartons and they were then chilled and transported to CSIRO at Coopers Plains in Brisbane by commercial refrigerated transport. They were then stored in a chiller operating at -1°C ± 0.5°C.

Samples were inspected weekly under good light conditions after four weeks of storage for any signs of green discolouration. After storage for 6 weeks, 9 weeks and 12 weeks, 3 samples of each cut from each pH range and each plant (total 54) were assessed organoleptically and at 6 weeks and 12 weeks sampled for microbiological analysis.

Packs were assessed by an experienced panel by scoring the standard of vacuum, appearance of the intact pack and the odour intensity on opening the pack on a 9-point scale with 8 being good vacuum, excellent appearance and no odour and 0 being no vacuum, bad discolouration and extreme off odour.

The lamb cuts were sampled for microbiological analysis by excising 2 x 10 cm^2 samples including both lean and fat surfaces where applicable. These were analysed for:

Total viable count
Lactic acid bacteria
Enterobacteriaceae, and
Pseudomonas

The two excised samples, each 2 – 4 mm thick were placed into a stomacher bag to which 100 mL of 0.85% saline was added and stomached for two minutes. A decimal dilution series was prepared for each sample in 0.85% saline, and these plated onto Petrifilm Aerobic count plates, Petrifilm Enterobacteriaceae plates and *Pseudomonas* CFC Agar for TVC, Enterobacteriaceae, and *Pseudomonas* spp. counts respectively. The dilutions were also prepared in MRS broth and plated onto Petrifilm Aerobic count plates according to the Petrifilm method for the enumeration of Lactic Acid bacteria (LAB). Petrifilm Aerobic count plates were incubated at 25°C ± 1°C for 72 ± 3 h; Petrifilm Enterobacteriaceae plates were incubated at 35°C ± 1°C for 24 ± 2h; *Pseudomonas* CFC agar plates were incubated aerobically at 25°C ± 1°C for 48 ± 3 h; LAB films were incubated anaerobically at 25°C ± 1°C for 120 ± 3 h.

After microbiological sampling, the pH of the samples was measured using a TPS WP80 pH meter fitted with an Ionode IJ44C intermediate junction electrode. Meat colour was measured using a Minolta CR400 meter using a D65 light source on a freshly exposed portion of muscle that had been allowed to bloom in a chiller at 2.5°C for at least 30 minutes.

3.3 Inoculation trial

Samples were collected from plant C during the Spring pH survey. Carcases were tagged with a colour-coded label when the LD muscle was within the following pH ranges:

Normal (green tag):	≤5.7
Intermediate (blue tag):	5.71 – 5.99
High (purple tag)	≥6.0

Eight carcases of each pH range were selected. These were then boned as a group and the left and right racks (frenched, cap off) were removed from each carcase, labelled, vacuum packed and cartoned. Temperature loggers were placed into the cartons and they were then chilled and transported to CSIRO at Coopers Plains in Brisbane.

At the CSIRO laboratory, the original packaging was removed and four samples from each pH range re-packaged in either a high oxygen-transmission rate (OTR) or a low OTR film and then stored at either -1°C or +2°C. These were the control samples.

The remaining racks were inoculated with a cocktail of microorganisms expected to cause greening in vacuum-packaged meat. The cocktail included *Pseudomonas mephitica* (now called *Janthinobacterium lividum*) and isolates of *Aeromonas salmonicida* and *Rahnella* sp. which had previously been isolated as dominant microflora of vacuum packaged lamb that had turned green. Each bacterial strain was grown independently in nutrient broth prior to diluting and combining to achieve a cocktail broth concentration of approximately 5.00 log_{10}CFU/mL.

Following inoculation, representative control and inoculated samples were sampled for microbiological quality by excising 2 x 10 cm^2 samples from each lamb rack and analysing for:

Total viable count (TVC)
Lactic acid bacteria (LAB)
Enterobacteriaceae
Pseudomonas
Brochothrix

All lamb racks were then packaged in either a high (OTR) film or a low OTR film and stored at either -1°C or +2°C according to the following plan (Figure 1).

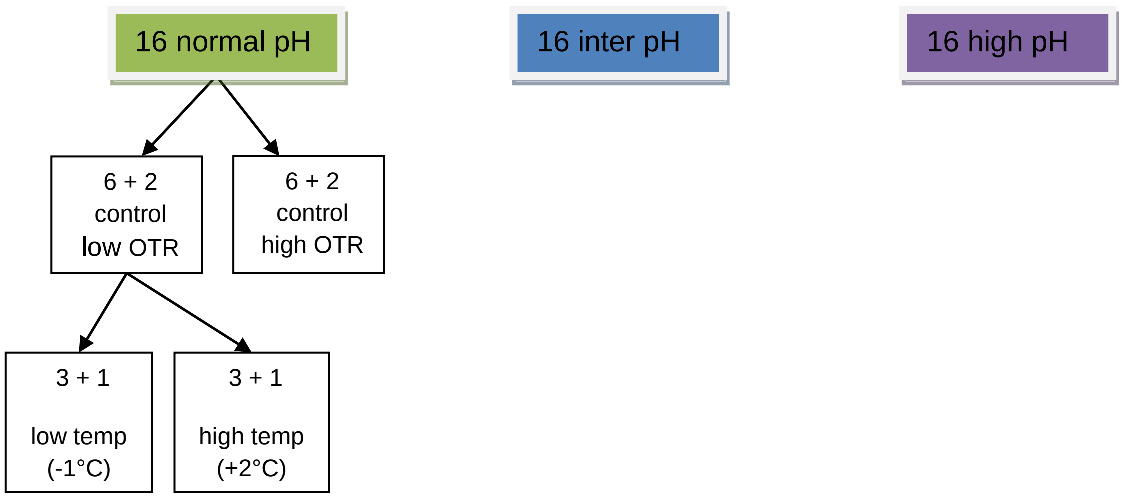

Figure 1: Sample allocation arrangement

After storage for 4 weeks, each pack was inspected for evidence of greening of the meat or the exudate in the vacuum bag. Packs were inspected at weekly intervals and the colour of the lean surface of the eye muscle of the rack measured through the vacuum film at 4, 6, 9, 10 and 12 weeks of storage. When packs were considered unacceptably green, they were opened and scored for appearance and odour as described earlier and sampled for microbiological analysis by excising 1 x 10 cm^2 core from the fat surface and 1 x 10 cm^2 core from the end of the eye muscle. The cores from each sample were pooled and treated as described under 3.2 above and analysed for:

Total viable count (TVC)
Lactic acid bacteria (LAB)
Enterobacteriaceae
Pseudomonas
Brochothrix

3.4 Statistical analysis

Data from the lamb pH surveys was analysed using REML in Genstat, using pH in each muscle as the Y-variate. Factors tested in each model as fixed effects were season (spring or autumn), new season lamb (NSL) nested within spring season (yes or no), breed, breed-code (Merino, other), source (saleyards, direct consignment), distance travelled and two and three way interactions. The terms included as random in the model were plant (=company), plant.date, plant.date.lot and plant.date.lot.carcass. Fat class and carcase weight were tested as covariates in the initial model. Due to the lack of Merinos in the population, this analysis was simplified to the only fixed effect being breed type, with the random terms still in the model. Insignificant terms were sequentially dropped out of the model. The final model was a parsimonious model with season, NSL nested within season, ES, and the covariate carcase weight.

4 Results and discussion

4.1 pH survey

The pH of a total of 1614 lambs was measured – 774 in the autumn survey and 840 in the spring survey. Each plant processed lambs sourced by both direct consignment and through saleyards (markets). The majority of lots were described as cross-bred with some described as first cross or second cross. There were several Merino lots and one lot of Dorper lambs.

Figure 1: Measuring the pH of a lamb carcase

The overall mean pH of the LD muscle of the rack was 5.79 which is lower than the knuckle and blade which were similar at 6.06 and 6.12 resp. (Figure 2). Table 1 shows the percentage of carcases with cuts in the different pH ranges. There was little difference between autumn and spring but there were large differences between cuts. Approximately 36% of racks had a pH of 5.7 or below but fewer than 3% of knuckles and 1% of blades were in that pH range. About 70% of blades, 50-60% of knuckles and 10-12% of racks had a pH of 6.0 and above. Summaries of the results of pH measurement for each lot at each plant are presented in Appendix 1.

There was no significant effect on pH of any of the cuts of method of sourcing or the distance travelled (P >0.05) and these terms were eliminated from the model. Figure 3 shows that there was no effect of distance travelled to the plant on the pH of the LD. This agrees with the results of a pH/dark cutting survey by Warner et al (1988) who found that there was no effect of distance travelled on pH and incidence of dark cutting in beef.

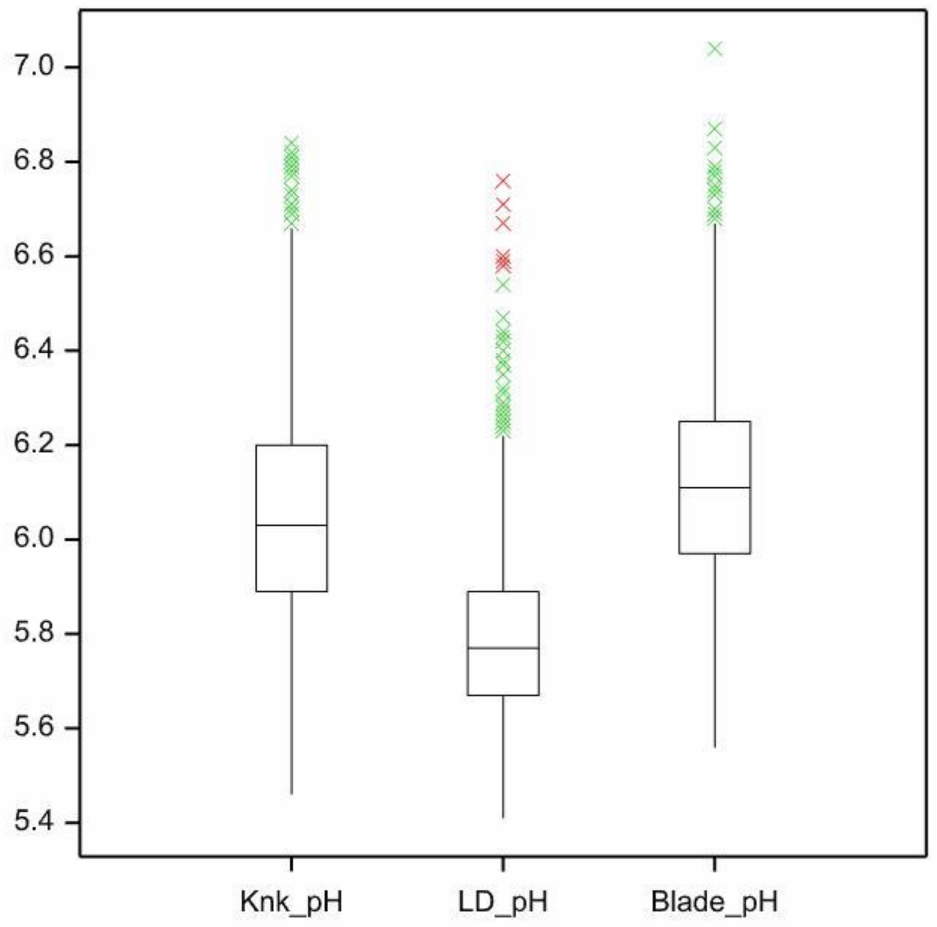

Figure 2: Boxplots showing the median and range in final pH for the three cuts (knuckle, LD and blade)

Table 1: Mean pH and percentage of readings in each of three pH ranges for the knuckle, rack and blade from autumn and spring surveys

Sample point	Parameter	Autumn	Spring
Knuckle	Mean pH	6.09	6.03
	%≤5.7	2.1	2.9
	% 5.71-5.99	38.4	47.1
	% ≥6.0	59.6	50.0
Rack	Mean pH	5.80	5.79
	%≤5.7	36.0	35.8
	% 5.71-5.99	51.4	54.4
	% ≥6.0	12.5	9.8
Blade	Mean pH	6.13	6.11
	%≤5.7	0.9	0.4
	% 5.71-5.99	27.5	31.9

	% ≥6.0	71.6	67.7
No. sampled		774	840

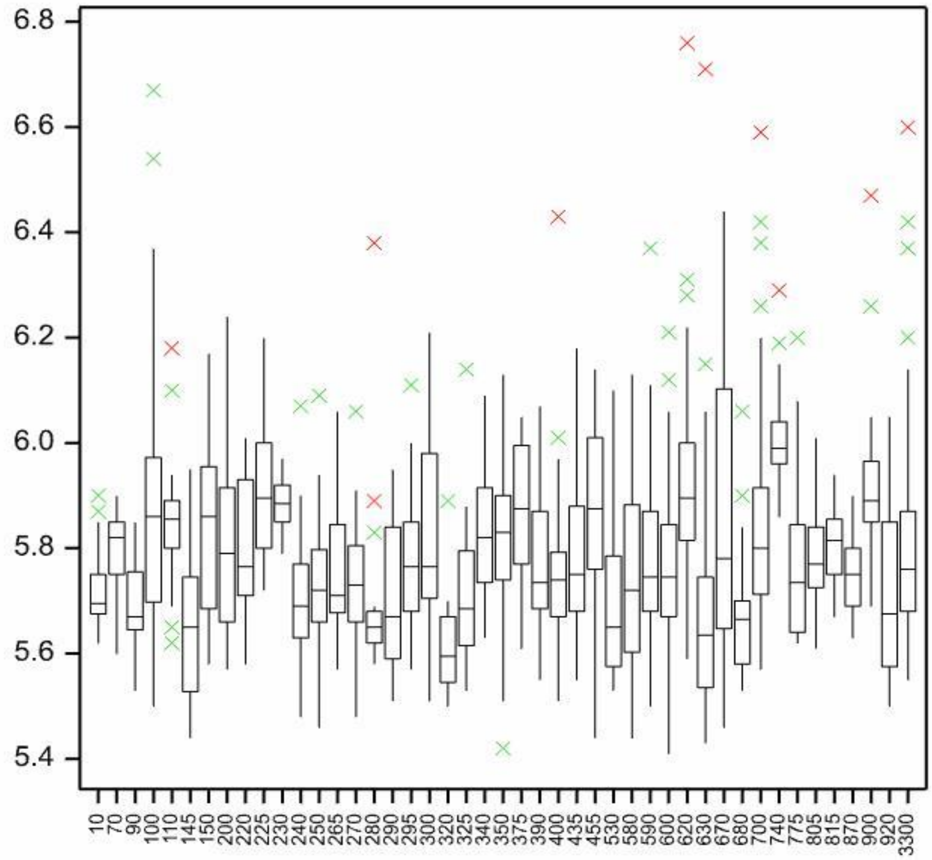

Figure 2: Boxplots showing the median and range in final pH for the LD for the distances travelled to the plant

Table 2 shows the significance (P values) for analysis of the effects of season, new season lamb nested within season, electrical stimulation, plant and the covariate hot carcase weight on the pH of the blade, rack and knuckle of lambs at the four plants during autumn and spring.

Table 2: The significance of the fixed effects season, new season lamb (NSL) nested within season, plant and electrical stimulation (ES) nested within plant and of the covariate hot carcase weight. The coefficient and standard error (SE) are included for the covariate.

	Blade pH	Rack pH	Knuckle pH
Fixed effects			
Season	0.147	0.155	0.057
Season.NSL	0.363	0.066	0.716
Plant	0.044	0.021	0.043

Plant.ES	<0.001	0.003	<0.001
Covariate			
Carcase weight	<0.001	<0.001	<0.001
Coefficient and SE	-0.015±0.0022	-0.014±0.0020	-0.017±0.0022

During the spring survey there was no significant difference (P >0.05) between the pH of new season lambs and lambs born the previous year. There was also no significant difference (P >0.05) between autumn and spring for any of the cuts measured (Table 3).

Table 3: Effect of season (autumn, spring) and new season lamb (NSL; yes, no) on the final pH for the blade, rack and knuckle. Values are predicted means and the standard error of the difference (SED) is shown.

	Blade pH	Rack pH	Knuckle pH
Spring-no NSL	6.11	5.81	6.00
Spring-yes NSL	6.11	5.74	6.02
Autumn	6.18	5.82	6.11
SED	0.036	0.030	0.039

Electrical stimulation had a significant effect (P<0.05) on the ultimate pH of all three muscles measured. It appeared to have the opposite effect to what might have been expected as the mean pH of the stimulated carcases was higher than that of the unstimulated ones (Table 4).

Table 4: Effect of electrical stimulation and plant on the final pH for the blade, rack and knuckle. Values are predicted means and the standard error of the difference (SED) is shown.

	Blade pH		Rack pH		Knuckle pH	
	-ES	+ES	-ES	+ES	-ES	+ES
Plant A	6.07	6.19	5.77	5.85	6.00	6.19
Plant B	6.08		5.78		6.00	
Plant C		6.17		5.82		6.08
Plant D		6.15		5.73		6.05
SED	0.038		0.040		0.050	

Carcases from Merino lambs had a significantly higher pH than that of cross-bred and other breeds (P <0.05) for the blade, rack and knuckle (Table 5). Heavier carcases had a lower pH.

Table 5: Effect of breed (Merino, other) on the final pH for the blade, loin and knuckle. Values are predicted means and the standard error of the difference (SED) is shown as well as the numbers in breed group and P-values.

	n	Blade pH	Rack pH	Knuckle pH
Merino	183	6.24	5.87	6.19
Other	1307	6.10	5.78	6.04
SED		<0.001	<0.001	<0.001
P-value		0.018	0.016	0.020

4.2 Storage trial

4.2.1 Pack assessment

No greening was evident in any of the vacuum packs during the first 11 weeks of storage but during assessment at 12 weeks two packs of racks showed very slight signs of greening. Both were high pH with readings at 12 weeks of 6.13 and 6.37. The results of the scores by a panel of five experienced assessors for appearance and aroma on opening are presented in Tables 6 and 7. There were only small and inconsistent differences between plants, therefore the results from both plants have been combined.

Table 6: Mean scores for appearance of vacuum-packed lamb cuts stored for up to 12 weeks (0 – severe discolouration, 8 – fresh, no discolouration; a score <4 indicates unacceptable)

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
6	7.6	7.0	7.4	7.8	7.8	7.8	7.6	7.7	7.7
9	7.0	7.3	7.0	7.1	7.2	6.9	7.2	7.1	7.0
12	6.1	5.7	5.8	5.6	5.1	5.4	6.3	6.0	5.9

Table 7: Mean scores for odour of vacuum-packed lamb cuts stored for up to 12 weeks (0 – extreme off odour, 8 –, no odour; a score <4 indicates unacceptable)

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
6	7.6	7.4	7.4	7.3	7.1	7.4	7.3	7.5	7.5
9	6.0	6.3	5.7	5.3	4.3	5.5	5.0	6.1	5.4
12	3.8	3.5	3.4	3.2	2.5	3.2	3.3	2.1	2.9

A score of 4 is considered marginal therefore all lamb packs were scored to be very good at 6 weeks, acceptable at 9 weeks but by 12 weeks at -1°C were unacceptable from the odour on opening although the appearance score indicated they were still acceptable. There was little difference in appearance and odour scores for samples from different pH ranges although there was a tendency for the low-pH samples to receive a higher score at 12 weeks. Some of the words used to describe the aroma from samples scored as unacceptable were: cheesy, eggy, rotten egg, sludge, acidic, sewage, faecal, sheepy, sour milk.

Table 8 shows the percentage of packs for each cut and pH range that were considered unacceptable based on the mean odour score from the assessment panel. No packs of knuckles were unacceptable at 9 weeks, whereas some racks and shoulders received low scores. This is possibly due to the knuckle having no original external surfaces that could have been contaminated during dressing and handling. There was no clear indication that samples from different pH ranges were less acceptable. Plots of odour score against pH after opening (Figures 1 to 3) also show little relationship between odour score and pH.

Table 8: Percentage of packs considered unacceptable (odour score <4) after storage for 6, 9 and 12 weeks

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	33.3	16.7	33.3	0.0	0.0
12	66.7	66.7	50.0	66.7	83.3	83.3	50.0	100.0	100.0

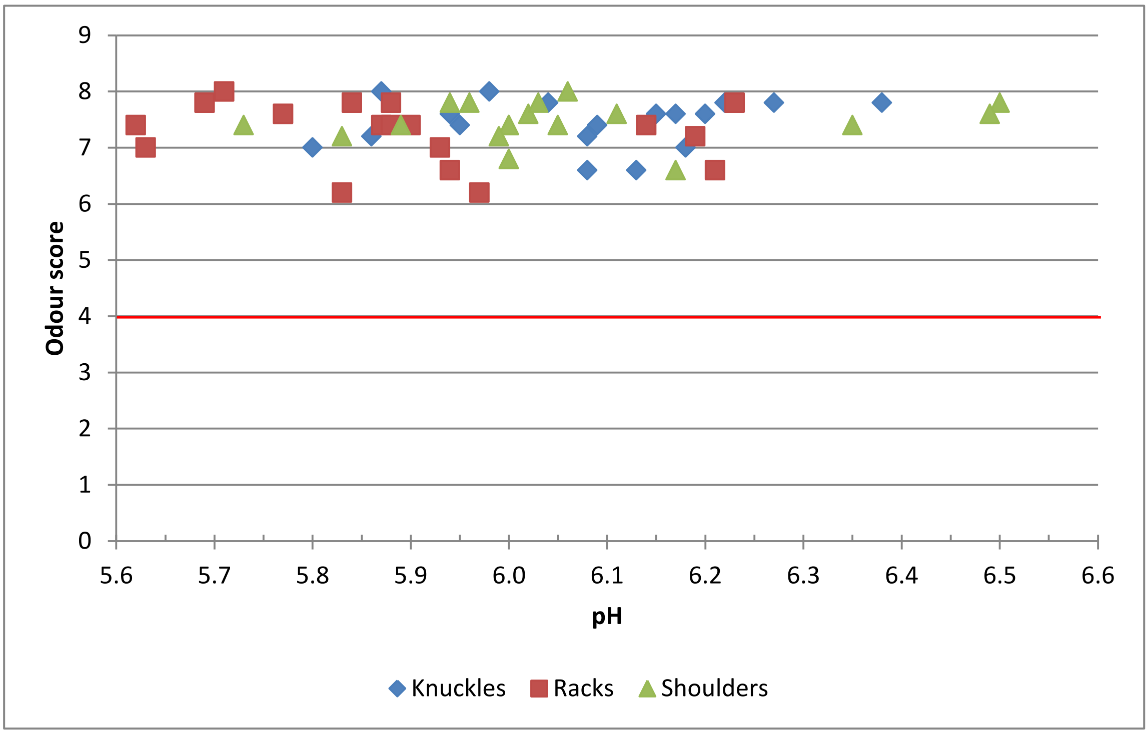

Figure 2: Odour score in relation to sample pH of lamb knuckles, racks and shoulders when assessed after storage at -1°C for 6 weeks

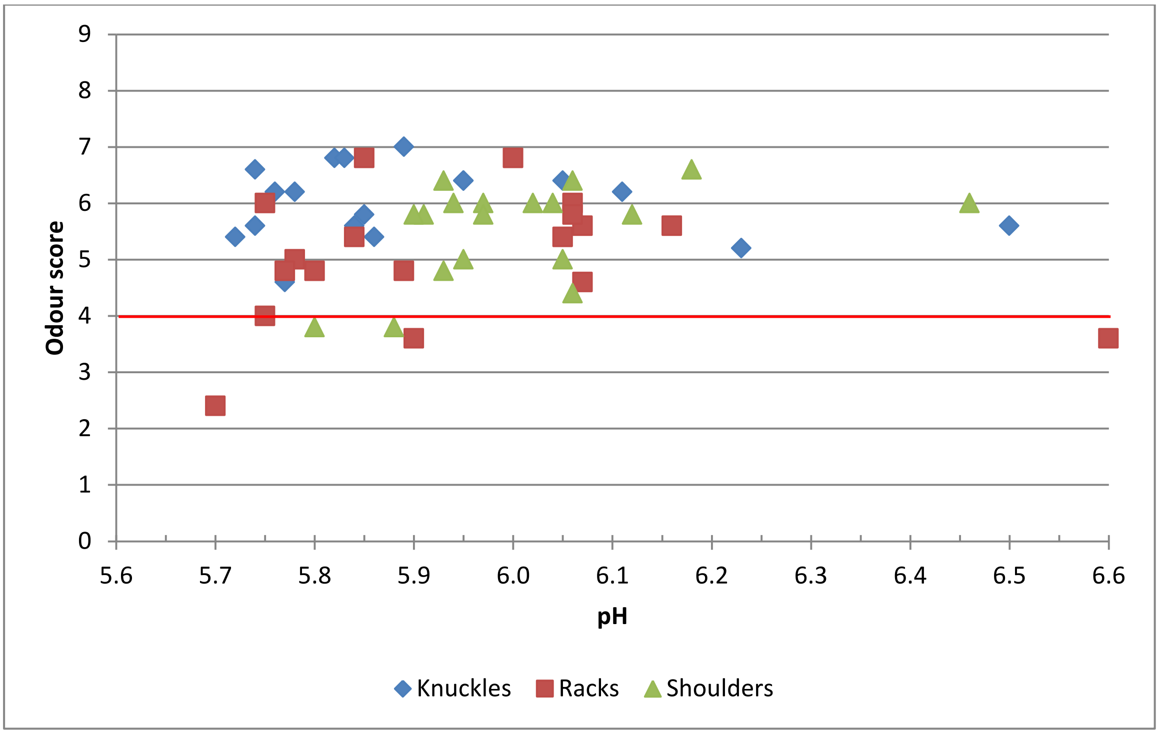

Figure 3: Odour score in relation to sample pH of lamb knuckles, racks and shoulders when assessed after storage at -1°C for 9 weeks

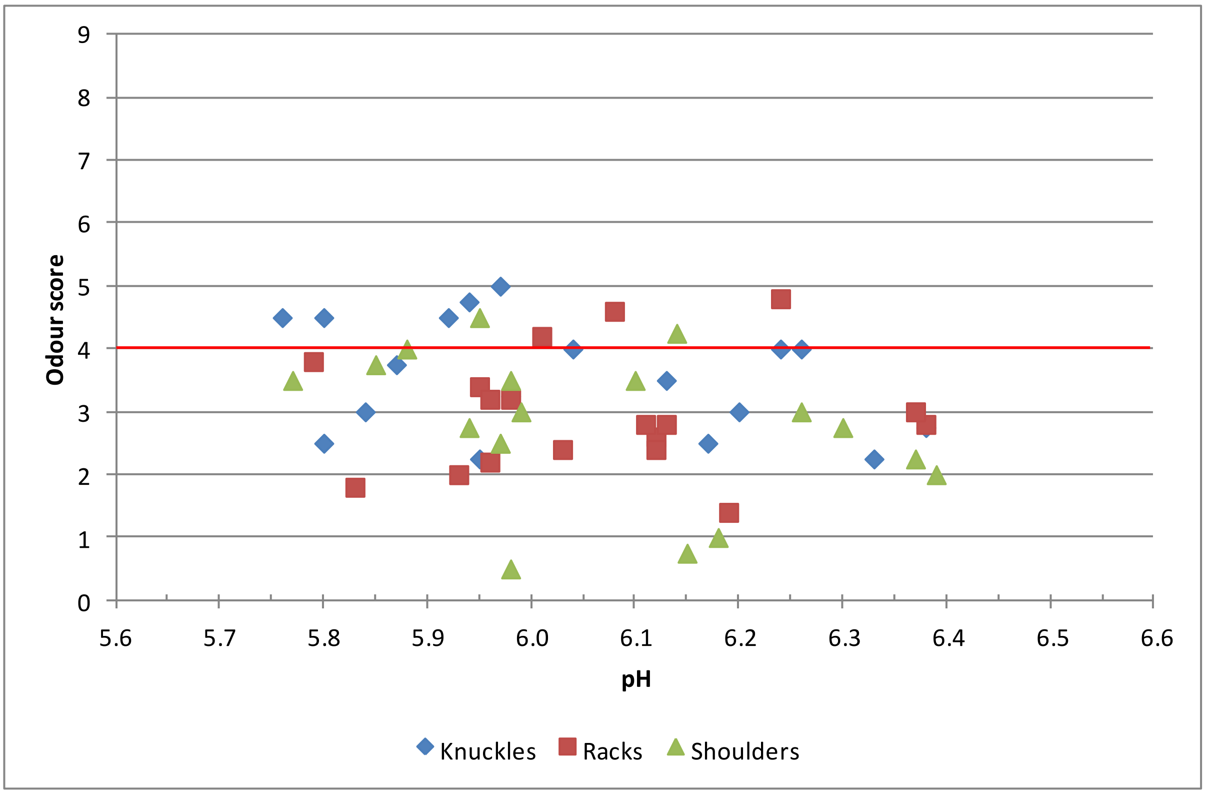

Figure 4: Odour score in relation to sample pH of lamb knuckles, racks and shoulders when assessed after storage at -1°C for 12 weeks

Following pack assessment and microbiological sampling after 6 week's storage, the high-pH knuckles, racks and shoulders were re-vacuum packed and stored in a chiller operating at +2.5°C. The samples were inspected at weekly intervals for evidence of greening. Approximately 50% showed some degree of greening after 2 weeks at 2.5°C and all were green after 5 weeks. Figure 5 shows one of the lamb racks in which greening was induced by higher temperature storage. Microbiological analysis of these green samples showed that the dominant microflora were *Aeromonas salmonicida* and *Rahnella* sp.

Figure 5: Lamb rack showing greening after re-packing and storage at +2.5°C

The results of the mean pH for each cut and pH group measured after opening the vacuum packs are presented in Table 9. Although cuts were allocated to the pH ranges based on the pH of the eye muscle of the rack prior to boning, the mean pH of the racks from the low-pH group was above 5.7 from 6 week's storage onwards. The knuckles and shoulders had a slightly higher pH than the racks.

Table 9: Mean pH of lamb knuckles, racks and shoulders after opening vacuum packs stored for 6, 9 and 12 weeks

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
6	5.96	6.14	6.13	5.73	5.95	6.03	5.91	6.12	6.16
9	5.79	5.94	6.01	5.83	5.89	6.13	5.92	6.01	6.10
12	5.92	6.05	6.13	5.96	6.04	6.20	5.95	6.14	6.10

The results of measurement of the colour of each cut after allowing to bloom in a chiller at 2.5°C for at least 30 minutes are presented in Table 10. These indicate that samples with a pH of 6.0 and above are darker and less red than those with a pH below 6.0.

Table 10: Mean values (± std error) for lightness (L*), redness (a*) and yellowness (b*) for lamb knuckles, racks and shoulder muscle measured after blooming for >30 min

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
L*									
6	39.40 ±1.43	40.78 ±1.41	37.94 ±1.10	38.40 ±0.47	38.23 ±1.55	37.02 ±0.71	39.48 ±1.09	39.55 ±0.99	36.64 ±0.62
12	40.72 ±1.47	40.61 ±0.50	37.91 ±0.77	40.82 ±1.45	39.45 ±0.53	38.77 ±1.73	41.51 ±0.82	41.70 ±0.64	40.12 ±0.78
a*									
6	24.43 ±0.60	23.21 ±0.81	22.20 ±0.72	22.92 ±0.54	20.19 ±0.79	20.63 ±1.06	22.77 ±0.75	23.28 ±0.43	23.16 ±0.61
12	21.49 ±0.61	20.13 ±1.01	20.52 ±0.61	22.74 ±1.11	21.60 ±0.90	20.07 ±1.02	20.55 ±0.59	19.21 ±0.70	21.14 ±0.76
b*									
6	4.93 ±0.86	4.58 ±0.92	3.81 ±0.99	5.24 ±0.53	3.04 ±0.98	2.92 ±0.66	5.88 ±0.66	6.05 ±0.61	4.50 ±0.36
12	5.12 ±0.66	3.81 ±0.54	2.92 ±0.43	5.62 ±0.40	3.94 ±0.62	2.95 ±1.09	4.91 ±0.37	3.22 ±0.81	4.30 ±0.66

4.2.2 Microbiological quality

The results of microbiological analysis of the vacuum-packed lamb cuts are presented in Table 11. These show an increase in microbial numbers with length of storage time but not always a difference between cuts of different pH range. It was anticipated that there would be a strong relationship between microbial growth at 6 and 12 weeks and sample pH. This was not the case, especially at 12 weeks (Figure 2).

Table 11: Mean $\log_{10}$ cfu/cm^2 TVC, Enterobacteriaceae, LAB an Pseudomonas spp. on surface of knuckles, racks and shoulders stored for 6 and 12 weeks at -1°C

Storage time (weeks)	Knuckles			Racks			Shoulders		
	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0	≤5.7	5.71 – 5.99	≥6.0
TVC									
6	3.70	4.98	4.26	4.26	4.43	4.72	3.81	5.11	4.54
12	5.28	6.52	5.79	5.50	7.00	5.63	5.58	6.90	5.99
Enterobacteriaceae									
6	0.90	2.37	1.96	2.46	2.37	2.85	1.71	3.87	2.40
12	2.36	3.91	3.20	4.16	5.40	4.55	3.95	5.60	4.49
LAB									
6	2.81	4.35	4.24	3.32	4.10	4.26	3.15	3.99	3.67
12	5.38	6.66	5.78	5.30	6.02	5.29	5.54	6.87	5.77
***Pseudomonas* spp.**									
6	3.06	3.56	3.56	3.67	3.88	4.02	3.08	4.73	3.50
12	3.52	4.98	4.40	4.77	6.74	5.19	5.02	6.15	5.40

4.3 Inoculation trial

Greening first began to appear in the weep of vacuum packs 4 to 5 weeks after commencement of storage (Table 12). This generally occurred in the lamb racks packed in the higher OTR film and stored at +2°C, although one sample in a low OTR film at 2°C showed definite greening at 5 weeks. The sample pH appeared to have less influence on time for greening to appear than storage temperature and film oxygen transmission rate.

Table 12: Time (weeks) for greening to appear on inoculated lamb racks stored in films of low and high oxygen transmission rate at -1 and +2°C (n=3 per group)

pH group	Low OTR (9.9 $cm^3/m^2/day$)		High OTR (36 $cm^3/m^2/day$)	
	-1°C	+2°C	-1°C	+2°C
Low (5.55 – 5.63)	9	5	6	6
Intermediate (5.75 – 5.94)	6	6	6	4
High (6.01 – 6.26)	8	6	6	5

Interestingly greening also occurred in un-inoculated control samples. As shown in Table 13, greening appeared at 5 to 7 weeks in samples stored at +2°C in vacuum bags of higher oxygen permeability. The low storage temperature, even with the higher OTR bags appeared to prevent greening. A low OTR bag delayed greening when samples were stored at the high temperature. Greening in the packs was often preceded or accompanied by the appearance of gas bubbles in the weep.

Table 13: Time (weeks) for greening to appear on control lamb racks stored in films of low and high oxygen transmission rate at -1 and +2°C (n=1 per group)

pH group	Low OTR (9.9 $cm^3/m^2/day$)		High OTR (36 $cm^3/m^2/day$)	
	-1°C	+2°C	-1°C	+2°C
Low (5.53 – 5.64)	Leaker	10	12	7
Intermediate (5.80 – 5.85	>12	10	>12	5
High (6.13 – 6.21)	11	>12	10	6

Objective measurement of meat colour by the Minolta through the plastic film gave no indication of the progression of greening of the vacuum packs. This is understandable as the greening occurred in the liquid phase within the pack and the meat colour still appeared quite normal.

The total viable counts (TVC) for samples from Table 8 that were sampled 1 to 2 weeks after showing indications of greening are presented in Table 14. This indicates that packs that were sampled after 4 to 6 week's storage (mainly those stored at high temperature and/or high OTR films) had already reached a similar microbial count to those that were not sampled until 8 to 9 week's storage.

Table 14: Total viable count (log_{10} cfu/cm^2) for lamb racks sampled after appearance of greening when stored in films of low and high oxygen transmission rate at -1 and +2°C

pH group	Low OTR (9.9 $cm^3/m^2/day$)		High OTR (36 $cm^3/m^2/day$)	
	-1°C	+2°C	-1°C	+2°C
Low (5.55 – 5.63)	8.04	7.80	7.53	7.64
Intermediate (5.75 – 5.94)	7.98	7.90	7.85	8.02
High (6.01 – 6.26)	8.09	8.17	7.93	7.85

5 Conclusions and recommendations

The results of a survey of the pH of lamb carcases at four abattoirs during autumn and spring indicated that the ultimate pH of muscles was not influenced by season, method of sourcing (saleyards or direct), transport distance or whether the lambs in spring were new season or old season. Breed had the main effect on pH with full-blood Merino lambs having a significantly higher pH ($P < 0.05$) than that of cross-bred lambs.

The results of the storage trial show that regardless of the pH of the lamb cut, a storage time of up to 9 weeks at -1°C is achievable. Very few samples were considered acceptable after 12 week's storage.

When lamb racks were inoculated with an organism expected to cause greening in the vacuum pack, greening occurred after only 4 weeks in packs stored at +2°C in a film of relatively high oxygen transmission rate and 5 weeks in packs with a film of low OTR. Storing the packs at a temperature of -1°C delayed greening by about 2 weeks in the high OTR film and up to 3 weeks in the low OTR film. Muscle pH appeared to have less influence on the susceptibility to greening than storage temperature.

Greening of lamb in vacuum packs can be avoided by maintenance of the cold chain. Product should be stored below 0°C and preferably at -1 to -1.5°C to maximise storage life.

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8 Appendix 1 – Summary of pH results for each lot

8.1 Plant A – Autumn 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
222	Market Merino X	Average	6.09	5.79	6.03
		Up to 5.7	0.0%	13.6%	0.0%
		5.71 – 5.99	31.8%	81.8%	45.5%
		≥6.0	68.2%	4.6%	54.5%
223	Market Merino X	Average	5.96	5.71	6.10
		Up to 5.7	5.0%	55.0%	0.0%
		5.71 – 5.99	50.0%	45.0%	40.0%
		≥6.0	45.0%	0.0%	60.0%
228	Direct Merino X	Average	6.03	5.89	6.13
		Up to 5.7	0.0%	5.3%	0.0%
		5.71 – 5.99	63.2%	89.5%	5.3%
		≥6.0	36.8%	5.3%	94.7%
220	Direct Merino	Average	6.33	6.01	6.42
		Up to 5.7	5.0%	0.0%	0.0%
		5.71 – 5.99	5.0%	60.0%	0.0%
		≥6.0	90.0%	40.0%	100.0%
227	Market Merino X	Average	6.01	5.70	6.07
		Up to 5.7	0.0%	47.6%	0.0%
		5.71 – 5.99	52.4%	52.4%	42.9%
		≥6.0	47.6%	0.0%	57.1%
217	Direct Merino X	Average	6.21	5.78	6.18
		Up to 5.7	0.0%	17.7%	0.0%
		5.71 – 5.99	5.9%	82.4%	11.8%
		≥6.0	94.1%	0.0%	88.2%
349	Direct Merino X	Average	6.37	6.07	6.33
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	10.0%	35.0%	0.0%
		≥6.0	90.0%	65.0%	100.0%
343	Market Merino X	Average	6.41	5.93	6.32
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	0.0%	72.7%	9.1%
		≥6.0	100.0%	27.3%	90.9%
346	Market Merino X	Average	6.29	5.96	6.28
		Up to 5.7	0.0%	6.3%	0.0%
		5.71 – 5.99	6.3%	75.0%	0.0%
		≥6.0	93.7%	18.7%	100.0%
340	Market Merino X	Average	6.36	5.99	6.31
		Up to 5.7	0.0%	5.0%	0.0%
		5.71 – 5.99	5.0%	65.0%	0.0%
		≥6.0	95.0%	30.0%	100.0%
346	Market Merino X	Average	6.08	5.88	6.13
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	50.0%	70.0%	30.0%
		≥6.0	50.0%	20.0%	70.0%
347	Market Merino X	Average	6.16	5.90	6.24
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	30.0%	85.0%	5.0%
		≥6.0	70.0%	5.0%	95.0%

8.2 Plant A – Spring 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
454	Market Merino X	Average	6.05	5.79	6.03
		Up to 5.7	0.0%	33.3%	0.0%
		5.71 – 5.99	37.5%	58.3%	54.2%
		≥6.0	62.5%	8.3%	45.8%
375	Market Merino	Average	6.38	5.99	6.28
		Up to 5.7	0.0%	20.0%	0.0%
		5.71 – 5.99	5.0%	35.0%	5.0%
		≥6.0	95.0%	45.0%	95.0%
376	Market Merino	Average	6.28	5.84	6.26
		Up to 5.7	0.0%	20.0%	0.0%
		5.71 – 5.99	5.0%	65.0%	10.0%
		≥6.0	95.0%	15.0%	90.0%
371	Market Merino X	Average	6.06	5.77	6.10
		Up to 5.7	0.0%	35.0%	0.0%
		5.71 – 5.99	50.0%	60.0%	25.0%
		≥6.0	50.0%	5.0%	75.0%
381	Market Merino X	Average	6.04	5.86	6.20
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	50.0%	80.0%	10.0%
		≥6.0	50.0%	10.0%	90.0%
379	Market Merino X	Average	6.08	5.75	6.16
		Up to 5.7	0.0%	55.0%	0.0%
		5.71 – 5.99	35.0%	30.0%	5.0%
		≥6.0	65.0%	15.0%	95.0%
382	Market Merino X	Average	5.97	5.79	5.99
		Up to 5.7	0.0%	23.8%	0.0%
		5.71 – 5.99	66.7%	71.4%	57.1%
		≥6.0	33.3%	4.8%	42.9%
481	Market Merino X	Average	5.88	5.86	6.03
		Up to 5.7	10.0%	20.0%	0.0%
		5.71 – 5.99	65.0%	50.0%	40.0%
		≥6.0	25.0%	30.0%	60.0%
479	Direct Merino	Average	6.23	5.77	6.17
		Up to 5.7	5.0%	35.0%	0.0%
		5.71 – 5.99	10.0%	60.0%	20.0%
		≥6.0	85.0%	5.0%	80.0%
480	Market Merino X	Average	6.05	5.77	6.13
		Up to 5.7	0.0%	40.0%	0.0%
		5.71 – 5.99	50.0%	50.0%	15.0%
		≥6.0	50.0%	10.0%	85.0%
491	Market Merino X	Average	5.93	5.82	6.04
		Up to 5.7	9.5%	23.8%	0.0%
		5.71 – 5.99	57.1%	61.9%	52.4%
		≥6.0	33.3%	14.3%	47.6%
488	Market Merino X	Average	5.97	5.73	6.07
		Up to 5.7	10.0%	45.0%	0.0%
		5.71 – 5.99	50.0%	50.0%	30.0%
		≥6.0	40.0%	5.0%	70.0%

489	Market Merino X	Average	5.78	5.60	5.97
		Up to 5.7	10.5%	94.7%	0.0%
		5.71 – 5.99	84.2%	5.3%	52.6%
		≥6.0	5.3%	0.0%	47.4%
484	Market Merino X	Average	5.92	5.70	6.02
		Up to 5.7	0.0%	85.0%	0.0%
		5.71 – 5.99	75.0%	10.0%	60.0%
		≥6.0	25.0%	5.0%	40.0%
483	Market Merino X	Average	5.99	5.75	6.13
		Up to 5.7	0.0%	50.0%	0.0%
		5.71 – 5.99	50.0%	45.0%	15.0%
		≥6.0	50.0%	5.0%	85.0%

8.3 Plant B – Autumn 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
3740	Direct	Average	6.04	5.71	5.96
		Up to 5.7	0.0%	59.6%	1.9%
		5.71 – 5.99	48.1%	38.5%	65.4%
		≥6.0	51.9%	1.9%	32.7%
3746	Direct Merino X	Average	5.98	5.76	6.06
		Up to 5.7	0.0%	30.0%	0.0%
		5.71 – 5.99	55.0%	70.0%	35.0%
		≥6.0	45.0%	0.0%	65.0%
3745	Direct Merino X	Average	5.90	5.69	5.93
		Up to 5.7	5.0%	70.0%	0.0%
		5.71 – 5.99	70.0%	30.0%	80.0%
		≥6.0	25.0%	0.0%	20.0%
3743	Direct 2nd X	Average	6.01	5.77	6.08
		Up to 5.7	0.0%	35.0%	0.0%
		5.71 – 5.99	50.0%	60.0%	30.0%
		≥6.0	50.0%	5.0%	70.0%
3747	Direct Dorset X	Average	5.85	5.70	5.94
		Up to 5.7	0.0%	60.0%	5.0%
		5.71 – 5.99	90.0%	40.0%	70.0%
		≥6.0	10.0%	0.0%	25.0%
3748	Direct Merino X	Average	5.91	5.71	6.01
		Up to 5.7	0.0%	80.0%	0.0%
		5.71 – 5.99	95.0%	20.0%	45.0%
		≥6.0	5.0%	0.0%	55.0%
3731	Market	Average	6.06	5.81	6.12
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	40.0%	85.0%	20.0%
		≥6.0	60.0%	5.0%	80.0%
3741	Market	Average	5.97	5.71	6.08
		Up to 5.7	0.0%	60.0%	5.0%
		5.71 – 5.99	75.0%	40.0%	30.0%
		≥6.0	25.0%	0.0%	65.0%
3744	Direct 2nd X	Average	6.04	5.80	6.19
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	50.0%	100.0%	0.0%
		≥6.0	50.0%	0.0%	100.0%

8.4 Plant B – Spring 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
146	Direct Cross bred	Average	5.95	5.84	6.06
		Up to 5.7	0.0%	4.6%	0.0%
		5.71 – 5.99	72.3%	95.5%	40.9%
		≥6.0	27.3%	0.0%	59.1%
149	Direct Border Leicester	Average	5.94	5.89	6.01
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	80.0%	100.0%	50.0%
		≥6.0	20.0%	0.0%	50.0%
141	Direct Cross bred	Average	5.90	5.79	6.08
		Up to 5.7	0.0%	17.7%	0.0%
		5.71 – 5.99	82.4%	82.4%	35.3%
		≥6.0	17.7%	0.0%	64.7%
125	Market Cross bred	Average	5.93	5.75	5.99
		Up to 5.7	4.8%	47.6%	0.0%
		5.71 – 5.99	61.9%	47.6%	71.4%
		≥6.0	33.3%	4.8%	28.6%
151	Direct Cross bred	Average	5.96	5.77	5.96
		Up to 5.7	0.0%	33.3%	0.0%
		5.71 – 5.99	80.0%	66.7%	66.7%
		≥6.0	20.%	0.0%	33.3%
152	Direct Cross bred	Average	6.04	5.85	6.01
		Up to 5.7	0.0%	15.0%	0.0%
		5.71 – 5.99	45.0%	75.0%	40.0%
		≥6.0	55.0%	10.0%	60.0%
150	Direct Cross bred	Average	6.18	5.92	6.13
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	15.0%	75.0%	15.0%
		≥6.0	85.0%	25.0%	85.0%
153	Direct Cross bred	Average	6.06	5.87	6.12
		Up to 5.7	0.0%	15.0%	0.0%
		5.71 – 5.99	50.0%	60.0%	30.0%
		≥6.0	50.0%	25.0%	70.0%

8.5 Plant C – Autumn 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
738	Direct 2nd cross	Average	5.95	5.60	5.95
		Up to 5.7	5.6%	100.0%	0.0%
		5.71 – 5.99	61.1%	0.0%	66.7%
		≥6.0	33.3%	0.0%	33.3%
744	Market 2nd cross	Average	6.31	6.03	6.34
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	0.0%	55.0%	0.0%
		≥6.0	100.0%	45.0%	100.0%
745	Market 2nd cross	Average	6.00	5.76	6.12
		Up to 5.7	11.1%	33.3%	0.0%
		5.71 – 5.99	33.3%	66.7%	16.7%
		≥6.0	55.6%	0.0%	83.3%
749	Market 2nd cross	Average	5.97	5.76	6.15
		Up to 5.7	0.0%	36.8%	0.0%
		5.71 – 5.99	52.6%	47.4%	26.3%
		≥6.0	47.4%	15.8%	73.7%
740	Market 2nd cross	Average	6.31	6.05	6.42
		Up to 5.7	0.0%	15.0%	0.0%
		5.71 – 5.99	15.0%	15.0%	20.0%
		≥6.0	85.0%	70.0%	80.0%
739	Market 2nd cross	Average	6.05	5.80	6.08
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	35.0%	90.0%	25.0%
		≥6.0	65.0%	0.0%	75.0%
760	Market 2nd cross	Average	6.25	5.96	6.29
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	10.0%	65.0%	0.0%
		≥6.0	90.0%	35.0%	100.0%
761	Market 2nd cross	Average	6.01	5.83	6.11
		Up to 5.7	0.0%	10.5%	0.0%
		5.71 – 5.99	52.6%	79.0%	26.3%
		≥6.0	47.4%	10.5%	73.7%
755	Market 2nd cross	Average	6.06	5.73	6.10
		Up to 5.7	0.0%	45.0%	0.0%
		5.71 – 5.99	45.0%	50.0%	15.0%
		≥6.0	55.0%	5.0%	85.0%

8.6 Plant C – Spring 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
274	Market	Average	5.91	5.72	6.05
		Up to 5.7	10.0%	60.0%	0.0%
		5.71 – 5.99	65.0%	35.0%	55.0%
		≥6.0	25.0%	5.0%	45.0%
275	Direct 1st cross	Average	5.96	5.70	6.10
		Up to 5.7	5.0%	70.0%	0.0%
		5.71 – 5.99	55.0%	20.0%	25.0%
		≥6.0	40.0%	10.0%	75.0%
276	Market	Average	6.15	5.83	6.24
		Up to 5.7	0.0%	10.0%	0.0%
		5.71 – 5.99	35.0%	75.0%	5.0%
		≥6.0	65.0%	15.0%	95.0%
277		Average	6.14	5.85	6.17
		Up to 5.7	0.0%	22.7%	0.0%
		5.71 – 5.99	27.3%	59.1%	18.2%
		≥6.0	72.3%	18.2%	81.8%
283	Direct 2nd cross	Average	6.07	5.84	6.23
		Up to 5.7	0.0%	15.0%	5.0%
		5.71 – 5.99	40.0%	70.0%	0.0%
		≥6.0	60.0%	15.0%	95.0%
271	Direct Dorper	Average	5.89	5.79	6.08
		Up to 5.7	0.0%	15.0%	0.0%
		5.71 – 5.99	85.0%	80.0%	35.0%
		≥6.0	15.0%	5.0%	65.0%
282		Average	6.13	5.93	6.22
		Up to 5.7	0.0%	0.0%	0.0%
		5.71 – 5.99	0.0%	90.0%	0.0%
		≥6.0	100.0%	10.0%	100.0%
303	Market	Average	5.94	5.79	6.08
		Up to 5.7	5.0%	20.0%	0.0%
		5.71 – 5.99	65.0%	75.0%	35.0%
		≥6.0	30.0%	5.0%	65.0%
304	Market	Average	6.16	5.80	6.22
		Up to 5.7	0.0%	30.0%	0.0%
		5.71 – 5.99	25.0%	55.0%	10.0%
		≥6.0	75.0%	15.0%	90.0%
310	Direct 1st cross	Average	6.02	5.75	6.06
		Up to 5.7	0.0%	30.0%	0.0%
		5.71 – 5.99	55.0%	70.0%	45.0%
		≥6.0	45.0%	0.0%	55.0%

8.7 Plant D – Autumn 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
17	Direct 2nd cross	Average	6.01	5.65	6.21
		Up to 5.7	26.7%	66.7%	0.0%
		5.71 – 5.99	26.7%	26.7%	20.0%
		≥6.0	46.7%	6.7%	80.0%
22	Direct 2nd cross	Average	6.03	5.73	6.07
		Up to 5.7	7.7%	69.2%	0.0%
		5.71 – 5.99	38.5%	11.5%	53.09%
		≥6.0	53.9%	19.2%	46.2%
23	Direct 2nd cross	Average	6.04	5.68	6.13
		Up to 5.7	3.8%	65.4%	0.0%
		5.71 – 5.99	32.7%	28.9%	19.2%
		≥6.0	63.5%	5.8%	80.8%
16	Market Merino	Average	6.19	5.82	6.30
		Up to 5.7	0.0%	30.4%	0.0%
		5.71 – 5.99	26.1%	43.5%	8.7%
		≥6.0	73.9%	26.1%	91.3%
20	Direct 2nd cross	Average	5.98	5.70	6.10
		Up to 5.7	4.6%	63.6%	0.0%
		5.71 – 5.99	40.9%	36.4%	36.4%
		≥6.0	54.6%	0.0%	63.6%
21	Market 2nd cross	Average	6.15	5.77	6.23
		Up to 5.7	0.0%	46.2%	0.0%
		5.71 – 5.99	11.5%	42.3%	15.4%
		≥6.0	88.5%	11.5%	84.6%

8.8 Plant D – Spring 2013

Lot No.	Source/Breed	pH range	Knuckle	Rack	Shoulder
24	Direct Merino X	Average	6.04	5.81	6.20
		Up to 5.7	7.1%	21.4%	0.0%
		5.71 – 5.99	28.6%	64.3%	17.9%
		≥6.0	64.3%	14.3%	82.1%
25	Direct Merino X	Average	6.10	5.82	6.07
		Up to 5.7	0.0%	25.0%	0.0%
		5.71 – 5.99	33.3%	58.3%	33.3%
		≥6.0	66.7%	16.7%	66.7%
26	Market Merino X	Average	5.85	5.59	5.94
		Up to 5.7	19.2%	84.6%	7.7%
		5.71 – 5.99	73.1%	15.4%	61.5%
		≥6.0	7.7%	0.0%	30.8%
24	Direct Merino	Average	5.92	5.68	6.19
		Up to 5.7	10.0%	65.0%	0.0%
		5.71 – 5.99	50.0%	35.0%	30.0%
		≥6.0	40.0%	0.0%	70.0%
25	Direct Merino	Average	5.97	5.87	6.16
		Up to 5.7	5.0%	30.0%	0.0%
		5.71 – 5.99	55.0%	35.0%	35.0%
		≥6.0	40.0%	35.0%	65.0%
26	Direct Merino	Average	6.08	5.77	6.24
		Up to 5.7	0.0%	45.0%	0.0%
		5.71 – 5.99	30.0%	45.0%	25.0%
		≥6.0	70.0%	10.0%	75.0%
28	Direct Merino	Average	6.02	5.73	6.09
		Up to 5.7	0.0%	50.0%	0.0%
		5.71 – 5.99	45.0%	45.0%	40.0%
		≥6.0	55.0%	5.0%	60.0%
33	Market Merino X	Average	6.15	5.68	6.15
		Up to 5.7	0.0%	80.0%	0.0%
		5.71 – 5.99	20.0%	15.0%	20.0%
		≥6.0	80.0%	5.0%	80.0%
36	Direct 2nd cross	Average	6.01	5.84	6.13
		Up to 5.7	0.0%	35.0%	0.0%
		5.71 – 5.99	50.0%	50.0%	20.0%
		≥6.0	50.0%	15.0%	80.0%