Client Report

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Venison Meat Quality Benchmarking

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Prepared for DEEResearch

C/- Game Industry Board

C O N F I D E N T I A L

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Summary

The aims of this programme are twofold; the first is to benchmark the current quality of both chilled and frozen venison. Based on these findings, the second is to evaluate alternative processing strategies that may further improve venison quality.

To achieve this, samples of both chilled and frozen venison were collected from four venison plants (two in the North Island and two in the South Island) over a 6-month period. Prior to sample collection, the process at each plant was audited with data collected on stunning, stimulation, pre-rigor pH fall and carcass chilling.

The overall results show that the tenderness of chilled venison is acceptable and largely resides within the current tenderness specifications. Three sub-primals were tested (shortloins, rumps and topsides), and all achieved the tenderness standard. However, the tenderness of both frozen and thawed venison is less acceptable and does not reach the current tenderness specification.

These results have been compared to the survey that was conducted by MIRINZ on behalf of the NZGIB in 1991. The tenderness of 21-day aged shortloins in this trial are similar to those recorded in the original work, while the tenderness of the frozen and the frozen/thawed (therefore unaged) shortloins has deteriorated somewhat.

The levels of drip loss during vacuum packed chilled storage (ageing) fluctuated between samples from different plants and between evaluations, with levels averaging between 2 and 5% during the 21 day ageing period. Drip losses from samples subjected to simulated retail display were also high with levels varying from 1 to as high as 10%.

The colour stability of shortloin samples was generally better than both topsides and rumps, with shortloins remaining colour stable for 2 days compared to 1 day for the other two primals. Freezing and thawing of shortloins resulted in a deterioration of colour stability by 0.5 of a day.

Process optimisation trials currently underway have focussed on strategies to improve the tenderness of frozen product and reduce the drip losses and prolong the colour stability of chilled product. The results of this work will be reported in June 2005.

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1. Introduction

In 1991, an accelerated conditioning and ageing processing specification was developed by MIRINZ for the Game Industry Board. This seminal work identified a process, based upon the use of low voltage electrical stimulation and a controlled chilling regime, that would generate acceptable tenderness for both chilled and frozen venison.

This aim of this programme is to review the existing processing specification and measure its effects on meat quality, in particular the rate of tenderness development, ultimate tenderness attained, textural attributes, colour and colour stability, and water binding capacity (tendency to drip). This information will provide a benchmark of both frozen and chilled product attributes.

To achieve this, samples of both chilled and frozen venison were collected from four venison plants (two in the North Island and two in the South Island) over a 6-month period. Prior to sample collection, the process at each plant was audited; data on stunning, stimulation, pre-rigor pH fall and carcass chilling was gathered. After either the required ageing period (for the chilled product), or a period of frozen storage, the meat quality was measured.

The data presented here shows the quality of chilled shortloins, topsides and rumps after 14 and 21 days of chilled vacuum-packed ageing, and frozen shortloins evaluated from either the frozen or the thawed state. The overall meat quality results across audits and plants are presented in the main body of the report. The detailed results (in bar chart format), showing differences between plants and audits is presented in Appendix 1. Appendix 2 shows the same results but presented as tables with the inclusion of statistical information.

Having measured the venison quality being generated by the existing specification, this programme is now evaluating two contrasting processes that are aimed at optimising the quality of frozen and chilled venison. These results will be reported in June and will form the basis of industry workshops.

2. Methodology

Two North Island and two South Island venison plants participated in a benchmarking and audit study where the meat quality of samples from the four plants was measured over a 6 month period: The first 3 months (September to November inc.) measured chilled venison quality and the second 3 month period (December to February inc.) measured frozen venison quality.

For each of these audits**,** ten deer carcasses (Prime, under 3 years and less than 85kg) were randomly selected. One shortloin from the left or right sides was removed after overnight chilling. For audit 1, an additional two cuts (rump and topside) from the Denver Leg Cuts were also selected

For the initial audit, AgResearch visited each plant to benchmark the carcass processing; the stunning and slaughter process and measurement of the electrical inputs used during processing were recorded. The pre-rigor pH fall and chilling rates were also measured. During these visits, staff at each of the plants were trained to enable them to undertake the chiller recording and sample collection procedures required for the routine benchmarking process.

During the initial audit (September), shortloin, rump and topside samples were collected and transported to MIRINZ Centre for meat quality assessments. Then, at monthly intervals over the 6-month period, samples of shortloin in either chilled or frozen form were collected from these plants.

2.1 **Audit 1 (September) – Chilled Product** (sub-primals: shortloins, topsides, rumps - aged for 14 and 21 days)

Meat quality attributes of three muscles; shortloin, topside and rump were examined after 14 and 21 days storage at -1.5ºC. The samples were measured for ultimate pH, drip loss (purge) in the vacuum pack, colour stability (measured after 21 days of ageing only), cook loss, shearforce and textural attributes, using the standard MIRINZ testing procedures outlined below.

2.2 **Audits 2 & 3 (October & November)** – Chilled Product (shortloins only, aged for 21 days)

These audits utilised chilled shortloin product. The meat quality attributes of drip loss during storage, ultimate pH, cook loss, shearforce and colour stability were measured after 21 days of storage at -1.5ºC.

2.3 Audits 4 to 6 (December to February) – Frozen Product (shortloins only, evaluated from both the frozen and thawed state)

These audits assessed the quality of frozen shortloin which was evaluated from both the frozen and thawed state. Cook loss and shear force were measured on the frozen product, while measurements to the thawed product (after thawing at 4°C for 48 hours) also included drip loss, ultimate pH, and colour stability

3. Meat Quality Measurement Procedures

3.1 Drip Loss

The weight of each sample was recorded before vacuum packaging at each plant. After the chilled ageing period, the samples were removed from the vacuum pack, blotted dry with absorbent paper towel and re-weighed. The difference in weight before and after storage was calculated as total weight loss (grams) and expressed as a percentage of the original sample weight.

3.2 Ultimate pH

The ultimate pH (pHu) was measured by inserting a calibrated pH probe (Mettler Toledo MP125 meter with an Inlab 427 probe) directly into the meat.

3.3 Cook Loss

The weight of the meat was recorded before and after cooking. After cooking the samples were blotted dry and re-weighed. The cook loss was calculated as amount of weight (grams) lost and expressed as a percentage of the original sample weight.

3.4 Shearforce

Individual samples were placed in cook-in-bags with a weight and durable identification tag. Samples were cooked in boiling water (100°C) until the internal temperature of the sample reached 75°C. A digital thermometer was used to measure the temperature at the centre of the sample during cooking. After the samples had cooked, they were immediately cooled on ice.

Ten 1 cm x 1 cm slices (bites) were prepared from the cooked sample with the muscle fibres running longitudinally along the slice. Each sample was then sheared with the long axis of the fibres running perpendicular to the blade, using a MIRINZ tenderometer. The results were expressed as shearforce (kgF).

3.5 Texture

A portion of the sample cooked for shearforce measurement was used to assess the textural attribute of compression. Up to 10 sample bites were prepared as for the shearforce measurement. Using a texture analyser (TAXT2 Micro Stable Systems) each bite was placed on a platform and deformed (compressed) using a compression probe and the force reqruied to compress the sample to a given distance or % strain was measured. The extent of the deformation and/or the resistance offered by the sample was recorded. During the analysis of the force-deformation curves, problems were encountered in the macro-driven commands of the software. This delayed the analysis, and thus the results of the textural evaluations will be reported as an addendum to the final report in June.

3.6 Drip Loss during Retail Display and Colour Stability Measurements

After storage, where applicable, each sample had a 20mm thick steak sliced, weighed and overwrapped on a polystyrene tray. The steaks were then helf for 7 days in a retail display cabinet running at 6°C. At the end of the retail display period, the steak was blotted dry with absorbent kitchen towel and re-weighed. The weight difference before and after the retail display was expressed as a percentage of weight lost.

Colour measurements using a HunterLab meter (Model Miniscan XE 45OL), calibrated using a 10^{o} observer angle and D65 light source) were taken from the samples over the 7-day period using the L*, a*, b* colour space where L* is lightness on a scale of 0 (all light absorbed) to 100 (all light reflected), a* is redness and b* is yellowness. Two colour readings were measured on each steak and then averaged. Care was taken to avoid fat and gristle when the measurements were made, although areas of browning were included within the measurement area.

4. Data Analysis

Data were tested for significance using a two-way analysis of variance (ANOVA) and a general linear model (GLM) using Unistat™ (Version 5.5, Microsoft Corp.).

5. Results and Discussion

5.1 Audit of Plant Processing Procedures

A summary of each plant's processing procedures and stimulation parameters are given in Table 1. All plants use captive bolt and low voltage stimulation (LVS), but the time of application from slaughter, and current parameters vary between plants. Plants A and D use spray chilling while Plants B and C use conventional air chilling.

Table 1. Plant Processing Conditions and Parameters.

Plant	Conditions	Comments
A	Overhead spray in yards Captive bolt LVS; lip - anus probe 48sec, 14.14Hz, 10ms 191mA Chiller loaded under reduced fan speed 0.06 to 0.09 m/sec Chiller loaded in 3 - 6 hrs, 8°C then 4°C Spray chilling - 24 cycles of 15 sec ambient spray every 30 min after loading rails	
B	Captive bolt LVS; lip - anus probe 53sec, 13.3Hz, 8ms, 180mA Chiller loaded 3 - 6 hrs, 12°C then 0°C	Slow chiller air speeds - 0.25 m/sec over loin, 0.19 m/sec over rump
C	Captive bolt LVS; lip - anus probe 55sec, 12.5Hz, 8ms, 344mA Chiller loaded 3 - 6 hrs, 12°C then 0°C	Slow chiller air speeds – 0.13 m/sec over loin 0.13,
D	Overhead spraying in yards (every 20 mins overnight) Captive bolt LVS; lip - anus probe 50sec, 13.3Hz, 2.5ms, 400mA Chiller loaded 3 - 6 hrs, 12°C then 0°C Spray chilling - 7 cycles of 30 sec ambient spray every 30 min	Slow chiller air speeds – 0.38 m/sec over loin 0.38.

At all four plants, the low voltage stimulation was applied within 5 minutes of slaughter, via clips to the nose and tail. The duration of stimulation was between 48 and 55 seconds and was therefore very close to the industry standard specification. The current flow during stimulation was higher at plants C and D compared to A and B.

5.2 pH Fall

The rate of pH fall was measured by direct probe measurements into the loin muscle of the carcass. The first measurements were made as soon as possible after slaughter and regular measurements were taken until the onset of rigor mortis.

The pre-rigor pH fall was faster at plants C and D compared to A and B, although 3.5 hours after slaughter, the pH was close to rigor at all plants. The faster rate of pH decline at plants C and D was probably due to the higher current levels generated by the low voltage stimulation. However, irrespective of these differences, the rate of pH fall from all plants was relatively fast.

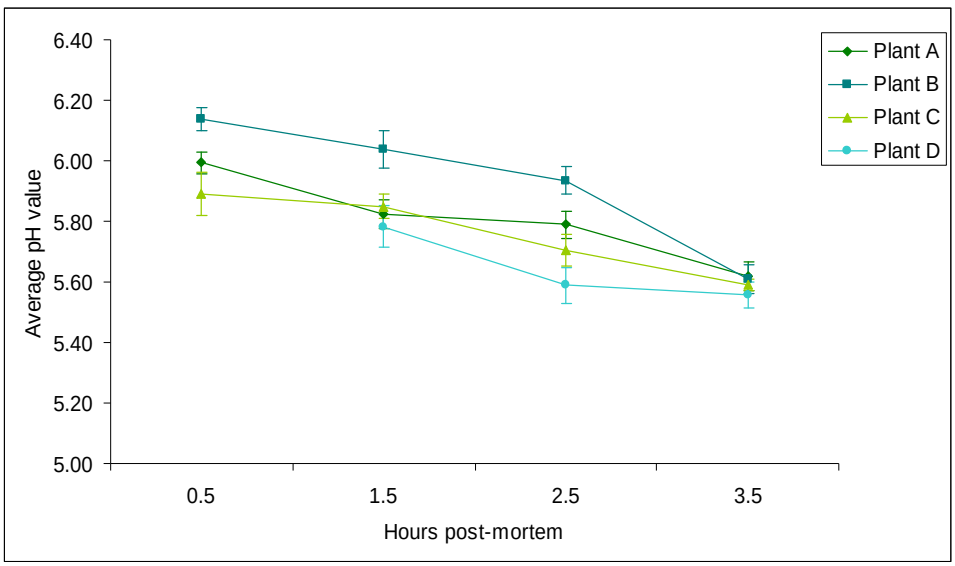


Figure 1. pH fall

Delphi loggers were used to record the carcass cooling; once the carcasses were railed into the chillers, the probes were placed in the loin and deep leg, and an additional logger was used to record air temperature over the carcass.

The loin chilling curves for the four plants are presented below, and show the fastest and slowest chill for each plant averaged over the six audits (Figure 2 to

Figure 5). Taken overall, Plant A (Figure 2) tended to have the slowest cooling, Plants B and C had similar cooling rates and Plant D had the fastest cooling rate. However, taken overall, the rate of cooling for all four plants was similar.

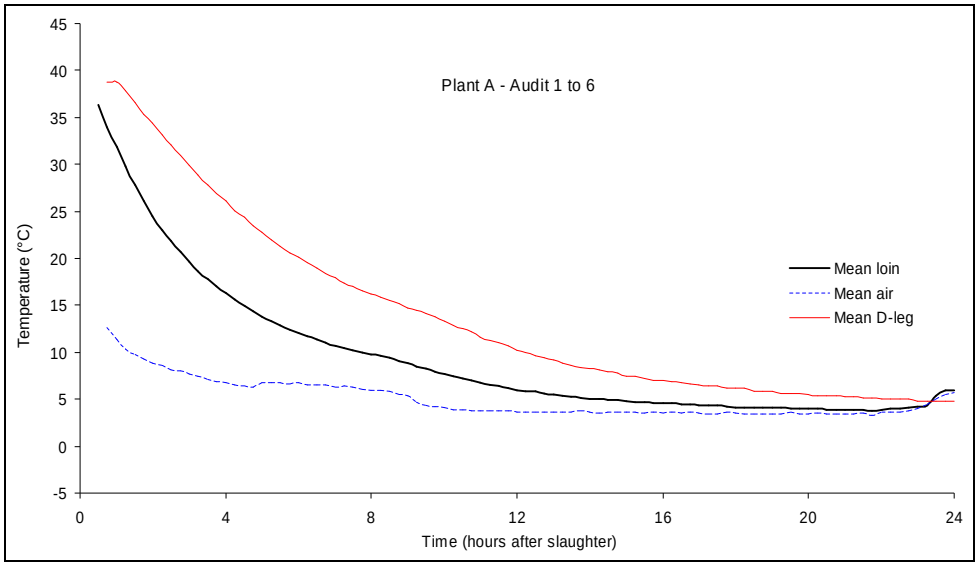


Figure 2. Plant A cooling profile

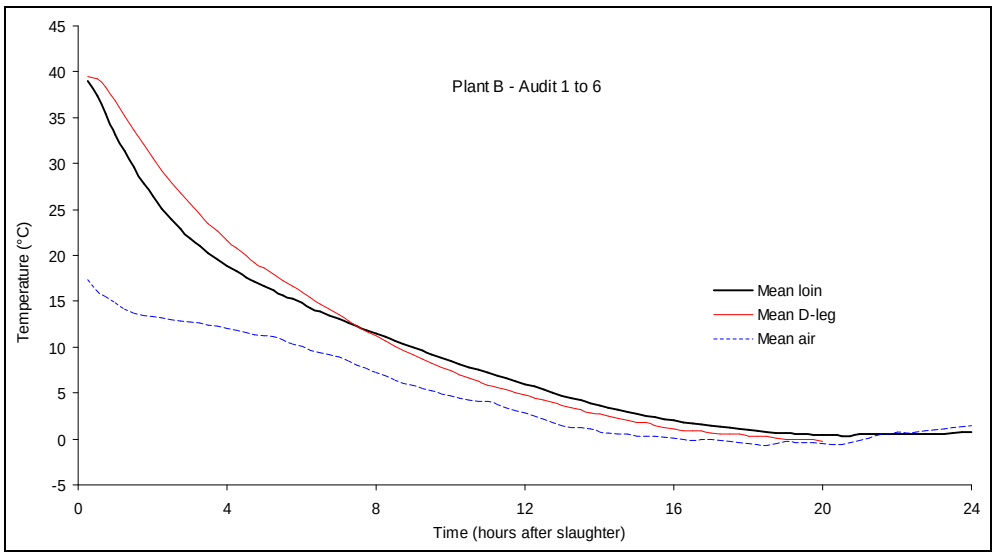


Figure 3. Plant B cooling profile

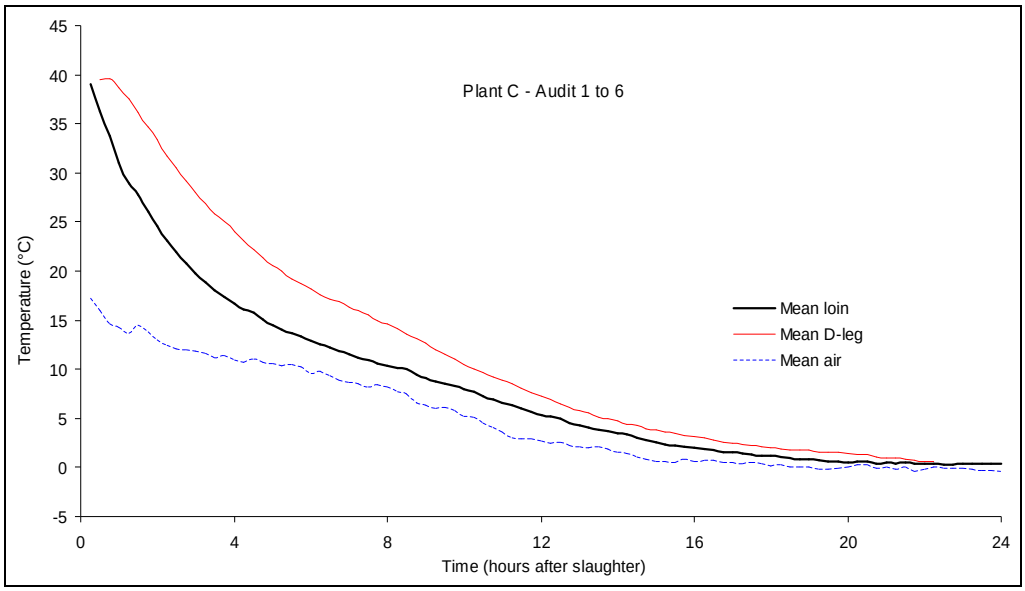


Figure 4. Plant C cooling profile

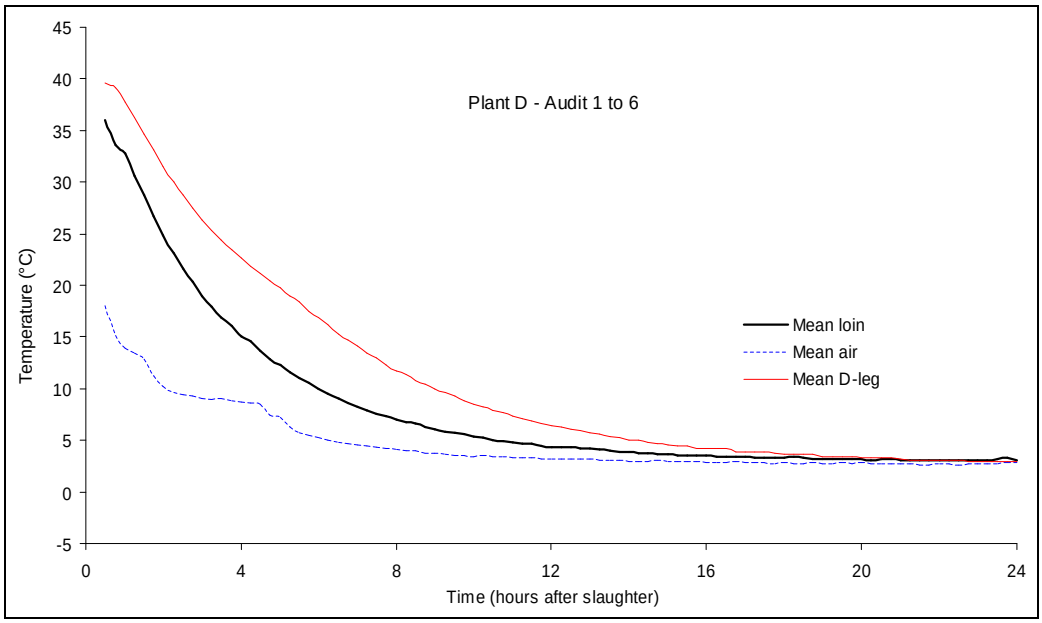


Figure 5. Plant D cooling profile

5.3 Overall Meat Quality Results

Shear Force

The New Zealand Deer Processors Industry Agreed Standards require that the mean tenderness of the shortloin, shall be less than or equivalent to 5 kgF (as measured by MIRINZ Tenderometer), with no shear force values exceeding 10 kgF and 90% of all samples ('bites') to have values of 8 kgF or less.

The results of this benchmarking exercise have demonstrated that after 14 and 21 days of chilled storage, the tenderness of shortloins are close to this specification but do not quite meet it (Table 2). Not unsurprisingly, shortloins that had been frozen after boning, did not meet this tenderness specification, having an average shear force of 8.9 kgF with only 46% of samples having shear force values of less than or equivalent to 8 kgF, with 27% of 'bites' having a shear force of greater than 10 kgF. Thawing prior to meat quality evaluation, resulted in some improvement in tenderness, although again, the results fall a little short of the specification (mean 6.0, 89% less than 8 kgF, 3% greater than 10 kgF).

The tenderness of the rump and topside sub-primals were also tested. These samples were tested after 14 and 21 days of ageing, and for both cuts, the results fell a little short of the specification after 14 days of ageing, but achieved the specification after 21 days of ageing (Table 2).

Table 2. Overall Shear force analysed according to tenderness specification requirement

		n	%>10kgF	%<8kgF	min	max	mean
Day 14	Shortloin	400	6	90	1.5	17.1	5.3
	Rump	400	1	99	1.7	10.3	3.8
	Topside	400	1	99	1.7	11.9	4.4
Day 21	Shortloin	1200	3	95	1.5	16.9	4.3
	Rump	399	0	99	1.5	8.9	3.7
	Topside	400	0	100	2.3	8.7	4.3
	Frozen	1200	27	46	3.3	22.8	8.9
	Thawed	1200	3	89	2.5	18.1	6.0

These results have all been summarised in histogram format below (Figures 6 to 13).

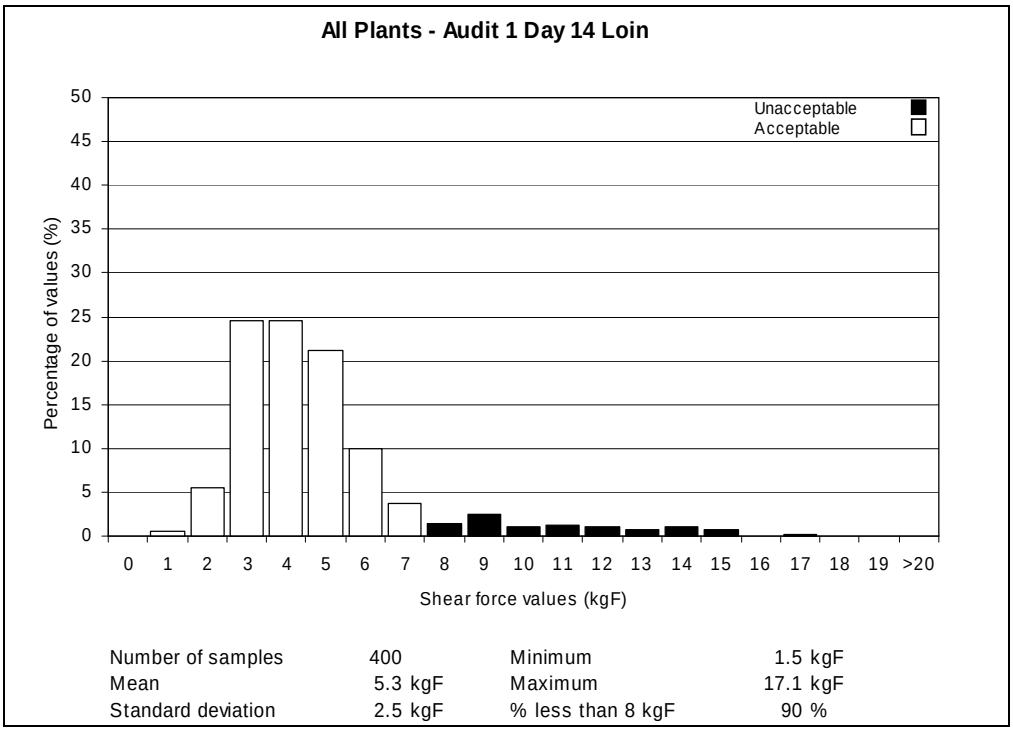


Figure 6. Shearforce histogram for day 14 – Shortloin.

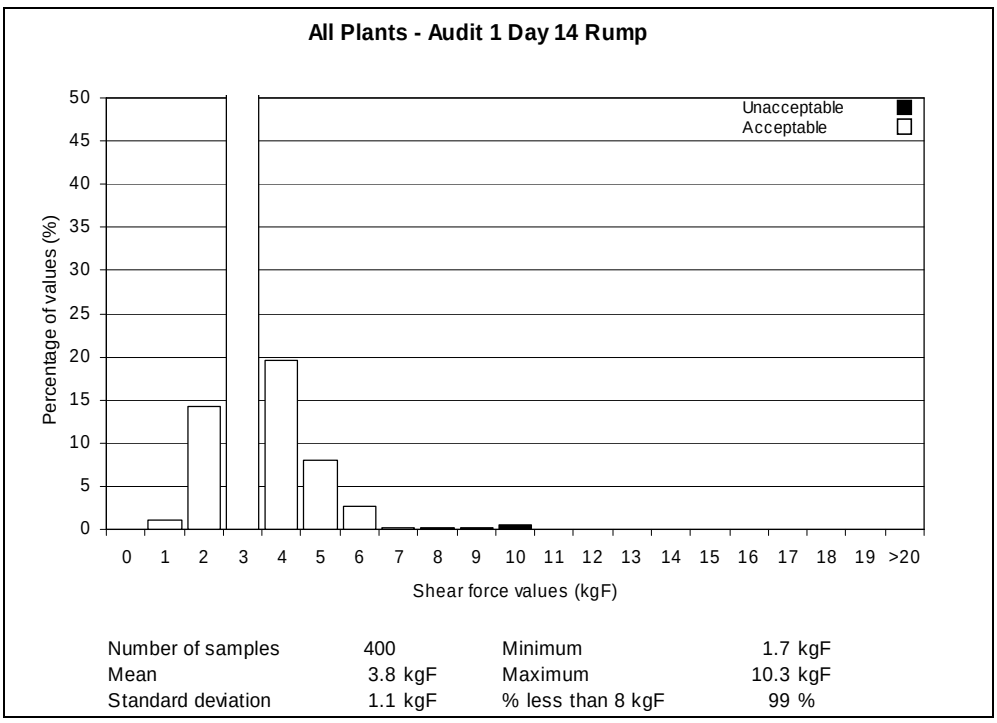


Figure 7. Shearforce histogram for day 14 – Rump.

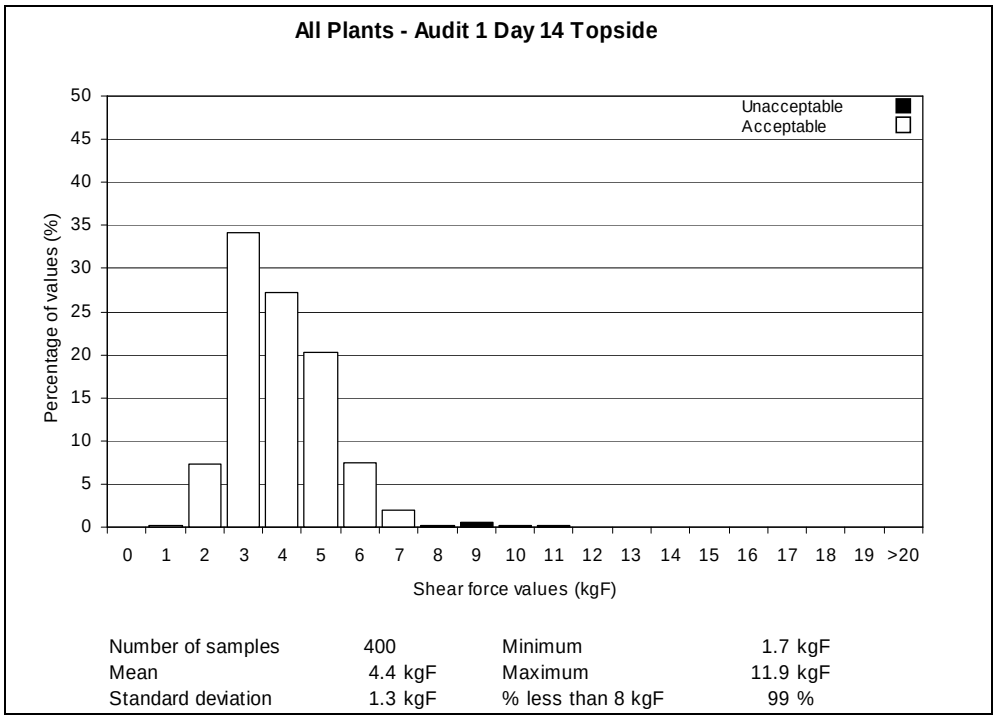


Figure 8. Shearforce histogram for day 14 – Topside.

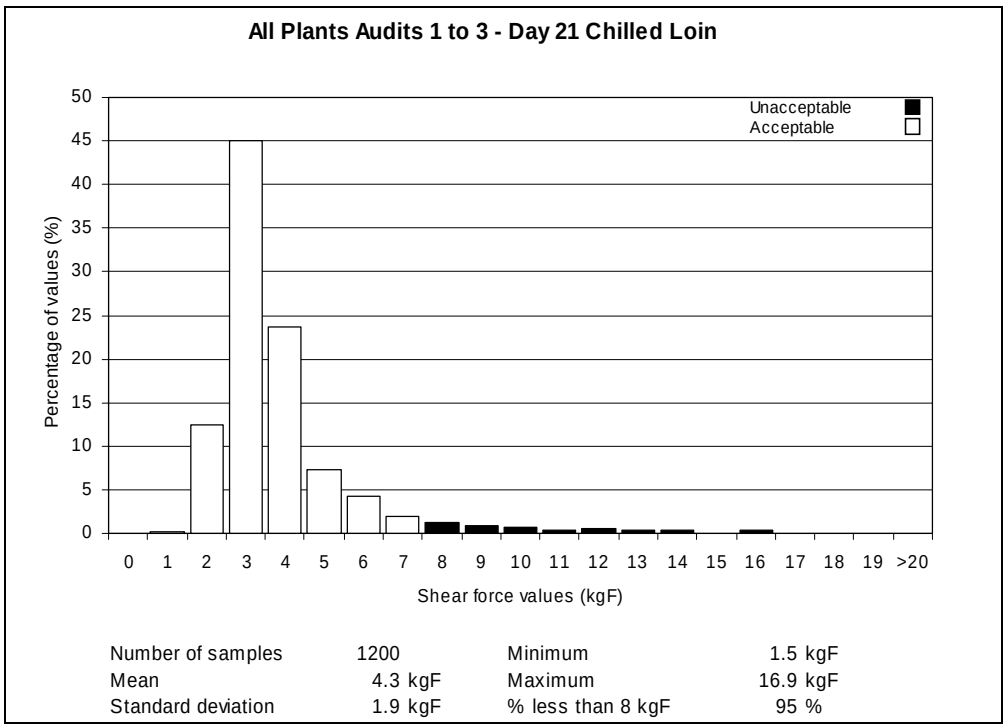


Figure 9. Shearforce histogram for chilled product – Shortloin.

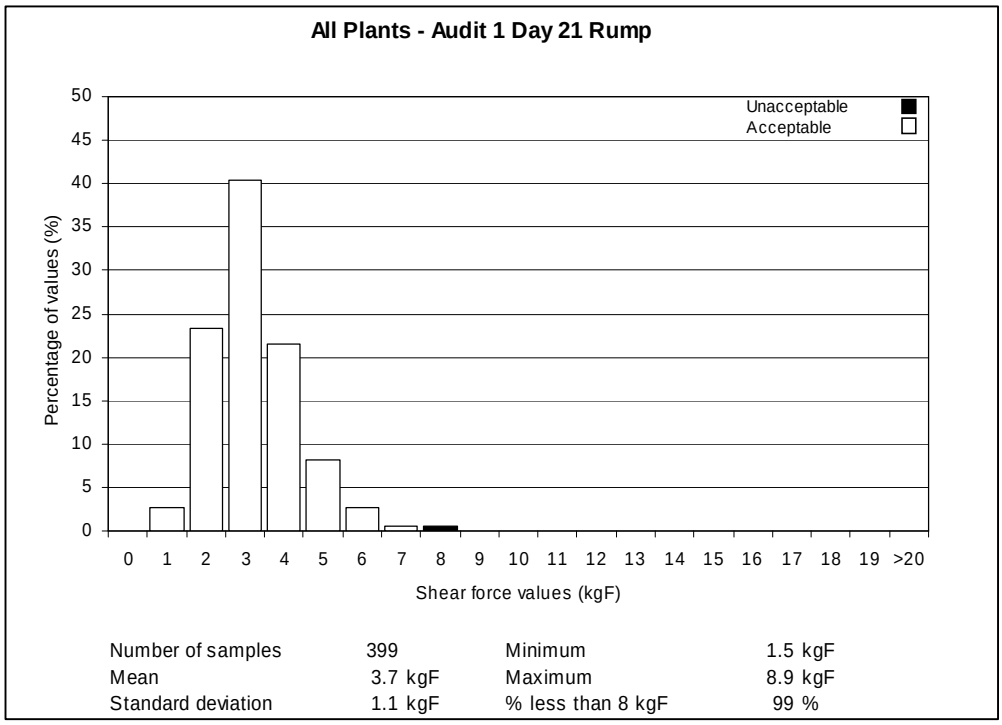


Figure 10. Shearforce histogram for chilled product – Rump.

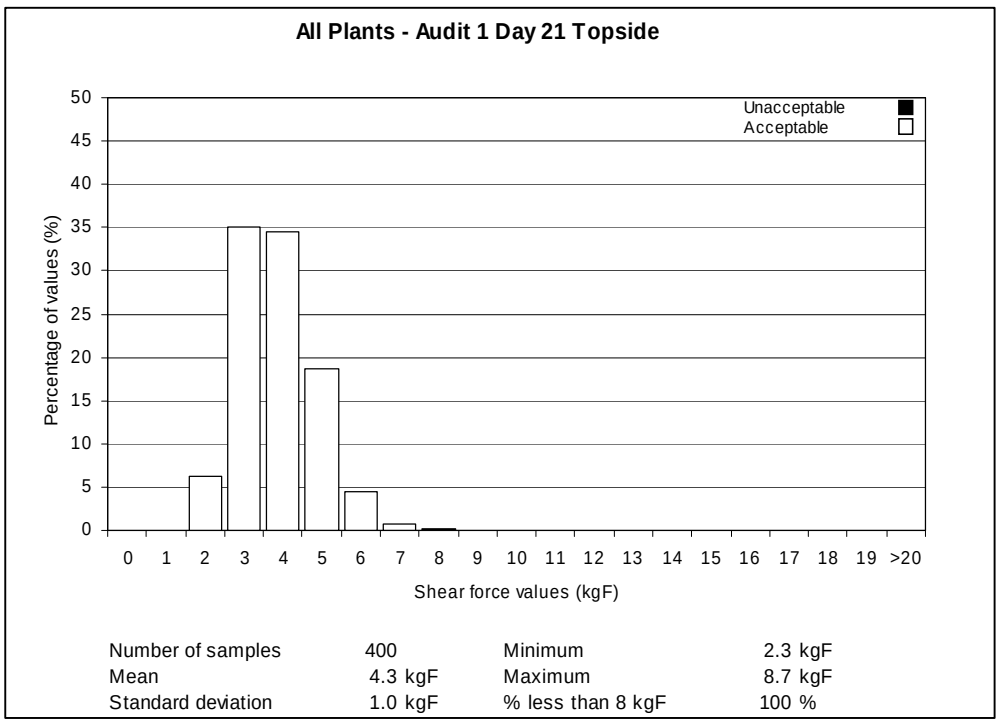


Figure 11. Shearforce histogram for chilled product – Topside.

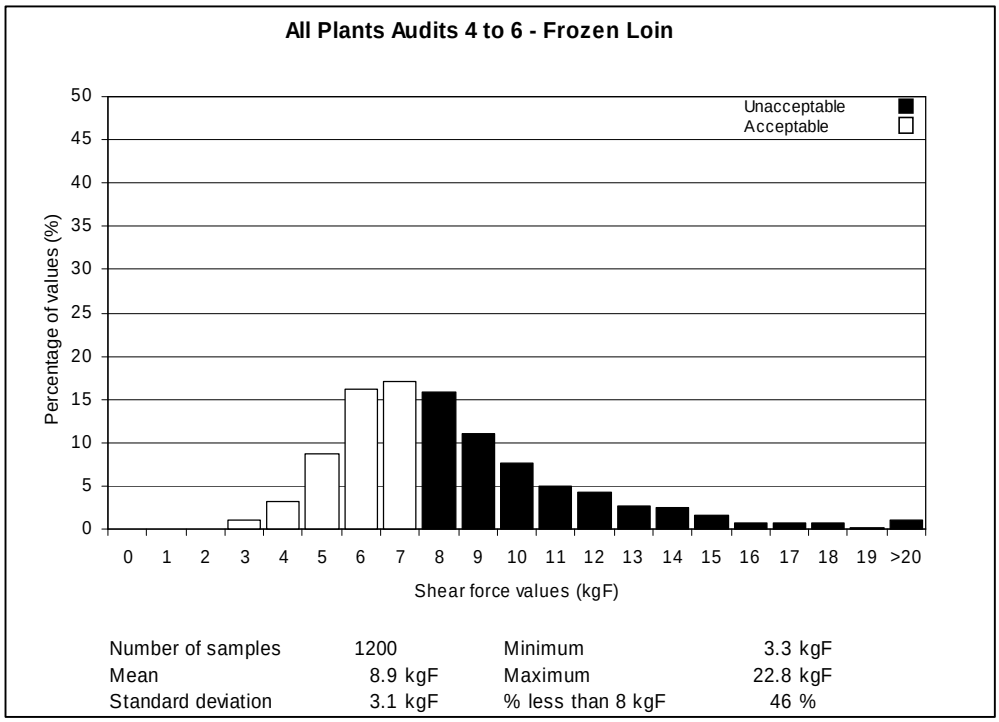


Figure 12. Shearforce histogram for frozen product.

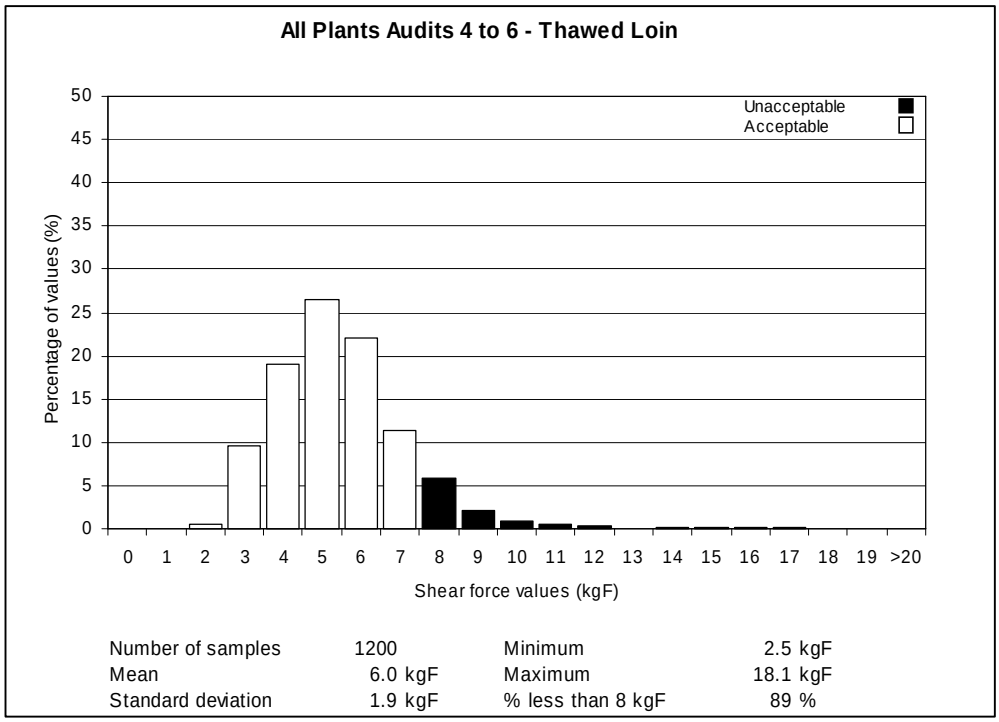


Figure 13. Shearforce histogram for thawed product.

Comparison with 1991 survey

These results have been compared to the survey that was conducted by MIRINZ on behalf of the NZGIB in 1991. The tenderness of 21-day aged shortloins in this trial are similar to those recorded in the original work (1991; mean 3.9 Kgf, 2004 – 4.3 Kgf), while the tenderness of the frozen and the frozen/thawed (therefore unaged) shortloins has deteriorated somewhat (1991; unaged – mean 5.4 Kgf, 2005; frozen – 8.9 kgF, frozen/thawed – 6.0 kgf).

The overall meat quality of 3 different cuts after either 14 or 21 days of ageing, is shown in Table 3.

Table 3. Meat Quality of 3 different cuts after 2 ageing periods

	Day 14			Day 21		
	Shortloins	Rump	Topside	Shortloins	Rump	Topside
Drip loss %	2.7	2.1	3.4	2.8	3.7	5.4
pH	5.54	5.54	5.53	5.61	5.56	5.53
Cook loss %	26.5	31.9	32.3	30.4	33.8	33.8
Shearforce (kgF)	5.3	3.8	4.4	4.3	3.7	4.3
Retail drip loss %	na	na	na	2.0	3.6	2.7

Table 4 shows the overall meat quality for chilled (21 days ageing), frozen and thawed shortloins .

Table 4. Overall Meat Quality of Shortloin Product after 21 days ageing

	Chilled	Frozen	Thawed
Drip loss %	3.1	na	3.2
pH	5.61	na	5.53
Cook loss %	30.4	28.8	30.4
Shearforce (kgF)	4.3	8.9	6.0
Retail drip loss %	2.4	na	5.6

Ultimate pH

The average ultimate pH values or all three sub-primals (shortloins, rumps and topsides) were in the acceptable range of 5.4 to 5.6 (Table 3). However, throughout this work, samples with ultimate pH values of greater than 5.7 were evident, and on occasion, this so called 'intermediate pH' had some impact upon tenderness. After 14 days of ageing, there were a total of three samples with pH values of ≥ 5.7. Of these, two were shortloin samples and one was a rump sample; of these, both shortloin samples had shear force values of greater than 12 kgF, and demonstrate the phenomenon of intermediate pH associated toughness, found routinely in beef. Similarly, of the 21 day aged samples, there were a total of 30 samples with ultimate pH values of ≥ 5.7. Of these, one was a rump sample and the remainder were shortloins; of these, seven had shear force values of > 8kgF and therefore show some level of intermediate pH associated toughness. These occurrences of intermediate ultimate pH (and associated toughening) were evenly distributed across all plants and all audits.

Drip loss

The average overall drip loss during chilled ageing in the vaccum pack ranged from between 2 to just over 5% of the sample weight (Tables 3 & 4). However, at certain times, the drip loss was in excess of 5% and tended to fluctuate between plants and between audits. This is certainly higher than those of both beef and lamb, and strategies to improve this will be a focus of the process optimisation stage of this project. Drip loss also tended to be higher from the topside samples compared to the rump and shortloin samples.

Drip loss during retail display was also high, with the average values fluctuating from between 2 and 4% (Table 3). Frozen then thawed samples lost the highest level of drip during retail display (Table 4).

Taken overall, drip loss represents a loss in product weight, and therefore, product value. Drip loss can also impact upon eating quality (due to a reduction in juiciness). Furthermore, high levels of drip loss in the retail pack look unsightly and will often result in consumer rejection. Process optimisation trials will identify methods to reduce these losses.

Colour Stability

The colour stability of all samples was measured after 21 days of ageing only. After this ageing period, the shortloin samples were slightly more colour stable than both the topsides and rumps, when assessed during simulated retail display (Figure 14): The colour of the shortloin samples were acceptable for two days, while the colour of the rumps and topsides were acceptable for just one day. The colour stability of frozen then thawed samples was better than 21-day aged topsides and rumps and was broadly equivalent to shortloins, having a shelf life of on average 1.5 days (Figure 15).

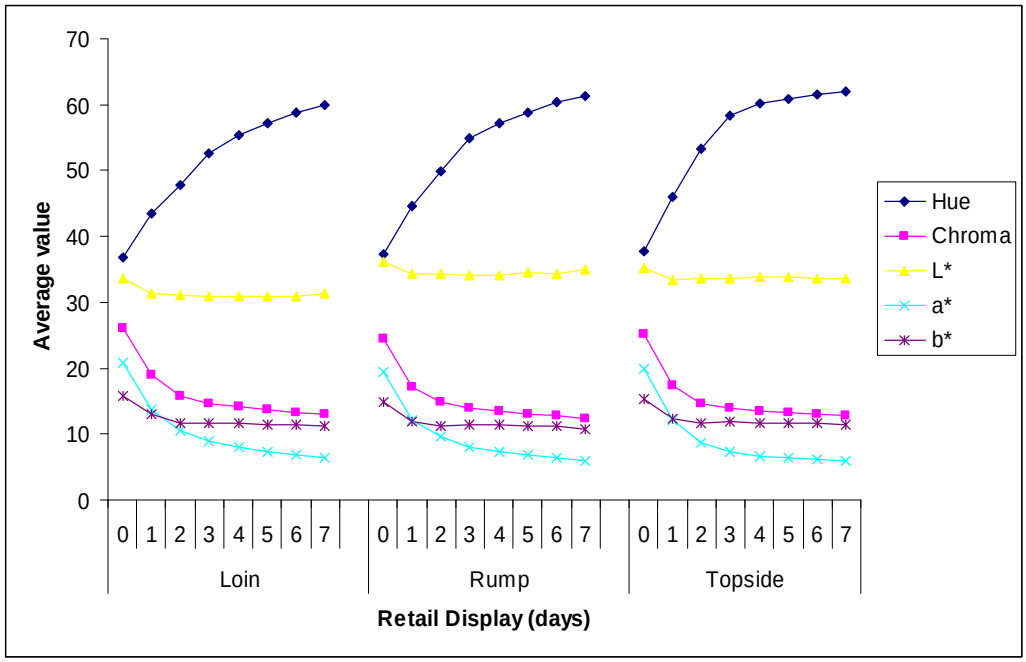


Figure 14. Colour stability of the three sub-primal cuts evaluated after 21 days of chilled ageing.

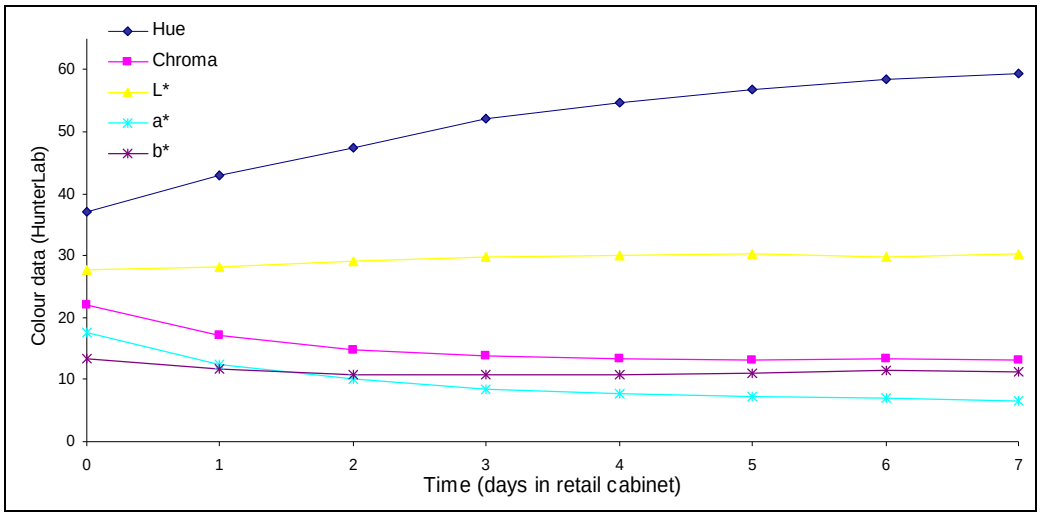


Figure 15. Colour Stability for Frozen/Thawed Product.

Next Step: Process Optimisation

The next stage of this project is to trial alternative processing specifications that are specifically tailored to

1. Chilled product (retail ready 3 weeks – to represent local market product and product that is air-freighted to overseas markets, and 12 weeks, that will represent product that is sea- freighted to overseas markets) and

2. Frozen product (frozen at 24 hours post slaughter). These data will form the basis of recommendations as to how the existing specification can be modified to incorporate these new opportunities.

Appendix 1. Detailed Results

Audit 1 – Chilled Product (sub-primals: shortloins, topsides, rumps - aged for 14 and 21 days)

Meat quality results for Audit 1 - comparisons of shortloin, rump and topside samples after both 14 and 21 days of vacuum packed chilled ageing are presented in Figure 16 to Figure 21.

Drip loss

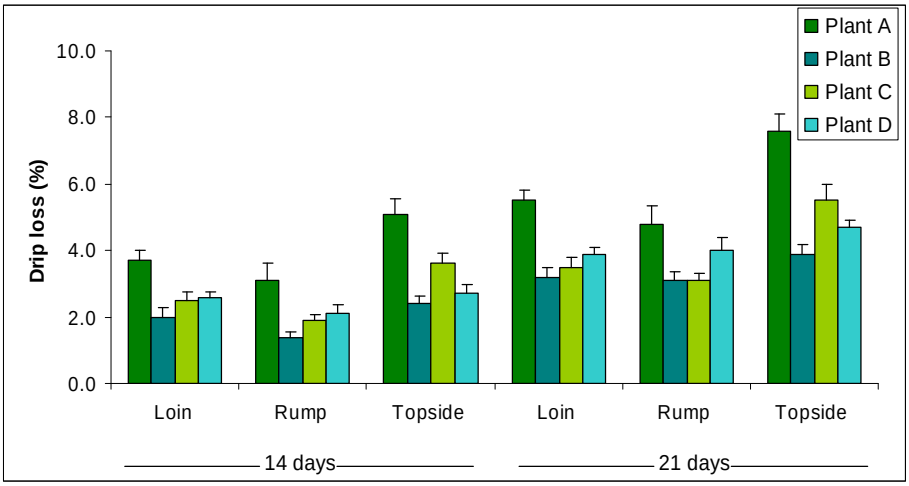


Figure 16. Drip loss (%) of shortloin, rump and topside following 14 and 21 days storage at -1.5ºC.

After each ageing period (14 or 21 days of ageing), and for each cut, there were significant differences in the amount of drip lost during chilled ageing between plants: Samples from Plant A lost the greatest amount of drip during both ageing periods for each cut, while samples from plant B generated the least amount of drip loss. Overall, as expected, the amount of drip loss was greater after 21 days of ageing compared to the drip lost after 14 days of ageing. Generally, the drip loss from topsides was higher than the drip loss from both rumps and shortloins.

Ultimate pH (pHu)

Overall, the average pHu for all three cuts was within the acceptable range after both ageing periods (Figure 17).

The pHu was lower at Plant C in all cuts after 14 days of ageing, although by 21 days of ageing, these differences only remained in the shortloin. After 21 days of

ageing, the pHu of all three cuts from Plant D was higher than the equivalent values from the remaining 3 plants.

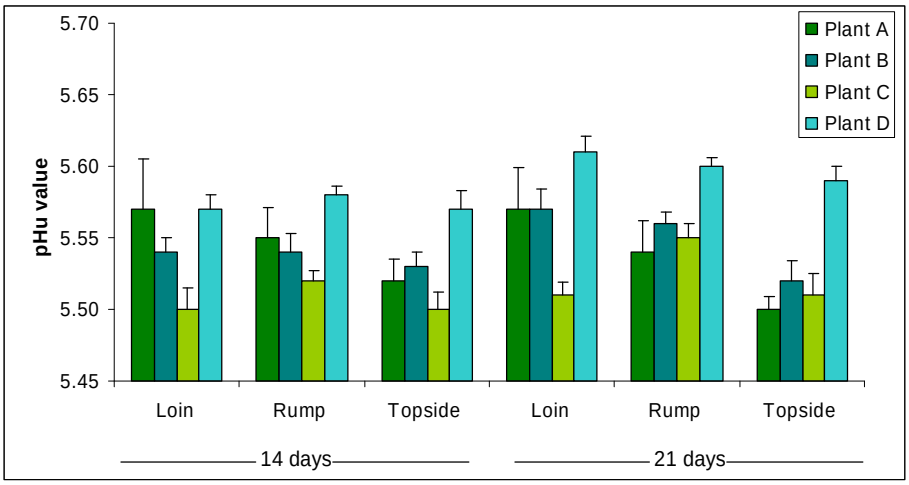


Figure 17. Ultimate pH values of shortloin, rump and topside following 14 and 21 days storage at -1.5ºC.

Cook loss

In general, the cook loss increased slightly with ageing time, while the shortloin had the lowest cook loss of the three cuts after both 14 and 21 days of ageing. Plant D tended to have the lowest cook loss overall although these differences were marginal (Figure 18).

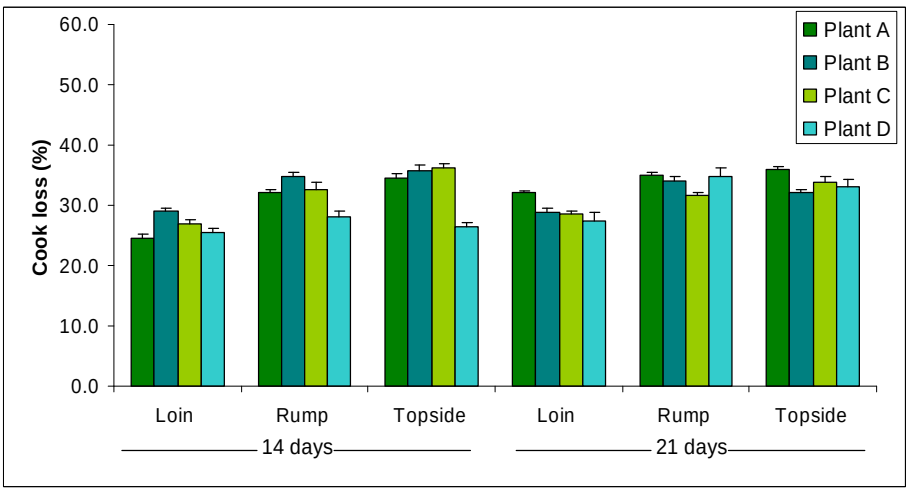


Figure 18. Cook loss (%) of shortloin, rump and topside following 14 and 21 days storage at -1.5ºC.

Shearforce

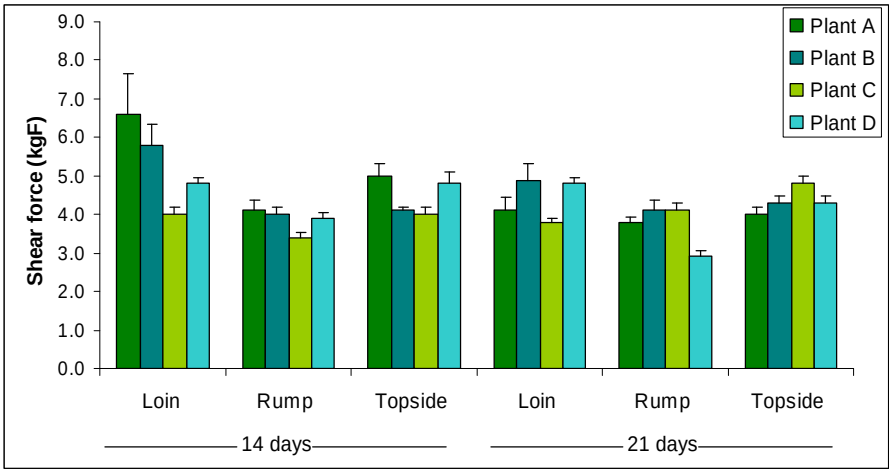


Figure 19. Shearforce (kgF) of shortloin, rump and topside following 14 and 21 days storage at -1.5ºC.

Generally, the shortloin samples had the highest shearforce after each ageing period while the rump samples had the lowest (Figure 19).

Plant C had the lowest shearforce values (more tender) in all cuts after 14 days of ageing compared to the other three plants, although these differences were only statistically significant in the shortloin. This trend was also in the shortloins from Plant C after 21 days of ageing. In contrast, the 21 day aged shortloin samples from Plant B had statistically higher shear force values compared to the shortloin samples from the other three plants, while the rump samples from Plant D were significantly lower than the other plants.

The venison standard for acceptable shearforce is that product should have a mean shearforce of at least 5 kgF with 90% of values (bites) below 8 kgF and none above 10 kgF. At day 14, there were some shortloin samples that were outside this specification; Only 74% of bites from Plant A and 86% of bites from Plant B were less than 8 kgF (individual data not shown), although both Plants C and D attained this specification. However, after 21 days of ageing, the shear force values had improved from Plants A and thus the shortloin samples from all plants were close to, or attained this specification.

Colour Stability and Retail Display Drip Loss

The colour stability was measured in all three cuts after 21 days of ageing only. All four plants showed similar colour stability results for all three cuts, and thus these data have been pooled in Figure 20 (this graph has also been shown in the results summary section).

The visual perception of meat colour is not effectively interpreted by L*, a* and b* values alone, and derived values such as hue angle and chroma tend to be more representative of the human perception of actual colour (hue) and the brightness of the colour (chroma). Typically, during retail display, L* a* and chroma values decrease as the meat becomes duller and losses it's redness, while b* and hue angles increase as the colour changes from red to brown.

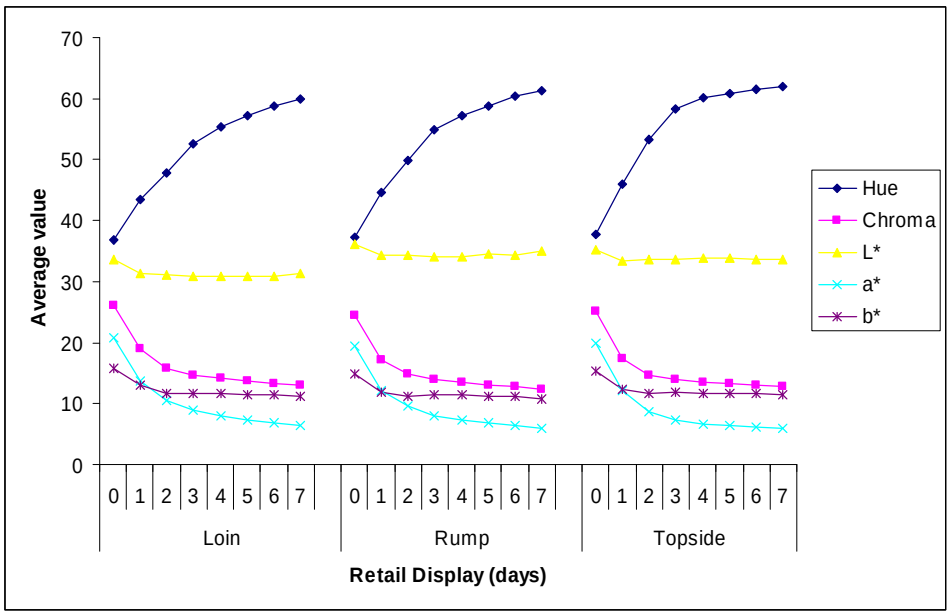


Figure 20. Colour stability for all plants after 21 days storage

Hue, a* and chroma tend to be the best predictor of consumer acceptability of colour. Using these criteria, and comparing data from this work to similar studies in beef and lamb, venison tends to be far less colour stable than either beef or lamb that have been through similar processing and ageing regimes. Typically beef and lamb, under the conditions reported here, would be colour stable for at least 4 days.

Samples from Plant D lost significantly more drip during retail display (Figure 21) compared to samples from the other three plants, irrespective of cut. Normal retail

display drip loss is in the region of 1-2%, while losses from samples from Plant D reached levels of greater than 10%. While it is not clear at this stage why these levels were so extreme, Plant D is being used as part of the process optimisation stage of this work, so strategies to reduce these losses will be considered in the light of processing procedures at this plant.

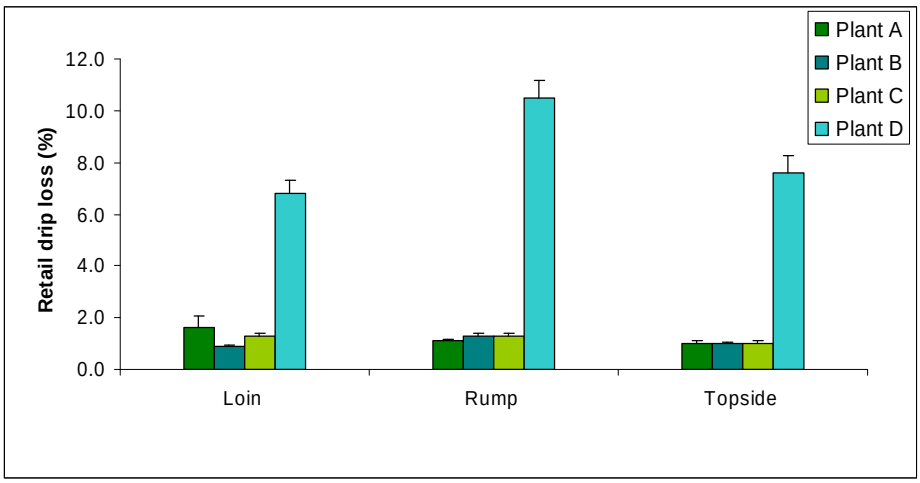


Figure 21. Retail display drip loss (%) of shortloin, rump and topside following 7 days retail display at 6ºC.

Audit 1 to 3 (Chilled shortloins - aged for 21 days prior to evaluation)

Over three consecutive months (September to November), chilled venison shortloin samples were assessed after 21 days of ageing. The meat quality results are presented in Figure 22 to Figure 29.

Drip Loss

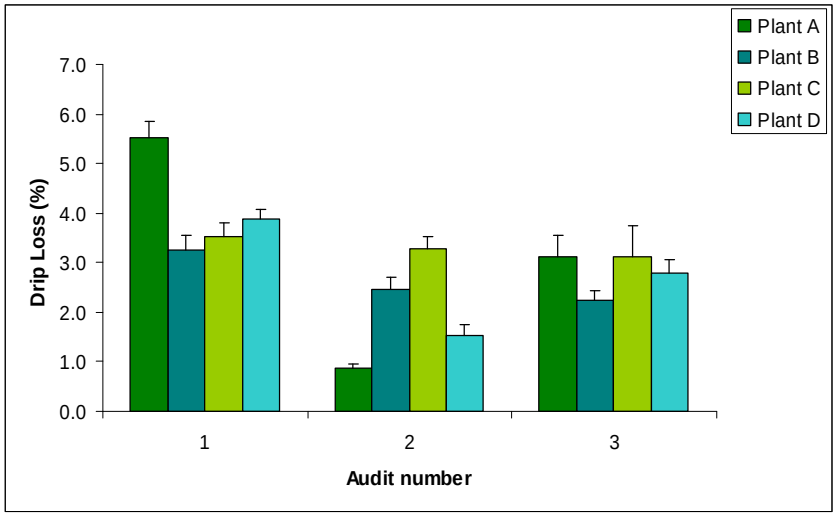


Figure 22. Drip loss (%) from Audit 1 to 3 following 21 days chilled storage.

Overall, the drip loss from all plants during audit 1 (September) was higher than the drip loss from audits 2 and 3 (October and November); the average drip loss for audit 1 was 4%, while for audits 2 and 3 the losses were 2.3 and 2.8% respectively. The losses from shortloin samples from Plant A tended to be higher than from the other three plants during audit 1, but during subsequent audits, these differences were no longer evident.

Ultimate pH

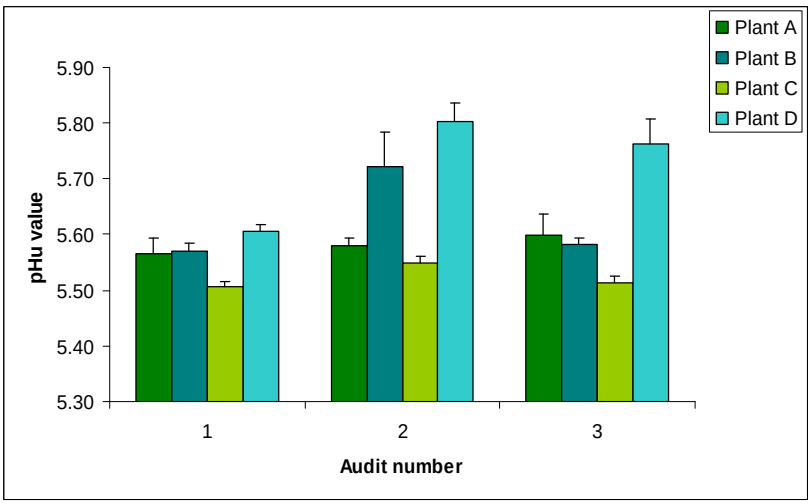


Figure 23. Ultimate pH from Audit 1 to 3 following 21 days chilled storage.

The pHu values for the shortloin samples tended to be lower for audit 1 (September) compared to audits 2 and 3 (October and November). These differences are due largely to the high average pHu for both plants B and D during audit 2 and for plant D at audit 3. Clearly, during these months, animals were coming into the plants with reduced levels of muscle glycogen, resulting in higher than average ultimate pH's.

Cook Loss

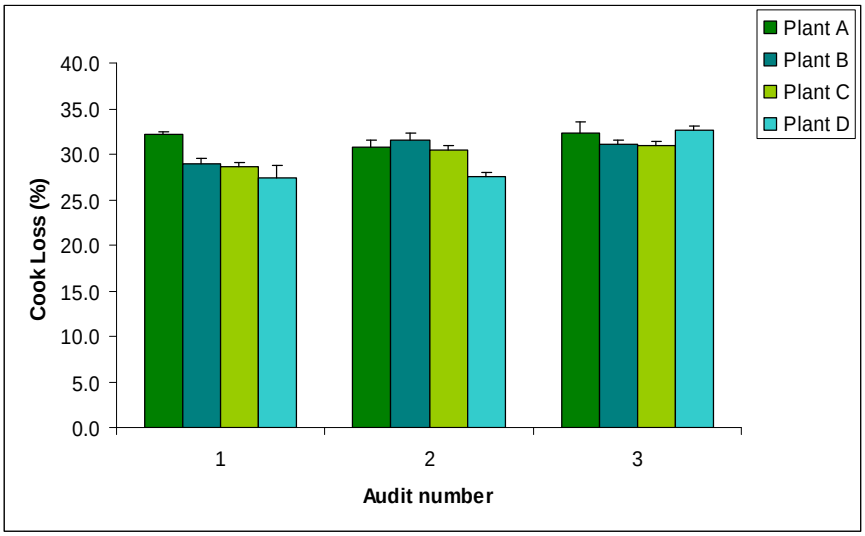


Figure 24. Cook loss (%) from Audit 1 to 3 following 21 days chilled storage.

Between plants and between audits there were no differences in cook losses and all remained within the acceptable range of 25 to 35%.

Shearforce

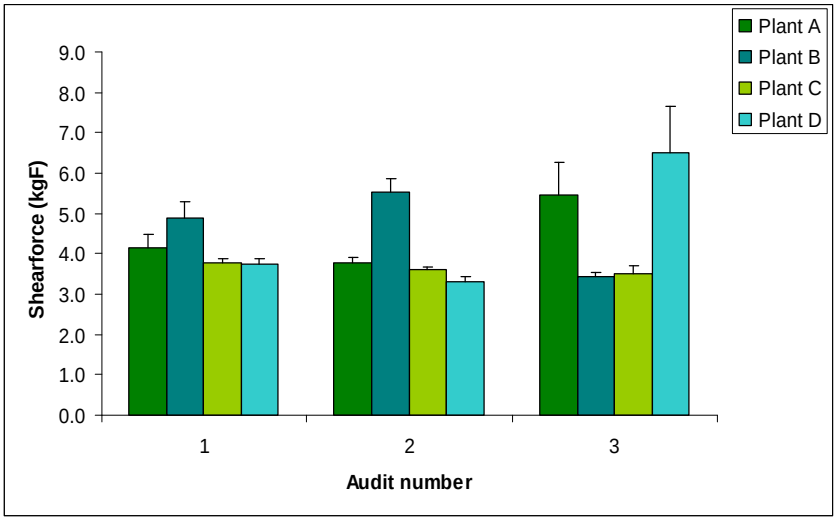
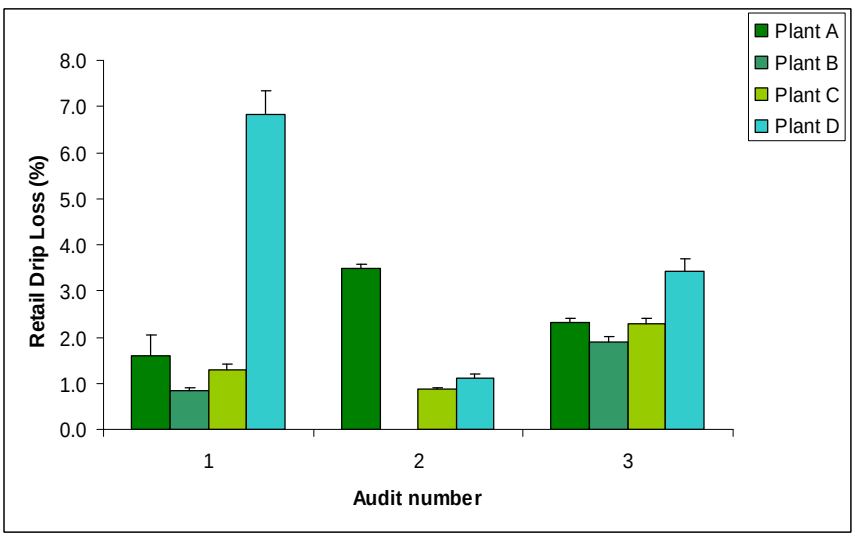


Figure 25. Shearforce (kgF) from Audit 1 to 3 following 21 days chilled storage.

Overall, the shear force was higher during audit 3 (November – average 4.7 Kgf) compared to audits 1 and 2 (September – 4.1 Kgf, October – 4.1 Kgf). The shear force of the shortloin samples from Plant B during audit 2 tended to be higher than those from the other three plants, and during audit 3, the shortloin samples from both Plants A and D were higher than the other two plants.

Colour Stability and Retail Display Drip Loss



NB plant B no valid data for audit 2 retail drip loss due to balance failure

Figure 26. Retail display drip loss (%) from Audits 1 to 3 following 7 days retail display at 6ºC storage.

The high drip loss during retail display from shortloin samples from Plant D - audit 1, is clearly illustrated in Figure 26. However, it is clear that these high drip loss levels do not persist through audits 2 and 3. If the losses from Plant D are excluded from the audit 1 results, then it is clear that drip loss during retail display tends to be higher from samples collected during audit 3 (November).

All plants showed similar colour stability results at each audit, and thus the results have been pooled. Figure 27 to Figure 29 show the pooled results for all four plants over the 3 audits. As these figures illustrate, between audits there was very little variation in the colour stability trends and they all follow the patterns previously described.

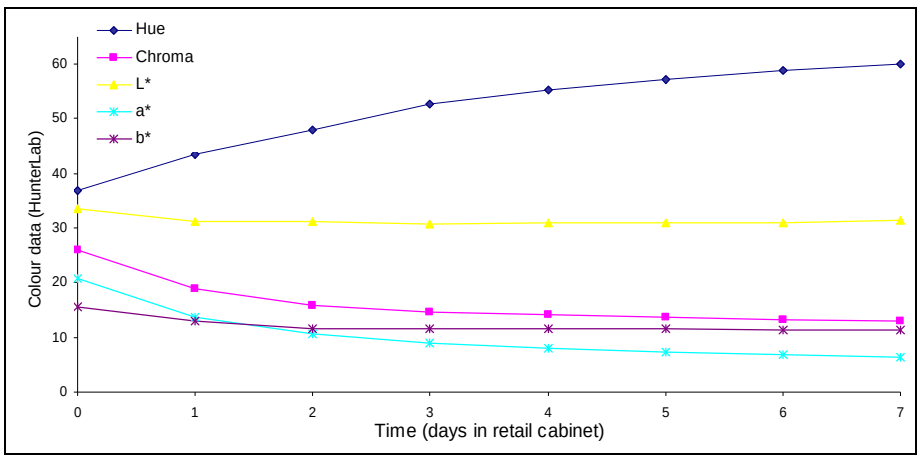


Figure 27. Colour Stability Audit 1 (Pooled Plants).

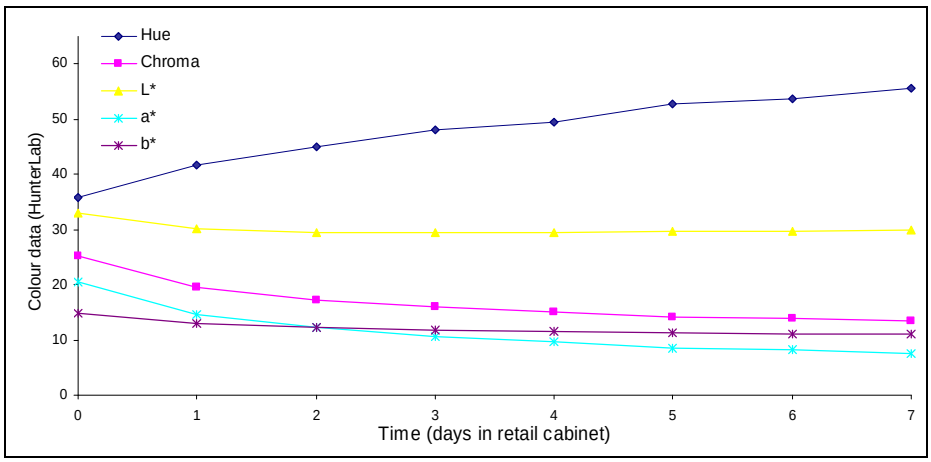


Figure 28. Colour Stability Audit 2 (Pooled Plants).

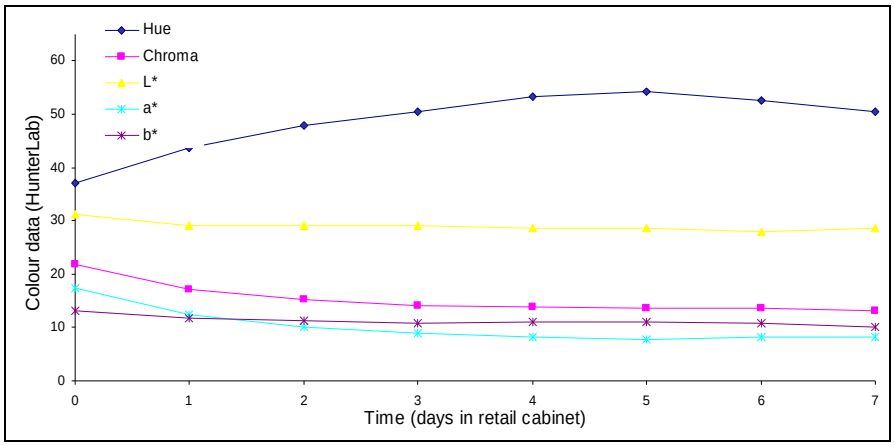


Figure 29. Colour Stability Audit 3(Pooled Plants).

Audit 4 to 6 (Frozen Product shortloins only, evaluated from both the frozen and thawed state)

Drip Loss (from thawing samples)

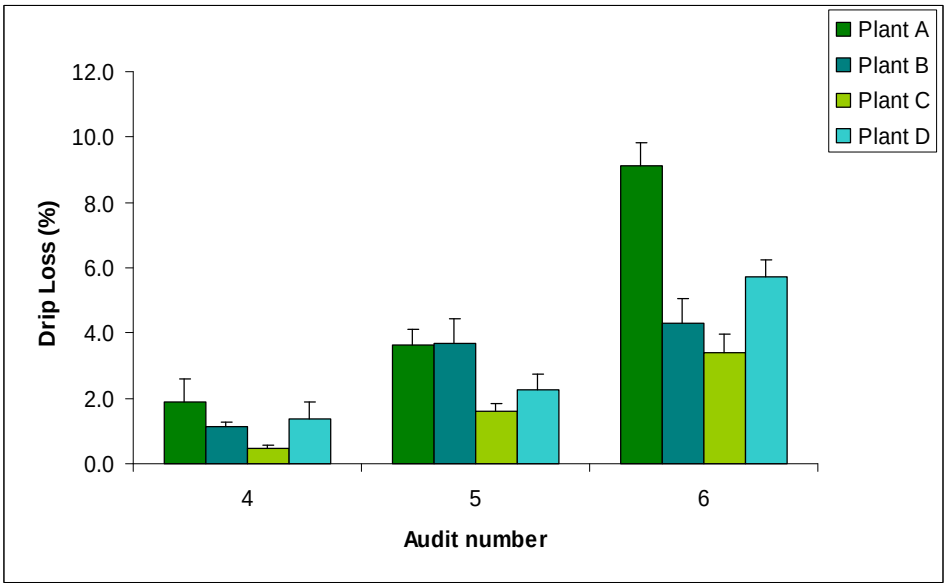


Figure 30. Drip loss (%) from Audit 4 to 6 after thawing.

Clearly, the drip losses, following freezing and thawing, were far greater from samples collected during audit 6 (February). The reasons for this are unclear given that the thawing regime was strictly controlled and consistent between the three audits. While the overall drip loss following thawing averaged 1.2 and 2.8% for audits 4 and 5 (December and January) respectively, levels increased to 5.6% for audit 6 (February). This trend was largely generated by the very high drip loss after thawing measured from the samples from Plant A, with the average loss

being 9.1%. However, it is unlikely that these exceptionally high levels were due to practices at the plant, and were more likely due to an aberration during the handling of this particular sample set – either during removal from frozen storage and/or during thawing. Therefore, in future, the temperature will be logged during thawing procedures here at the MIRINZ Centre.

Ultimate pH

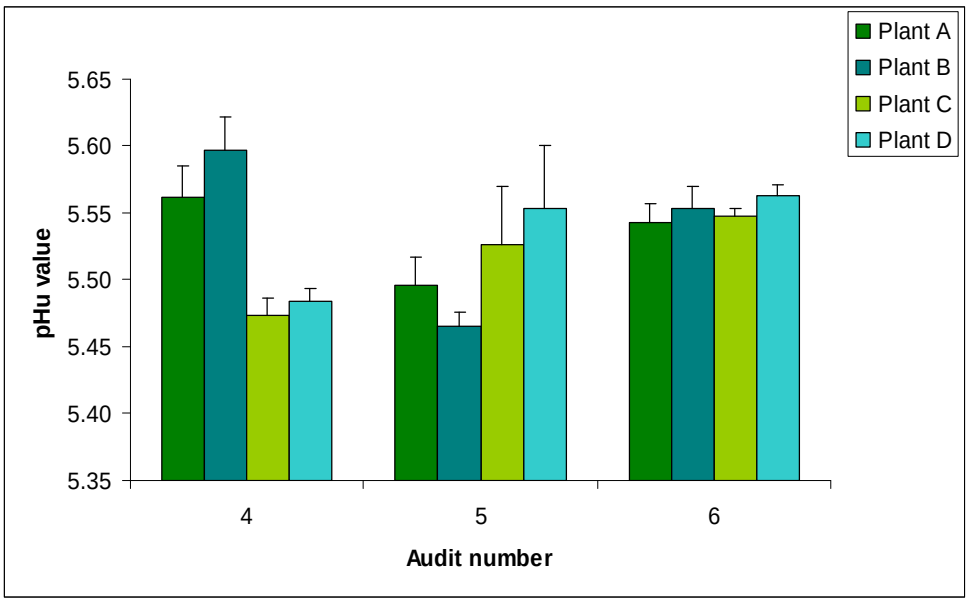


Figure 31. Ultimate pH from Audit 4 to 6 after frozen storage (thawed).

Overall, the pHu of the frozen samples collected during audits 4 to 6 (December, January and February), did not differ markedly. Plant B tended to generate samples with a slightly higher pHu during audit 4 (December), but these differences did not persist during subsequent audits.

Cook Loss

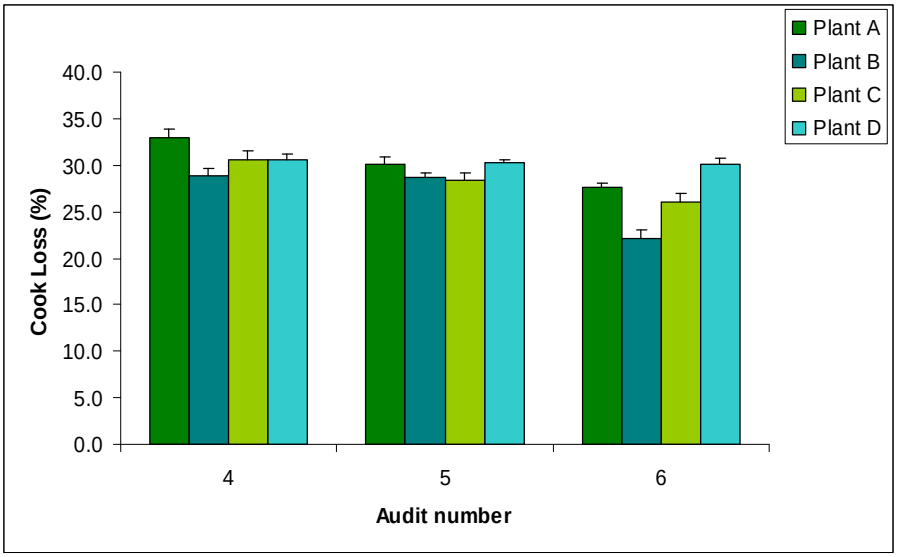


Figure 32. Cook Loss (%) from Audit 4 to 6 after frozen storage (from thawed).

As with audits 1 to 3 (chilled product), the cook loss from the frozen and the thawed samples remained within the expected range at all times. There were some differences in cook loss from samples between plants, but these were relatively minor. As has been demonstrated with previous studies of this nature, cooking from either the chilled, frozen or thawed state, does not tend to have a significant effect on cook loss.

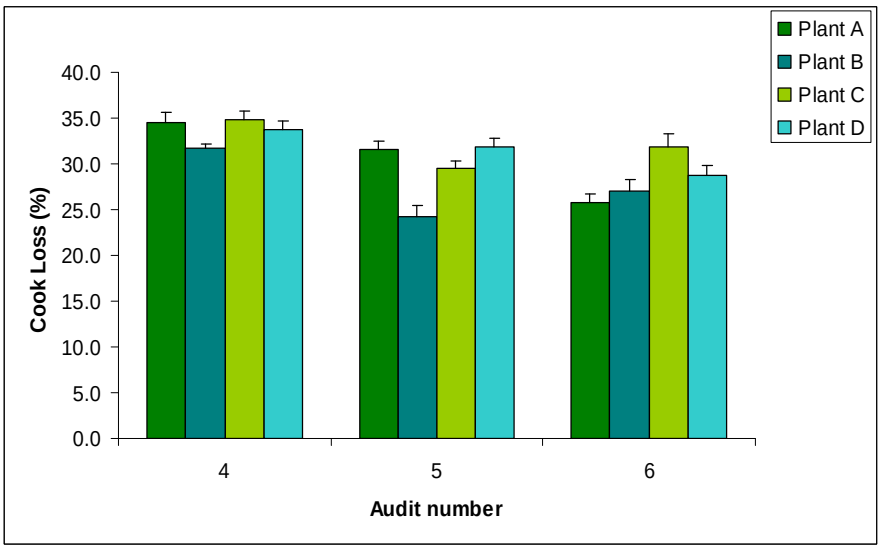


Figure 33. Cook Loss (%) from Audit 4 to 6 after frozen storage (from frozen).

Shearforce

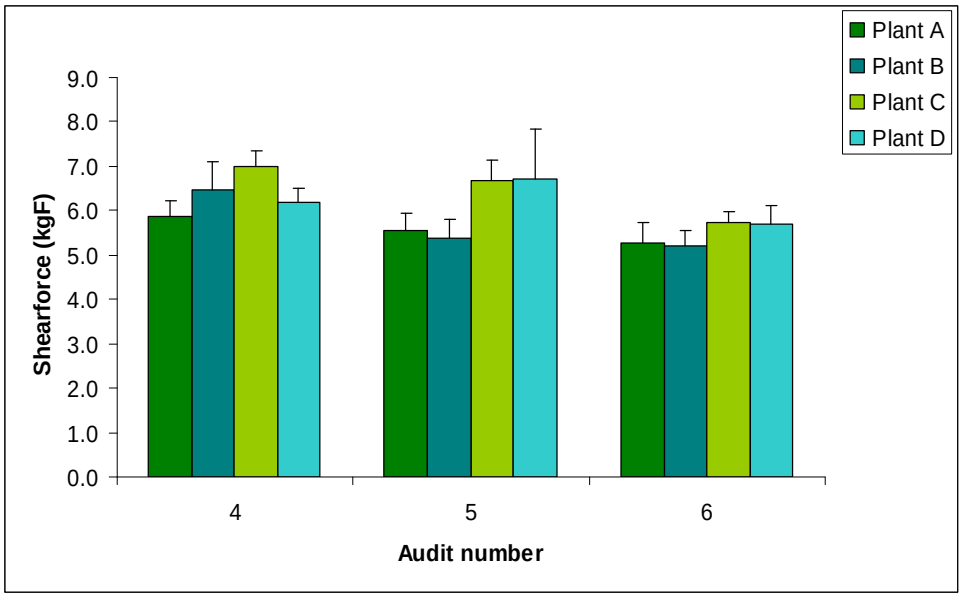


Figure 34. Shearforce (kgF) from Audit 4 to 6 . Samples frozen and then thawed prior to cooking.

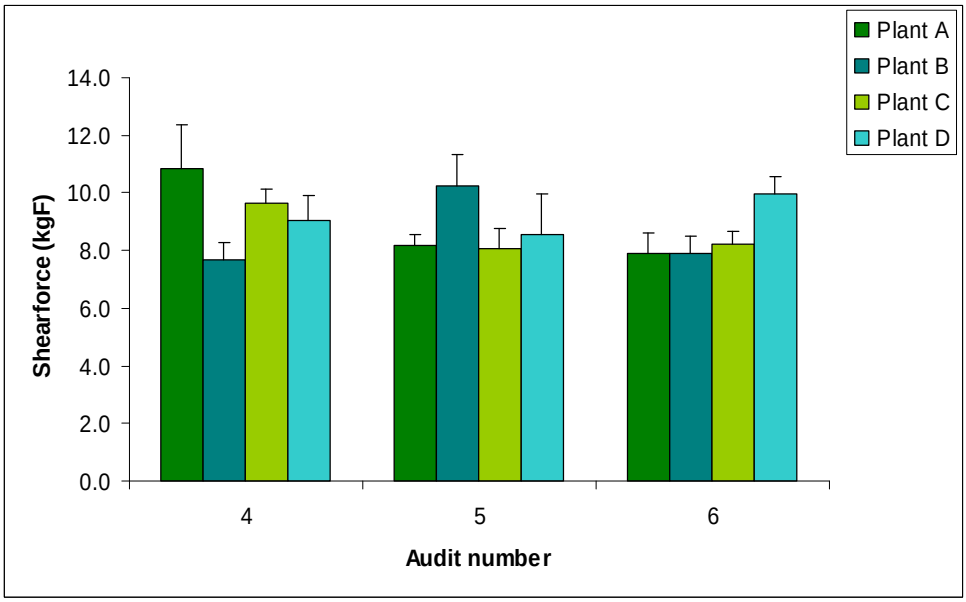


Figure 35. Shearforce (kgF) from Audit 4 to 6. Samples cooked from frozen state

The shear force values were on average, lower from samples that had been thawed prior to cooking (Figure 34) compared to those that were cooked from the frozen state prior to tenderometer testing (Figure 35). This result is expected as some level of additional sample ageing typically occurs during the thawing

process. Furthermore, it has been shown that the rate of ageing during thawing can be accelerated due to the effect of the prior freezing process on the muscle fibres: The disruption or damage caused by freezing can render the fibres more susceptible to enzyme mediated breakdown or ageing.

There were no differences in the shear force values of the shortloins between plants or between audits when the samples were cooked from either the frozen or thawed state.

Colour Stability and Retail Display Drip Loss

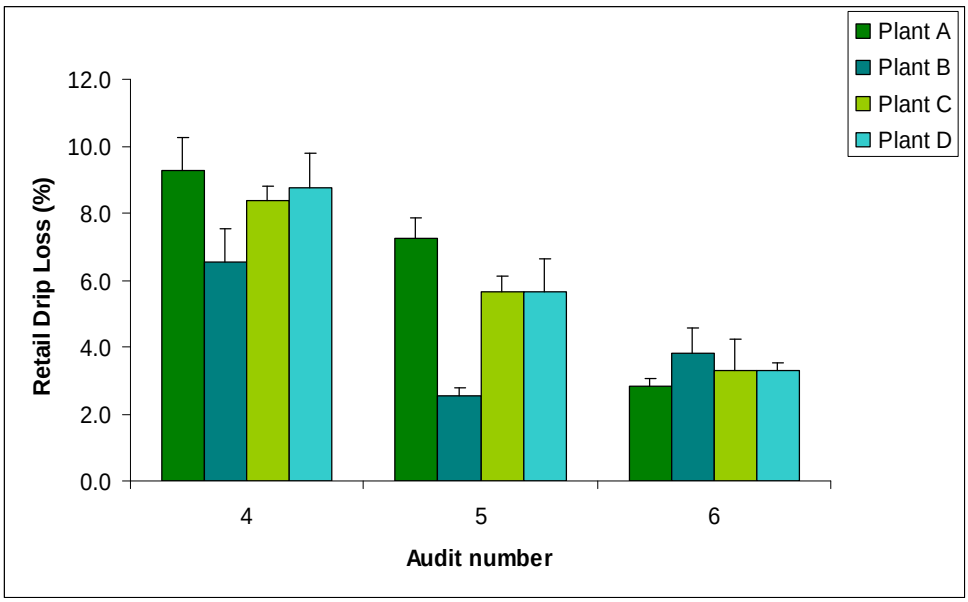


Figure 36. Retail display drip loss (%) from Audit 4 to 6, after thawing and following 7 days retail display at 6ºC storage.

The overall drip loss during retail display was higher during audit 4 (December – 8.2%) compared to the other two audits (January – 5.3.%, February – 3.3%). The reasons for this are unclear; the temperature of the retail display cabinet was continuously logged and remained consistently at 6°C during the 7-day retail display period for all 3 audits. In contrast, the drip loss from plant B during audit 5 was significantly lower than the losses from the other 3 plants during this audit. Clearly there are some anomalies with these data and further work on this during the process optimisation trials may help to explain some of these findings.

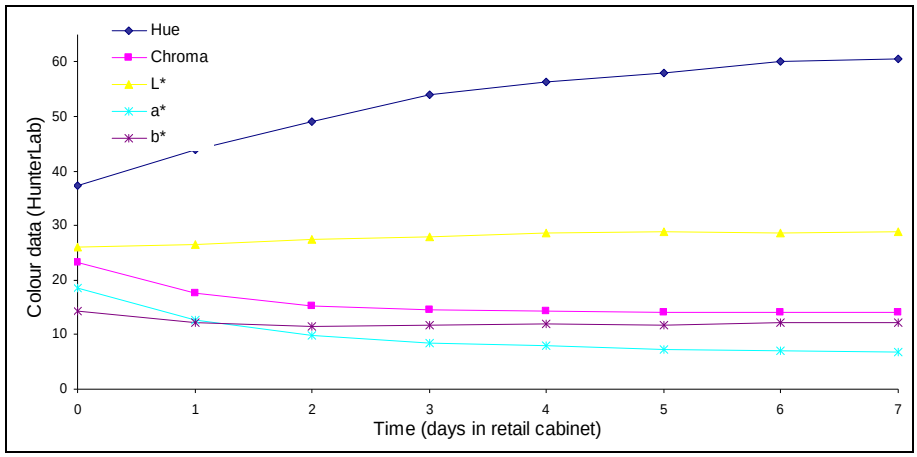


Figure 37. Colour Stability Audit 4 (Pooled Plants).

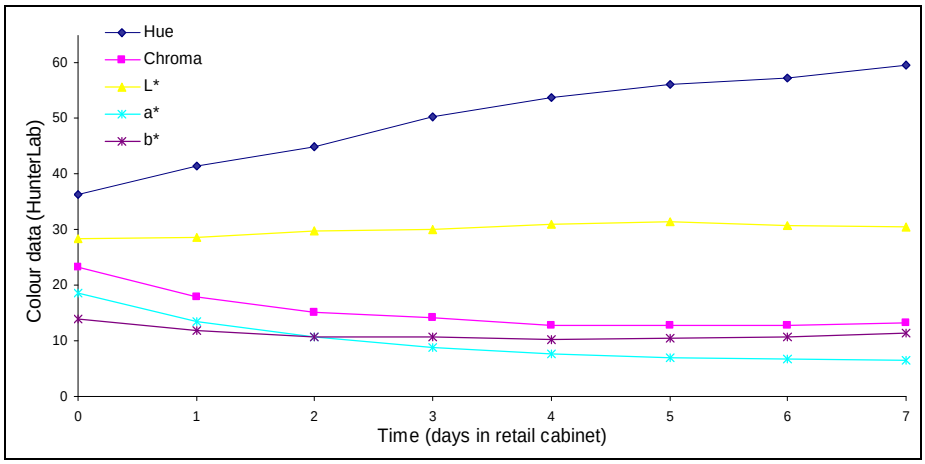


Figure 38. Colour Stability Audit 5 (Pooled Plants).

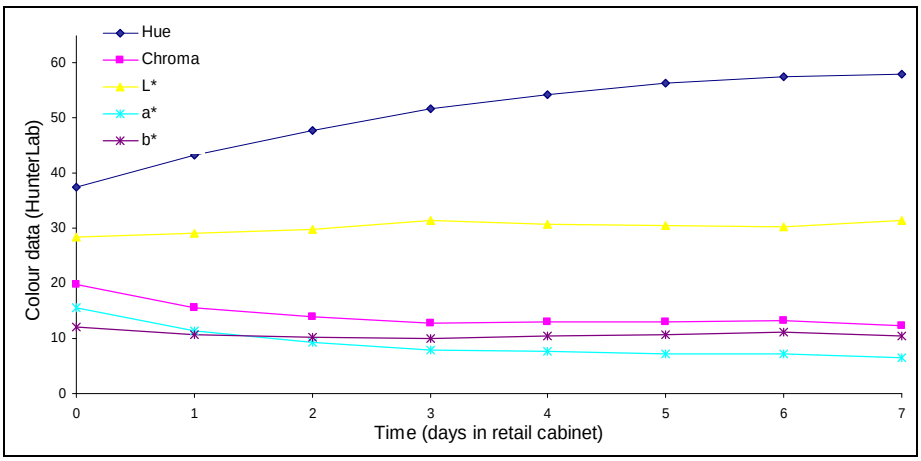


Figure 39. Colour Stability Audit 6 (Pooled Plants).

As with previous colour stability results, there were no differences between plants and thus the results have been pooled across plants for each of the 3 audits. Similarly, there were no differences in colour stability between audits and all data followed the trends previously described (Figures 37 to 39).

Appendix 2. Tables of Detailed Results

Audit 1

Table A2.1. Drip loss (%) from shortloin, rump and topside after 14 and 21 days storage at -1.5ºC.

Storage time	Muscle	Plant A	Plant B	Plant C	Plant D	Significance
14 days	Shortloin	3.7 (1.0)^{a}	2.0 (0.8)^{b}	2.5 (0.8)^{b}	2.6 (0.5)^{b}	P<0.001
	Rump	3.1 (1.6)^{a}	1.4 (0.4)^{b}	1.9 (0.5)^{b}	2.1 (0.8)^{ab}	P<0.01
	Topside	5.1 (1.5)^{a}	2.4 (0.7)^{b}	3.6 (1.0)^{b}	2.7 (0.9)^{b}	P<0.001
21 Days	Shortloin	5.5 (1.1)^{a}	3.2 (1.0)^{b}	3.5 (0.9)^{b}	3.9 (0.6)^{b}	P<0.001
	Rump	4.8 (1.7)^{a}	3.1 (0.8)^{b}	3.1 (0.7)^{b}	4.0 (1.3)^{ab}	P<0.01
	Topside	7.6 (1.6)^{a}	3.9 (0.9)^{b}	5.5 (1.6)^{c}	4.7 (0.7)^{bc}	P<0.001

Within a row, values with different superscripts are significantly different

Table A2.2. Ultimate pH (pHu) from shortloin, rump and topside after 14 and 21 days storage at -1.5ºC.

Storage time	Muscle	Plant A	Plant B	Plant C	Plant D	Significance
14 days	Shortloin	5.57 (0.11)^{a}	5.54 (0.03)^{a}	5.50 (0.05)^{b}	5.57 (0.03)^{a}	P<0.05
	Rump	5.55 (0.07)^{ab}	5.54 (0.04)^{ab}	5.52 (0.02)^{a}	5.58 (0.02)^{b}	P<0.05
	Topside	5.52 (0.05)^{ab}	5.53 (0.03)^{ab}	5.50 (0.04)^{a}	5.57 (0.04)^{b}	P<0.01
21 Days	Shortloin	5.57 (0.09)^{ab}	5.57 (0.04)^{ab}	5.51 (0.03)^{a}	5.61 (0.03)^{b}	P<0.01
	Rump	5.54 (0.07)^{a}	5.56 (0.03)^{ab}	5.55 (0.03)^{ab}	5.60 (0.02)^{b}	P<0.05
	Topside	5.50 (0.03)^{a}	5.52 (0.04)^{a}	5.51 (0.05)^{a}	5.59 (0.03)^{b}	P<0.001

Within a row, values with different superscripts are significantly different

Table A2.3. Cook loss (%) from shortloin, rump and topside cooked after 14 and 21 days storage at -1.5ºC.

Storage time	Muscle	Plant A	Plant B	Plant C	Plant D	Significance
14 days	Shortloin	24.6 (1.8)^{a}	29.0 (1.5)^{b}	27.0 (1.9)^{bc}	25.5 (1.8)^{ac}	P<0.001
	Rump	32.1 (1.9)^{a}	34.7 (2.4)^{a}	32.7 (3.4)^{a}	28.1 (2.8)^{b}	P<0.001
	Topside	34.6 (2.1)^{a}	35.8 (2.6)^{a}	36.2 (2.0)^{a}	26.5 (2.0)^{b}	P<0.001
21 Days	Shortloin	32.1 (1.2)^{a}	28.9 (1.8)^{b}	28.6 (1.5)^{b}	27.4 (4.1)^{b}	P<0.001
	Rump	34.9 (1.9)^{a}	34.0 (2.4)^{ab}	31.6 (1.5)^{b}	34.8 (4.3)^{ab}	P<0.05
	Topside	36.0 (1.6)^{a}	32.1 (1.7)^{b}	33.7 (3.0)^{ab}	33.2 (3.7)^{ab}	P<0.05

Within a row, values with different superscripts are significantly different

Table A2.4. Shearforce values (kgF) of shortloin, rump and topside after 14 and 21 days storage at -1.5ºC.

Storage time	Muscle	Plant A	Plant B	Plant C	Plant D	Significance
14 days	Shortloin	6.6 (3.3)^{a}	5.8 (1.8)^{ab}	4.0 (0.6)^{b}	4.8 (0.4)^{ab}	P<0.05
	Rump	4.1 (0.8)^{a}	4.0 (0.6)^{ab}	3.4 (0.4)^{ab}	3.9 (0.5)^{ab}	P<0.05
	Topside	5.0 (1.0)^{a}	4.1 (0.2)^{ab}	4.0 (0.7)^{b}	4.8 (1.0)^{ab}	P<0.05
21 Days	Shortloin	4.1 (1.1)^{ab}	4.9 (1.3)^{b}	3.8 (0.3)^{a}	4.8 (0.5)^{a}	P<0.05
	Rump	3.8 (0.4)^{a}	4.1 (0.8)^{a}	4.1 (0.6)^{a}	2.9 (0.5)^{b}	P<0.001
	Topside	4.0 (0.6)^{a}	4.3 (0.5)^{ab}	4.8 (0.6)^{b}	4.3 (0.6)^{ab}	P<0.05

Within a row, values with different superscripts are significantly different

Table A2.5. Retail drip loss (%) from shortloin, rump and topside after 7 days retail display at 6ºC.

Muscle	Plant A	Plant B	Plant C	Plant D	Significance
Shortloin	1.6 (1.5)^{a}	0.9 (0.1)^{a}	1.3 (0.4)^{a}	6.8 (1.6)^{b}	P<0.001
Rump	1.1 (0.2)^{a}	1.3 (0.4)^{a}	1.3 (0.3)^{a}	10.5 (2.0)^{b}	P<0.001
Topside	1.0 (0.3)^{a}	1.0 (0.2)^{a}	1.0 (0.3)^{a}	7.6 (2.0)^{b}	P<0.001

Within a row, values with different superscripts are significantly different

Audits 1 to 3 (Chilled Product)

Table A2.6. Drip loss (%) after 21 days chilled storage at -1.5ºC.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
1	5.5 (1.05)^{ab}	3.2 (0.97)^{ab}	3.5 (0.91)^{a}	3.9 (0.57)^{b}	P<0.0001
2	0.9 (0.13)^{a}	2.5 (0.70)^{b}	3.3 (0.82)^{a}	1.5 (0.64)^{b}	P<0.0001
3	3.1 (1.36)^{a}	2.2 (0.67)^{a}	3.1 (1.84)^{a}	2.8 (0.90)^{b}	ns

Within a row, values with different superscripts are significantly different

Table A2.7. Ultimate pH (pHu) after 21 days chilled storage at -1.5ºC.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
1	5.57 (0.09)^{ab}	5.57 (0.04)^{ab}	5.51 (0.03)^{b}	5.61 (0.03)^{b}	P<0.01
2	5.58 (0.04)^{a}	5.72 (0.19)^{b}	5.55 (0.04)^{a}	5.80 (0.10)^{b}	P<0.0001
3	5.60 (0.12)^{a}	5.58 (0.04)^{a}	5.51 (0.04)^{a}	5.76 (0.15)^{b}	P<0.001

Within a row, values with different superscripts are significantly different

Table A2.8. Cook loss (%) after 21 days chilled storage at -1.5ºC.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
1	32.1 (1.15)^{a}	28.9 (1.79)^{b}	28.6 (1.48)^{b}	27.4 (4.12)^{b}	P<0.001
2	30.7 (2.36)^{a}	31.6 (2.42)^{a}	30.5 (1.57)^{a}	27.5 (1.38)^{b}	P<0.001
3	32.3 (3.59)^{a}	31.0 (1.64)^{a}	30.9 (1.53)^{a}	32.6 (1.77)^{a}	ns

Within a row, values with different superscripts are significantly different

Table A2.9. Shearforce (kgF) after 21 days chilled storage at -1.5ºC.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
1	4.1 (1.07)^{ab}	4.9 (1.30)^{b}	3.8 (0.33)^{a}	3.7 (0.52)^{a}	P<0.05
2	3.8 (0.41)^{a}	5.5 (1.04)^{b}	3.6 (0.26)^{a}	3.3 (0.46)^{a}	P<0.0001
3	5.5 (2.55)^{ab}	3.4 (0.37)^{b}	3.5 (0.56)^{b}	6.5 (3.69)^{a}	P<0.01

Within a row, values with different superscripts are significantly different

Table A2.10. 7-day retail display drip loss at 6ºC (after 21 days chilled storage at -1.5ºC).

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
1	1.6 (1.51)^{a}	0.9 (0.12)^{a}	1.3 (0.35)^{a}	6.8 (1.56)^{b}	P<0.0001
2	3.5 (0.36)^{b}		0.9 (0.15)^{a}	1.1 (0.25)^{a}	P<0.0001
3	2.3 (0.27)^{a}	1.9 (0.37)^{a}	2.3 (0.38)^{a}	3.4 (0.89)^{b}	P<0.0001

Within a row, values with different superscripts are significantly different

Audits 4 to 6 (Frozen Product)

Table A2.11. Drip loss (%) from thawing after frozen product.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
4	1.9 (2.25)[a]	1.1 (0.54)[a]	0.5 (0.30)[a]	1.4 (1.68)[a]	ns
5	3.7 (1.42)[b]	3.7 (2.37)[b]	1.6 (0.78)[a]	2.2 (1.50)[ab]	p<0.05
6	9.1 (2.34)[b]	4.3 (2.35)[a]	3.4 (1.78)[a]	5.7 (1.76)[a]	p<0.0001

Within a row, values with different superscripts are significantly different

Table A2.12. Ultimate pH (pHu) from thawing after frozen product.

Audit #	Plant A	Plant B	Plant C	Plant D	Significance
4	5.56 (0.07)[b]	5.60 (0.0408)[b]	5.47 (0.04)[a]	5.48 (0.03)[a]	p<0.0001
5	5.50 (0.07)[a]	5.47 (0.03)[a]	5.53 (0.14)[a]	5.55 (0.15)[a]	ns
6	5.54 (0.04)[a]	5.55 (0.05)[a]	5.55 (0.02)[a]	5.56 (0.03)[a]	ns

Within a row, values with different superscripts are significantly different

Table A2.13. Cook loss (%) after frozen product.

Product	Audit #	Plant A	Plant B	Plant C	Plant D	Significance
Frozen	4	34.6 (3.10)[a]	31.7 (1.61)[a]	34.8 (3.07)[a]	33.7 (3.25)[a]	ns
	5	31.6 (3.07)[b]	24.1 (4.40)[a]	29.5 (2.74)[b]	31.9 (2.57)[b]	p<0.0001
	6	25.8 (2.92)[a]	27.0 (3.97)[a]	31.9 (4.56)[b]	28.7 (3.64)[ab]	p<0.01
Thawed	4	32.9 (3.39)[b]	28.9 (2.20)[a]	30.7 (2.58)[ab]	30.6 (2.02)[ab]	p<0.05
	5	30.1 (2.80)[a]	28.7 (1.79)[a]	28.4 (2.70)[a]	30.2 (1.42)[a]	ns
	6	27.6 (1.55)[a]	22.1 (2.71)[a]	26.0 (3.29)[a]	30.1 (1.75)[a]	p<0.0001

Within a row, values with different superscripts are significantly different

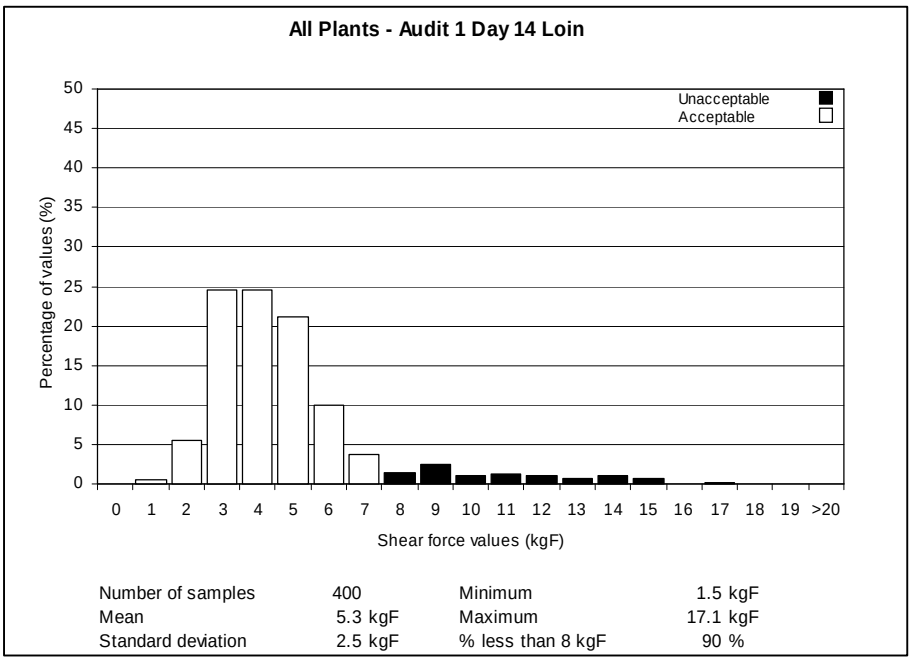
Table A2.14. Shearforce (kgF) after frozen product.						
Product	Audit #	Plant A	Plant B	Plant C	Plant D	Significance
Frozen	4	10.9 (4.79)[a]	7.7 (1.93)[a]	9.6 (1.70)[a]	9.1 (2.74)[a]	ns
	5	8.2 (1.25)[a]	10.2 (3.45)[a]	8.1 (2.20)[a]	8.6 (4.42)[a]	ns
	6	7.9 (2.24)[a]	7.9 (1.70)[a]	8.2 (1.39)[a]	10.0 (1.77)[a]	ns
Thawed	4	5.9 (1.07)[a]	6.5 (2.03)[a]	7.0 (1.11)[a]	6.2 (41.08)[a]	ns
	5	5.6 (1.20)[a]	5.4 (1.36)[a]	6.7 (1.43)[a]	6.7 (3.58)[a]	ns
	6	5.3 (1.46)[a]	5.2 (1.05)[a]	5.7 (0.81)[a]	5.7 (1.29)[a]	ns

Within a row, values with different superscripts are significantly different

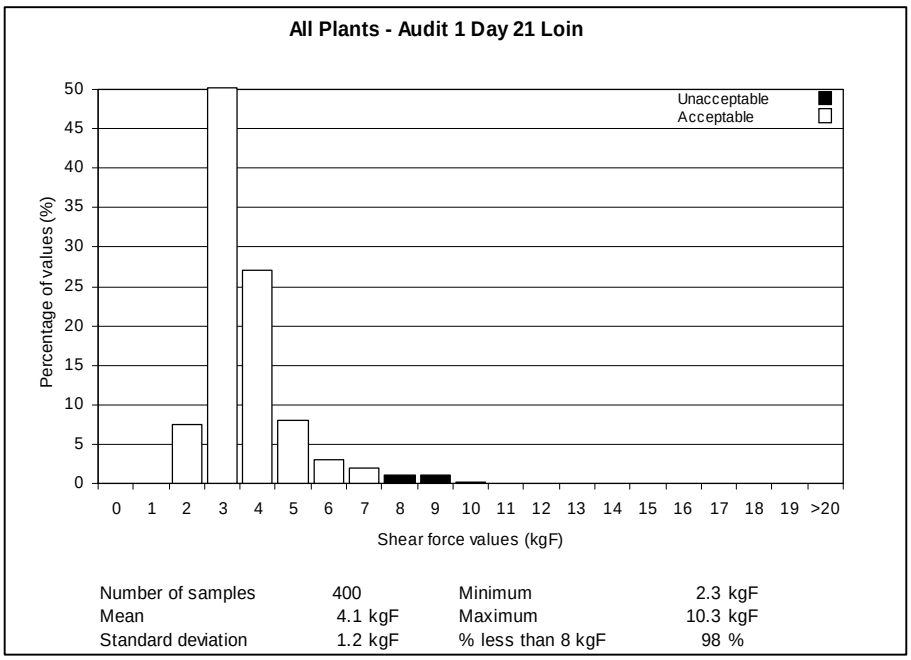
Table A2.15. 7-day retail display drip loss at 6ºC (after thawing from frozen product).					
Audit #	Plant A	Plant B	Plant C	Plant D	Significance
4	9.3 (3.14)[a]	6.5 (3.14)[a]	8.4 (1.24)[a]	8.8 (3.20)[a]	ns
5	7.3 (1.91)[b]	2.5 (0.67)[a]	5.7 (1.39)[b]	5.7 (3.02)[b]	p<0.0001
6	2.8 (0.65)[a]	3.8 (2.39)[a]	3.3 (2.89)[a]	3.3 (0.65)[a]	ns

Within a row, values with different superscripts are significantly different

Appendix 3. Complete Set of Audit Histograms

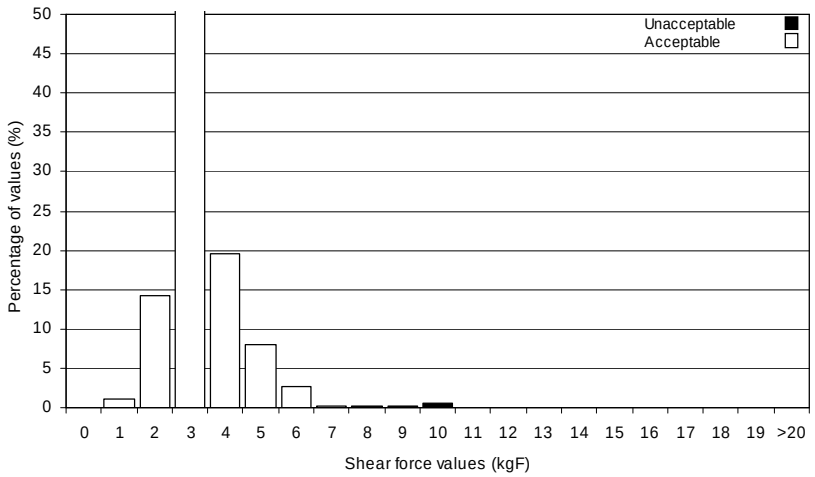


Number of samples	400	Minimum	1.5 kgF
Mean	5.3 kgF	Maximum	17.1 kgF
Standard deviation	2.5 kgF	% less than 8 kgF	90 %



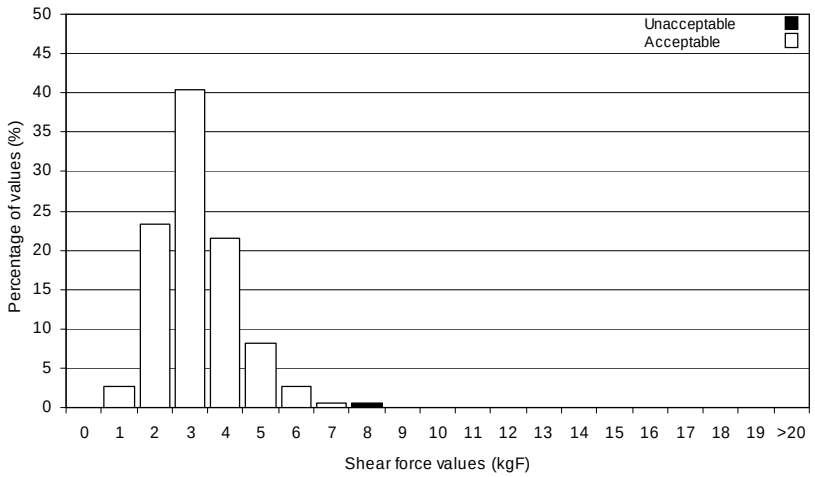
Number of samples	400	Minimum	2.3 kgF
Mean	4.1 kgF	Maximum	10.3 kgF
Standard deviation	1.2 kgF	% less than 8 kgF	98 %

All Plants - Audit 1 Day 14 Rump

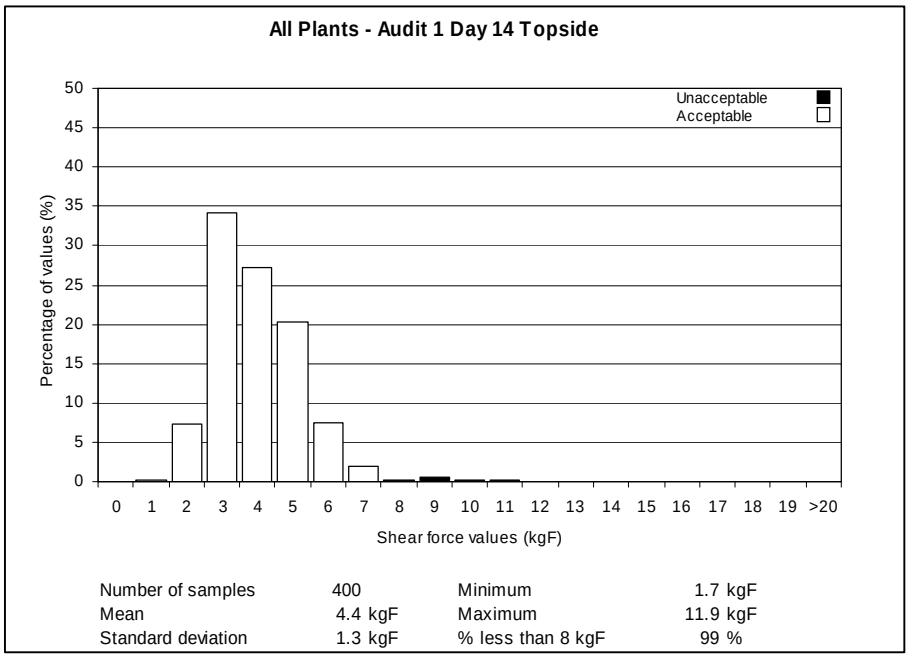


Number of samples	400	Minimum	1.7 kgF
Mean	3.8 kgF	Maximum	10.3 kgF
Standard deviation	1.1 kgF	% less than 8 kgF	99 %

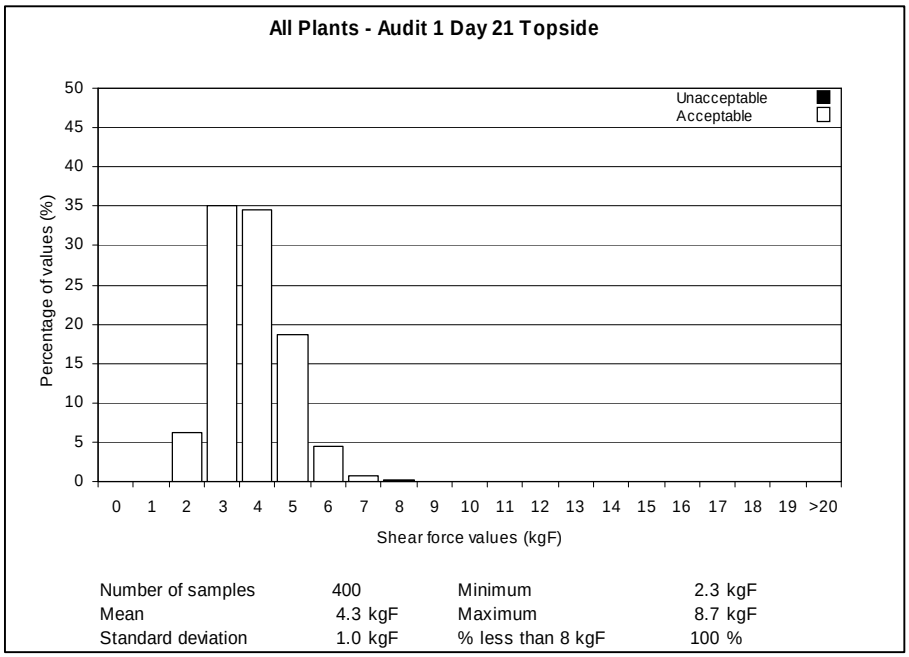
All Plants - Audit 1 Day 21 Rump



Number of samples	399	Minimum	1.5 kgF
Mean	3.7 kgF	Maximum	8.9 kgF
Standard deviation	1.1 kgF	% less than 8 kgF	99 %

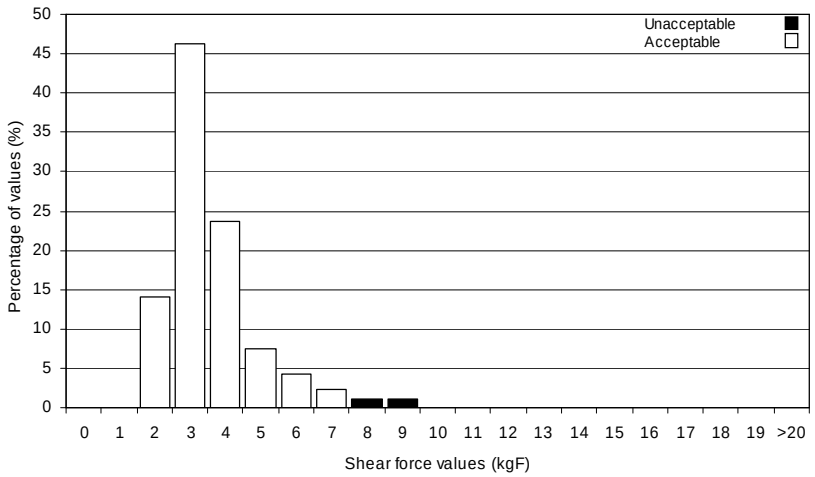


Number of samples	400	Minimum	1.7 kgF
Mean	4.4 kgF	Maximum	11.9 kgF
Standard deviation	1.3 kgF	% less than 8 kgF	99 %



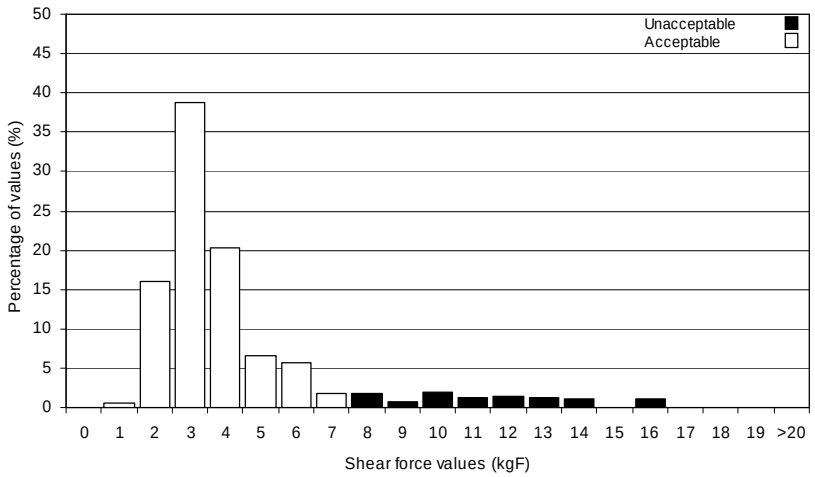
Number of samples	400	Minimum	2.3 kgF
Mean	4.3 kgF	Maximum	8.7 kgF
Standard deviation	1.0 kgF	% less than 8 kgF	100 %

All Plants - Audit 2 Loins

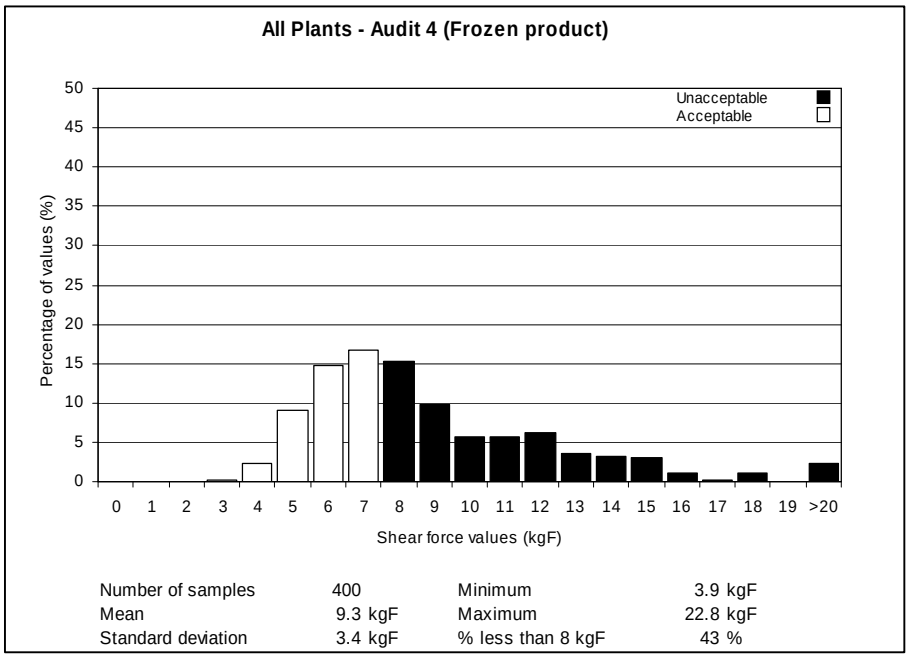


Number of samples	400	Minimum	2.3 kgF
Mean	4.0 kgF	Maximum	9.9 kgF
Standard deviation	1.3 kgF	% less than 8 kgF	98 %

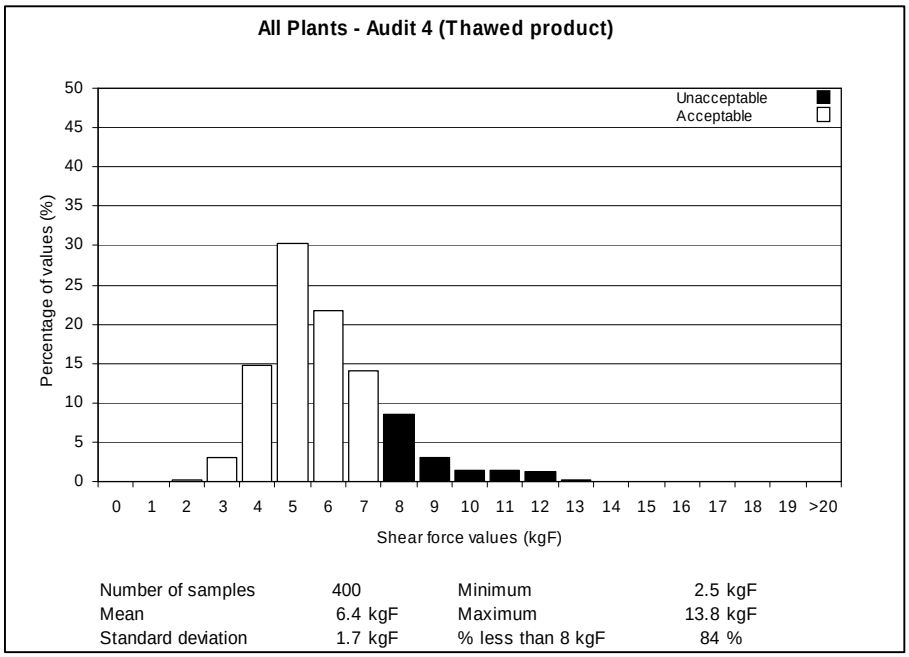
All Plants - Audit 3 Loins



Number of samples	400	Minimum	1.5 kgF
Mean	4.7 kgF	Maximum	16.9 kgF
Standard deviation	2.7 kgF	% less than 8 kgF	90 %

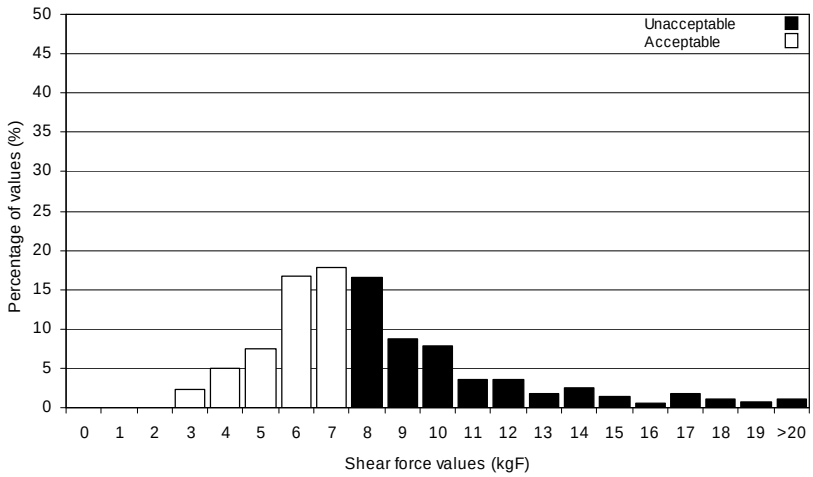


Number of samples	400	Minimum	3.9 kgF
Mean	9.3 kgF	Maximum	22.8 kgF
Standard deviation	3.4 kgF	% less than 8 kgF	43 %



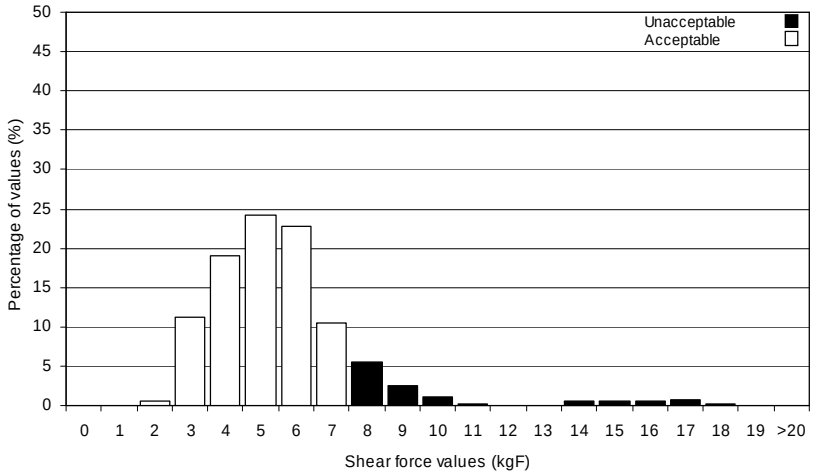
Number of samples	400	Minimum	2.5 kgF
Mean	6.4 kgF	Maximum	13.8 kgF
Standard deviation	1.7 kgF	% less than 8 kgF	84 %

All Plants - Audit 5 (Frozen product)



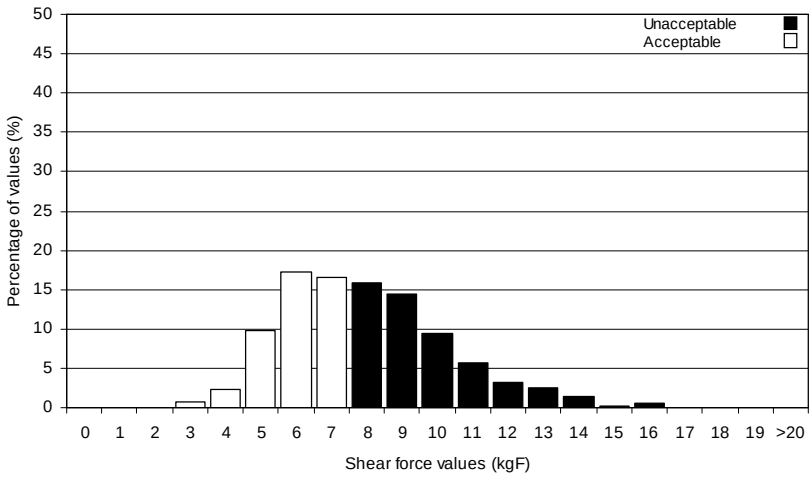
Number of samples	400	Minimum	3.3 kgF
Mean	8.8 kgF	Maximum	21.4 kgF
Standard deviation	3.4 kgF	% less than 8 kgF	49 %

All Plants - Audit 5 (Thawed product)



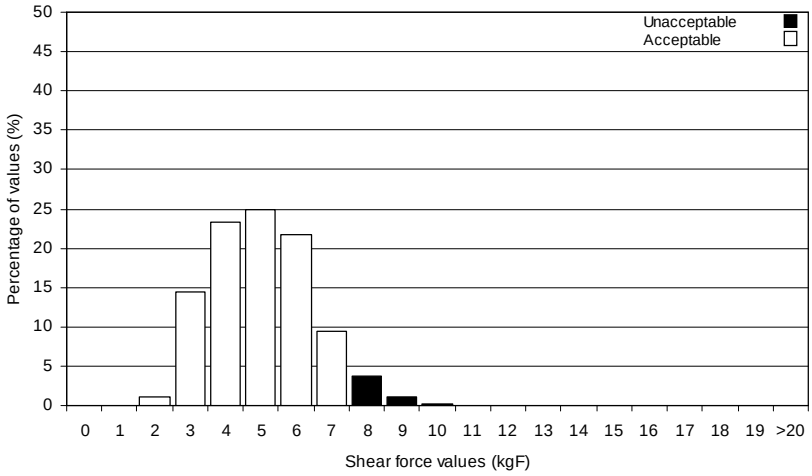
Number of samples	400	Minimum	2.7 kgF
Mean	6.1 kgF	Maximum	18.1 kgF
Standard deviation	2.3 kgF	% less than 8 kgF	88 %

All Plants - Audit 6 (Frozen product)



Number of samples	400	Minimum	3.5 kgF
Mean	8.5 kgF	Maximum	16.9 kgF
Standard deviation	2.3 kgF	% less than 8 kgF	47 %

All Plants - Audit 6 (Thawed product)



Number of samples	400	Minimum	2.7 kgF
Mean	5.5 kgF	Maximum	10.1 kgF
Standard deviation	1.4 kgF	% less than 8 kgF	95 %