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Addressing key issues affecting compliance rates of pasture-fed cattle in southern Australia

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Abstract

Dark cutting is the major cause of non-compliance for MSA graded carcasses, with high incidences during autumn and winter in southern Australia. In South Australia, older, non-curfewed animals which were moved in the week prior to consignment, grazing grass dominant pastures with <3000 kg DM/ha with low magnesium, were at heightened risk of dark cutting. In Tasmania, non-supplemented cattle, drinking from dams and consuming pastures low in magnesium had higher incidences. Mycotoxins are also affecting the incidence of dark cutting. In spring when feed dries off, supplementation of cattle with 25 MJ energy/hd/day using a grain based pellet increases carcass weight, muscle glycogen and reduces risk of dark cutting, but lupins were not effective. The uncoupling of pH and colour was not very prevalent in carcasses graded in southern processors. Ageing increased the bloom depth and eliminated the difference in colour at retail display. There was an immensely wide range of carcass fatness and weights presented to southern processors, for which lean meat yield could be predicted with moderate accuracy using MSA measures. The intramuscular fat genetic value has the largest impact on the MSA index. An increase in IMF EBV of 1 SD would improve the MSA Index by 0.28 and 0.1 units for cattle long feedlot finished and finished on pasture respectively.

Until now, an MSA minimum requirement of meat colour 1B – 3 was in place. There is now no evidence that meat colour has an impact on eating quality. Consumers do not visually discriminate against meat colours (greater than 3) at the point of sale, where pH is an acceptable level. The MSA Beef Taskforce endorsed the removal of meat colour as a specification for the MSA eating quality grading system in December 2016; however, this project reports on the influences of meat colour as contracted prior to 2016. The removal of meat colour as an MSA specification will have minimal impact on the MSA grading process. Other industry standards such as the AUS-MEAT grain fed specifications will still apply (meat colour 1B – 3). For grain fed carcases being MSA graded, this will need to be included as a company specification in the relevant PBR line.

Executive summary

Factors affecting the incidence of dark cutting

This project quantified the variation between months in the incidence of dark cutting, in southern Australia. Four years of MSA grading data, from nine individual beef processors in Western Australia (WA), South Australia (SA), Victoria (VIC) and Tasmania (TAS), was utilised for the analysis. The dataset contained 42,162 slaughter groups, of 10 or more grass-fed cattle, which allowed for the percentage of dark cutters per slaughter group to be analysed. The incidence of dark cutting was highest for all states during the period from February to June. This data analysis drove the direction of this project as the causes of the higher incidences during the autumn and winter period were not well understood.

On-farm management, pasture quality and liver mineral status was recorded from July 2014 to December 2016 for 3280 cattle over 68 separate slaughter groups from the Limestone coast region of SA. Five hundred and seventy six (17.5%) of carcasses were non-compliant for pH and/or meat colour and deemed “dark cutters”. Older cattle (> 24 months of age) had more than double the incidence of dark cutting compared to younger cattle (29.2 vs 13.6% respectively). Movement of cattle to a different paddock within one week of slaughter resulted in significantly higher incidence of dark cutting (32.4%) compared with those moved at later intervals (24.7%). In this data set, cattle that underwent a curfew prior to slaughter had a lower incidence of dark cutting than those which were not curfewed (30.0 vs. 18.5%) which could be linked to greater defaecation during transport and lairage, and increased slipping and/or pre-slaughter washing. Consignments grazing pure grass pastures had higher rates of dark cutting than those grazing mixed pastures (26.4 vs. 17.9%). Pasture availability in the week prior to slaughter of greater than 3000 kg DM/ha reduced the incidence of dark cutting significantly (14.9 vs. 22.9%). Pasture magnesium concentration was the only pasture compositional trait to show a relationship with the incidence of dark cutting. The high pasture nitrogen and/or potassium levels encountered in lush green feed along with increased rumen passage rates inhibit magnesium uptake and leading to sub-clinical hypomagnesemia, heightens an animals sensitivity to stress.

King Island pasture raised cattle (n=3,185) sent for slaughter on mainland TAS were evaluated to determine which on farm factors increased the incidence of dark cutting. Cattle were sent in groups (n=66) to slaughter from March - June 2015. Animals grazing pasture with magnesium concentration exceeded 0.24% had a 26% decreased relative risk of dark cutting. Cattle accessing dam water had a 50% increase in relative dark cutting risk compared to groups drinking from a trough. Feeding supplementary feed (hay/silage) in the last seven days prior to slaughter reduced the dark cutting relative risk by 25%. There was a high prevalence of mycotoxins detected in the pasture across all farms.

Supplementation experiments

The aim of this experiment was to evaluate the impact of nutritional supplementation over 14 days prior to slaughter on the rates of dark cutting in pasture fed cattle in two southern regions during the period of pasture decline. Nineteen lots (n=959) of cattle from WA and 10 lots (n=619) from SA were divided into treatment and control groups. Treatment animals were supplemented with 2.5

kg/head/day of a high-energy pelleted ration in WA and 2 kg/head/day of lupins in SA, while still grazing pasture for approximately 14 days before slaughter. The control animals grazed pasture only. The rate of dark cutting was low throughout the trial and supplementation did not reduce the rate of dark cutting in either state. However, the nutritional supplementation with pelleted feed resulted in an increase in muscle glycogen ($P<0.001$) and carcase weight of 2.72 kg (when adjusted for starting weight) compared to controls. The carcass weight gain alone made the pelleted treatment economically viable, and an increase in muscle glycogen could likely buffer at risk animals against dark cutting. Short-term nutritional intervention has the potential to reduce the non-compliance due to dark cutting of at risk cattle during late spring and early summer.

Short-term magnesium supplementation (4-7days) prior to slaughter could be very beneficial for pasture-finished beef cattle during autumn and winter due to the low levels of pasture magnesium. Magnesium is not stored in the body so must be consumed daily. Due to the bitter taste of magnesium, supplementation provides challenges with palatability for daily intake. Substantial economic gains are possible if it increases muscle glycogen concentration and decreases dark cutting carcass percentages. The supplementation experiment demonstrated that pasture fed beef cattle would consume pellets daily if trained prior to the four to seven day period. Ensuring sufficient quantity of magnesium intake along with providing a palatable supplement is key to success for short-term supplementation.

Rates of uncoupling between pH and meat colour

Meat Standards Australia grading data from nine plants in southern Australian were analysed for the occurrence of dark cutting and the correlation of pH and meat colour data. While there is generally a strong association between colour and pH, this relationship can become 'uncoupled'. However, the current rate of uncoupling in these nine processors is extremely low and is often less than 0.1% of all carcases graded from individual processors (Non-compliant for pH only for all plants, mean 0.15 % ± 0.91; range = 0 to 25%; Non-compliant for meat colour only for all plants, mean 0.33% ± 2.01; range 0 to 89.7 %). Meat colour has no impact on eating quality. It is therefore recommended that MSA grading use only pH and not meat colour when assessing dark cutting.

Until now, an MSA minimum requirement of meat colour 1B – 3 was in place. There is now no evidence that meat colour has an impact on eating quality. Consumers do not visually discriminate against meat colours (greater than 3) at the point of sale, where pH is an acceptable level. The MSA Beef Taskforce endorsed the removal of meat colour as a specification for the MSA eating quality grading system in December 2016; however, this project reports on the influences of meat colour as contracted prior to 2016. The removal of meat colour as an MSA specification will have minimal impact on the MSA grading process. Other industry standards such as the AUS-MEAT grain fed specifications will still apply (meat colour 1B – 3). For grain fed carcases being MSA graded, this will need to be included as a company specification in the relevant PBR line.

Rib fat and carcass weight compliance

Hot standard carcass weight and rib fat data from nine plants in the southern areas of Australia were collated over a four-year period (2010-2013). The total non-compliance based on fat ranged from 0.27% to 0.91%, with the highest rate over this period for an individual plant being 1.59%. Cattle from Grass fed systems had a fat non-compliance rate of 0.74% while grain fed systems had a low rate of 0.086%. Carcases that weighed less than 200 kg had a rate of 2.8% non-compliance for fat. Frequency data of carcass weight and carcass fatness across all years and plants is a great tool to understand the specifications of the cattle slaughtered in the southern regions.

Lean Meat Yield determination

The best methods for determining lean meat yield are those that cannot be applied to the industry (CT and manually fabricated yield) due to cost and time constraints. Industry yield determinants predict the yield based on multiple regression equations. By predicting the percentage muscle in carcases, the Australian beef industry will have the ability to identify more valuable carcases. The measurements taken by MSA describe a range of carcass attributes including a number for fatness, maturity and muscling measures. By using the MSA measures of left side hot carcase weight, rib fat and eye muscle area from historic CT data sets, lean meat yield could be predicted describing 62-73% of the variation with RMSE of 2.68 to 3.14. By adding feedtype (Grass or grain) and sex to the prediction equations, the prediction power of the equation improved. Total prediction power is limited by the number of carcases in the CT data set.

Genetic effects on eating quality

BREEDPLAN reports estimated breeding values (EBVs) for many traits. With the exception of carcass weight, there are no EBVs specifically for the inputs into the MSA index. It is not known how the selection for current BREEDPLAN EBVs influences the MSA index and if these relationships are the same for different market endpoints. This study investigated the extent to which MSA Index of commercial animals is related to EBVs of sires.

Data from 12 industry or research data sets totalling 6997 animals from four breeds (Angus, Charolais, Hereford and Limousin) and 433 sires were included for analysis. Carcass traits (IMF, MSA marbling, EMA, MSA Index, Rib fat, Ossification and HSCW) were regressed on BREEDPLAN sire EBVs (IMF EBV, EMA EBV, 600 day weight EBV, Rib EBV). Sire variance components were estimated for each of the 12 datasets Table to determine whether the genetic variance in MSA index and its indicator traits change with carcass weight.

The genetic (sire) variation in carcass traits changes with marked end point for all carcass traits except ossification. The largest difference between market end points was observed in IMF where there was a 5.5 fold increase in the sire standard deviation for a Long feedlot finish system relative to pasture (1.63 % Long vs 0.04% pasture finish). For HSCW, Rib Fat, Marbling and MSA index there was at least a X 1 increase in the sire standard deviation for Long feedlot finish compared to pasture.

The sire EBV that had the greatest effect on MSA index was IMF. An increase in IMF EBV of 1 SD would improve the MSA Index by 0.28 units for cattle long feedlot finished cattle or 0.10 units for cattle finished on pasture. Currently the IMF EBV is +2.9 for the top 10% of Angus sires (Angus Australia, 2017) and the breed average is +1.6 %, this equates to a 0.65% superiority in IMF EBV in progeny from

these sires. If commercial producers selected bulls from the top 10% for IMF EBV they would only deliver a 0.08 (Pasture) and 0.22 (Long) increase in MSA Index.

For the same trait (e.g. IMF), it was expected that half of the sire superiority would be passed on to progeny. However, this was commonly less than 0.5 for Pasture finished and much greater for Long-fed cattle. This affects the premiums that commercial producers should pay for bulls based on EBVs in addition to the issues of being able to capture additional value for superior carcasses.

Table of contents

1 Background....13

1.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts....13

1.1.1 Mycotoxins....13

1.1.2 Minerals....14

1.2 Assessed current industry compliance to fat and weight specifications using MSA data....14

1.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes....14

1.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle....15

1.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield....17

1.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield....17

1.7 Genetics of BREEDPLAN carcass traits and meat eating quality....18

1.7.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality....18

1.7.2 Relationship between BREEDPLAN EBVs and meat eating quality....18

1.7.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits 20

2 Project objectives....21

3 Methodology....21

3.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts....21

3.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia 21

3.1.1.1 Statistical Analyses....22

3.1.2 Farm management and feed quality factors contributing to dark cutting in King Island 23

3.1.2.1 Statistical Analysis....24

3.2 Assessed current industry compliance to fat and weight specifications using MSA data....25

3.2.1 Methods and materials....25

3.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes....25

3.3.1 Lot analysis....25

3.3.2 pH analysis....26

3.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle 26
3.4.1 End of Season nutritional intervention 26
3.4.1.1 Experimental Design 26
3.4.1.2 Weather Analysis 27
3.4.1.3 Pasture Quality Analysis 27
3.4.1.4 MSA Measurements 27
3.4.1.5 Glycogen Analysis and pH Decline 29
3.4.1.6 Statistical Analysis 29
3.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield 30
3.5.1 Data 30
3.5.2 Methods 33
3.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield 34
3.7 Investigating relationships between market end point and expression of carcass traits associated with eating quality 34
3.7.1 Meat Standards Australia data 34
3.7.2 Slaughter group information 34
3.7.3 Data Analysis 34
3.8 Genetics of BREEDPLAN carcass traits and meat eating quality 35
3.9 Relationship between BREEDPLAN EBVs and meat eating quality 35
3.9.1 Data and Measurements 35
3.9.2 Statistical Analyses 40
3.9.2.1 Relationship between BREEDPLAN EBVs and meat eating quality 40
3.9.2.2 Genetic parameters between current BREEDPLAN traits and meat eating quality traits 40
4 Results 41
4.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts 41
4.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia 41
4.1.1.1 Mob composition and pre-slaughter management effects on % dark cutting 41
4.1.1.2 Pasture composition effects on dark cutting 45
4.1.1.3 Liver Mineral Status 47
4.1.2 Farm management and feed quality factors contributing to dark cutting in King Island 52
4.1.2.1 Magnesium 52

4.1.2.2 Water 52
4.1.2.3 Supplementary feed 52
4.1.2.4 Sex 52
4.1.2.5 Mycotoxins 53
4.2 Assessed current industry compliance to fat and weight specifications using MSA data. 55
4.2.1 Analysis of individual plant fat and weight frequencies 55
4.2.1.1 Plant 1 55
4.2.1.2 Plant 2 57
4.2.1.3 Plant 3 59
4.2.1.4 Plant 4 61
4.2.1.5 Plant 5 63
4.2.1.6 Plant 6 65
4.2.1.7 Plant 7 67
4.2.1.8 Plant 8 69
4.2.1.9 Plant 9 71
4.2.2 Analysis of fat compliance in the southern plants 74
4.2.2.1 Rates of non-compliance per plant 74
4.2.2.2 Rates of non-compliance per feeding system 76
4.2.2.3 The effect of carcase weight on the rates of non-compliance for fat depth 76
4.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes. 78
4.3.1 Data 79
4.3.2 The time of grading across all plants 100
4.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle 106
4.4.1 End of Season nutritional intervention 106
4.4.1.1 Weather Analysis 106
4.4.1.2 Pasture Analysis 106
4.4.1.1 Animal and Carcass Performance 107
4.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield. 117
4.5.1 MSA regression 117
4.5.1.1 Application to retail beef yield data sets 117

4.5.2 Additional carcase measurements for predicting LMY % defined, captured, and analysed, utilising the carcasses being employed for the cut-weight validation of the MSA Index. 118

4.5.2.1 Feed type 118

4.5.2.2 Other measures 118

4.5.3 Further development of a simple equation for the use in industry 126

4.5.3.1 Equation of best fit 126

4.5.3.2 Equation HSCW only 128

4.5.3.3 Equation HSCW and Rib Fat only 129

4.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield. 129

4.6.1 Measurement of Yield 129

4.6.2 Lean meat yield and saleable meat yield 130

4.6.3 International yield grades 130

4.6.3.1 USDA Yield Grade 131

4.6.3.2 Japan 131

4.6.3.3 EUROP 132

4.6.4 A discussion of the limitations of predicting percentage muscle 133

4.6.4.1 Accuracy of point measures and the use of VIA 133

4.6.4.2 Point measures taken during MSA grading and potential new measures 133

4.6.4.3 Usefulness of morphometric measurements 134

4.6.4.4 Impact of breed or stage of maturity on yield prediction 134

4.6.4.5 Impact of beta agonists on yield 135

4.7 Genetics of BREEDPLAN carcass traits and meat eating quality 135

4.7.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality 135

4.7.2 Relationships between BREEDPLAN EBVs and meat eating quality 141

4.7.2.1 Relationship between progeny carcass traits and sire BREEDPLAN EBVs 141

4.7.2.2 Relationship between MSA Index and BREEDPLAN carcass EBVs 143

4.7.2.3 Relationship between pH and BREEDPLAN carcass EBVs 144

4.7.2.4 Sire variances in carcass traits 144

4.7.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits 147

5 Discussion 152

5.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts. 152

5.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia 152

5.1.2 Farm management and feed quality factors contributing to dark cutting in King Island 156

5.2 Assessed current industry compliance to fat and weight specifications using MSA data. .157

5.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes. 157

5.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle 158

5.4.1 Effect of nutritional intervention on dark cutting 158

5.4.2 Muscle Glycogen and pH 160

5.4.3 Effect of treatment on HSCW 162

5.4.4 Cost benefit analysis of nutritional intervention 162

5.4.5 Further Research 163

5.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield. 164

5.5.1 Possibilities for MSA yield grade predictions 164

5.6 Genetics of BREEDPLAN carcass traits and meat eating quality 164

5.6.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality 164

5.6.2 Relationship between BREEDPLAN EBVs and meat eating quality 167

5.6.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits 168

6 Conclusions/recommendations 169

6.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts. 169

6.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia 169

6.1.2 Farm management and feed quality factors contributing to dark cutting in King Island 170

6.2 Assessed current industry compliance to fat and weight specifications using MSA data. .170

6.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes. 171

6.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle 173

6.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield. 173

6.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield. 174

6.7 Genetics of BREEDPLAN carcass traits and meat eating quality 174
7 Key messages.....175
7.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts.....175
7.2 Assessed current industry compliance to fat and weight specifications using MSA data. .175
7.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes.....175
7.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle 176
7.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield. 176
7.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield. 176
7.7 Genetics of BREEDPLAN carcass traits and meat eating quality 177
8 Bibliography 177
8.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts.....177
8.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia 177
8.1.2 Farm management and feed quality factors contributing to dark cutting in King Island 180
8.2 Bibliography for section 2-6.....181
8.3 Genetics of BREEDPLAN carcass traits and meat eating quality 185
9 Appendix 187
9.1 Genetics of BREEDPLAN carcass traits and meat eating quality 187
9.1.1 Relationship between BREEDPLAN EBVs and meat eating quality 187
9.1.2 Genetic parameters between current BREEDPLAN traits and meat eating quality traits 188
9.1.3 Investigating relationships between market end point and expression of carcass traits associated with eating quality 189

1 Background

1.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

Meat with a high ultimate pH (>5.7) is typically dark in colour and is known as 'dark cutting' or 'dark, firm and dry beef'. Beef that is classified as dark cutting results in inferior eating quality and costs the Australian beef industry up to $55m per annum due to not meeting the pH and/or meat colour requirements for grading by Meat Standards Australia (Jose *et al* 2015). Of the 3.2million Australian cattle graded in 2014-15, the annual dark cutting rate was approximately 5.9%, however seasonal and geographical variation can push average rates up to 35% in pasture-based cattle (unpublished data). Dark cutting results from low muscle glycogen concentration at slaughter. Previous research has identified the major factors on muscle glycogenesis and glycogenolysis for commercial beef cattle and as such dark cutting and muscle glycogen storage is widely portrayed in the industry as a function between good on farm nutrition and minimising stress and exercise in the pre-slaughter period. The highest incidences of dark cutting occur at the shoulders of the pasture growing season and at the start of winter (McGilchrist *et al* 2014). However, there is still considerable variability in dark cutting rates between beef producers at certain times of the year.

Perennial ryegrass (*Lolium perenne*) is the mainstay of temperate perennial pasture based beef systems in southern Australia, estimated to be sown over approximately 6 million hectares, predominately in regions with high winter rainfall (Foot 1997). Perennial ryegrass can have high mycotoxin concentration at the end of summer/early autumn and mineral imbalances during winter when the pasture is short, lush and rapidly growing. These factors have known effects on health and productivity in livestock however, the relationship with dark cutting has not been previously explored.

1.1.1 Mycotoxins

Random sampling of Australian perennial ryegrass pastures identified very high infection rates with the naturally occurring fungal endophyte *Neotyphodium Lolii,* with mean frequencies of 78% and up to 90% in older ryegrass cultivars (Reed *et al*, 2000, Reed and Moore, 2009). Concentrated in the basal leaf sheaths and flowering stems and seeds, the endophyte forms a symbiotic relationship with the tyegrass providing vigour and pest resistance via the production of mycotoxins, secondary alkaloid metabolites (Lane. 1999, Keogh *et al*. 1996, di Menna *et al*. 1992). *N. lolii* produces hundreds of different alkaloids, of which many are potentially toxic to grazing livestock and result in an array of adverse effects including neurological and behavioural changes, increased muscle contraction, reduced feed intake and growth rate, immunosuppression and lameness, all of which could impact glycogen storage (Lean *et al* 2016). The concentration of *N. Lolii* hyphae in the plant fluctuates seasonally, as to individual metabolite concentrations however all typically rise in the spring and when the plant is stressed and then drop off in late autumn (di Menna *et al*, 1992). Peak pasture mycotoxin levels correspond when the nutritional quality of perennial ryegrass thus often autumn ill-thrift and poor performance is often solely attributed solely to poor nutrition (Lean *et al*, 2016). We hypothesise that cattle grazing pastures with high mycotoxin concentrations will have an increased incidence of dark cutting.

1.1.2 Minerals

Temperate Australian pastures during winter are typically grass dominant, young, short and rapidly growing. Pastures are typically lush with a high water content, high protein and high potassium (K) content but low in calcium (Ca) and magnesium (Mg) concentrations. These parameters can result in impaired magnesium absorption in grazing cattle and cause a metabolic disease known as hypomagnesaemia (HypoMg) or grass tetany (Schonewille 2013). Magnesium is an essential dietary mineral and cofactor for numerous physiological and biochemical functions including nerve conduction, muscle contraction and catecholamine release. HypoMg can result in the animal appearing nervous or excited, with muscle twitching and in severe cases can lead to clinical tetany and death (Mayland 1988). HypoMg (grass tetany) may cause dark cutting by reducing the animal's feed intake (Mayland 1988) thus reducing muscle glycogenesis. It is likely to increase glycogenolysis due to neuromuscular hyperexcitability and increased adrenaline responsiveness to stress (Schonewille 2013; Mayland 1988). The grass tetany index or tetany ratio is a commonly used indicator of whether cattle pastures a particular pasture are as risk of developing HypoMg using the equation K/Ca+Mg expressed in milliequivalents (Kempt and Hart 1957). We hypothesise that cattle grazing pastures with a higher grass tetany index will have an increased incidence of dark cutting.

1.2 Assessed current industry compliance to fat and weight specifications using MSA data

Lean meat yield is an important factor in determining overall carcass value. A carcass with more muscle and less fat is clearly a more valuable product than one that has a higher proportion fat. Currently in the MSA grading system, carcases are only graded for quality and not yield and thus producers have no benchmark to work on to obtain a higher yielding carcass which is of increased value. Most processing companies offer a fat and weight payment grid for producers that is a crude measure of carcass yield. The payment grids will penalise the producer and reduce carcase value if the desired fat specifications for the desired market are not met. Grade based payment systems remain inconsistent throughout Australia and MSA graded beef due to variation in target markets, availability of cattle and aspirations of the processor to change yield. This milestone identified and reported carcase weights and rib fat values of MSA graded carcasses processed through the nine collaborating processing plants in southern Australia.

1.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

An analysis of Meat Standards Australia (MSA) data for nine plants in southern Australia from 2010 to 2013 was conducted to establish a better understanding of the incidence of carcases being ungraded due to falling outside the pH and or colour limits set for the MSA grading system. These limits are set at a pH > 5.7 and or the colour score > 3 at the time of measurement. A combination of high pH and

darker surface colour is an indication that the meat could be dark firm and dry (DFD). As inferred, DFD meat is dark in colour and has an increased water holding capacity. This results in meat feeling firm and dry.

The MSA meat colour system is based on grading the surface colour of the loin muscle on a scale of 1 to 7 of which there are nine possible scores (1A, 1B, 1C and 2 to 8). On the other hand, pH is measured using a pH meter and the actual pH is recorded and used to 2 decimal points, likely ranging from less than 5.40 to greater than 6.50.

This report investigates the frequency of non-compliant carcases for colour and pH and the occurrence of non-compliance for just colour or pH, or the so-called "uncoupling" of pH and colour. This will give an indication of the relevance of commercial MSA grading in understanding this issue in southern beef processing plants and suggestions for MSA grading will be offered.

1.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

Dark cutting in beef is one of the most prominent meat quality issues impacting beef industries worldwide. Dark cutting is a meat quality defect that results in beef that is dark in colour, bland in flavor, variable in tenderness and has a reduced shelf life, all of which impact on the overall quality of beef and render it unsuitable for consumers (Ferguson et al., 2001). Due to these negative impacts on meat quality and consumer demand, the Meat Standards Australia (MSA) grading system penalises carcasses that are deemed to be dark cutting (Thompson, 2002). Jose et al. (2015) estimated that in 2014, producers were penalised on average at a rate of $AU0.59/kg HSCW costing Australian producers up to $AU25.7 million per annum. Penalties and loss of income not only affects the producer but also processors and the Australian beef industry as a whole. In 2014, the economic cost of dark cutting in MSA graded cattle was up to $AU55.75 million (Jose et al., 2015). With only one third of Australian carcasses graded under the MSA system each year this value could potentially be 3 times the amount, thus portraying the magnitude dark cutting has on the profitability of the Australian beef industry.

MSA defines dark cutting as carcasses that have an ultimate pH (ph_u) greater than 5.7 (measured at greater than 18 hours post slaughter or 8 hours post slaughter with electrical stimulation) and/or an AUS-MEAT meat colour greater than 3 (Thompson, 2002). Dark cutting is predominately caused by low levels of muscle glycogen at slaughter. Stored muscle glycogen is utilised shortly after slaughter to provide ATP to the muscles via glycolysis. Since this occurs under anaerobic conditions, lactate is produced, and due to the cessation of circulation, lactate and the resultant hydrogen ions build up in the muscle and subsequently lower the muscle pH. The breakdown of glycogen via anaerobic glycolysis occurs until the substrates are exhausted or enzyme activity is diminished (Muir et al., 1998a). Thus when there is insufficient muscle glycogen at slaughter, the lactate and hydrogen ions produced are not sufficient enough to decrease the ultimate pH from the physiological value of 7.1

down to a pH of at least 5.7, resulting in dark cutting (Maltin et al., 2003). Tarrant (1989) indicated that when the glycogen levels are lower than 57µmol/g, dark cutting often ensues.

The muscle glycogen levels available at slaughter is defined as the resting muscle glycogen levels established on farm minus the amount of glycogen that is lost during the pre-slaughter period (McGilchrist et al., 2012). This will vary between animals and even in the same herd due to intrinsic physiological differences as well as other extrinsic conditions. Low muscle glycogen is typically an indication of a poor nutritional plane and or that the animal has been exposed to stressors during the pre-slaughter period. To buffer against pre-slaughter stressors, it is essential that the animal comes from a high plane of nutrition pre-slaughter as this is known to increase muscle glycogen stores (Gardner et al., 2001; Pethick et al., 1999). The higher the starting muscle glycogen levels, the more stress that the cattle can be subject to prior to reaching the critical level of 57µmol/g of muscle glycogen (Pethick et al., 1995; Tarrant, 1989) and thus minimising the potential risk of dark cutting (Muir et al., 1998a). Therefore, nutrition on farm may be one of the most important factors minimising dark cutting.

The seasonal impact on pasture is highly variable and it has been shown to strongly influence the basal muscle glycogen in grazing animals (Knee et al., 2004). The mediterranean climate in southern Australia, particularly South Australia (SA) and Western Australia (WA) show that the incidence of dark cutting in pasture fed cattle is lowest during the middle of spring and then gradually increased through the period of pasture decline (McGilchrist et al., 2014). Therefore pasture fed cattle can be identified as being at greater risk of dark cutting in the late spring, summer period due to the change in pasture quality, which can impact on the levels of muscle glycogen concentration. Previous studies by McGilchrist et al. (2014) showed that over a four year period, 2010-2013, SA had a dramatic difference of 10.91% ± 0.61 in the rate of dark cutting between the highest and lowest months, ranging from 12.44% ± 0.86 in March to 1.53% ± 0.75 in October. Alternatively, in WA the highest rate of dark cutting was in February at 9.56% ± 0.79 and the lowest in October 6.96% ± 0.76. While this difference of 2.6% ± 0.46 indicates less variation in the incidence in dark cutting between the months, it also shows a consistently high rate of dark cutting in WA.

In feedlot cattle, muscle glycogen levels are generally higher and less variable than those of pasture fed cattle (Pethick et al., 1999; Pethick et al., 1995) due to the consistent level of nutrition supplied. This is results in a lower incidence of dark cutting (Muir et al., 1998b) compared to that of pasture fed cattle. Previous studies on the supplementation of grass fed cattle have had varied results in increasing muscle glycogen concentration. Knee et al. (2007) showed that muscle glycogen levels similar to those seen in feedlot cattle could be achieved by supplementation with ab-libitum amounts of high energy total mixed ration for 1 week during a period of pasture decline. Gardner et al. (2001) showed that a moderate energy hay supplementation, providing approximately 8-8.5 MJ of metabolisable energy /kg DM over 3 days, was not adequate in replenishing muscle glycogen. However, a higher energy barley supplement with 11.3MJ of metabolisable energy /kg DM was sufficient in increasing muscle glycogen stores (Gardner et al., 2001).

This study aimed to investigate the potential for restricted supplementation of pasture fed cattle with a high energy ration pre-slaughter to decrease the rate of dark cutting. The influence this nutritional supplementation had on muscle glycogen concentration and live weight gain will be quantified as well as its economic viability. It is hypothesised that the provision of a high energy

ration of 25MJ/head/day to pasture fed cattle during periods of pasture decline in Southern Australia will improve muscle glycogen concentration and halve the rate of dark cutting from 10% to 5%. It is further hypothesised that the addition of increased the levels of metabolisable energy through a high-energy supplement will result in increased growth rates.

1.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

Lean meat yield, or more accurately, the percentage of muscle that makes up a carcass, is identified as having a significant impact on the profitability of the meat industry. Most livestock industries place a great importance of generating slaughter stock which are genetically larger, and also have more muscle and less fat. Consumers will typically only consider paying for muscle when purchasing meat cuts and consider fat and bone of very little value, thus it is clearly more profitable to produce carcasses with a higher percentage of muscle. Furthermore, when a carcass has a high lean meat yield (% muscle) and thus a lower fat content, the carcass, by default is more valuable. Less fat, results in less trim wastage, less labour and a higher proportion of the valuable meat/muscle product. It is important to have an indication of the percentage muscle to estimate the “real” value of the carcass. The Meat Standards Australia (MSA) grading system, currently grades beef carcasses on eating quality merits, with carcasses fitting in the MSA specifications being awarded a premium and sold at a higher price. Although, carcasses may be of the highest eating quality, the MSA grade does not correctly capture the entire carcass value that is defined by the combination of meat quantity and quality. This report explores the ability of the MSA grade point measures that are routinely taken in Australian abattoirs to describe the % muscle in a carcase.

1.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield

Lean meat yield, or more accurately, the percentage of muscle that makes up a carcass, is identified as having a significant impact on the profitability in the meat industry and accordingly most livestock industries place a great importance of generating slaughter stock that are genetically larger, and also have more muscle and less fat. Consumers will typically only consider paying for muscle when purchasing meat cuts and consider fat and bone of very little value, thus it is clearly more profitable to produce carcasses with a higher percentage of muscle (Pethick et al., 2010). Furthermore, when a carcass has a high lean meat yield (% muscle) and thus a lower fat content, the carcass, by default is more valuable. Less fat, results in less trim wastage, less labour and a higher proportion of the valuable meat/muscle product. It is important to have an indication of the percentage muscle to estimate the “real” value of the carcass. The MSA grading system, currently grades beef carcasses on eating quality merits, with carcasses fitting in the MSA specifications being awarded a premium and sold at a higher price. Although, carcasses may be of the highest eating quality, the MSA grade does not correctly capture the entire carcass value, which is defined by the combination of meat quantity and quality.

Yield components have been included in international grading systems for a number of decades, allowing feedback on carcass yield at processing. Grading systems for the USA and Japan use calculated equations to determine yield and quality grades, while the European system relies primarily on visual appearance to measure yield only, with no measure of quality. The purpose of

this review is to assess the current methods used to measure percentage muscle around the world for feasibility, accuracy, and economic values to evaluate if an indicator of yield would be of benefit to the Australian beef industry for use alongside the MSA grading system.

1.7 Genetics of BREEDPLAN carcass traits and meat eating quality

1.7.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality

There are both management and genetic strategies in making improvements in beef eating quality. Response to genetic improvement programs is a function of selection intensity, heritability and phenotypic variance. Where there is no phenotypic variance, e.g. all animals had the lowest AUS-MEAT Marble score (0) there will be no response to selection. For carcass traits, the additive genetic variance (heritable component of phenotypic variance) tends to increase with trait mean. Across market end point Reverter *et al*. (2003) reported increased additive genetic variance of HSCW with increasing mean carcass weight. Importantly this was a function of phenotypic variance rather than changing heritability, which is the relative proportion of phenotypic variance which is genetic. For example, Reverter *et al.* (2003) reported phenotypic variance that was 53% greater for carcass weight (581 vs. 382) for export than domestic endpoints despite similar heritability (0.40 vs. 0.42). Greater phenotypic variance in export carcasses compared with domestic carcasses are observed for rib (250%) and P8 (213%) fat depth, intramuscular fat percent (340%), AUS-MEAT Marble score (205%) and eye muscle length by width (79%).

This project seeks to identify the relationship between carcass end point defined either by weight or marbling and phenotypic variance. It is expected that increasing lot mean carcass weight will be associated with increasing phenotypic variance in HSCW. It is also expected that higher lot mean Marbling and HSCW will be associated with increased phenotypic variance in Marbling. Therefore, there is potential feedlot-finished cattle with higher mean Marbling may also have higher phenotypic variance at a given carcass weight. This would subsequently change the magnitude of the regression coefficient for Marbling on BREEDPLAN IMF EBV. A large data set for southern Australia carcasses with MSA grading was used to investigate relationships between carcass traits at the lot level.

1.7.2 Relationship between BREEDPLAN EBVs and meat eating quality

The Meat Standards Australia system was developed to improve the consistency of beef eating quality (Polkinghorne *et al.* 2008). The system assigns one of four eating quality grades (unsatisfactory, 3 star, 4 star and 5 star) based on a statistical prediction model, designed to predict the degree of consumer satisfaction for individual muscles of meat based on a number of grading inputs (proportion of *Bos indicus*, hormonal growth promotant (HGP) use, sex, hanging method, hot standard carcass weight, ossification score, marbling score, rib fat, ultimate pH and number of days aged (Polkinghorne *et al.* 2008b). The MSA index is a single number between 30 and 80 (expressed to two decimal places) that is used to predict the eating quality and potential merit of the carcass. It is a tool for producers and lot feeders to use to improve the quality of their product.

The primary on-farm drivers for the MSA index include carcass weight, *Bos indicus* content, use of Hormonal Growth Promotants, marbling, and ossification. Currently, there are no estimated breeding

values (EBVs) specifically for marbling, ossification or the MSA index itself. Producers can select for increased intramuscular fat (IMF) using BREEDPLAN EBVs to improve marbling and in turn increase MSA Index. It is also possible that cattle with higher carcass weight EBVs are likely to reach market specifications for carcass weight at younger ages and so may have lower ossification than lower growth cattle, however they are also likely to have lower marbling and rib fat (Wilkins *et al.* 2008).

When buying bulls, producers are provided with BREEDPLAN EBVs for multiple (commonly 17) traits plus a number of selection indices depending on the market endpoint. An obvious issue for breeders is how much of the superiority in EBVs can be captured by them, i.e. what is the likely return on investment. There are two aspects to this question and an additional issue for this specific project:

1. What is the relationship between carcass performance and EBV for a given trait?
2. How much more will be paid for superior carcasses? and
3. What is the relationship between MSA index and BREEDPLAN EBVs?

The regression coefficient (*b*) of carcass traits on EBV of the sire is a function of the genetic correlation (r_G) between the traits (could be same trait at different endpoints), the heritability (h^2) of the trait, variation of the carcass trait (σ_P) and the variation in EBV (σ_{EBV}). This is all multiplied by 0.5 as progeny only received half of their genes from their sire.

$$b_{MSA,EBV} = 0.5\ x\ r_G x \frac{\sqrt{h^2\ x\ \sigma_P^2}}{\sigma_{EBV}}$$

Equation 1.1. The relationship between MSA carcass traits and BREEDPLAN sire EBVs.

It is hypothesised that for the same trait in the stud versus commercial grass-fed herd, the genetic correlation between traits is likely to be 1, the heritability and the variation in EBV are likely to remain constant so the regression is expected to be 0.5. Alternatively, a change in the variance of the carcass traits is likely to be the primary cause of deviations from this.

Given that differences in the phenotypic variance are likely to change the magnitude of the regression coefficient, there is a need to understand the extent that the variance changes between markets and groups of cattle. Furthermore, rather than assume constant genetic relationships, it is important to understand the underlying genetic relationships between the MSA Index (and its components) with other performance traits. The relationship between BREEDPLAN EBVs (e.g. 400 day weight, IMF%) and expression of meat quality traits (MSA Index and components including MSA marbling, ossification), and the interactions with finishing systems (grain vs. pasture) are not published for modern production systems and carcass end points in Australia.

Reverter *et al.* (2003) reported heritability estimates and genetic correlations between steers finished for different market endpoints (domestic vs export, combined Japanese and Korean) for both temperate and tropical breeds. Genetic correlations between market endpoints were very high for carcass weight, IMF and subcutaneous fat. However, additive genetic variance increased substantially with end market. Whilst there was little evidence of G x E, carcass weight means were substantially lower than the 400 kg end point that BREEDPLAN carcass EBVs are now reported at in Angus. For example, the domestic carcass weight was 216 kg and the export carcass weight was 297 kg. The mean carcass weight for MSA graded carcasses is approximately 300 kg however, the EBVs for the most numerous breed in southern Australia (Angus) are reported at 400 kg. This presents a potential issue when considering the increase in variance observed for key traits associated with increases carcass weight by Reverter *et al.* (2003). The realised relationship between EBVs and MSA index is less clear because it is dependent on the variance of carcass traits as well as the genetic correlation (likely to be high but less than 1).

In addition to marbling, reducing ossification by increasing weight for age is an important driver for the MSA Index. BREEDPLAN EBVs for growth are based on weight at a given age whereas carcass traits are based on age at a given weight. Those with higher 400 day weight EBV will reach market weights faster and are therefore likely to have lower ossification. The actual relationship between the EBVs and MSA index for pasture finished cattle is not clear. The expression of marbling and rib fat depth in higher growth genotypes at younger ages finished on pasture needs to be quantified.

The motivation behind this study is to examine the extent to which MSA Index of commercial animals is related to estimated breeding values (EBVs) of sires.

1.7.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits

There are very few genetic parameter estimates between BREEDPLAN traits and meat eating quality traits particularly MSA index and MSA marbling. Johnston *et al.* (2003) noted that there is significant interest from beef producers to increase eating quality through genetic selection. With the development of MSA (Polkinghorne *et al*. 2008) and MSA Index, the interest by the industry to improve eating quality through genetic selection has increased. In investigating genetics underlying eating quality and carcass traits Reverter *et al*. (2003) noted that it was important to determine whether there significant genotype by environment (GxE) interactions for finishing systems (pasture- vs. feedlot-finished). Where large GxE exist but are not accounted in selection, the efficiency of selection would be low. Reverter *et al.* (2003) and Johnston *et al*. (2003) reported on genetic parameters for temperate cattle breeds for feedlot- vs. pasture-finished for a range of growth, body composition, carcass and meat quality traits. They reported generally increasing additive genetic variance with increasing market weight but minimal GxE and subsequent re-ranking of sires. However, they concluded that accounting for changes in genetic variance for genetic evaluation was of high importance. Whilst their work considered a large range of carcass traits, genetic parameters were not reported for ossification or MSA Marbling (Marb). This project seeks to build on the work of Johnston *et al*. (2003) and Reverter *et al*. (2003) by reporting genetic parameter estimates and quantifying GxE for MSA Index, marbling and ossification for pasture- and feedlot-finished MSA graded cattle. Given

marbling and ossification both have a major role in the MSA Index it is important to estimate genetic parameters for these traits to inform genetic evaluation, breeding objectives and animal selection.

2 Project objectives

1. Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts.
2. Assessed current industry compliance to fat and weight specifications using MSA data.
3. Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes.
4. Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle.
5. Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield.
6. Identified and evaluated appropriate technologies for measuring Lean Meat Yield.
7. Quantified the relationships between BREEDPLAN EBVs and meat eating quality.
8. Provided estimates of genetic parameters for associations between current Breedplan traits and meat eating quality traits.
9. Provided data to the B.SBP.0111 project team (Enhancing the BeefSpecs System) for validation of their expanded prediction equations.
10. Validated estimates of the phenotypic effects of EBVs on the MSA Index and its components for an independent herd of Angus cattle (using data provided by B.SBP.0111)

3 Methodology

3.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

3.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia

From July 2014 to Dec 2017, individual producers with historically high and low levels of MSA non-compliance were identified. Mobs of cattle from these pasture-based finishing systems were identified ahead of their designated slaughter date. For each mob sampled, the property of origin was visited as near to slaughter date as possible and a range of pre-slaughter management information obtained from the producer (Table 3.1). In addition, a pasture sample and estimate of feed on offer (FOO) was taken from the paddock/s available to the stock in the four weeks leading up to slaughter. These samples were oven-dried for dry matter content, and sent to Cumberland Valley Analytical Services, Bendigo Victoria for full feed quality and trace mineral profile analysis by wet chemistry.

Table 3.1. Pre-slaughter management information matrix

MANAGEMENT PARAMETERS	CATEGORIES			
Age of cattle	<24 months		>24 months	
Sex	Steers	Heifers	Mixed	
Source	Vendor bred		Purchased	
Cattle removed from mob	<1 week	1-2 weeks	2-4 weeks	>4 weeks
Cattle introduced from mob	<1 week	1-2 weeks	2-4 weeks	>4 weeks
New paddock	<1 week	1-2 weeks	2-4 weeks	>4 weeks
Curfew	Yes	with feed and water	Partial (race or laneway)	No
Pasture composition	Grass		Mixed grass/legume	
Fertiliser history (<12 months)	Yes		No	
Feed on offer (kg DM/ha)	<2000	2000-2500	2500-3000	>3000
B12 injection	<6 months		>6 months	
Drench	<6 months		>6 months	
Distance to abattoir	<100km		>100km	
Transport type	Private		Contract	
Transport timing	Day of slaughter		Day before slaughter	

A 2-3 g liver sample was taken from every animal following evisceration, stored on ice and frozen at -20 ºC. Following MSA grading and collation of data, liver samples from high pH animals in each mob, along with an equivalent number of compliant pH animals were selected and analysed for trace mineral concentration at the CSIRO laboratories, Waite Campus, Adelaide South Australia.

3.1.1.1 *Statistical Analyses*

The percentage of 'dark-cutters' (% DC, ultimate carcase pH >5.70 and/or AUS-MEAT meat colour >3) for each mob was analysed as the primary trait. Farm management and feed base was recorded as binary traits (YES/NO) for each category. A total of 3280 animals from 68 slaughter groups form the dataset analysed and presented herein.

Management parameters with a suitable distribution and no bias to a given vendor were selected for analysis. Each category within a given mob and management factor was analysed for its relationship with percentage dark cutting (% DC) using a generalised linear model with individual vendor fitted as a random effect. Pasture type and availability factors were analysed for their relationship with % DC using a generalised linear regression. Predicted means were calculated for each trait as presented in

Table 3. Pasture composition measurements were fitted as continuous variables. % DC was tested against pasture composition measurements and the estimated effect (slope) calculated (Table 4.2).

Carcass pH values are effectively truncated and so not normally distributed (Fig 6). Thus, the values were transformed back to raw hydrogen ion concentration ($pH=-\log[H^+]=10^{-pH}$). The calculated hydrogen ion concentration data was normally distributed (Fig. 4.8), thereby allowing analyses of individual liver mineral data in a linear mixed model against hydrogen ion concentration. Individual mob was fitted as a random effect to account for any mob-specific effects on dark cutting.

To determine if there was a difference in mineral status between animals that were dark cutters relative to those that weren't, a mixed model with dark cut (yes or no) as a fixed effect and mob as a random term was fitted to the individual mineral data. A binary logistic model was fitted to the binomial data (with dark cutting animal=1, and non-dark cutting=0) to allow determination of the probability of dark cutting as the concentration of liver minerals changed. All analysis was conducted using Genstat 15th Edition (VSN international), excluding the binary logistic analysis which was performed in ASRemL® with significance defined as $P<0.05$.

3.1.2 Farm management and feed quality factors contributing to dark cutting in King Island

Groups (n=61) of cattle (n=3,185) of varying sexes, ages and breeds, were pasture raised on King Island, Tasmania before transport to mainland Tasmania on a ship between March and June for slaughter, all at the same processing plant. Animal and management factors for each group of cattle were recorded; water source (dam or trough), pasture type, supplementary feed (yes or no), lifetime yardings, lifetime truckings, average age, weaning age, weaning method, days since last draft, trace element supplementation in the last 6 weeks (yes or no), hours of curfew off feed prior to shipping and trucking distance from farm gate to King Island port. Environmental factors for each shipment date were recorded including weather forecast, maximum and minimum temperature, wind speed and direction, sea state, swell, wave direction and wave period.

Pasture availability in kg Dry Matter per hectare was calculated using the average of fifteen 0.1 m^2 quadrant cuts oven dried. A 500 g sample of pasture sward and supplementary feed for each group were collected via random grab samples and freeze dried. Pasture quality and minerals were analysed using Near Infra-red and Wet Chemistry (Dairy One, Ithaca, New York, USA). Forage quality included metabolisable energy, crude protein, dry matter, metabolisable energy, acid detergent fibre, effective neutral detergent fibre, in vitro true digestibility, trace element and mineral concentrations (Mg, K, Ca, Sodium, Chloride (Cl), Copper, Molybdenum) using Near Infra-Red and Wet Chemistry (Dairy One, Ithaca, New York, USA). The grass tetany index was calculated using the equation (K/(Ca+Mg)) in milliequivalents (MEq), where indices greater than 2.2 suggest an increased risk of HypoMg (Schonewille 2013).

Mycotoxin analysis was conducted by Biomin at Romer Labs, Singapore. The method was as described by Hafner et al, using a high-performance liquid chromatography-electrospray ionization-mass spectrometry using an Eksigent ultraLC100-XL HPCL coupled to an Applied Biosystems 5500 Qtrap mass spectrometer (Hafner 2008). The major mycotoxins and their families tested were

Ochratoxin-A, Zearalenone, Fumonisins, Aflatoxins, Ergot Alkaloids, β-trichothecenes and α-trichothecenes. The individual mycotoxins analysed included; 15AcetylDeoxynivalenol, 3AcetylDeoxynivalenol, AflatoxinB1, AflatoxinB2, AflatoxinG1, AflatoxinG2, Deoxynivalenol, Diacetoxyscirpenol, FumonisinB1, FumonisinB2, FumonisinB3, FusarenonX, HT2Toxin, Neosolaniol, Nivalenol, OchratoxinA, T2Toxin, Zearalenone, Ergocornine, Ergocorninine, Ergocristine, Ergocristinine, Ergocryptine, Ergocryptinine, Ergometrine, Ergosine, Ergotamine, Ergotaminine, Fumonisins.

All carcasses were graded by qualified Meat Standards Australia graders where the *longissimus thoracis* must be pH ≤5.7 and/or meat colour ≤3 to be eligible for grading.

3.1.2.1 *Statistical Analysis*

Statistical analysis was performed using Stata (SE v 14, USA). The combined total of carcasses ineligible for grading (pHu>5.7 and/or meat colour >3) were used to give a total number and a percentage of dark cutting per group. The size of the groups in the study were not evenly weighted thus a random-effects negative binomial regression analysis model was used to explore the effect of each univariate variable (environmental, pasture & management factors) on dark cutting per group with the group size weighted. Variables with $P < 0.2$ was assessed in a multivariate model (XTNBREG) with stepwise regression with number of cattle per group weighted to account for the unbalanced data. Hausman et al., (1984) equation 3.1 (pp 922) details the negative binomial regression model and model weight accounted for by equation 3.5 (pp 927). The dependent variable was the total number of dark cutting carcasses per group. Fixed effects included animal factors (sex and consignment date) and management factors previously listed. Continuous terms included in the model were other management factors (lifetime yarding's, days since last draft, weaning age, trucking distance on King Island and paddock size), pasture quantity (available pasture), quality (metabolisable energy, crude protein, effective neutral detergent fiber and acid detergent fiber) and the grass tetany index. The grass tetany index was not significant. The individual minerals K, Mg, Ca were put into the model along with sodium, molybdenum and Chloride). Pasture magnesium was further evaluated via a dichotomous transformation of > 0.24% and ≤ 0.24%. Mycotoxins were regressed in the model firstly as continuous variables then transformed into quartiles and dichotomous exposure cut points. The cut points were chosen evaluating histograms of exposure. The mycotoxin dichotomous transformations levels were; ergot alkaloid >600PPB, 3acetyldeoxynivalenol >5PPB, fumonisinb1 >5PPB, 15acetyldeoxynivalenol >0PPB, 3acetyldeoxynivalenol >8PPB, aflatoxing1 >0PPB, fumonisinb2 >0PPB, ochratoxina >0.4PPB, ergocristine >0PPB, fumonisins >0PPB, aflatoxins>0PPB, btrichothecenes >50PPB, nivalenol >50PPB, Zearalenone >100PPB, ergometrine >0PPB, ergosine>500PPB. Final model fit was evaluated using Wald Chi statistic, Akaike's information criterion and Bayesian information criterion.

3.2 Assessed current industry compliance to fat and weight specifications using MSA data

3.2.1 Methods and materials

The MSA carcass weight and rib fat data of nine processing plants throughout southern Australia were collated over 4 years (2010, 2011, 2012 and 2013). Four processing plants were located in Western Australia (Plant 1, Plant 2, Plant 3 and Plant 4), two located in South Australia (Plant 5 and Plant 6), 2 located in Tasmania (Plant 7 and Plant 8) and one located in Victoria (Plant 9). Weights are reported as total Hot Standard Carcass weight (HSCW) which is measured on the chain once the carcass has been dressed and split. Fat is reported as rib fat and is measured in the cold carcass at the quartering site located at either the 10^{th}-11^{th}, 11^{th} or 12^{th} or the 12^{th}-13^{th} rib depending on the plant.

The data is presented in two sections, with the first being the presentation of individual plant fat and weight frequencies. The data for individual plants is presented as percentages of the total carcases for each year at 10kg increments for HSCW and 1mm increments for rib fat. A cumulative total of percentage carcases is also presented across the HSCW and rib fat distribution. This allows for the interpretation where the majority of the carcasses for each plant lie for weight and fat data.

In the second section, the non-compliance rate for carcases not fitting the fat specs of MSA (rib fat of 2 or less) is presented. The effect of feeding system, carcase weight, month and, state and plant are all presented.

3.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

3.3.1 Lot analysis

Data were collated into lots to enable an analysis of non-compliance due to pH, meat colour or both within a lot. Lots of less than 20 animals were excluded from the data set because this report has analysed the proportion of non-compliant carcases within a lot and small numbers can easily skew the results (i.e. 1 non-compliant carcass in a lot of 20 head = an incidence of 5%). Analysis was carried out to incorporate month within the four years of data and month by year. The MSA pH and colour scores for each lot were collated into proportions of those that failed for pH and meat colour (pH > 5.7 and MC >3); meat colour only (MC >3 and pH ≤5.7) and pH only (pH>5.7 and MC≤3). This data for each plant can be seen in Tables 4.15-4.23. The correlation between pH and meat colour was also calculated for each Lot. To aid this analysis, meat colour that were 1A, 1B and 1C were given a numerical value of 1, 1.33 and 1.67. Intercept and root mean square of the error (RMSE) data was also noted (Table 4.13). Dark cutting data is presented for each plant for each year on a monthly basis. Two graphs are presented per plant: one for % Non-compliance on a meat colour and pH basis, and one for the occurrence of those that fail on MC only (pH≤5.7).

3.3.2 pH analysis

The frequency of pH data is presented for all data, and for each plant individually. The histograms contain two lines; the red line is that of normal distribution and the green line, is the actual distribution. It became of particular attention that pH data just greater than 5.7 (5.71 to 5.75) was very limited. A closer look at the frequency of pH occurrence was warranted (Tables 4.15-4.23). These tables show the frequency of data points close to the MSA threshold for pH (5.67-5.73) and the relative colour scores for each. The data was separated into two groups, Low pH (5.7 and below) and high pH (5.71 and above). Particular pH measurements close to the cut off were specified in ranges of 0.02 unit with the midpoint used at the category name (ie 5.69 = pH 5.68-5.7).

3.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

3.4.1 End of Season nutritional intervention

3.4.1.1 *Experimental Design*

A total of 19 lots of cattle (n=959) from 10 different producers in the southern region of Western Australia and nine lots of cattle (n=619) from four producers in South Australia were used in this experiment over two summer seasons. From late September through to January of both years, grass fed cattle producers were approached to take part in the experiment. Producers were required to have mobs of at least 30 head of pasture fed cattle that were at least two weeks from consignment.

At the beginning of the trial, each lot of cattle was weighed on farm and this was recorded against their National Livestock Identification Number (NLIS). The cattle were then randomly sorted using a left/right draft into control and treatment groups and then placed into one divided paddock or separate but similar paddocks. The course of the nutritional intervention ran from 10 to 20 days prior to consignment to the abattoir. In Western Australia the treatment cattle were supplemented with a high energy commercial pellet, Milne Feeds, Vitalize (13.3MJ/kg DM of metabolisable energy, 14.4% crude protein/kg DM, 19.1% NDF; Milnes Feeds, Welshpool, Western Australia, Australia). Alternatively the treatment cattle in South Australia were supplied with cracked lupins (11MJ/kg DM of metabolisable energy, 31% crude protein/kg DM, 30.5% NDF). The pellets and lupins were provided to the cattle daily at a minimum quantity of 25 MJ of energy per head per day. In addition to pasture, these supplements were supplied to the treatment cattle via a self feeder, trough or scattered on rubber matting on the ground. These supplements were supplied at the same approximate time each day. The control groups were left to graze the pasture only. The producers simulated the same level of contact with both the treatment and control groups despite not supplement feeding the control cattle to account for acclimatisation to human contact.

At the completion of the feeding period the cattle were reweighed and a final live weight was recorded (WA only) and transported to a commercial abattoir for slaughter. The cattle were kept in their treatment groups for transport as per MSA requirements. At the abattoir the cattle were slaughtered by exsanguination after stunning. A small sample of the *m. Longissimus thoracis* was then taken upon the entrance to the chiller, approximately 40 minutes post slaughter. These samples were stored at -20°C and analysed for glycogen concentration at a later date.

3.4.1.2 *Weather Analysis*

Meteorological data compiled by the Bureau of Meteorology was used to analyse minimum temperatures, maximum temperatures and rainfall. This was recorded on the day of transport at the weather station closest to the farm and the day of slaughter at the abattoir. Data was only collected for Western Australian locations for the 2015 period.

3.4.1.3 *Pasture Quality Analysis*

In order to avoid paddock bias the pasture quality and feed on offer (FOO) was measured at entry and exit from the paddocks for both treatment and control cattle. This was calculated by collecting 15 x 0.1 m^2 quadrants of pasture from each paddock. These samples were oven dried to calculate the mean dry matter available in kilograms of feed per hectare. Grab samples of the pasture were also taken as the cattle entered and exited the paddock. These samples were taken at grazing height throughout the paddock and used to measure the pasture quality. Pastures were kept frozen at -20^{o}C. Pasture samples were weighed wet in their bag. They were then broken up and aerated, and placed in a Venticell, MMM Medcenter Einrichtungen GmbH at 65ºC for an average of 72 hours – until all moisture was removed. Once dried, they were weighed along with their bags, (subtracted from the original weight) and their dry matter % calculated (dry weight (g)/wet sample (g)). Dried pastures were stored in an airtight bag prior to shipping for further analysis by Dairy One (DairyOne, Ithica, NY) (DairyOne, 2015). A full Near Infrared Reflectance Spectroscopy (NIRS) was conducted with Foss NIRSystems Model 6500 with Win ISI II v1.5 (Foss NIRSystems, Laurel, MD).

- Metabolisable energy (ME) was expressed as MJ/kg DM using an IKA C2000 basic Calorimeter System (IKA Works Inc, Wilmington, NC).
- Acid Detergent Fibre (ADF) and Lignin were analysed using the ANKOM Technology Method 5 and 9 respectively (A200 (4-13-11); AOAC 973.18) (ANKOM, Macedon, NY).
- Neutral Detergent Fibre Digestibility (NDF) was measured using ANKOM Technology Method 3 – and In-Vitro True Digestibility (IVTD) using the DaisyII Incubator (08/05), both for a 24 hour period (Goering and Van Soest, 1970).
- Crude Protein (CP) samples were analyzed by combustion using a CN628 Carbon/Nitrogen Determinator.
- Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, Mo, Co, and S were digested using CEM Microwave Accelerated Reaction System (MARS6) with MarsXpress Temperature Control using 50ml calibrated Xpress Teflon PFA vessels with Kevlar/fiberglass insulating sleeves then analyzed by ICP using a Thermo iCAP 6300 Inductively Coupled Plasma Radial Spectrometer.

3.4.1.4 *MSA Measurements*

All carcases were graded using the Meat Standard Australia grading system. AUS-MEAT certified MSA graders measured the pH and meat colour along with hot standard carcass weight, marbling, ossification, fat colour and subcutaneous rib fat the morning following slaughter. The carcasses must

be less than 12°C in the *M. longissimus thoracis* and be hung for at least 18 hours post slaughter or 8 hours post slaughter with electrical stimulation in order to be graded (AUS-MEAT, 2005). Using this data the carcasses were classified as dark cutting if the pH_u was greater than 5.7 and/or the AUS meat colour score was greater than 3. The carcass measurements used for analysis include:

Ultimate pH (pHu) measurements were taken in the *M. longissimus dorsi* at the quartering site, this was done with a meter that is fitted with a temperature adjustment (Bendall Equation) to 7°C (MLA, 2007).

Meat colour was assessed based on the AUS-MEAT meat colour reference standards in the *M. longissimus dorsi* at the site of quartering, most commonly between the 12th and 13th ribs. Colour is assessed on a scale of 1 to 7 with the colour requirement for MSA grading to be between 1B to 3 (AUS-MEAT, 2005).

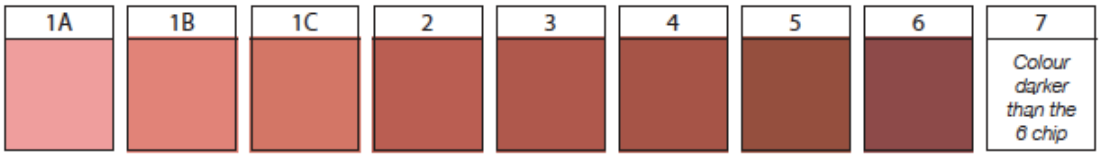

Fig. 3.1. AUS-Meat meat colour reference standards, scale of 1 – 7 (AUS-MEAT, 2005)

Hot Standard Carcass Weight (HSCW) is the weight of the carcass at the end of the slaughter chain with the carcass dressed to AUS-MEAT standards, measured in kilograms (AUS-MEAT, 2005). MSA marbling, subcutaneous fat depth and eye muscle area are all measured as the quartering site of the *M. longissimus thoracis* (AUS-MEAT, 2005). MSA marbling score provides an indication of the quantity and distribution of intramuscular far and given in a score ranging from 100 to 1100 (Fig. 3.2) in increments of 10 (MLA, 2007). Subcutaneous rib fat depth is measured in millimeters (AUS-MEAT, 2005). Eye muscle area is the number of square centimeters at the quartering site however this is not an MSA requirement as it does not impact on eating quality but it is still recorded at the abattoir. Ossification score is assessment of physiological age on a scale from 100 to 590 in increments of 10. It is assessed by measuring the calcification of the spinous process in the sacral, lumbar and thoracic vertebrae (AUS-MEAT, 2005). The MSA Index is provided for all carcasses that meet the MSA requirements, it is a value between 30 and 80 which represents the potential eating quality of the whole carcass (MLA, 2007).

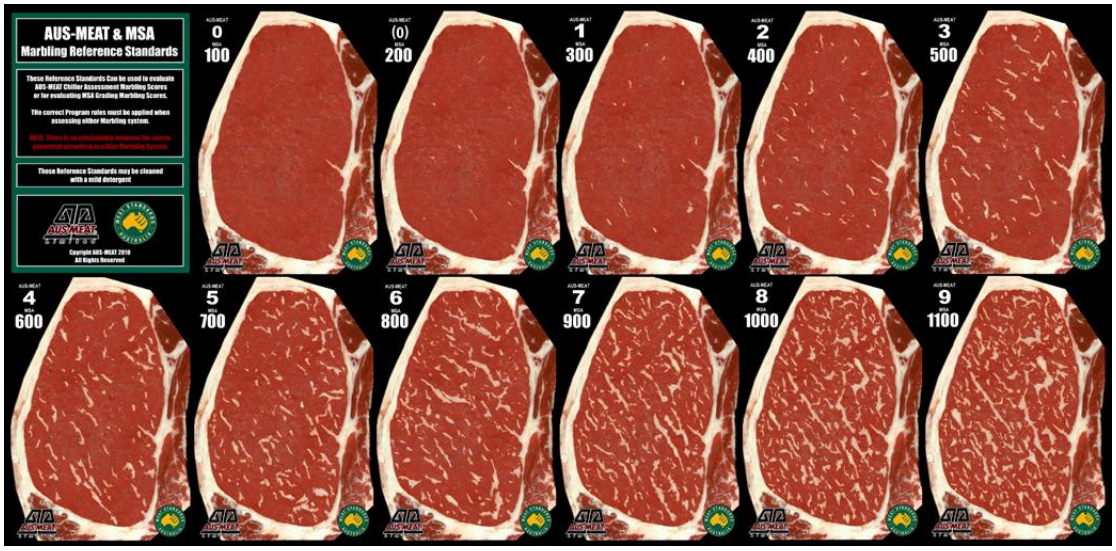

Fig. 3.2. Meat Standard Australia (MSA) Marbling Scores 200-1100 (AUS-MEAT, 2005)

3.4.1.5 *Glycogen Analysis and pH Decline*

Analysis of the muscle glycogen samples was performed on an Olympus AU 400 auto analyser (Olympus Diagnostics, Tokyo, Japan). This was done using the enzymatic method of Chan & Exton (1976) excluding the filter paper step. Due to the loss of integrity glycogen analysis was only performed on samples from seven lots in WA (n=254) and four lots in SA (n=313).

3.4.1.6 *Statistical Analysis*

The data were analysed using a general linear mixed effects model (SAS, 2001). Pasture analysis was conducted using the fixed effects of time (start and end of trial), treatment and trial to test if the pasture quality and quantity was declining or varied between treatments. The majority of paddocks were only used once, therefore with n=1 analysis of lots on an individual basis was inapplicable.

Due to these low rates of dark cutting, the dark cutting rates on a lot basis were not analysed. The analysis focused on the individual MSA measures of meat colour and pH as well as muscle glycogen. The models included fixed effects for treatment and trial number and plus their interactions. The year component was checked for significance between dependent variables and data was analysed in separate years as well as both years combined. Other animal and carcass measures were used as covariate terms. The effect of treatment on live weight gains and HSCW were analysed with starting weight as a covariate to adjust for any biased for body weight. Each state was analysed separately due to the different treatments used. Non-significant terms were removed at a P-value of greater than 0.05 in a stepwise manner.

Until now, an MSA minimum requirement of meat colour 1B – 3 was in place. There is now no evidence that meat colour has an impact on eating quality. Consumers do not visually discriminate against meat colours (greater than 3) at the point of sale, where pH is an acceptable level. The MSA Beef Taskforce endorsed the removal of meat colour as a specification for the MSA eating quality grading system in December 2016; however, this project reports on the influences of meat colour as contracted prior to 2016. The removal of meat colour as an MSA specification will have minimal impact on the MSA grading process. Other industry standards such as the AUS-MEAT grain fed specifications will still apply (meat colour 1B – 3). For grain fed carcases being MSA graded, this will need to be included as a company specification in the relevant PBR line.

3.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

3.5.1 Data

Five historic CT data sets are used for this analysis. Untrimmed primal cuts from the left side of each carcass in these data sets were CT scanned as primals. All data sets have CT analysis for the percentage CT muscle as well as MSA grading point measures. The five data sets are described as, “Muscling”, “CRC”, “WA”, “Grass” and “Grain”. A description of the contents of each data set is shown in Tables 3.2 to 3.7 below. The muscling, grain and grass data sets were sets of serial kills which used grain and grass fed cattle of varying muscling levels (high, low and myostatin). The CRC data set had a number of breeds including Hereford, Angus and Wagyu Angus crosses. The WA data set tested heifers that ranged in fat levels with consistent live weight. There were a total of 374 carcases with CT Muscle % and MSA data measurements. These measurements included Left side Hot standard carcase weight (leftsideHSCW), Rib Fat (RFT), marbling score (USMB), ossification (OSS) and Eye muscle area (EMA). Additional measures, including hump height, forearm and hindlimb circumference were not taken in the CRC data set only. The spread of fixed effects are shown in Tables 3.8 and 3.9. There were only two data sets with heifers with only the Muscling data set having both sexes. No cattle for which CT data was measured had been HGP treated or had an estimated percentage Bos indicus (EPBI) greater than 0. The feed types were also only available in the muscling, grass and grain data sets only.

When the leftside hot carcase weight was plotted versus rib fat (Fig. 3.3) it is clear that the WA data set could not be incorporated with the other two data sets to regress a prediction equation for percentage muscle. This clearly shows that these animals varied minimally in carcase weight but a large amount in Rib fat (or overall fatness). Additionally, the CT lean in the WA data set was calculated by a different method to that of the other data sets. The WA data set was calculated by the group at Murdoch University by a simple thresholding method. While the other data sets were calculated by NSW DPI by a baysian like method. Because of all the above information it was decided to not use the WA data set to regress an equation from the MSA data available (N=324).

Table 3.2. Descriptive data of MSA measurements for all CT data compiled.

All data								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	374	59	290.88	139.91	47.83	128	105	174
Hump	254	30	100	53.66	12.82	55	45	60
EMA	374	38	124	68.80	15.43	67	58	80
OSS	374	100	230	132.81	18.96	140	120	140
USMB	374	120	1180	347.27	125.59	340	290	390
RFT	374	1	30	7.84	5.35	6	3	12
Forearm	254	31	70	44.92	8.13	43	41	45
HindLeg	254	86	125	106.16	8.08	106.25	100	112
CT lean	374	40.8	66.59	55.73	5.14	56.30	52.4	59.74

Table 3.3. Descriptive data of MSA measurements for the muscling data set.

Muscling								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	127	59	202	114.78	36.71	105	87	134
Hump	127	30	80	47.95	12.41	45	40	55
EMA	127	38	110	64.13	14.40	62	54	75
OSS	127	100	230	132.05	24.41	130	110	150
USMB	127	120	510	279.29	89.09	290	210	340
RFT	127	1	13	4.47	3.48	3	2	6
Forearm	127	31	70	46.65	10.97	42	39	49
HindLeg	127	86	122	102.58	8.79	101	96	109
CT lean	127	49.14	66.59	57.09	3.56	57.23	54.62	59.75

Table 3.4. Descriptive data of MSA measurements for the CRC data set.

CRC								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	120	76	290.88	165.25	59.27	159.25	116.75	217.15
Hump	0	.	.	.	.	.	.	.
EMA	120	38	124.00	73.74	18.85	73.5	57.5	88
OSS	120	100	190.00	129.50	19.18	130	110	140
USMB	120	130	1180.00	412.67	168.58	375	310	505
RFT	120	1	30.00	9.21	5.95	8.5	4	15
Forearm	0	.	.	.	.	.	.	.
HindLeg	0	.	.	.	.	.	.	.
CT lean	120	40.8	64.84	55.38	6.83	57.37	49.14	61.5

Table 3.5. Descriptive data of MSA measurements for the Grass data set.

Grass								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	40	111	156	129.13	9.94	129.5	124	135
Hump	40	45	65	55.75	5.72	55	50	60
EMA	40	51	84	66.65	7.55	66	60.5	71.5
OSS	40	100	140	129.75	9.47	130	130	140
USMB	40	190	430	328.00	54.64	330	305	360
RFT	40	1	9	4.90	1.72	5	4	6
Forearm	40	38	50	42.86	2.34	43	41	44.5
HindLeg	40	100	116	107.65	3.23	107	105.25	110
CT lean	40	53.16	65.85	58.53	3.14	58.10	56.25	61.29

Table 3.6. Descriptive data of MSA measurements for the Grain data set.

Grain								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	37	156	219	181.62	15.57	180	170	191
Hump	37	50	100	70.00	10.87	70	65	75
EMA	37	69	94	80.46	6.67	80	75	84
OSS	37	110	150	138.11	10.23	140	140	140
USMB	37	280	580	393.78	69.70	380	340	440
RFT	37	6	15	9.89	2.49	10	8	12
Forearm	37	40	49	44.78	2.27	45	43	46
HindLeg	37	110	125	115.70	3.56	116	114	117
CT lean	37	48.82	60.20	54.18	2.85	53.88	51.94	56.91

Table 3.7. Descriptive data of MSA measurements for the WA data set.

WA								
Variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Median*	*25th Pctl*	*75th Pctl*
LeftSideHSCW	50	96.4	151.4	120.72	12.87	120.8	112.8	129.3
Hump	50	45	75	54.40	7.05	55	50	60
EMA	50	44	80	61.88	8.17	62	57	68
OSS	50	130	160	141.20	5.94	140	140	140
USMB	50	320	380	344.00	16.90	340	330	350
RFT	50	7	24	13.94	3.38	13	12	16
Forearm	50	35	47	42.26	2.20	42	41	43
HindLeg	50	100	118	107.00	4.06	106	104	110
CT lean	50	43.43	62.15	52.04	3.76	51.69	50.07	54.44

Table 3.8. Distribution of sex per data set

Data set	*Steer*	*Heifer*
Muscling	78	49
CRC	120	0
WA	0	50
Grass	37	0
Grain	40	0
Total	275	99

Table 3.9. Distribution of Feed type per data set.

Data set	*Grass*	*Grain*	*NA*
Muscling	96	31	0
CRC	0	0	120
WA	0	0	50
Grass	40	0	0
Grain	0	37	0
Total	136	68	170

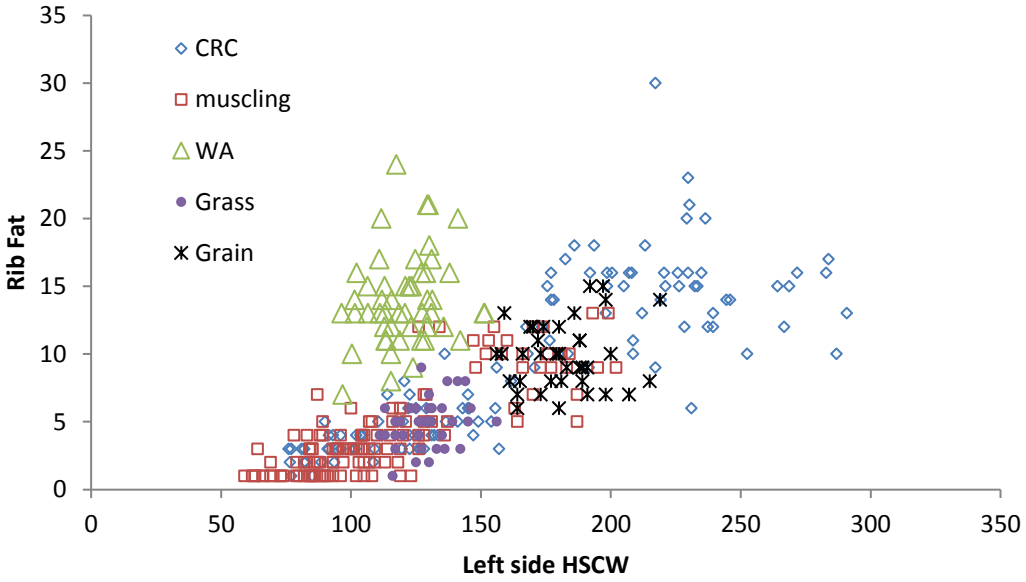

Fig. 3.3. Left side hot carase weight versus rib fat for each carcass in all data sets.

3.5.2 Methods

The data was handled and analysed in a number of steps to test the robustness of the equations derived. Firstly, equations for the prediction of percentage muscle were derived in SAS using the general linear model procedure. The equations were initially regressed to the best fitting model with 1 three-way interaction (LeftsideHSCW x RFT x EMA) with all other appropriate terms (F and P values can be seen in Table 4.37). The individual terms in the model were tested by further regressing these equations. A total of 7 different equations were tested in the current analysis. These equations, derived in the combined data set (muscling, CRC, grass and grain), and were then applied to each individual data set (including WA) to test the transportation of the equations. The newly predicted percentage muscle was compared to the CT lean values of each data set and the R squared and RMSE are presented (Table 4.38). For the next step, the same models were used in the GLM but applied to individual data set and a new equation derived. These new equations were then transported into the remaining data sets to test the true transportation or robustness of these equations. Data for the transportation in presented in the matrix in Table 4.39.

The same method was used to test the predictability of using fixed effect (feedtype only) and additional measures, hump height, forearm and hindlimb circumference. Because of the limitations on the data available these analysis used only modified data sets to derive equations.

The final step in the analysis was checking the transportation of the most useable equation across the MSA data available to test the suitability of the equation for use in the industry. The prediction from this equation was also compared against the current industry standard of using only carcase weight and fat depth to place carcases into company spec grids.

3.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield

3.7 Investigating relationships between market end point and expression of carcass traits associated with eating quality

3.7.1 Meat Standards Australia data

Producers who supply cattle to a processor to be slaughtered and graded under the MSA beef grading system, are required to submit a National Vendor Declaration (NVD) and MSA Vendor Declaration. The NVD identifies property of origin and a description of the cattle breed, sex and hormonal growth promotant (HGP) status. Data from the NVD is merged with slaughter and carcass grading data prior to uploading to the MSA database, where this study's data was extracted from.

To process MSA eligible cattle, the processor must be licensed by MSA and undergo regular audits to ensure compliance to minimum standards within lairage, processing and chilling. Various data fields are collected during the slaughter process. At grading, mandatory attributes are recorded; Marbling, ossification score and rib fat depth. Although not part of the MSA grading system, eye muscle area is also measured using appropriate AUS-MEAT grids. Data was accessed for cattle from nine processing plants in southern Australia for 2010-2013 representing more than 1.7M records.

3.7.2 Slaughter group information

A slaughter group, or lot, is defined by cattle delivered to a processor by a producer and killed on the same day. The slaughter group data was edited to generate best possible realistic representations of management groups with sufficient cattle to be confident in summary statistics generated for each group. There were initially 37,637 slaughter groups. All slaughter groups with cattle less than 20 head and those from saleyards were excluded. After interrogation of the data, carcass records were excluded where mean lot ossification exceeded 250. This removed lots where individuals had very high ossification (e.g. indicative of mature stock). The data set was also trimmed for lots where variation in carcass weight and ossification were high (indicative of mixed lots comprising some prime stock and some mature stock). The thresholds were a standard deviation in carcass weight of 50kg and ossification of 30 scores.

3.7.3 Data Analysis

Summary statistics were generated using the Proc Means procedure in SAS. Pearson correlation coefficients were estimated between HSCW, marbling, ossification and the MSA index for both lot means and standard deviations (SD), using Proc Corr in SAS. Carcass trait means and standard deviations were regressed on carcass weight using Proc Reg in SAS to determine the change in the mean and variation of carcass traits for a 100kg increase in carcass weight.

3.8 Genetics of BREEDPLAN carcass traits and meat eating quality

At the start of the project it was envisaged that we would be able to secure pasture finished pedigreed carcass data for lifetime management groups. This proved to be far more difficult than we anticipated. Put simply, external to BINs, the only large commercial herds with pedigree are part of Team Te Mania. We worked with Te Mania Angus to secure pedigreed pasture finished carcass data. We were prepared to pay a premium of $50/steer to achieve this. However, Team Te Mania steers are in strong demand, especially for long feeding regimes. Overall, rather than be able to secure sufficient numbers of steers within the project, feedlots increased the attractiveness of their offers to suppliers to secure steers for their feeding regimes. It was apparent that the project team would not be able to secure sufficient numbers of records within the project budget constraints. The team took an alternative approach that focussed on harvesting as much information from research data sets as possible.

On the positive side, we have two solutions: First, the Black Baldy project in Tasmania and NZ progeny test projects in partnership through the new Trans-Tasman Maternal Efficiency project (pending) will provide industry with grass-fed carcass data from animal's management in lifetime contemporary groups that have detailed phenotypic records. We believe this approach will allow many carcass records (approximately 5000 animals across all projects over 3 years) to be used effectively in genetic evaluation. Second, we have analysed existing data to develop a strategy for harvesting genetics data from commercial herds in future. This has been included in the report as Appendix 9.1.3.

3.9 Relationship between BREEDPLAN EBVs and meat eating quality

3.9.1 Data and Measurements

Data from 12 industry or research data sets totalling 6997 animals from four breeds (Angus, Charolais, Hereford and Limousin) and 433 sires have been included for analysis. Table provides a brief summary of each data set used. For detailed descriptions for the research herds from Maternal Productivity (MP – Vasse) animals (Pitchford *et al.* 2017) , Regional Combinations (RC – NSW, RC – SA, RC – WA, RC – Vic) animals (McKiernan *et al.* 2005), Rockdale (Herd *et al*., 2017) and Trangie (Arthur *et al.*, 2005). Both Team Te Mania datasets are industry datasets, Clowes is located in the Central West NSW with calves born in early spring. The Toolong data comes from an autumn calving herd in Western Victoria. Both herds source their bulls from the Team Te Mania. The three BIN datasets (Angus BIN, Charolais BIN, and Hereford BIN) are part of a nation-wide progeny test initiative established through the MLA Donor Company and co-funded by five breed societies. The datasets contain a range of growth paths (slow vs. fast), finishing regimes (Short feedlot <200 days, Long feedlot >200 days and pasture) and carcass end point (200-500kg carcass weight) included in the analysis. A summary of the data collected is presented (Table 2.11). The carcass traits included hot standard carcass weight (HSCW, kg), ossification (Oss), eye muscle area (EMA, cm^2), pH, rib fat (Rib, mm), intra muscular fat (IMF %, measured in the laboratory), MSA marbling (Marb), and MSA Index. For the regional combinations datasets predicted eating quality of the striploin (PEQ –sl) was also analysed.

Table 3.10. Summary of data sets

Data set	# head	# sires	Birth years	Brief Description
Angus BIN	1762	141	2011 - 2014	Ongoing project with additional data to be collected. Angus sires with heifer and steer carcass records that were all feedlot finished for > 200 days.
Charolais BIN	362	20	2010	Ongoing project with additional data to be collected. Limousin and Charolais sires with heifer and steer carcass records either pasture or short feedlot finished.
Hereford BIN	1687	56	2011-2015	Ongoing project with additional data to be collected. Hereford sires with heifer and steer carcass records either pasture or feedlot finished.
MP – Vasse	101	18	2010	Progeny from Beef CRC Maternal Productivity Project where Angus cows were either divergent in RFI or Rib fat EBV. Slaughtered at 1 year old after short period of grain assisted ration (Pitchford *et al.*, 2017).
RC - NSW	558	34	2001-03	Structured multisite project across southern Australia with fast vs. slow post weaning growth paths and genotypes including high IMF (Angus and Wagyu sires) and high yield (Angus, Charolais and Limousin sires). Multiparous Hereford cows were used. All feedlot finished (McKiernan *et al.*, 2005).
RC – SA	396	31	2002-04	Link site to NSW. Same sire breeds as NSW crossed to composite cows with a varying proportion of British and Dairy breeds. All progeny finished on pasture (McKiernan *et al.*, 2005).
RC - Vic	662	27	2002-04	Link site to NSW. Same sire breeds as NSW crossed to British and European breed cows. Progeny finished on pasture or feedlot (McKiernan *et al.*, 2005).
RC – WA	941	23	2002-04	Link site to NSW. Same sire breeds as NSW crossed to composite cows with a varying proportion of British and Dairy breeds Progeny finished on pasture or feedlot (McKiernan *et al.*, 2005).
Rockdale	208	26	2006	Purebred Angus, part of NSW DPI RFI selection lines. RFI steers 2-3 generations in divergent selection for RFI. Some Angus Elite Progeny sires. Fed for 251 days (Herd *et al.*, 2017).

TTM - Clowes	68	18	2013	Spring 2013 born steers. Grown on pasture and killed at average age of 461 days, 279kg HSCW.
TTM - Toolong	122	29	2013	Autumn 2013 born steers. Grown out on pasture and killed at an average of 606 days, 296kg HSCW
Trangie	130	10	1998	Purebred Angus, part of the NSW DPI Residual Feed Intake (RFI) selection lines. Approximately 1 generation of divergent selection for RFI (Arthur *et al.* 2005). Fed for > 200 days.

Table 2.11. Carcass trait summary statistics for each dataset

	Angus BIN	Char BIN	Here BIN	MP Vasse	RC NSW	RC SA	RC Vic	RC WA	Rock.	TTM Clowes	TTM Toolong	Trangie
HSCW												
Mean	*450*	258	320	234	362	269	293	258	415	279	296	387
SD	*37*	35	35	21	32	33	29	29	27	15	15	38
Min.	*277*	177	202	183	266	169	220	140	355	248	253	253
Max.	*575*	354	439	298	451	355	369	355	494	324	332	477
Oss												
Mean	154	143	126	107	182	154	170	140	141	136	135	161
SD	20	13	16	10	14	22	30	19	10	19	12	19
Min.	110	110	100	100	140	110	130	100	110	110	100	130
Max.	280	180	190	140	220	200	400	220	160	170	170	200
EMA												
Mean	*85.1*	65.4	73.5	69.5	81.7	66.8	74.3	67.2	77.0	69.1	72.1	80.4
SD	*8.0*	5.0	7.4	6.6	9.3	8.0	9.0	7.2	3.3	4.2	8.3	9.1
Min.	*62.6*	46.0	51.0	57.0	62.0	47.0	50.0	38.0	68.0	58.0	55.0	60.0
Max.	*114.0*	74.0	97.0	89.0	119.0	92.0	113.0	93.0	85.0	78.0	89.0	108.0
pH												
Mean	5.50	5.54	5.50	5.55	5.54	5.53	5.62	5.56	5.52	5.56	5.57	
SD	0.06	0.11	0.09	0.03	0.14	0.12	0.16	0.14	0.06	0.05	0.11	
Min.	5.30	5.37	5.31	5.50	5.34	5.40	5.35	5.40	5.42	5.47	5.40	
Max.	5.85	5.93	6.33	5.66	6.63	6.05	6.37	6.68	5.68	5.68	6.11	
Marb												
Mean	515	294	342	329	347	307	362	322	504	356	384	358
SD	121	78	64	59	57	55	88	76	107	35	48	63
Min.	160	150	130	200	180	180	200	130	350	300	280	220
Max.	1030	490	600	490	620	540	680	670	830	480	530	580
Rib Fat												
Mean	*16.9*	8.6	10.1	7.9	11.0	8.0	7.5	9.5	17.9	6.2	8.3	14.1
SD	*4.9*	2.6	5.0	1.8	4.3	3.4	3.6	4.5	5.6	1.8	2.9	4.4
Min.	*5.8*	3.0	1.0	4.0	3.0	2.0	1.0	1.0	6.0	4.0	3.0	5.0

Max.	*36.8*	14.0	30.0	14.0	25.0	22.0	23.0	33.0	34.0	13.0	18.0	27.0
IMF lab												
Mean	*10.6*	2.7			3.9	4.5	3.0	3.9	14.5			
SD	*4.0*	0.7			1.6	1.7	1.3	1.6	3.1			
Min.	*3.0*	1.6			1.01	1.2	0.2	0.1	8.3			
Max.	*29.4*	5.2			15.23	10.8	9.6	13.6	22.7			
Index												
Mean	65.04	60.55	62.34		60.18	59.67		61.05		61.63	62.50	
SD	1.69	1.79	0.87		1.41	1.75		1.99		1.50	1.32	
Min.	59.15	54.82	56.94		52.88	55.22		52.64		58.6	59.44	
Max.	70.48	66.62	66.26		64.37	63.55		68.48		64.83	67.07	

NB – numbers in italics have been BREEDPLAN pre-adjusted

Blank cells were not measured in that dataset

3.9.2 Statistical Analyses

3.9.2.1 *Relationship between BREEDPLAN EBVs and meat eating quality*

A number of different statistical approaches were taken to determine the degree to which the current MSA index and its indicator traits are related to BREEDPLAN EBVs. Carcass traits (IMF, MSA marbling, EMA, MSA Index, Rib, Ossification and HSCW) were regressed on BREEDPLAN sire EBVs (IMF EBV, EMA EBV, 600 day weight EBV, Rib EBV) after taking into account contemporary groups (a concatenation of dataset, management group and kill date), appropriate genetic "line" effects (high IMF, high yield, high RFI etc.) and management (Pasture, Short-fed, Long-fed) for each dataset. Sire BREEDPLAN EBVs were standardised by subtracting the mean sire EBV of a breed and dataset group within each breed within each dataset to allow for between breed comparisons and to account for EBVs being estimated at different times for each dataset. A general linear model was fitted in ASReml (Gilmour *et al.* 2009) which included dataset contemporary groups as fixed effects, standardised sire EBVs and interactions between finishing system, breed, dataset and the standardised sire EBVs to determine if there was a significant difference in the magnitude and or direction of the relationships between carcass traits and sire EBVs.

Sire variance components were estimated in ASReml (Gilmour *et al.* 2006) for each of the 12 datasets in Table to determine whether the genetic variance in MSA index and its indicator traits changes with carcass weight. The same fixed effects used as for the regression analysis (excluding the sire EBVs and interactions) were fitted. These included contemporary group and the appropriate genetic line effect (breed, high IMF, high yield) and management (pasture, Short-fed) effects. Sire was included as a random effect in the benchmark model. Additional random effects were tested as interactions with sire: finish by sire, breed by sire and dataset by sire were included in separate models with separate sire variance components for finish regime, breed and dataset estimated. The log likelihood ratio test statistic was calculated to determine if the additional random terms significantly improved the model.

3.9.2.2 *Genetic parameters between current BREEDPLAN traits and meat eating quality traits*

Data (2557 animals) from all four sites of the Regional Combinations project (McKiernan *et al.* 2005) was used to test the importance of genotype by environment interactions (GxE) by estimating genetic correlations between the same carcass trait under pasture and short-fed finishing regimes. These were the only datasets where the same sires had progeny across both grass and Short-fed finishing systems. The fixed effects included in this model were site (NSW, SA, Victoria, and WA), sex (F, M), growth (slow, fast), finish (feedlot, pasture), genetic line (high yield, high eating quality, both), finish by kill date and management group. Sire and sire by finish were included as random terms, with the sire covariance and correlations estimated between each finish system for carcass traits informing the MSA Index (HSCW, Rib fat, Ossification, MSA Marbling, P8, EMA and IMF), predicted eating quality of the strip loin (PEQ-sl) and the MSA Index.

4 Results

4.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

4.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia

The total number of carcases with non-compliant pH values was 576 (17.5%). Individual mob percentages of non-compliance due to pH ranged from 0-56%.

4.1.1.1 *Mob composition and pre-slaughter management effects on % dark cutting*

Producers who bred their own cattle (vendor bred) and consigned them for slaughter had a 15.4% higher average percentage of dark cutters than those who purchased stock for finishing (Fig. 4.1).

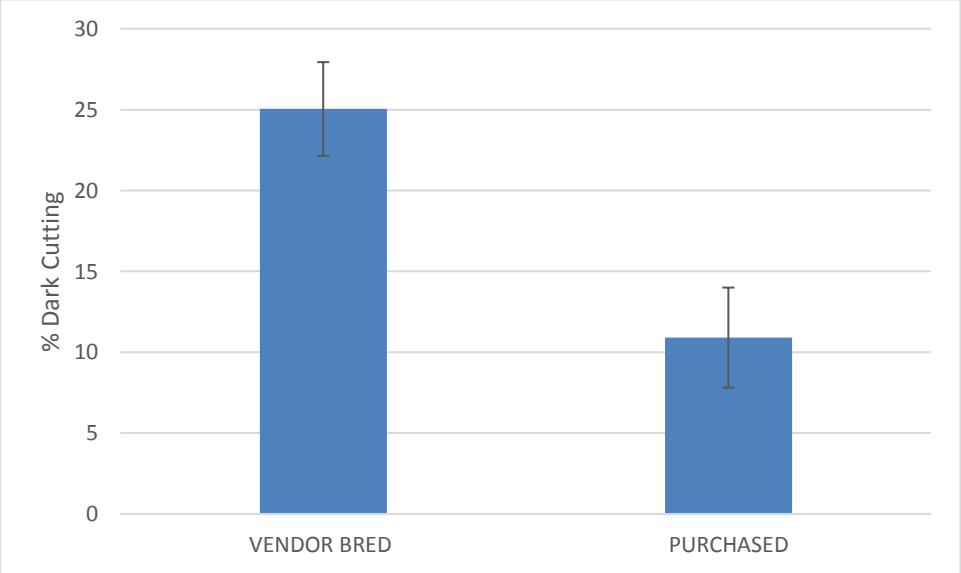

Fig. 4.1: Predicted mean % dark cutting for slaughter groups either bred by the consigning vendor or purchased in as weaned stock.

Slaughter groups greater than 24 months of age had 15.6% higher DC than those less than 24 months of age (Table 3.1, Fig. 4.2).

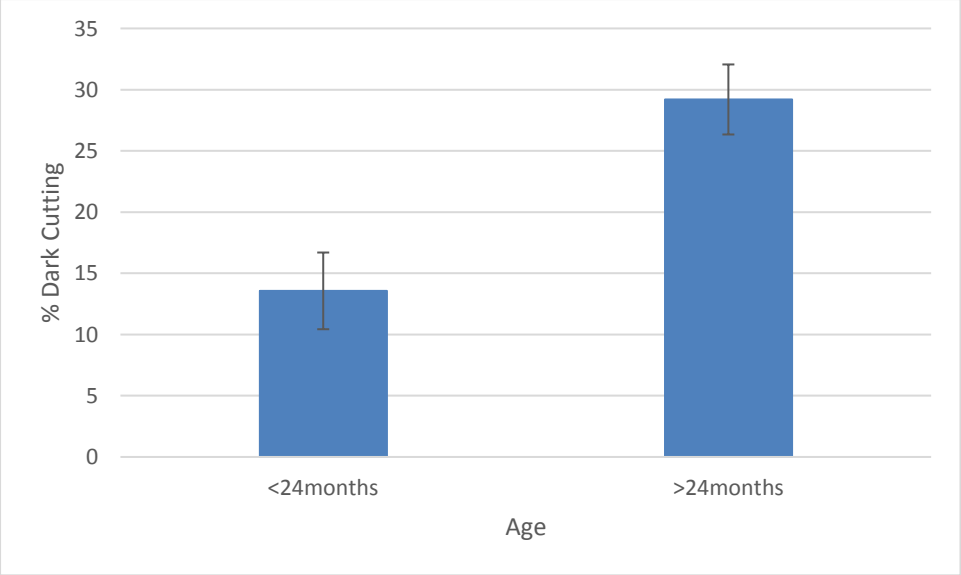

Fig. 4.2: Predicted mean % dark cutting for slaughter groups aged above or below 24 months of age at slaughter.

Movement of a mob into a new paddock within one week of slaughter led to a 10.7% higher incidence of DC (Fpr= <0.001) compared to those moved at times further out from slaughter (Table 3.1). The incidence of DC was lowest in groups moved between 1-2 weeks pre-slaughter, and whilst the mean dark cutting was not significantly different for those moved at 2-3 and >4 weeks, there appears to be a trend for an increase in DC as time progresses (Table 3.1, Fig. 4.3).

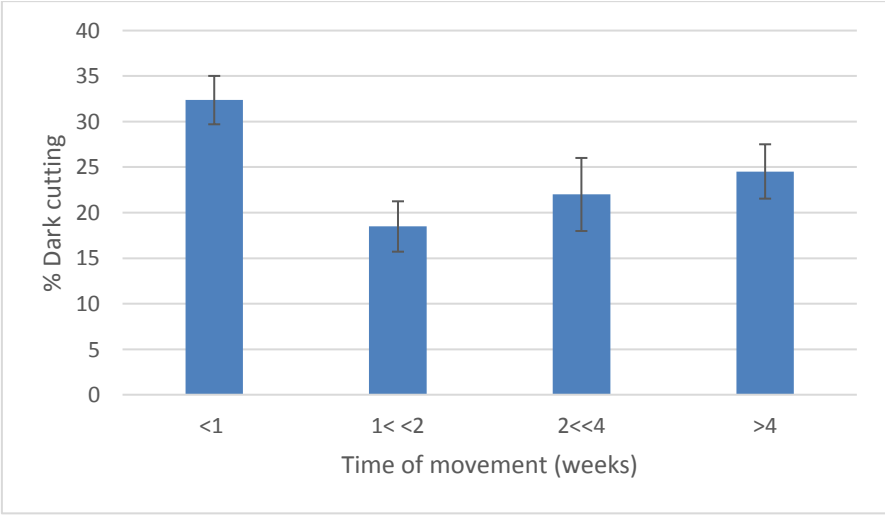

Fig. 4.3: Predicted mean % dark cutting of mob paddock movements prior to slaughter

There was a significant effect of curfew type, with those cattle taken straight from the paddock, or moved into a laneway or holding paddock prior to loading (partial curfew) having between 10.51 and

12.5% higher incidence of dark cutting than those cattle yarded the night before transport both with and without feed and water (Table 3.1, Fig. 4.4).

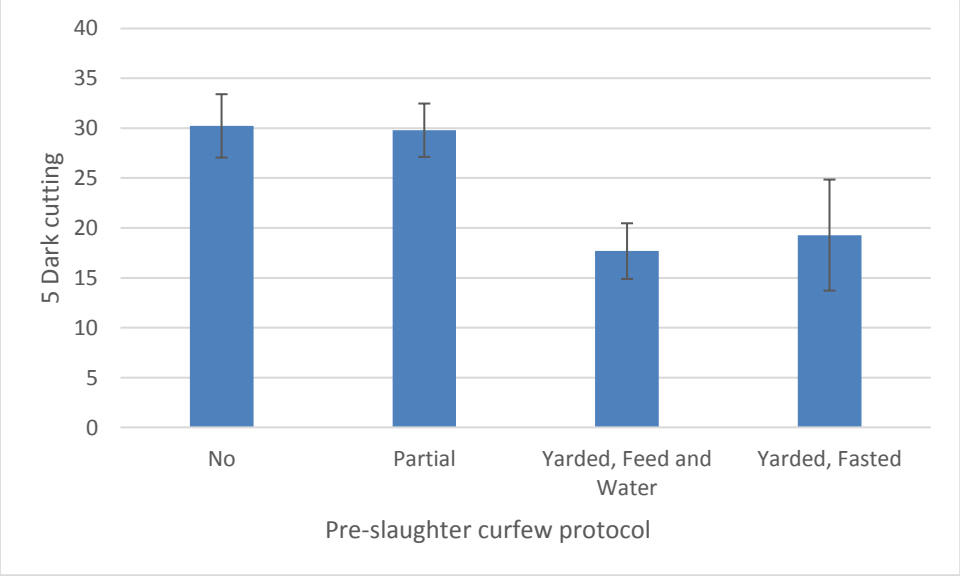

Fig. 4.4: Predicted mean % dark cutting of different pre-slaughter curfew management methods

There was no significant effect of whether cattle were killed on the day after transport (conventional practice) or the day of transport (tailgate kill). Classification of the pasture base as either grass (ryegrass/fescue/phalaris) or mixed (containing a legume) revealed that cattle coming off mixed pastures had and 8.5% lower incidence of DC (Table 3.1, Fig. 4.5).

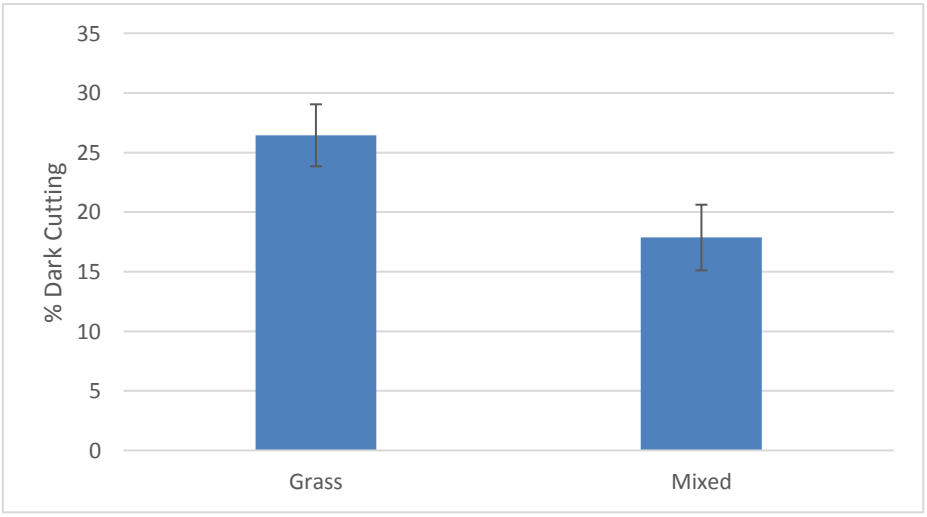

Fig. 4.5: Predicted mean dark cutting % for grass dominant of mixed grass/legume pastures

Feed on offer (FOO) in the last week prior to slaughter had a significant effect on %DC, with the mean incidence 6.5% lower for those with FOO greater than 3000kg DM/ha than any FOO below 3000kg DM/ha (Table 3.1, Fig. 4.6).

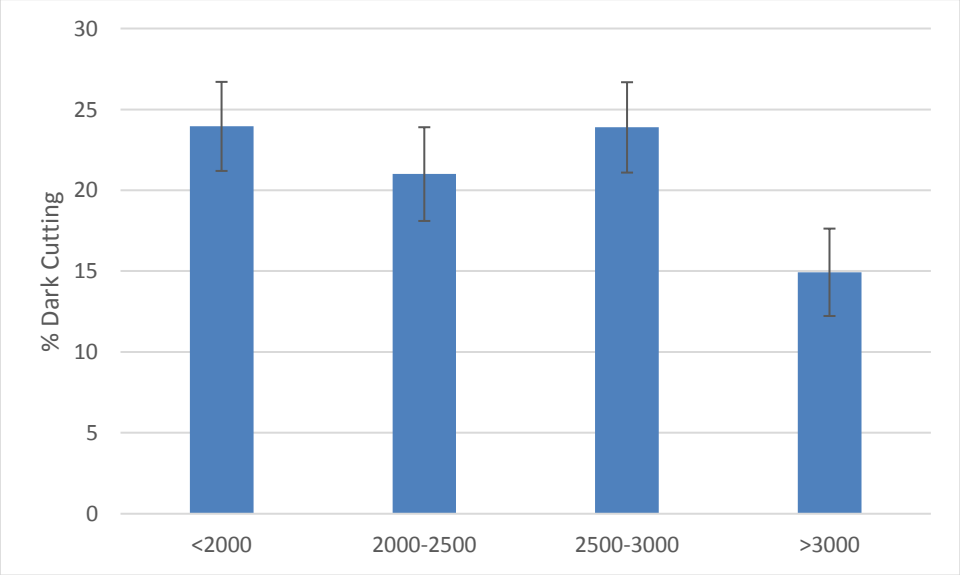

Fig. 4.6: Predicted mean dark cutting % for different feed on offer (FOO) levels in the week before slaughter

Table 3.1. Tests of significance and predicted means for farm management factors on slaughter group incidence of dark cutting (DC)

CATEGORY	F Pr.	CLASSIFICATION	Predicted Mean	±SEM
Stock Source	0.001	Vendor Bred	25.1	2.9
		Purchased	10.9	3.1
Age	<0.001	<24 months	13.6	3.1
		>24 months	29.2	2.9
Paddock change pre-slaughter	<0.001	<1 week	32.4	2.6
		1-2 weeks	18.5	2.7
		2-4 weeks	31.1	6.3
		>4 weeks	24.5	2.9
Curfew	<0.001	No Curfew	30.2	3.2
		Partial Curfew (Laneway)	29.8	2.6
		Yarded, Feed and Water	17.7	2.8
		Yes	19.3	5.5
Pasture base	<0.001	Grass	26.4	2.6
		Mixed	17.9	2.7
Pasture availability (kg DM/ha)	<0.001	<2000	23.9	2.7
		2000-2500	21	2.9
		2500-3000	23.9	2.8
		>3000	14.9	2.7

4.1.1.2 *Pasture composition effects on dark cutting*

Summary statistics on the pasture mineral concentrations measured, the dietary requirements for growing cattle and the proportion of pasture samples above and below that requirement are presented in Table 4.2. Pasture Magnesium concentrations were within the desired range, excluding one high and one low sample (Table 4.2). The majority of pasture potassium levels were sufficient except for 13% which were in excess. Minimum sodium requirement was met by all samples (Table 4.2). One pasture sample had higher than required S levels, 2 samples had below requirement whilst the remainder were in a suitable range for growing cattle. Calcium and Phosphorous levels are reported (Table 4.2), but their level relative to requirements is not reported as this is dependent on the extent of protein deposition (NRC. 2000), which was not quantified in this study. A total of 65 out of 68 (95%) of pasture samples reported had below adequate levels of Copper required for growing cattle (Table 4.2). All samples had suitable levels of Iron, but 14 and 68% of samples were deficient in Manganese and Zinc respectively (Table 4.2).

Table 4.2. Summary statistics, dietary requirements for growth and proportion of samples above and below NRC requirements for pasture mineral concentrations.

	%						mg/kg DM			
	Mg	K	Na	S	Ca	P	Cu	Fe	Mn	Zn
MIN	0.13	0.54	0.13	0.12	0.23	0.11	2	83	13	7
MAX	0.4	4.13	1.9	1.14	4.11	0.62	14	677.7	263	61
MEAN	0.2	2.0	0.4	0.2	0.8	0.3	6.1	202.9	66.6	25.8
SD	0.1	0.8	0.3	0.1	0.6	0.11	2.20	117.9	58.5	10.2
CV	0.28	0.38	0.69	0.52	0.67	0.40	0.36	0.58	0.88	0.39
Requirement for growth	0.1	0.6	0.06-0.08	0.15			10	50	20	30
Maximum tolerable in diet	0.4	3		0.4			100	1000	1000	500
% below requirement	2	2	0	3			95	0	14	68
% above requirement	2	13		2			0	0	0	0

National Research Council (2000)

The digestible (Acid Detergent Fibre, ADF) and indigestible (Neutral Digestible Fibre, NDF) content of pasture had a significant effect on the incidence of DC (Table). Estimation of pasture digestibility by the use of the ratio of ADF to NDF did not affect DC. Both crude protein (CP) and metabolisable energy (ME) content of feed did not have an effect on DC despite large ranges (25% and 5.7 megajoules (MJ) respectively) measured for each trait.

The trace element and mineral composition of pasture grazed pre-slaughter had minimal effect on the incidence of DC, except for the Magnesium (Mg) content (F pr. = 0.039, Table). For every 1% increase in Magnesium content in pasture, the estimated DC would be -57.42%. Thus, in real terms, across the 0.27% range in pasture Mg measured, a 0.1% increase in Mg concentration would result in a 5.7% decrease in DC (Table). The effect of pasture Iron (Fe) approached significance (F Pr.=0.053), resulting in an increase of 0.03% DC per 1PPM increase in pasture Fe. Given that the range in Fe measured in this study was 594ppm, this would result in a 17.8% range on DC.

The Dietary Cation Anion Difference (DCAD) effect on DC also approached significance (F Pr.=0.076), with every 1 milli-equivalent increase in DCAD associated with a 0.03% increase in DC. The range in DCAD measured covered a 449.59 Meq range, which would result in a 13.5% range in DC.

Table 4.3. Tests of significance and estimated effects for pasture quality effects on slaughter group incidence of dark cutting (DC)

PASTURE COMPOSITION TRAIT	F Pr.	Estimated effect on %DC (per unit increase in pasture trait)
ADF (%)	0.897	0.052
NDF (%)	0.831	0.061
ADF/NDF (%)	0.725	-0.11
CP (%)	0.179	0.37
ME (MJ ME/kg DM)	0.151	1.9
Ca %	0.592	-1.7
Cl %	0.477	2.5
K %	0.273	2.6
Na %	0.423	-5.1
P %	0.268	18.1
S %	0.937	1.2
Fe mg/kg DM	0.053	0.032
Zn mg/kg DM	0.525	0.12
Mn mg/kg DM	0.621	0.021
Mg mg/kg DM	0.039	-57
Cu mg/kg DM	0.724	0.31
DCAD Milli-equivalents	0.076	0.035

4.1.1.3 *Liver Mineral Status*

A subset of 725 out of the 3280 individual liver samples taken were analysed for mineral content. Summary statistics for the parameters measured are presented (

Table). Based on the published reference ranges, the proportion of the sampled population were defined as clinically deficient, deficient, marginal, adequate, high or toxic. Although liver magnesium concentration is not typically used to determine magnesium status, published values exist and can serve as an indication of long term magnesium status. All samples analysed were in the marginal range, indicating no chronic long term deficiency of the mineral (

Table). Copper was the most deficient element, with 51% of animals sampled exhibiting sub-clinical levels (<20 mg/kg DM). A further 21 and 27.5% were deficient or marginal, with a single individual recording adequate levels as per the reference standard (

Table). Liver Iron concentration was measured as marginal in 98% of samples, with two individual samples in the adequate range (

Table). No deficiency was observed in Phosphorous content of the liver with all samples over 1400 mg/kg DM. Forty four samples (6%) were deficient in Zinc, with 88% at a marginal level, and a total of forty three samples at an adequate level

Table).

Table 4.4. Summary Statistics, reference standards and proportion of samples relative to reference ranges for liver mineral concentrations.

		Liver Mineral Concentration (mg/kg DM)								
		Ca	K	Mg	Na	S	Cu	Fe	P	Zn
	MIN	18.5	1730	101	319	1240	0.8	25.7	1970	15
	MAX	90	3670	202	1230	2650	142	164	3850	72.8
	MEAN	36.7	2905.1	156.4	592.5	1971.9	24.1	51.1	3007.1	31.6
	SD	7.4	344.2	20.3	114.1	265.7	19.7	14.8	381.7	5
	CV	0.2	0.1	0.1	0.2	0.1	0.8	0.3	0.1	0.2
Reference Standards (mg/kg DM)	Clinically deficient						<20			
	Deficient			<40			<33	<40	<1400	<25
	Marginal			40-100			33-125			25-40
	Adequate			100-250			125-600	45-300	>1400	40-200
	High						600-1250	300-700		300-600
	Toxic						>1250			>1000
Population incidence %	Clinically deficient						51			
	Deficient			0			21	0.5	0	6
	Marginal			100			27.5	98		88
	Adequate			0			0.5	1.5	100	6
	High									
	Toxic									

(Kincaid. 1999; National Research Council 2000)

Carcass pH values are effectively truncated and so not normally distributed (Fig. 4.6). The values were transformed back to raw hydrogen ion concentration ($H^+=10^{-pH}$). The calculated hydrogen ion

concentration data was normally distributed (Fig.), thereby allowing analyses of liver mineral data in a linear model against hydrogen ion concentration.

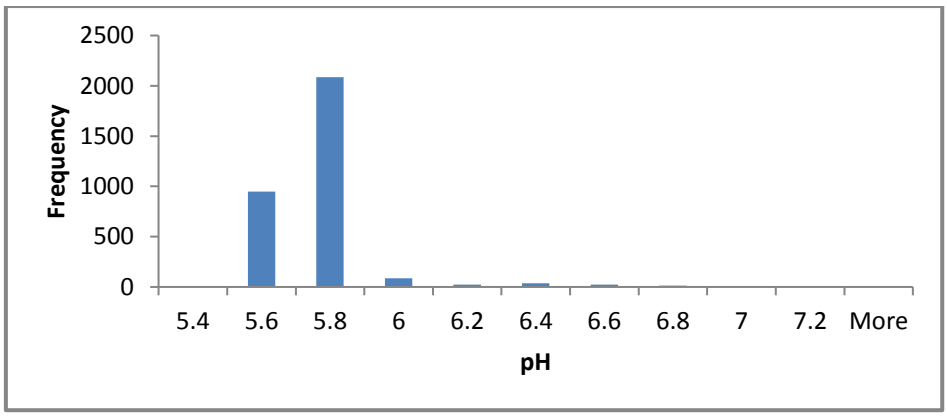

Fig. 4.7: Frequency distribution of carcass pH values

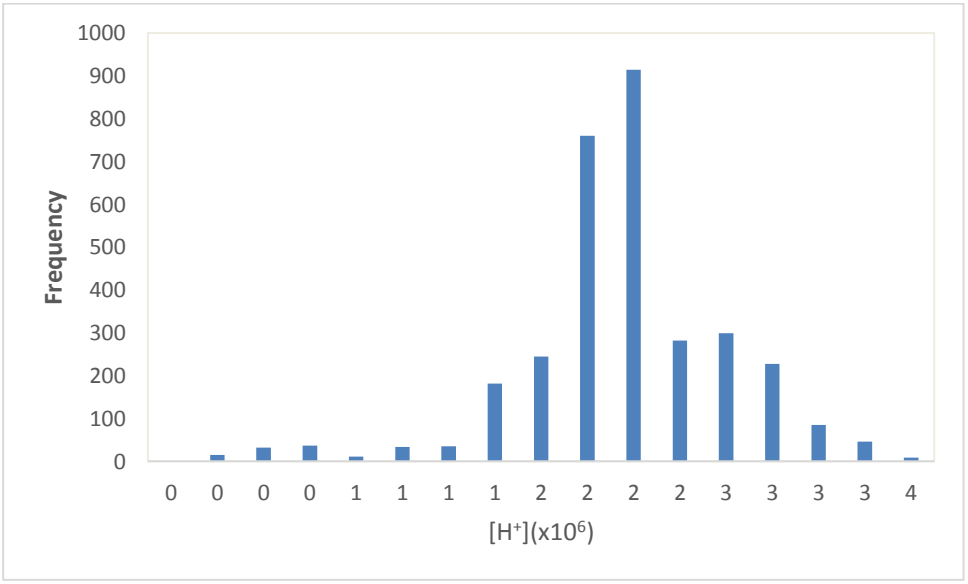

Fig. 4.8: Frequency distribution of ultimate carcass hydrogen ion concentration ($x10^6$), as calculated from carcass pH by ($H^+=10^{-pH}$)

Table 4.5. Summary statistics for ultimate carcass pH and hydrogen ion concentration

	pH	$[H^+]$x 10^6
MIN	5.41	91
MAX	7.03	398
MEAN	5.65	232
SD	0.155	56
CV	0.027	0.241

Having identified that there is a range of mineral status within the sampled population, analyses of the relationship between the elements and carcass grading result was undertaken. In the first analysis series of linear regressions of liver mineral concentration against H ion concentration were performed with mob fitted as a random term. The relationship between ultimate carcass hydrogen ion concentration and both Magnesium and Copper approached significance (P Value= 0.062 and 0.090 respectively, Table). The only liver mineral concentration to have a significant relationship with hydrogen ion concentration was Sulphur (P-value= 0.008, Table 4.6. F-statistic and significance values for the relationship between ultimate carcass hydrogen ion concentration and liver mineral concentrations.). The regression equation for Sulphur on hydrogen ion concentration is:

Table 4.6. F-statistic and significance values for the relationship between ultimate carcass hydrogen ion concentration and liver mineral concentrations.

Liver Trace Mineral	**P-value**
Calcium	0.167
Potassium	1.000
Magnesium	***0.062***
Sodium	0.704
Sulphur	**0.008**
Copper	***0.090***
Iron	1.000
Zinc	0.680
Phosphorous	1.000

Binary logistic analysis of liver mineral data showed that liver Sulphur concentration was significantly different between animals that were (Scored 1) or were not (Scored 0) dark cutters (Fig. 4.89). As liver concentration increased from 1240 to 2650 mg/kg, the probability of dark cutting decreased by 38% (P=0.011).

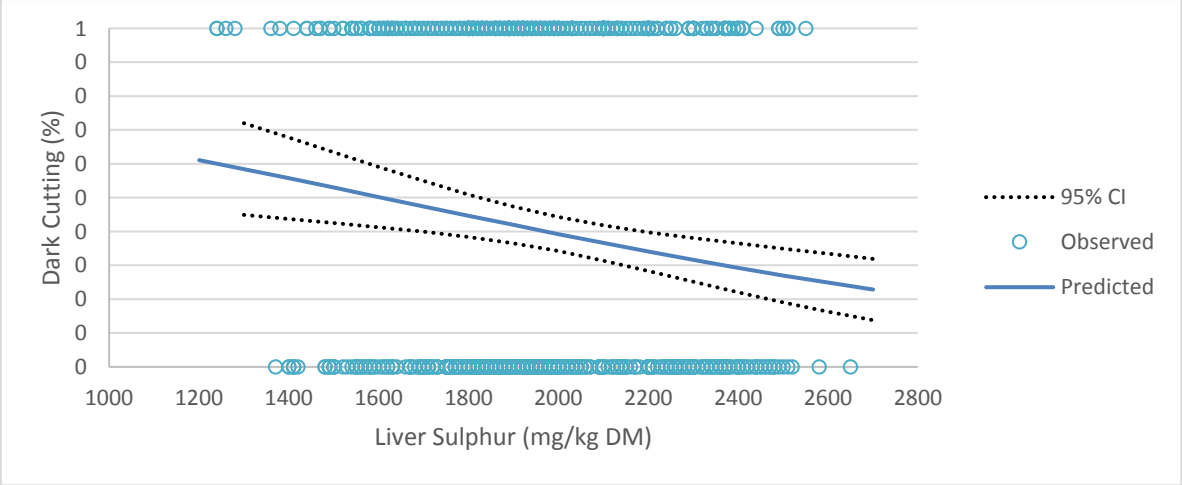

Fig. 4.9: The effect of liver Sulphur concentration on the probability of dark cutting.

As for the hydrogen ion concentration analysis, liver Magnesium concentration approached significance for its effect on whether an animal was a dark cutter or not (P=0.061). As liver magnesium concentration increased from 101 to 202 mg/kg, the probability of dark cutting decreased by 24.73% (Fig.).

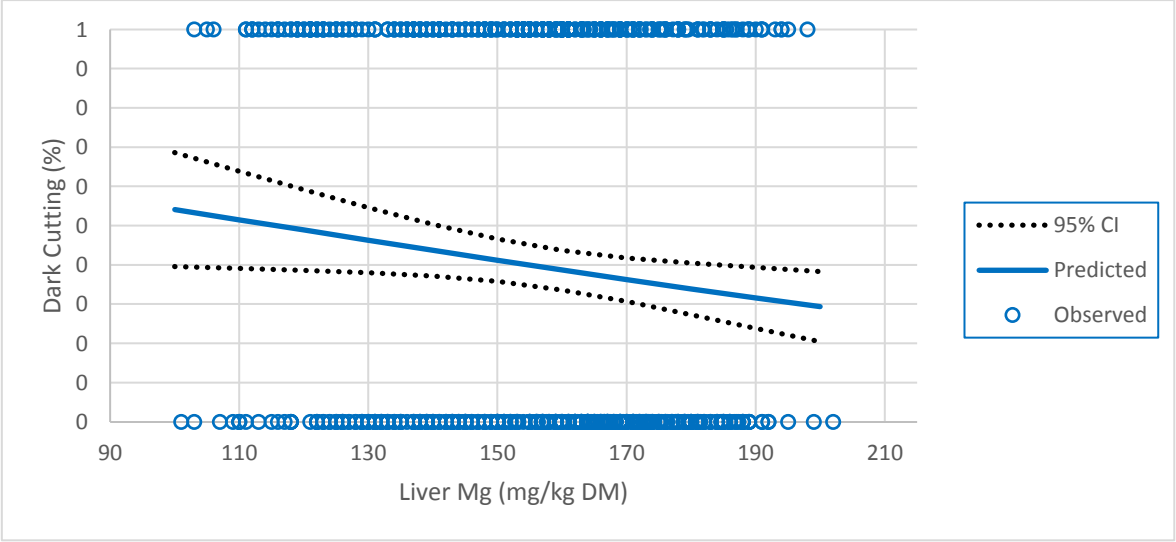

Fig. 4.10: The effect of liver Magnesium concentration on the probability of dark cutting.

4.1.2 Farm management and feed quality factors contributing to dark cutting in King Island

4.1.2.1 *Magnesium*

The incidence of dark cutting per group was not associated with the grass tetany index however pasture Mg independent of K and Ca did have a significant association (P=0.06).

Pasture magnesium was moderate risk factor for dark cutting, there was a 26% decreased relative risk of dark cutting in cattle grazing pastures where pasture magnesium concentration exceeded 0.24%. 42groups were grazing pasture magnesium was ≤ 0.24% vs 24groups grazing magnesium > 0.24%.

4.1.2.2 *Water*

Water source had a marked and significant impact on the incidence of dark cutting per group (P=0.001). Cattle sourcing water from a dam had a 50% increased relative risk of dark cutting compared to those drinking from a trough. All trough water was pumped from holding dams that were spring fed or runoff water. No troughs contained bore water. There were 34 groups sourcing water from a dam vs 32 groups sourcing trough water. Twelve groups of cattle accessing troughs had trace element supplementation supplied via the water; eight groups had copper-sulphate and four had copper-sulphate, cobalt and magnesium.

4.1.2.3 *Supplementary feed*

Supplementary feed was significantly associated with dark cutting (P=0.28). Groups fed supplements in the last seven days prior to slaughter had a 25% decreased relative risk of dark cutting compared to groups that received none. Supplement metabolisable energy, water-soluble carbohydrate and crude protein content was significantly lower (P<0.05) than the pastures and supplement Neutral Detergent Fiber and Acid Detergent Fiber were significantly higher than the pastures (P<0.01). Twenty-six groups had access to supplementary feed compared with 40 groups with no supplementary feed.

4.1.2.4 *Sex*

The sex of the groups had a significant impact in the incidence of dark cutting (P<0.01). Heifer groups had the least dark cutting risk, a 47% reduced risk compared to steer groups whilst mixed sex groups were 27% less likely to cut dark than steers.

Table 4.7: Multivariate model

	IRR	Std. Err.	z	P> |z|	95% Conf. Interval	
Supplementary Feed (Fed)	0.746	0.996	-2.19	0.028	0.574	0.969
Water Source (Dam)	1.495	0.181	3.33	0.001	1.180	1.896
Pasture Magnesium (>0.24%)	0.743	0.118	-1.88	0.060	0.545	1.013
Sex						
Mix	0.733	0.158	-1.44	0.151	0.481	1.119
Heifer	0.531	0.080	-4.18	0.000	0.395	0.715
FumonisinB1 (exposure >5PPB)	1.423	0.186	2.70	0.007	1.101	1.838
Ergot Alkaloids (exposure >600PPB)	1.549	0.296	2.29	0.022	1.064	2.254
3acetyldeoxynivalenol (exposure >5PPB)	0.634	0.118	-2.46	0.014	0.441	0.912

4.1.2.5 *Mycotoxins*

The pastures tested were perennial ryegrass (*L. perenne*) dominant, with approximately 80% having undergone no pasture renovation in the last 10years. There was a high prevalence of mycotoxins detected in the pastures (Fig.4.11). 100% of cattle had exposure to ≥ 3 major families (Ergot alkaloids, β-trichothecenes, α-trichothecenes, Aflatoxins, Fumonisins and Zearalenone) and 20% had exposure to all six. Ergot Alkaloids were detected at highly toxic levels in 91% of pastures and Zearalenone metabolites medium-high risk in 14% of all pastures whereas the other families were all considered low risk. BIOMIN considers Ergot concentration high risk to beef cattle when they are >400PPB and Zearalenone medium-high risk >200PPB. Total Ergot Alkaloids and FumonisinB1 were negatively associated with dark cutting ($P<0.05$). Those groups grazing pastures higher in total Ergot Alkaloids and FumonisinB1 had higher incidence of dark cutting. Available pasture (kg DM/Ha) had no impact on incidence of dark cutting.

The mycotoxins that were significant for dark cutting included combined Ergot Alkaloids, FumonisinB1 and 3acetyldeoxynivalenol. Pastures with Ergot Alkaloid exposure >600PPB had a 45% increase risk of dark cutting. Pastures which contained any level of FumonisinB1 had a 58% increased relative risk however those that contained exposure to any level of 3acetyldeoynivalenol had a 37% decreased relative risk.

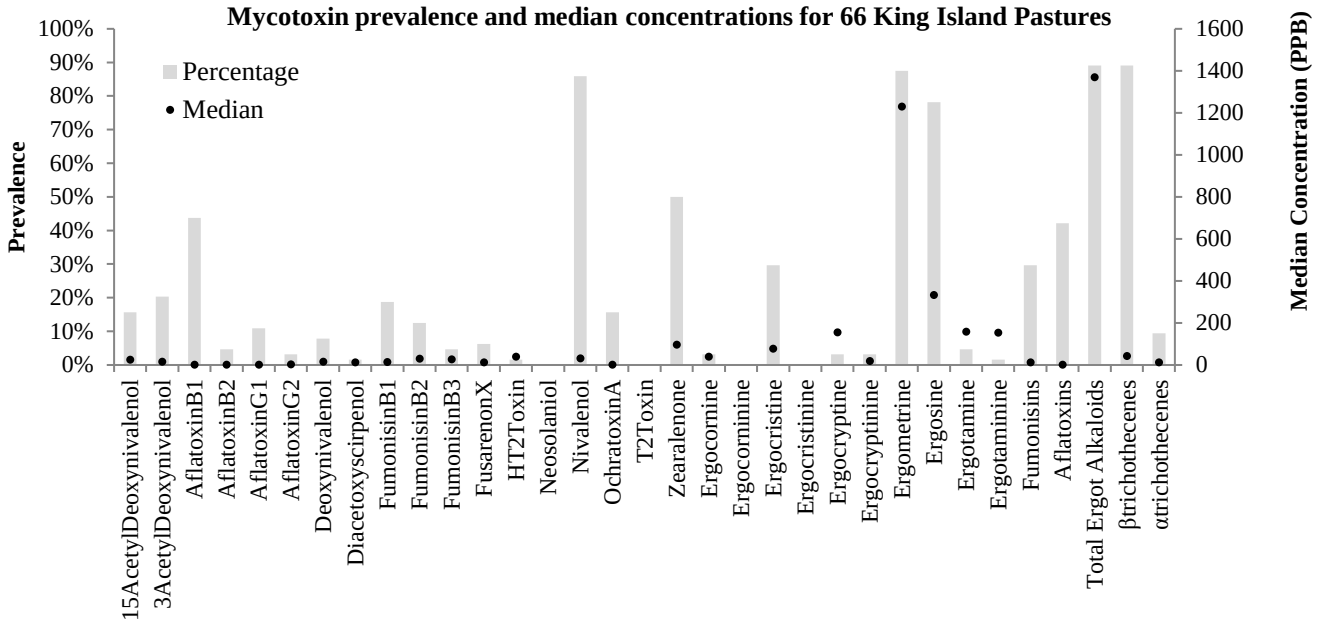

Fig. 4.11. Prevalence of farms with exposure to mycotoxins and the median concentration detected.

4.2 Assessed current industry compliance to fat and weight specifications using MSA data

4.2.1 Analysis of individual plant fat and weight frequencies

4.2.1.1 *Plant 1*

The HSCW data is for Plant 1 over all 4 years is very consitent (Fig. 4.12) with a small shift in 2013 towards a heavier carcass (Fig. 4.13) with 38% of carcases being under 250kg compared to 47% in 2011. Rib fat was also consistent through the 4 years with the majority of carcases between the 7-10mm range (Fig. 4.14). Carcases in 2010 seemed to have a higher proportion towards the leaner end (Fig. 4.15) possibly due to the drought which WA experienced that year.

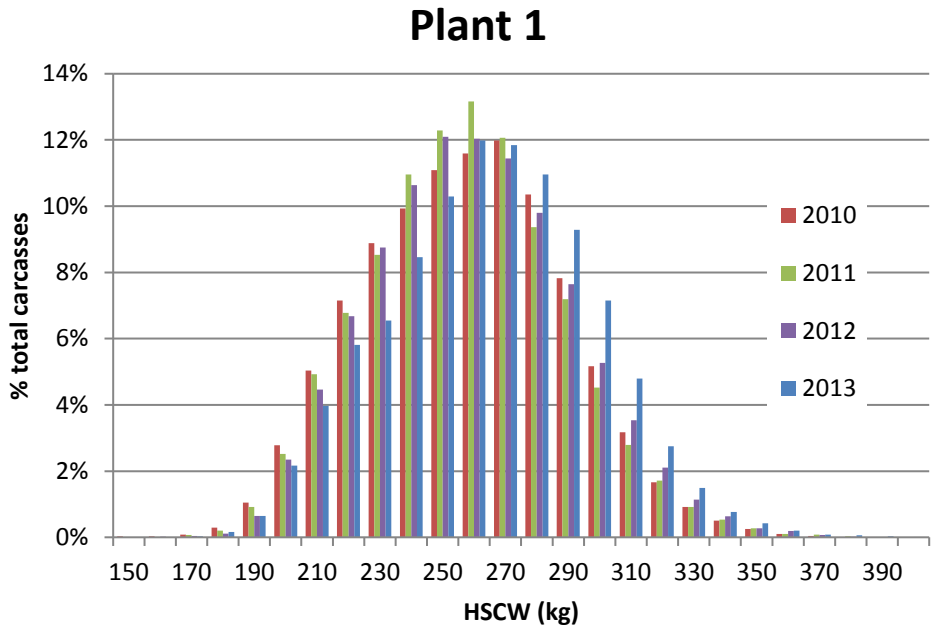

Fig. 4.21. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 1

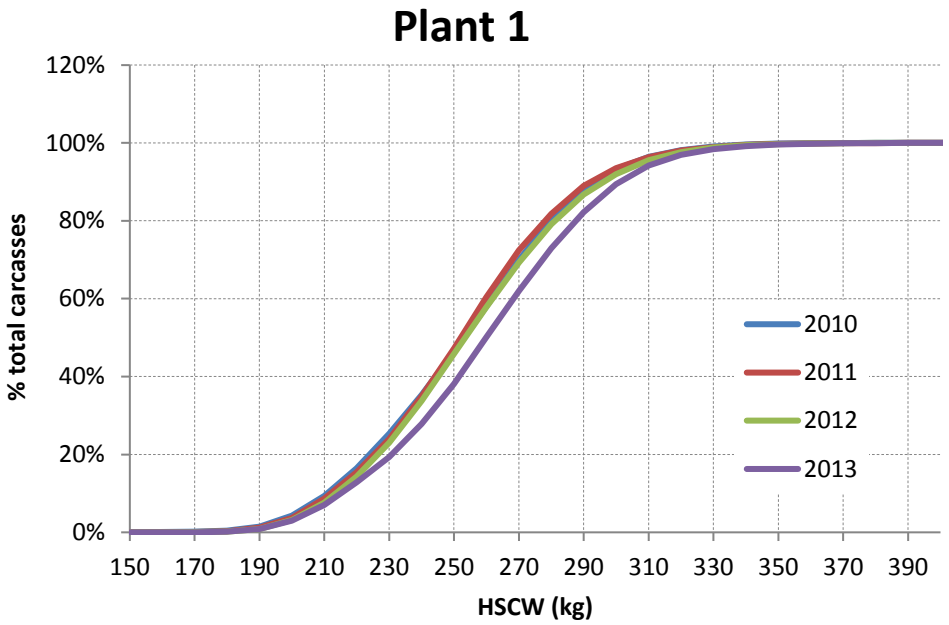

Fig. 4.13. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for PLANT 1

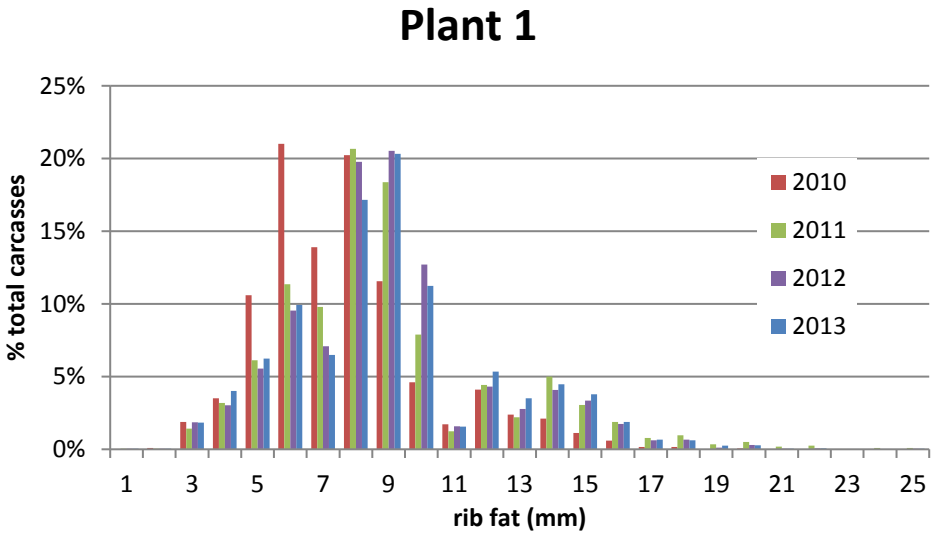

Fig. 4.14. Frequency of rib fat as a percentage of total carcasses per year for Plant 1

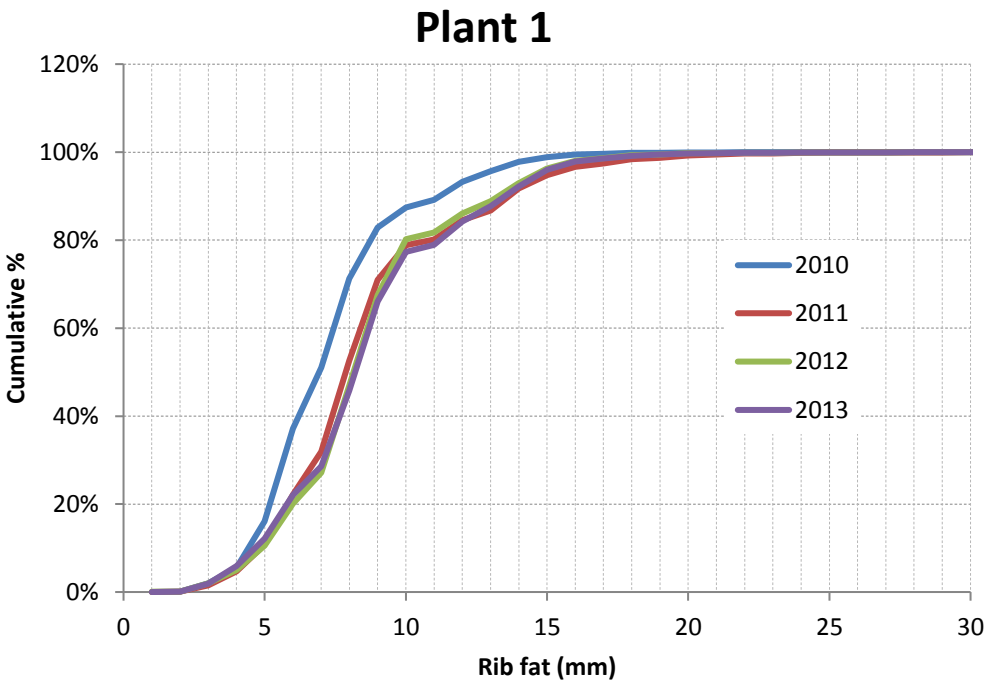

Fig. 4.15. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 1

4.2.1.2 *Plant 2*

Plant 2 was probably the most consistant across the 4 years for HSCW but also processed the lightest carcasses with about 70% of all carcasses below 250kg (Fig. 4.16 and 4.17). Rib fat was well spread with most of the data between 4 and 14mm with a peak towards leaner carcasses in 2011 (Fig. 4.18 and 4.19).

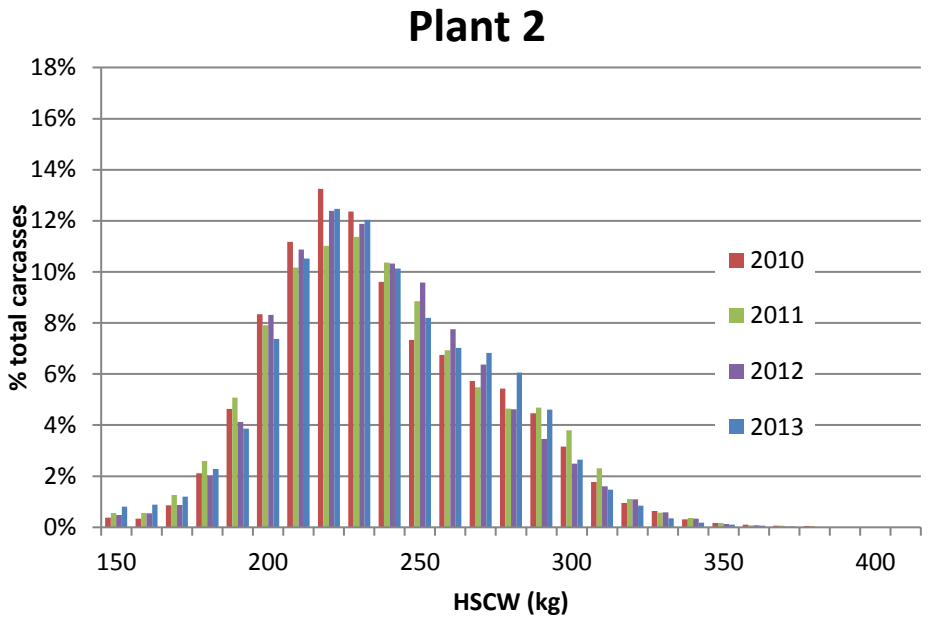

Fig. 4.16. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 2

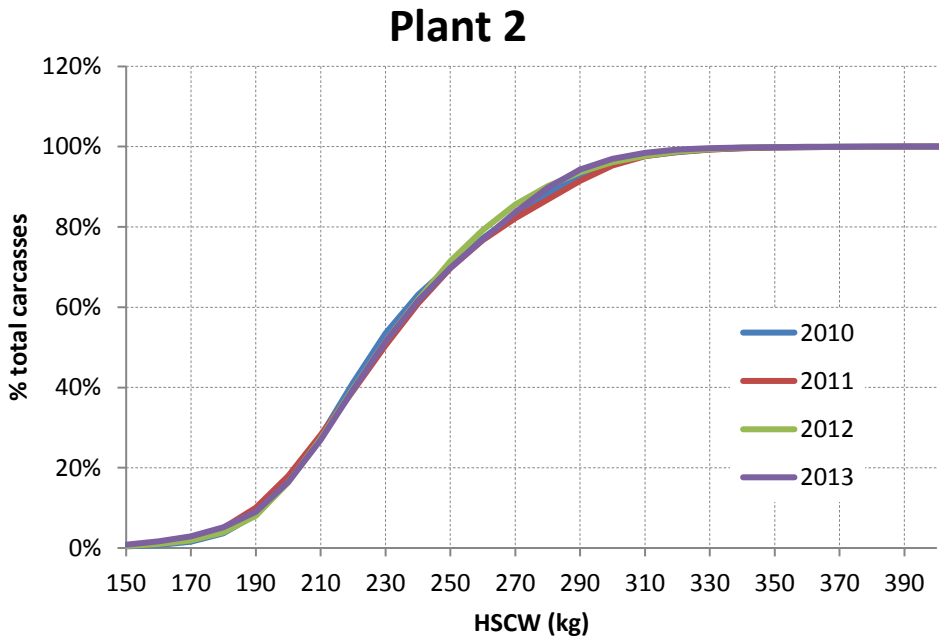

Fig. 4.17. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 2

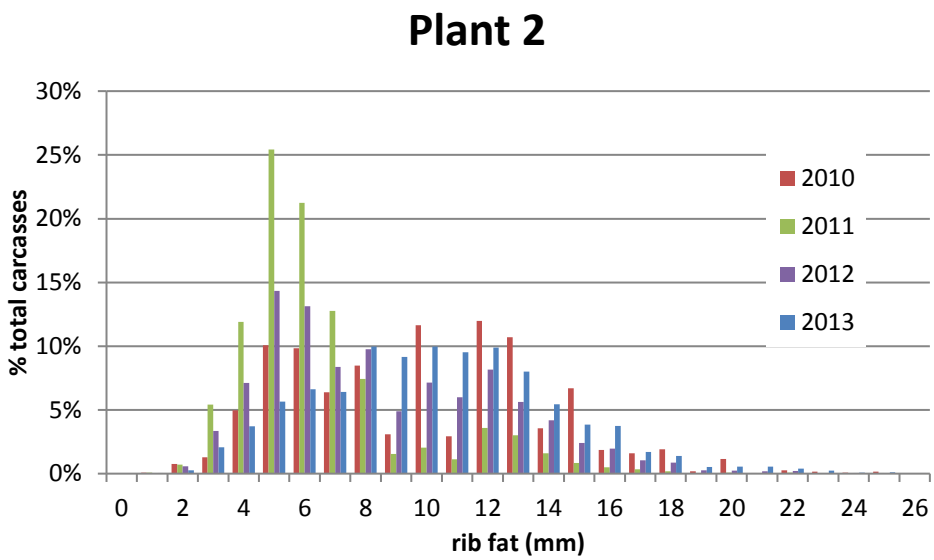

Fig. 4.18. Frequency of rib fat as a percentage of total carcasses per year for Plant 2

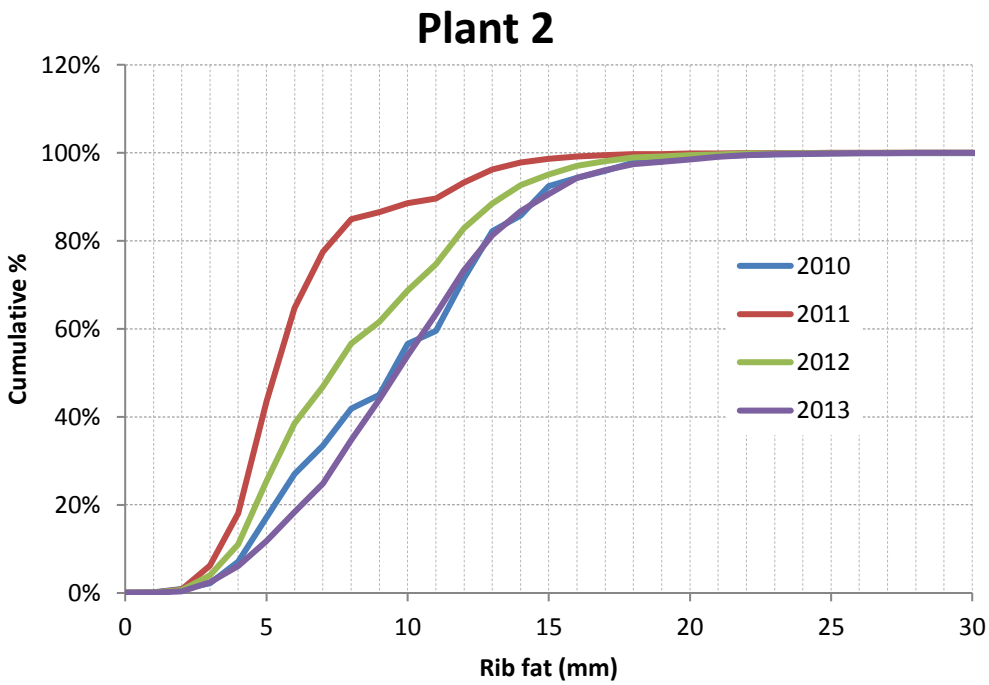

Fig. 4.19. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 2

4.2.1.3 *Plant 3*

Carcasses after 2010 shifted towards lighter carcass weights while most of the data was between 220 -290kg in probably the tightest spread of all data sets (Fig. 4.20). Rib fat however did not reflect this spread and tended to show biased towards the 8 or 9 measurements (Fig. 4.22). In 2012, over 50% of the data was estimated as having 9mm. Although the HSCW data was partcularly tight, the rib fat seems to be questionable and is unlikely to represent true bovine biology.

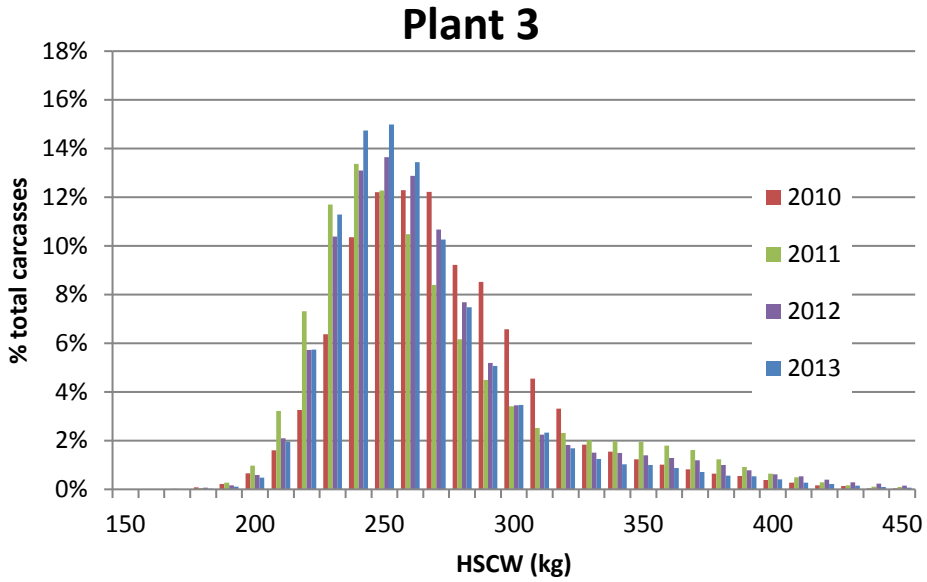

Fig. 4.20. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 3

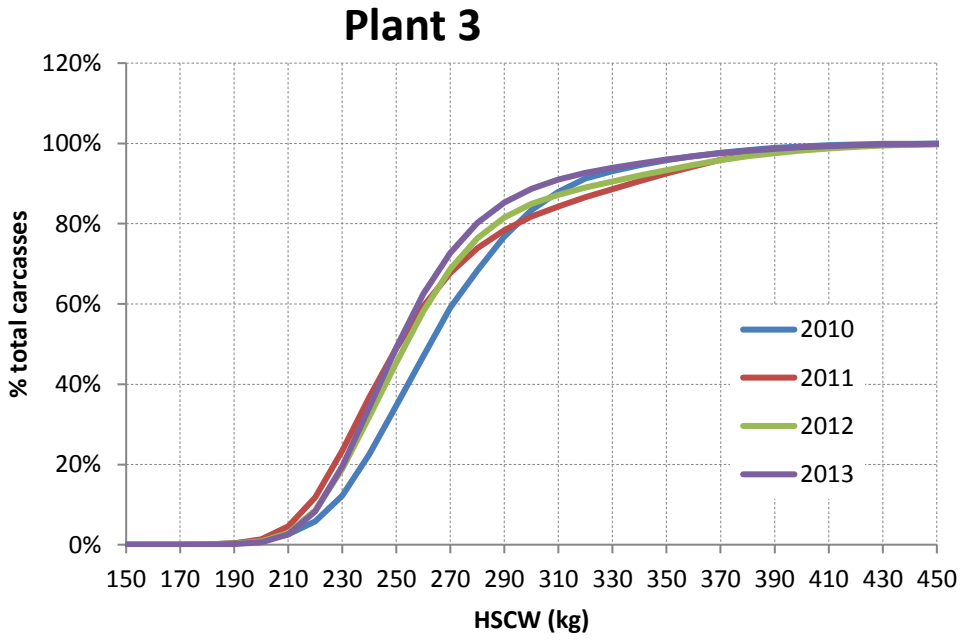

Fig. 4.21. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 3

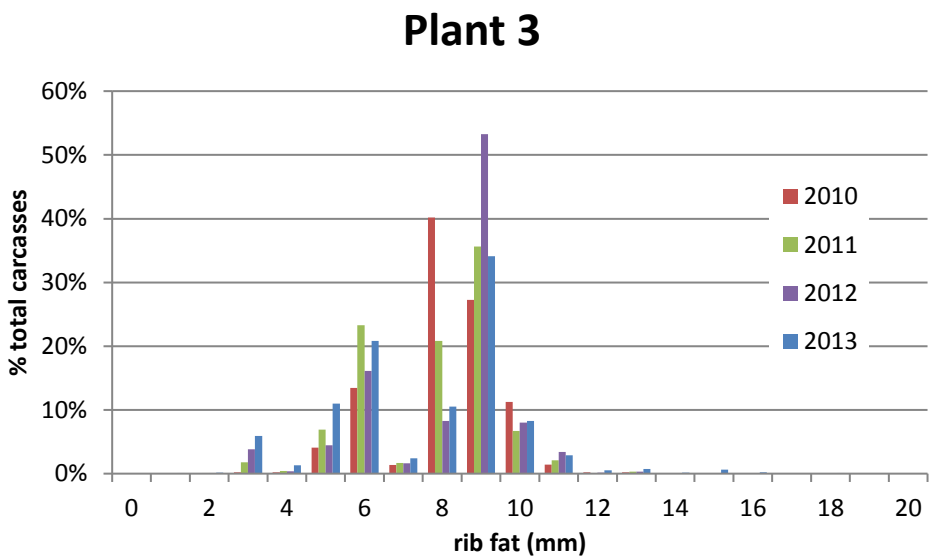

Fig. 4.22. Frequency of rib fat as a percentage of total carcasses per year for Plant 3

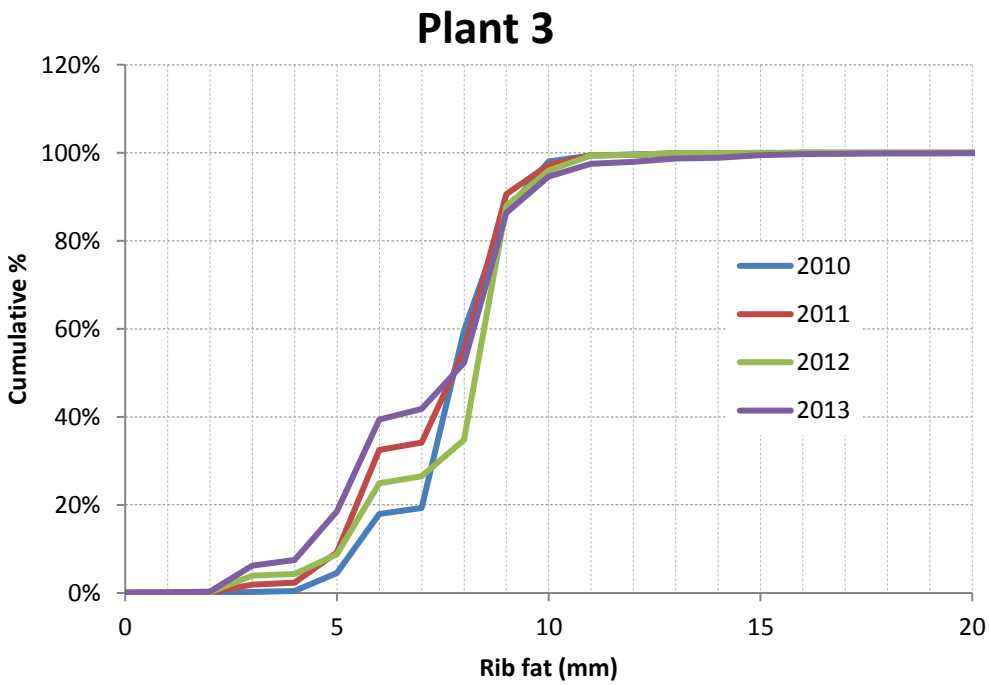

Fig. 4.23. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 3

4.2.1.4 *Plant 4*

The HSCW data from Plant 4 was the least consistent of all data sets, however only a small number of carcasses were recorded in 2010 (Fig. 4.24). Data shifted from 72% of carcasses being under 250 kg in 2011 to 55% and 50% the following two years (Fig. 4.25) possibly due to a large proportion of milk fed vealers being processed at this plant. Rib fat data was well spread from 4 to 12 mm with no visible trends (Fig. 4.26 and 4.27).

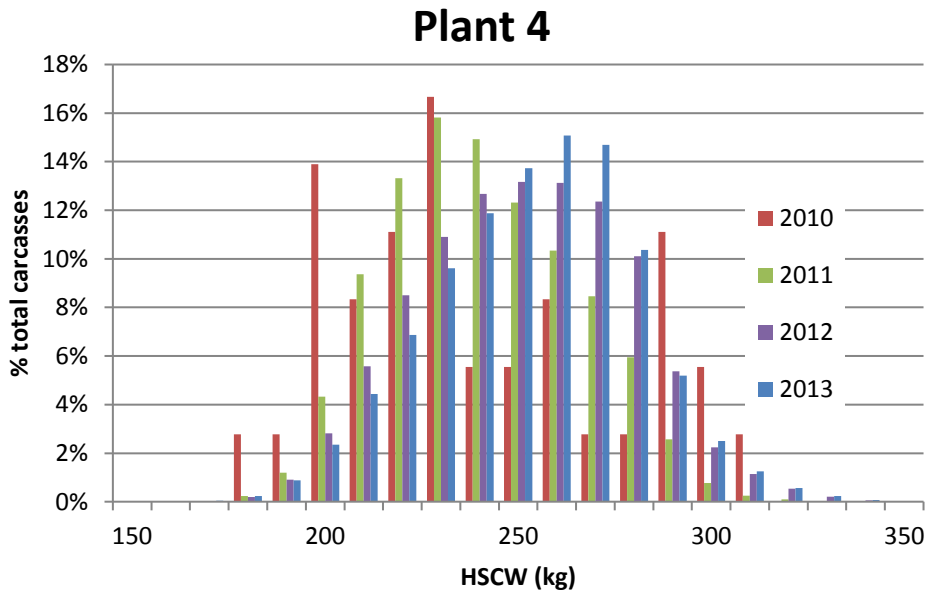

Fig. 4.24. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 4

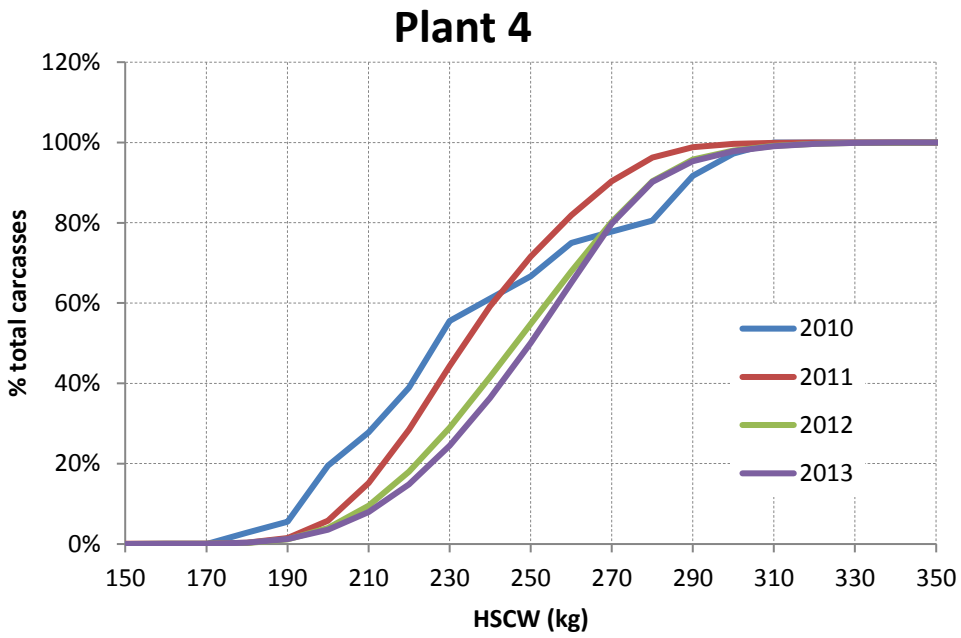

Fig. 4.25. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 4

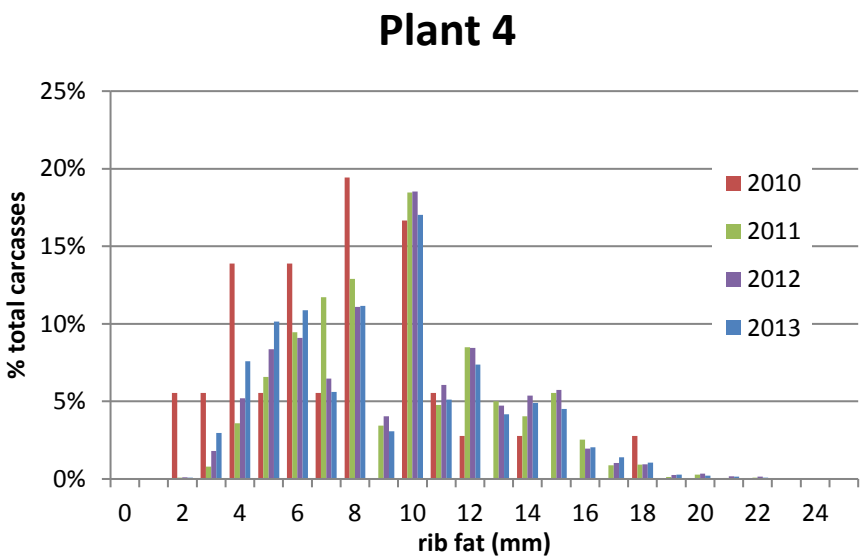

Fig. 4.26. Frequency of rib fat as a percentage of total carcasses per year for Plant 4

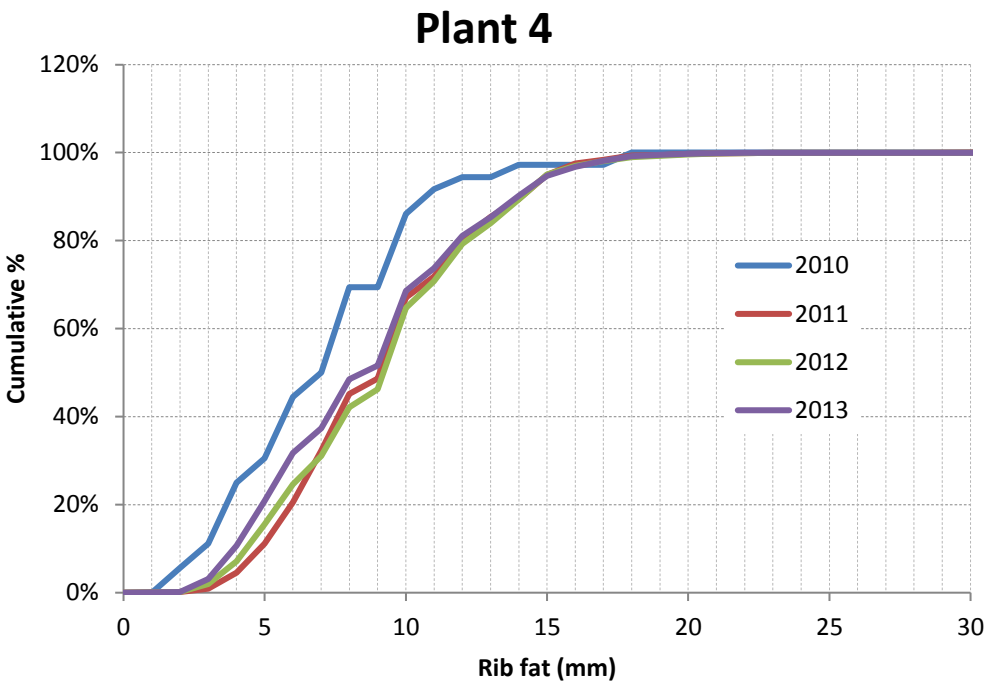

Fig. 4.27. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 4

4.2.1.5 *Plant 5*

The HSCW data was consistent throught the 4 year time period however target carcass weights were the heaviest of all plants with carcasses under 250 kg contributing to between 11-18% of all carcasses (Fig. 4.28 and 4.29). The rib fat was spread 3 mm to16 mm across all years (Fig. 4.30).

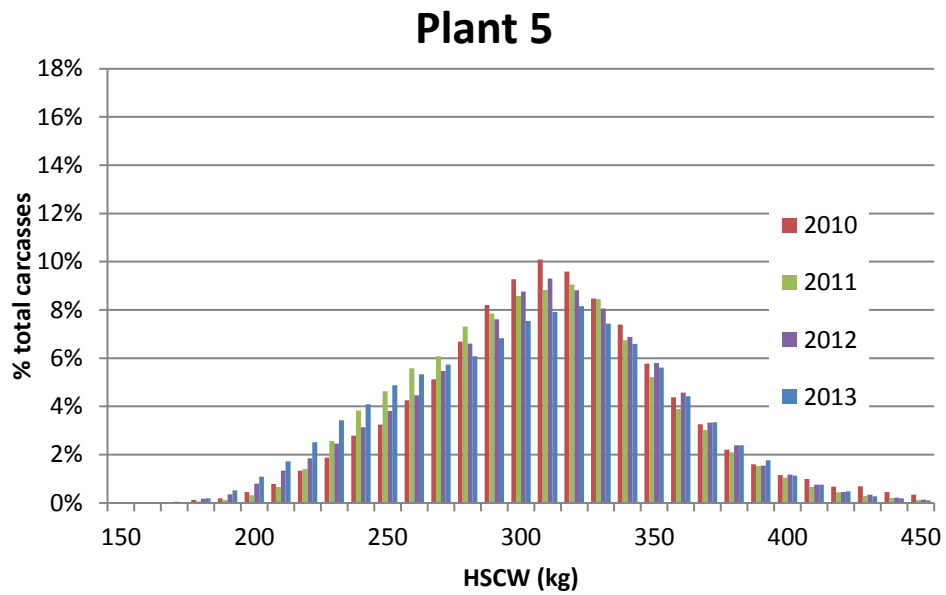

Fig. 4.28. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 5

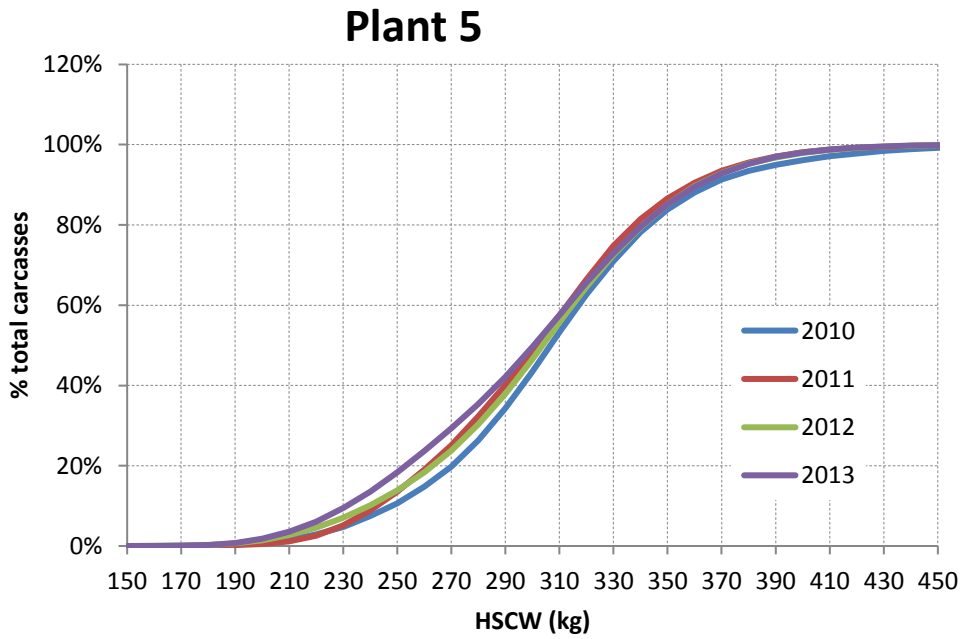

Fig. 4.29. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 5

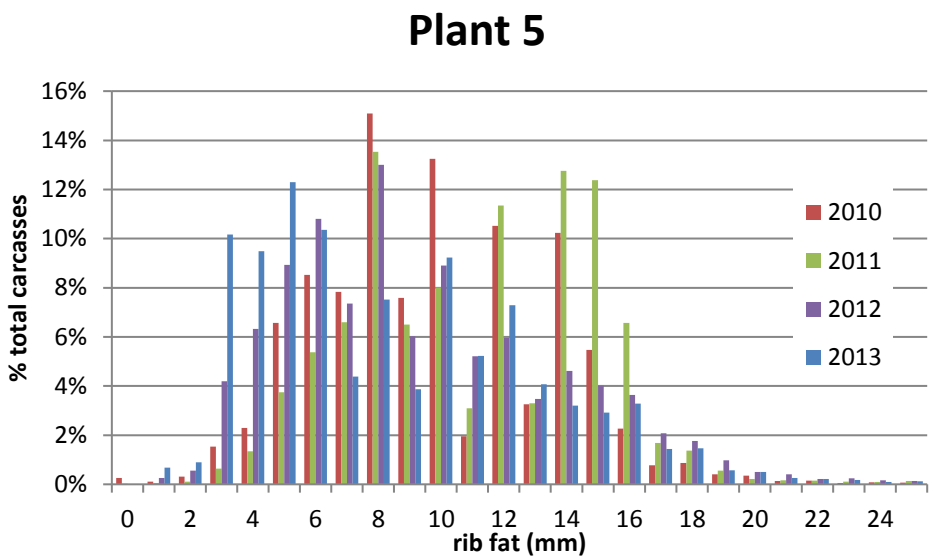

Fig. 4.30. Frequency of rib fat as a percentage of total carcasses per year for Plant 5

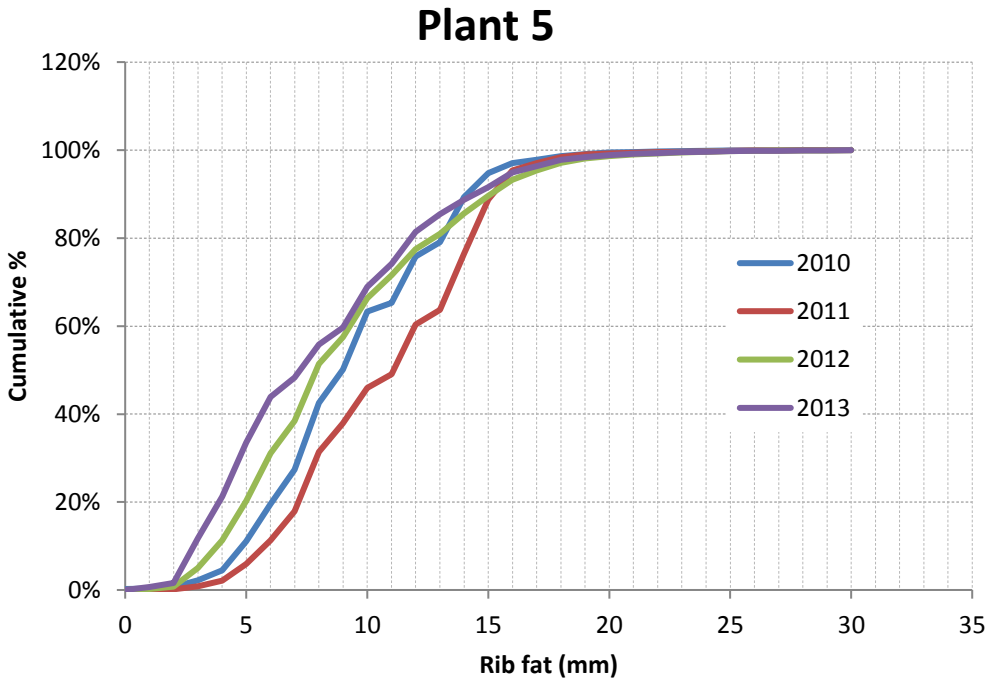

Fig. 4.31. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 5

4.2.1.6 *Plant 6*

HSCW data from Plant 6 shifted between years and also did not show the same curve/peak in data as the data from other plants particularly in 2010 (Fig. 4.32 and 4.33). Between 30 to 42% of the data was under 250 kg and a large amount of rib fat was recorded as 8 mm, with most the data between 5 and 9 mm (Fig. 4.34).

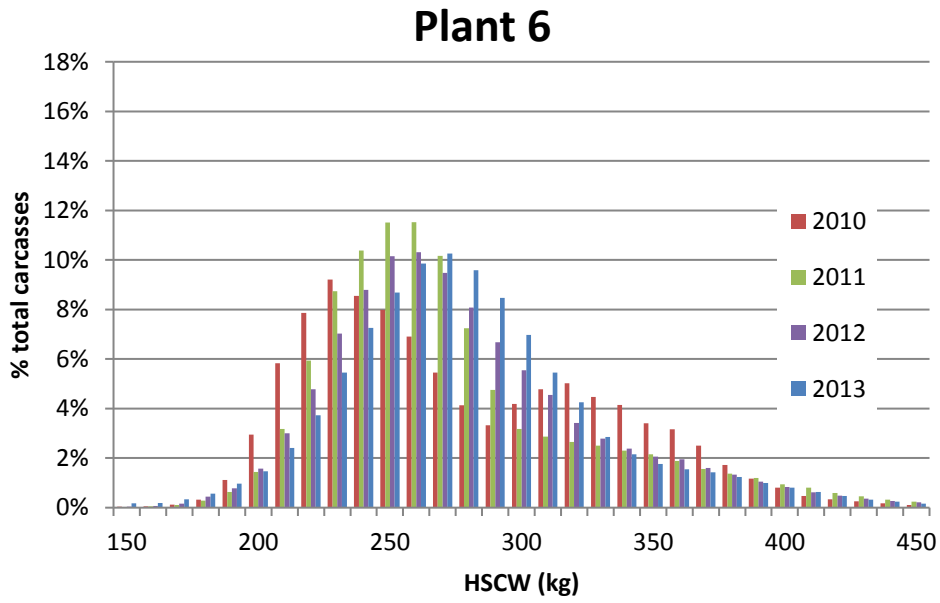

Fig. 4.32. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 6

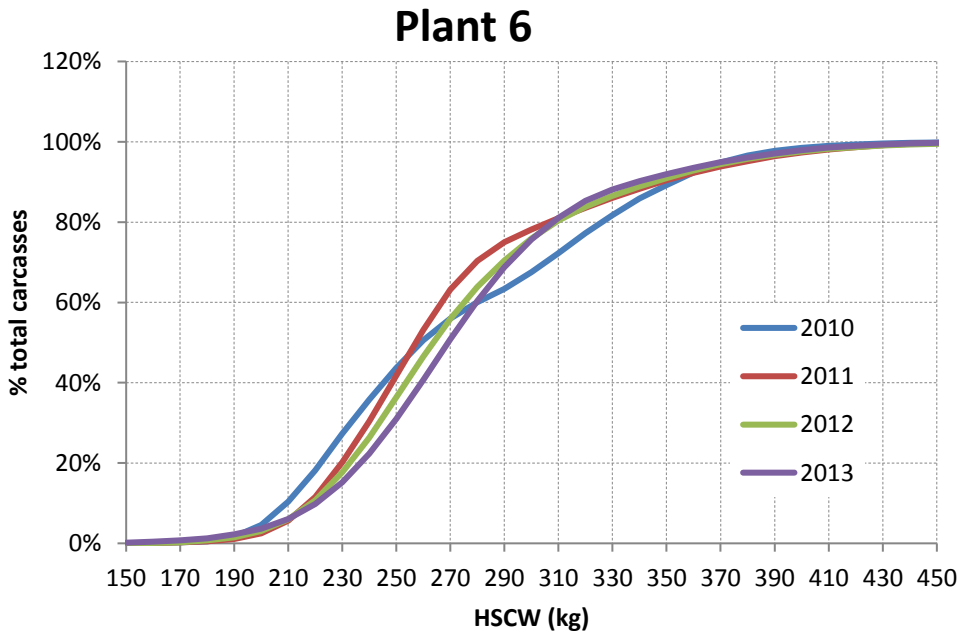

Fig. 4.33. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 6

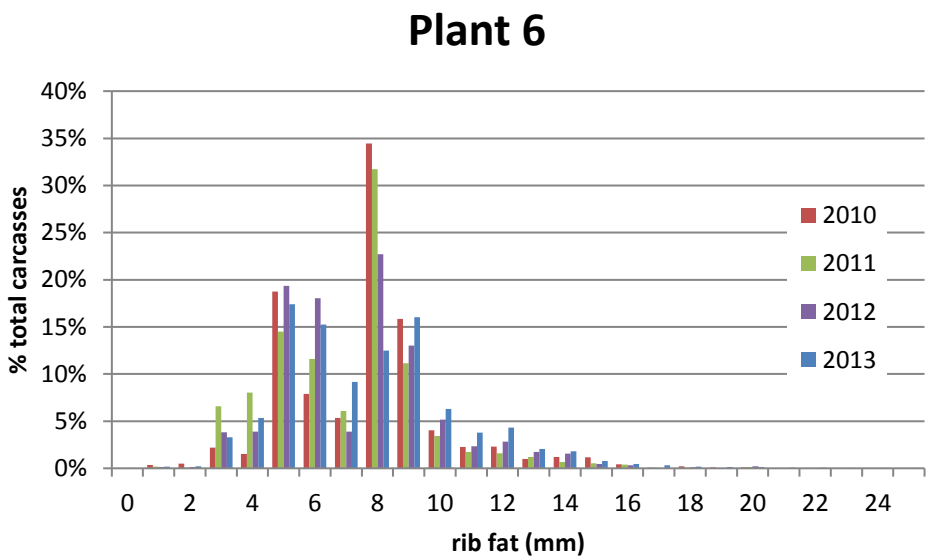

Fig. 4.34. Frequency of rib fat as a percentage of total carcasses per year for Plant 6

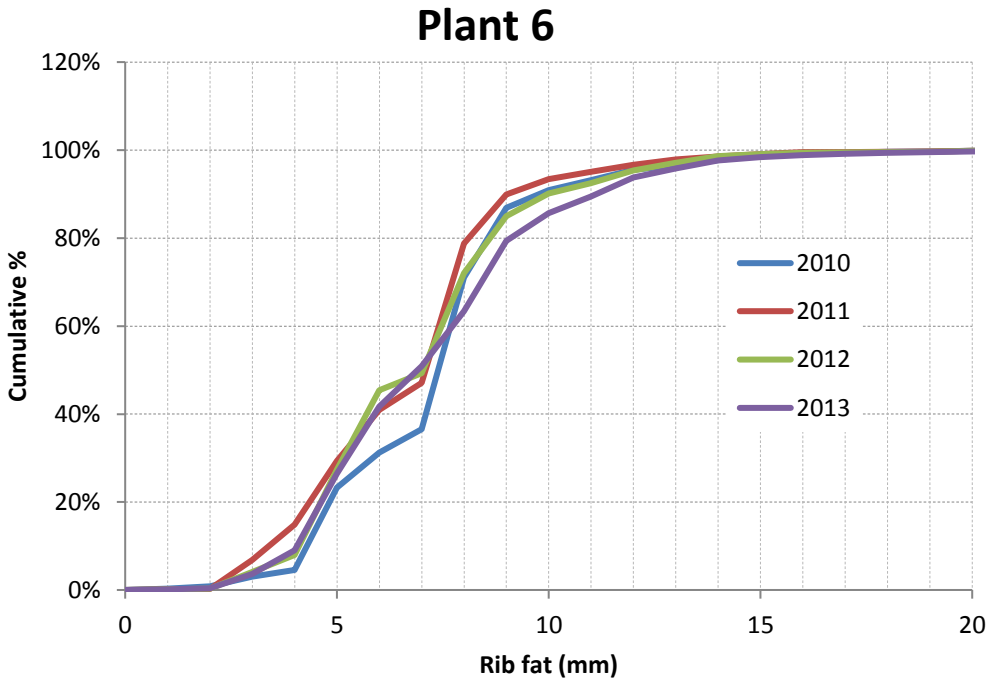

Fig. 4.35. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 6

4.2.1.7 *Plant 7*

Carcasses processed after 2010 were observed to get heavier with about 41% of carcasses being below 250 kg in 2010 compared to between 25-29% for the following years (Fig. 4.36 and 4.35). After 2010, the weights and fat were consistent.

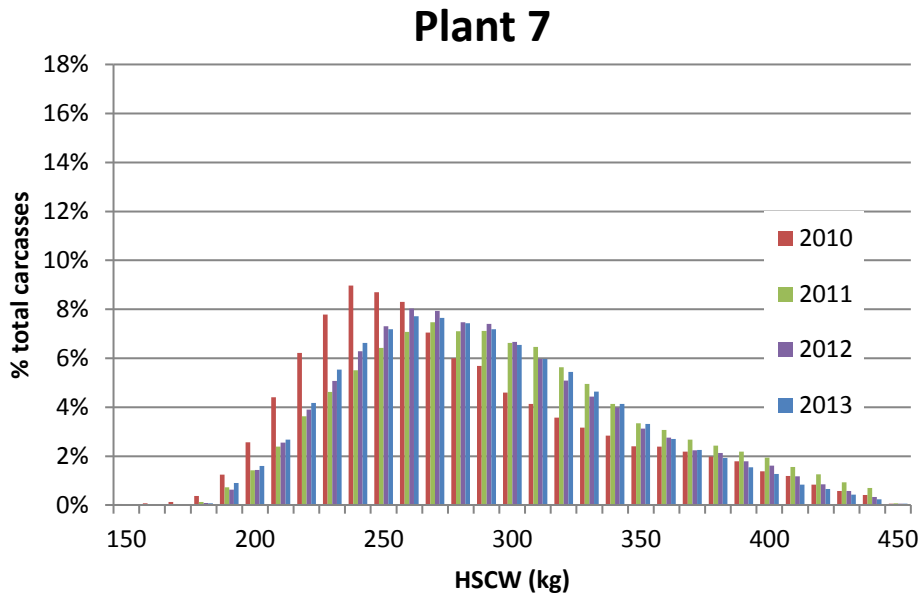

Fig. 4.36. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 7

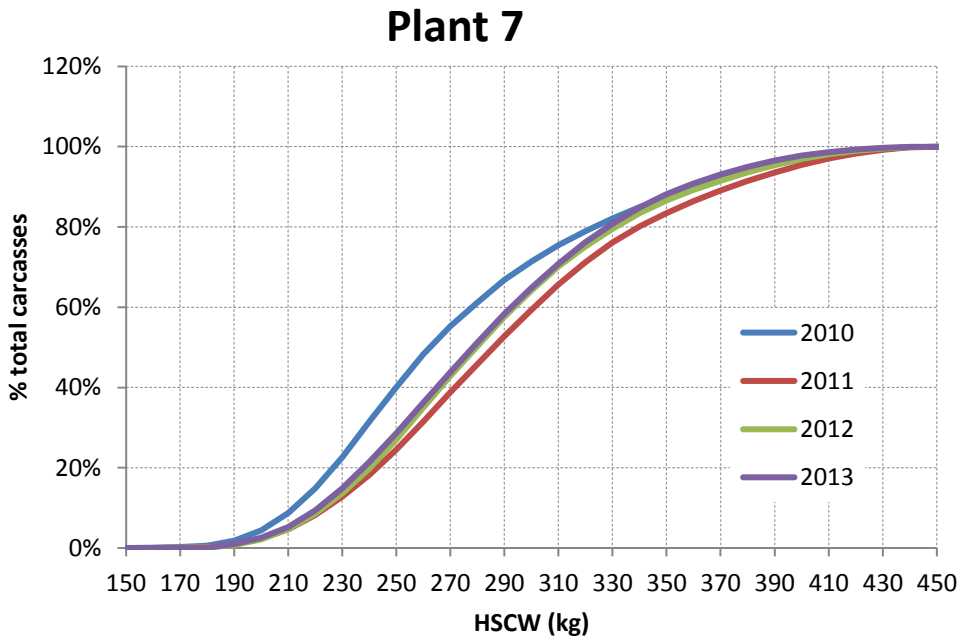

Fig. 4.37. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 7

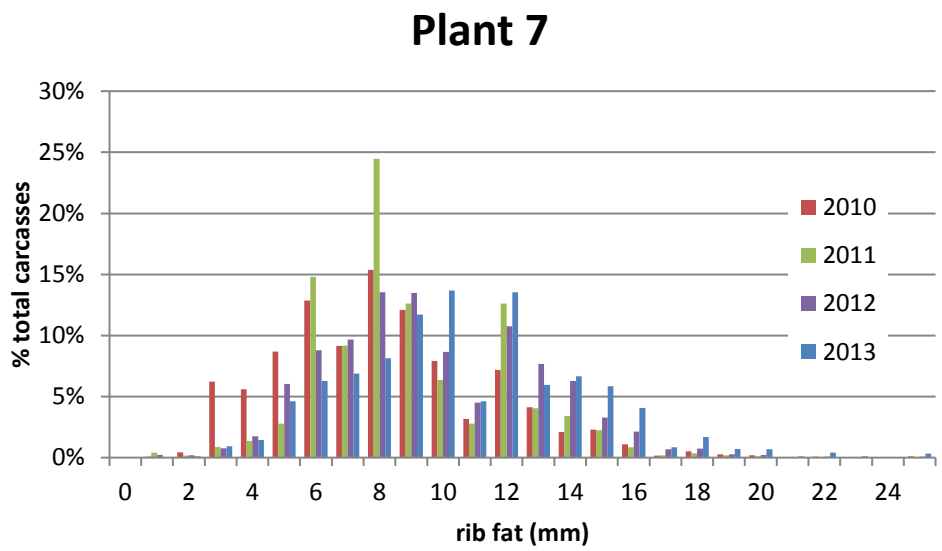

Fig. 4.38. Frequency of rib fat as a percentage of total carcasses per year for Plant 7

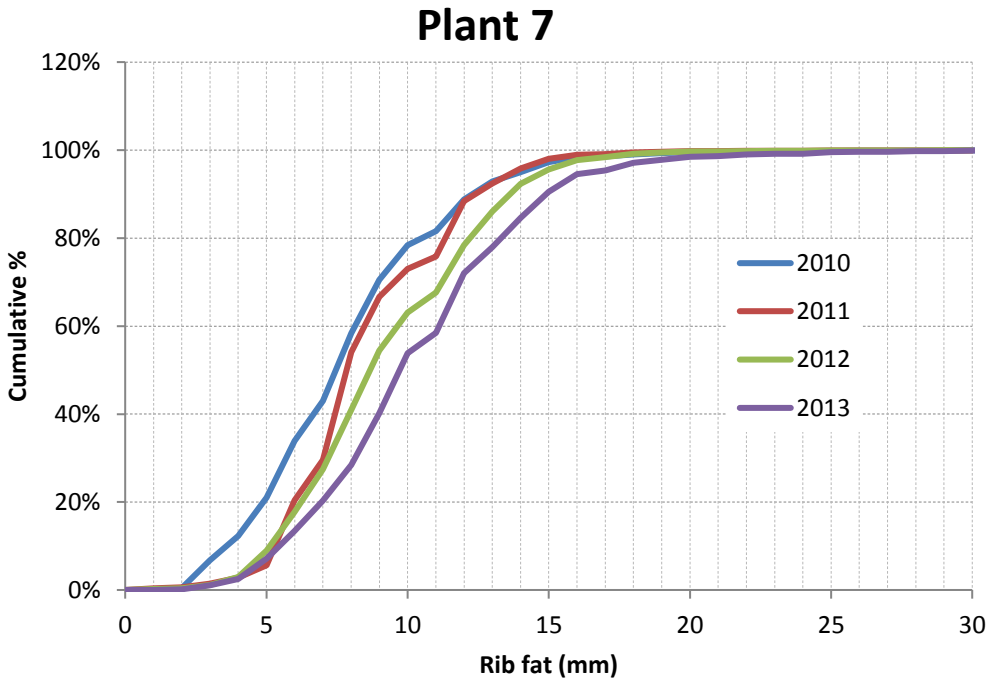

Fig. 4.39. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 7

4.2.1.8 *Plant 8*

The HSCW data set was very consistent throught 2010-2013 with about 30% of carcasses being below 250 kg (Fig. 4.40 and 4.41). Rib fat data was inconsistent and data in 2010 seemed biased towards scores of 5 mm and 6 mm contributing to over 80% of the data in that year (Fig. 4.42 and 4.43).

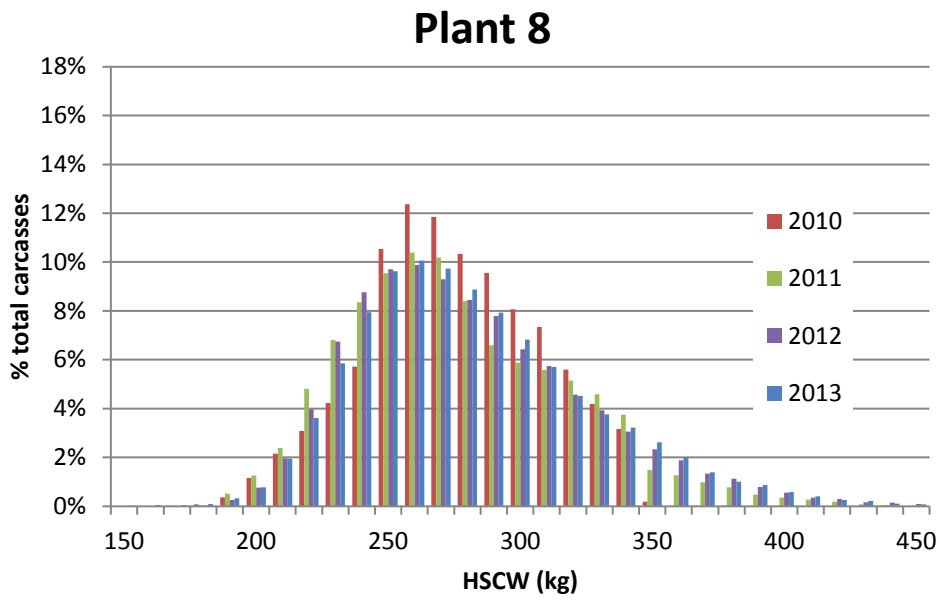

Fig. 4.40. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 8

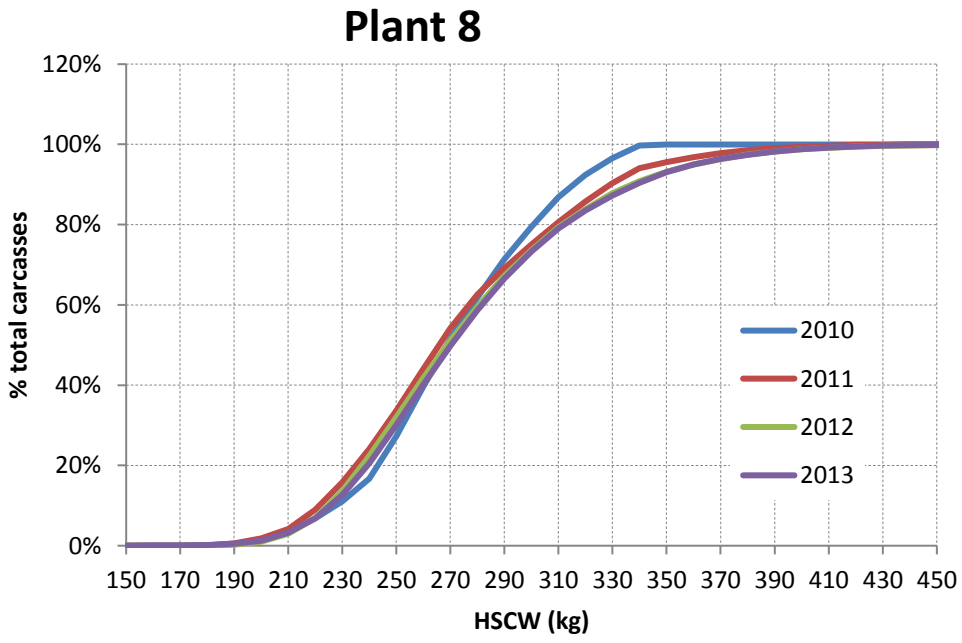

Fig. 4.41. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 8

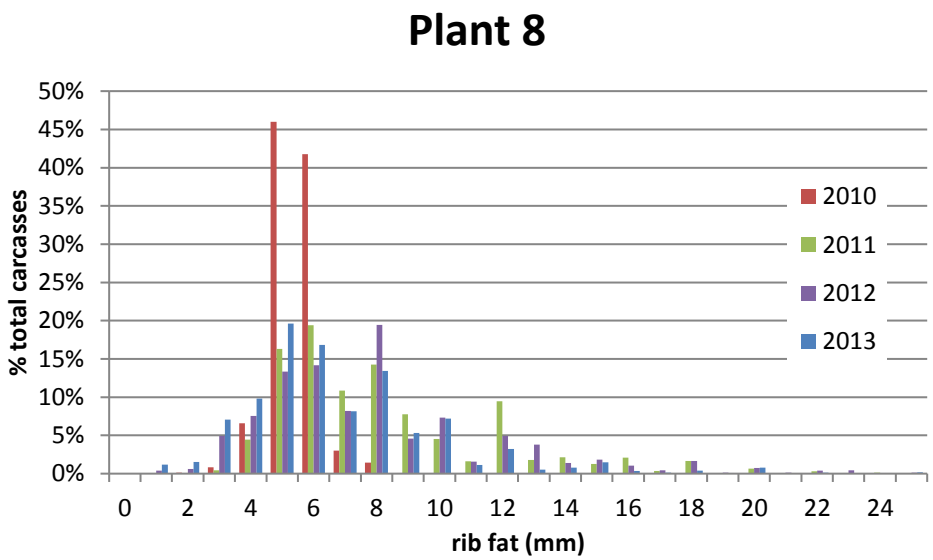

Fig. 4.42. Frequency of rib fat as a percentage of total carcasses per year for Plant 8

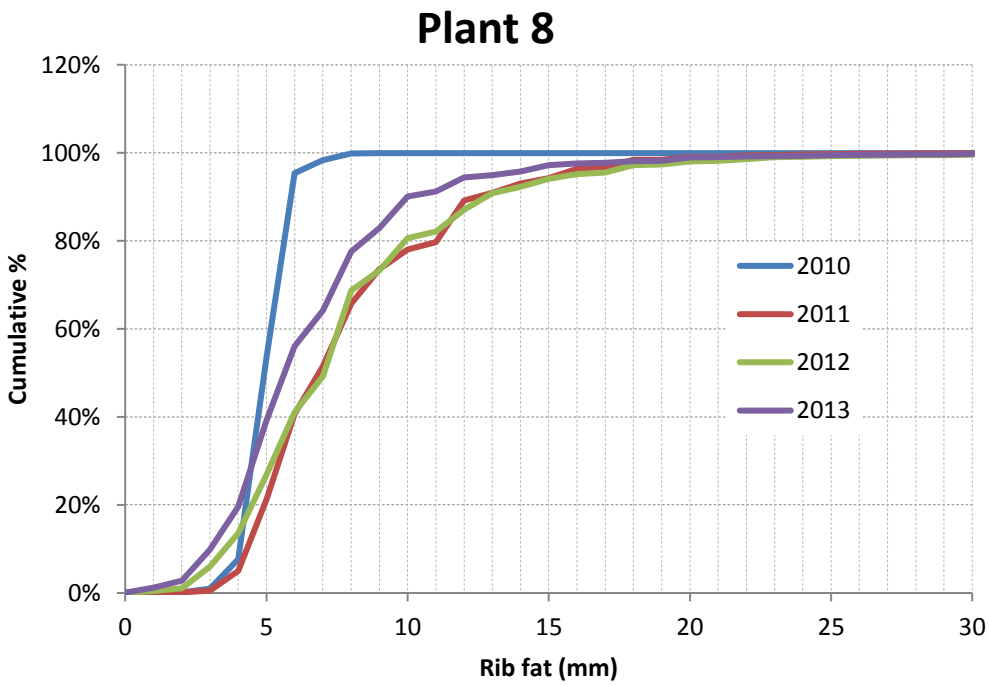

Fig. 4.43. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 8

4.2.1.9 *Plant 9*

The HSCW clearly shifted after 2010 to processing lighter carcasses (Fig. 4.44). About 6% of carcasess in 2010 were below 250 kg, while this value was about 40% the following 3 years (Fig. 4.45). This shift was also clearly evident in the rib fats observed over these periods (Fig. 4.46 and 4.47).

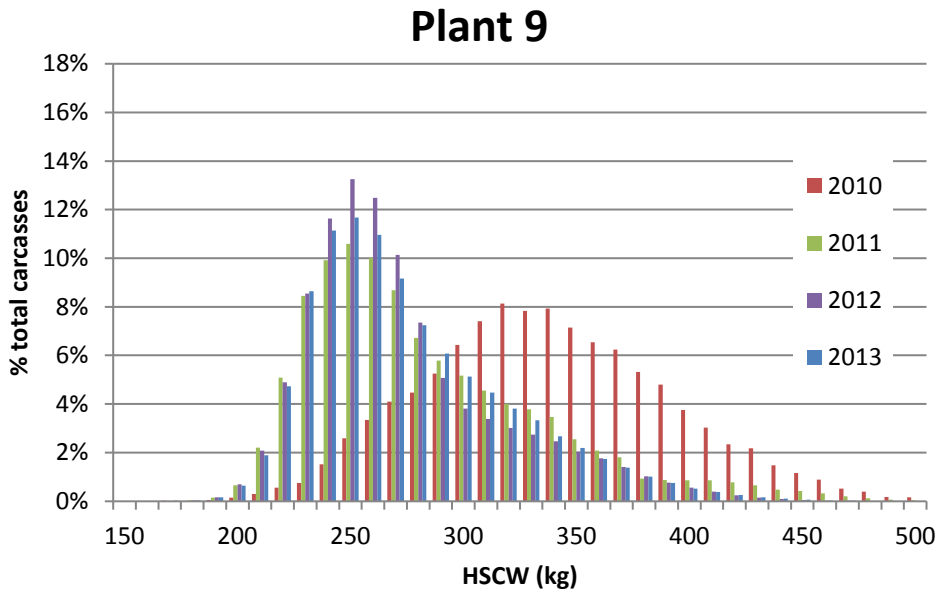

Fig. 4.44. Frequency of hot carcass weights as a percentage of total carcasses per year for Plant 9

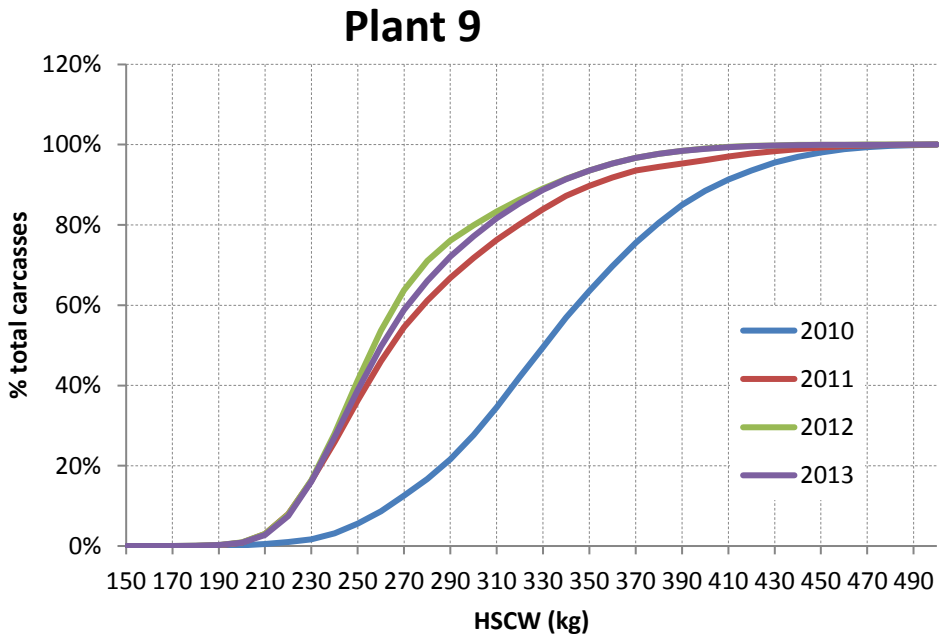

Fig. 4.45. Cumulative totals of the percentage of total carcasses across the hot carcass weight range per year for Plant 9

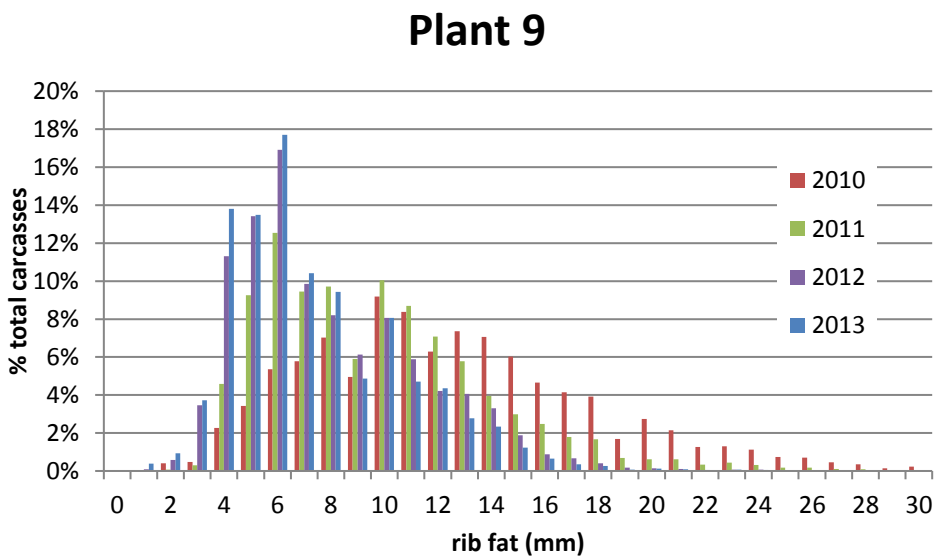

Fig. 4.46. Frequency of rib fat as a percentage of total carcasses per year for Plant 9

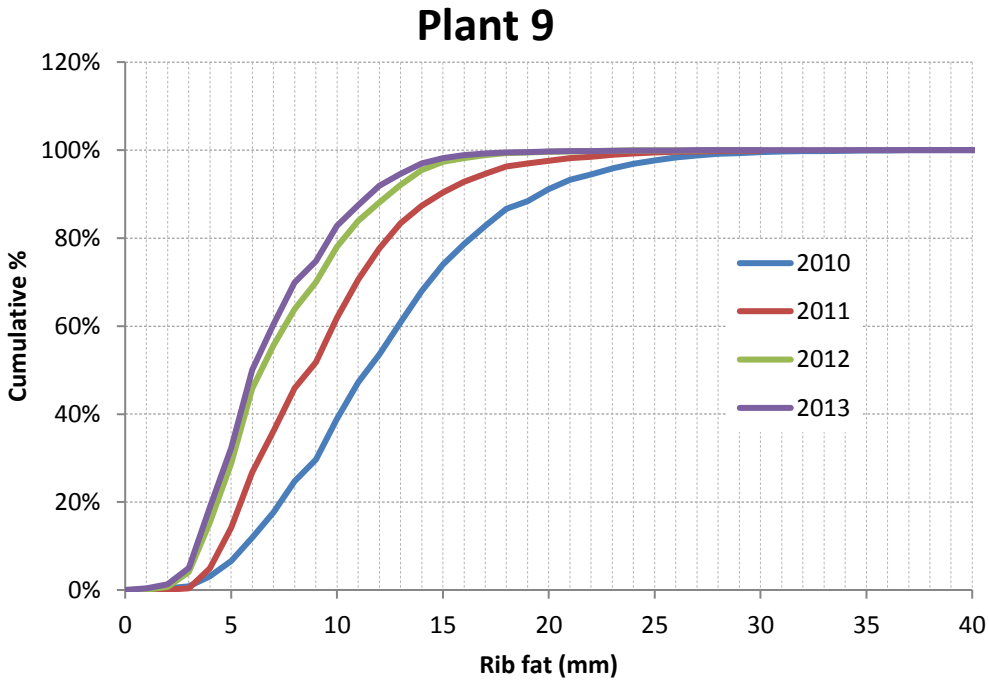

Fig. 4.47. Cumulative totals of the percentage of total carcasses across the rib fat range per year for Plant 9

4.2.2 Analysis of fat compliance in the southern plants

4.2.2.1 *Rates of non-compliance per plant*

The total Percentage non-compliance for fat doubled to 0.914% in 2013 compared to previous years, with these values being heavily influenced by the increases from plants 5, 8 and 9 during this time (table 4.8). Data from WA has shown to have the lowest rate of non-compliance due to fat depth, with compliance rates from WA farms resulting in 0.21% non-compliance overall due to fat (Table 4.9). Considering the frequency of rib fat observed from the WA plants (Plants 1-4) other than plant 2. It is difficult to believe this is a true representation of the cattle presented for MSA slaughter. It may be logical to assume that not all data was reported and if carcases were out of fat compliance they were not entered into the MSA system. Farms from SA, TAS and VIC that make up the majority of the southern kill had an overall non-compliance of at least 3 times this amount and ranged from 0.69 to 0.85% (Table 4.9). NSW, QLD and the NT farms made up a small proportion of the kill, however cattle from the NT had a non-compliance due to fat depth of 3.62% although less than 4000 animals were killed from NT farms (Table 4.9). This could however be attributed to the change of conditions or cattle type in the central Australian farms.

There are a number of seasonal spikes observed on the non-compliance rate, particularly from cattle from plants 8 and 9 (Fig. 4.48). Considering these plants have the highest non-compliance rate in grass fed cattle (Table 4.11) it is possible that this is an observed effect of poor feed conditions or growth, where cattle are utilizing their fat stores. In particular, plant 8 would be killing primarily pastoral cattle and thus is influenced greater by the summer conditions, where as in winter the fat condition of the animals is likely to be better and thus more compliance. Interestingly the other Tasmanian plant does not seem to have these seasonal variations. Cattle from the SA plant, plant 5, are observed to have the greatest non-compliance during the winter months (Fig. 4.48).

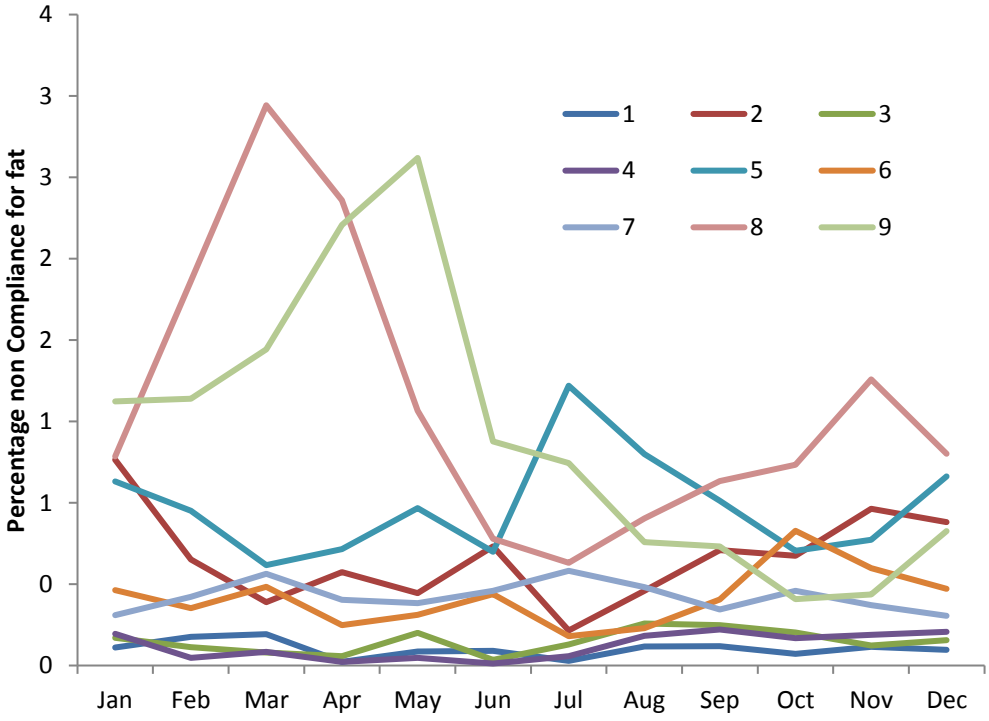

Fig. 4.48. The frequency of non-compliance for fat depth on a month basis from 4 years of data for the 9 southern plants.

Table 4.8. The frequency of non-compliance for fat across the 9 southern plants from 2010-2013.

Plant	Compliance	2010	2011	2012	2013	Total
1	Non-compliant fat	40	24	30	23	117
	Total	33077	29168	27002	26971	116218
	percent Non-compliant	0.121%	0.082%	0.111%	0.085%	0.101%
2	Non-compliant fat	225	172	97	57	551
	total	26020	22137	15889	17584	81630
	percent Non-compliant	0.865%	0.777%	0.610%	0.324%	0.675%
3	Non-compliant fat	10	51	89	224	374
	total	53245	48749	69236	75609	246839
	percent Non-compliant	0.019%	0.105%	0.129%	0.296%	0.152%
4	Non-compliant fat	2	22	76	77	177
	total	36	18858	54523	57312	130729
	percent Non-compliant	5.56%	0.117%	0.139%	0.134%	0.135%
5	Non-compliant fat	351	100	518	1510	2479
	total	52075	49548	63960	95025	260608
	percent Non-compliant	0.674%	0.202%	0.810%	1.589%	0.951%
6	Non-compliant fat	330	214	419	394	1357
	total	38510	87106	133832	97450	356898
	percent Non-compliant	0.857%	0.246%	0.313%	0.404%	0.380%
7	Non-compliant fat	329	386	270	111	1096
	total	63470	64778	61834	67434	257516
	percent Non-compliant	0.518%	0.596%	0.437%	0.165%	0.426%
8	Non-compliant fat	17	18	350	1567	1952
	total	12355	18909	34543	57139	122946
	percent Non-compliant	0.138%	0.095%	1.013%	2.742%	1.588%
9	Non-compliant fat	51	27	604	1786	2468
	total	12180	34797	89710	134387	271074
	percent Non-compliant	0.419%	0.078%	0.673%	1.329%	0.910%
	total non-compliant	1355	1014	2453	5749	
	total	290968	374050	550529	628911	
	total percentage non-compliant	0.466%	0.271%	0.446%	0.914%	

Table 4.9. The frequency of non-compliant fat depth by sate of origin

Stat of origin	Non-Compliant	Fat compliant	Total carcases	Percentage non-compliant
NSW	572	63389	63961	0.89%
NT	142	3784	3926	3.62%
QLD	9	1694	1703	0.53%
SA	3047	409054	412101	0.74%
TAS	2982	348677	351659	0.85%
VIC	2141	309699	311840	0.69%
WA	1217	584668	585885	0.21%

4.2.2.2 *Rates of non-compliance per feeding system*

Understandably, feeding system impacts on the rates of non-compliance due to fat depth (Table 4.10). Grain fed cattle are considered to be on a higher plain of nutrition, grow faster and would thus have greater fat stores available, resulting in greater carcase fat depths. The nutrition suppled from pasture fed cattle can often vary due to weather and rainfall conditions, while also not offering the same energy dense diets that grain typically does. Overall, Cattle from grass fed systems had a non-compliance rate of 0.74% compared to grain fed at 0.086% (Table 4.10). However, almost a third of all data provided came from an unknown feeding system and thus the actual rates are likely to be different.

As expected, most of the cattle from the southern plants are from grass fed systems, and in all plants these systems had less compliance fat depths compared to grain fed systems (Table 4.11).

Table 4.10. The influence of feeding system on the rates of non-compliance for fat depth

Feeding system	Non-Compliant	Fat compliant	Total carcases	Percentage non-compliant
Grass	7115	954278	961393	0.740%
Grain	195	227188	227383	0.086%
Unknown	2800	539499	542299	0.516%

4.2.2.3 *The effect of carcase weight on the rates of non-compliance for fat depth*

As shown in Table 4.12, as the weight group became larger the rate of non-compliance became smaller, and is thus a good representation of the positive relationship between carcase weight and fat depth ($P<0.001$). For every kg of carcase weight rib fat will increase by 0.02mm ($P<0.001$, data not shown). Carcases that are under 200kg have an overall non-compliance rate due to fat depth of 2.8%, and although only 2.73% of all carcases are in this range they make up 13.11% of all the fat non-compliant carcases (data not shown).

Table 4.11. The influence of feeding system on the rates of non-compliance for fat depth on a plants basis

Plant	Feeding system	Non-Compliant	Fat compliant	Total carcases	Percentage-non compliant
1	**Grass**	66	66319	66385	0.099%
	Grain	1	2594	2595	0.039%
	Unknown	50	45766	45816	0.109%
2	**Grass**	271	40535	40806	0.664%
	Grain	1	3606	3607	0.028%
	Unknown	255	35361	35616	0.716%
3	**Grass**	322	135075	135397	0.238%
	Grain	34	35481	35515	0.096%
	Unknown	11	73801	73812	0.015%
4	**Grass**	148	99766	99914	0.148%
	Grain	15	26573	26588	0.056%
	Unknown	1	175	176	0.568%
5	**Grass**	911	57994	58905	1.547%
	Grain		179	179	0.000%
	Unknown	1566	200450	202016	0.775%
6	**Grass**	1049	200901	201950	0.519%
	Grain	109	98232	98341	0.111%
	Unknown	388	59002	59390	0.653%
7	**Grass**	632	158643	159275	0.397%
	Grain	8	8121	8129	0.098%
	Unknown	454	89312	89766	0.506%
8	**Grass**	1852	96192	98044	1.889%
	Grain		247	247	0.000%
	Unknown	23	20104	20127	0.114%
9	**Grass**	1864	98853	100717	1.851%
	Grain	27	52155	52182	0.052%
	Unknown	52	15528	15580	0.334%

Table 4.12. The influence of hot standard carcase weight on the rate of non-compliance for fat depth.

HSCW group	Non-Compliant	Fat compliant	Total carcases	Percentage non-compliant
50-149	105	785	890	11.80%
150-199	1220	45159	46379	2.63%
200-249	4473	540661	545134	0.82%
250-299	3282	655719	659001	0.50%
300-349	890	323360	324250	0.27%
350 +	140	155351	155491	0.09%

4.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

A recent paper in press by McGilchrist *et. al.* (2014) has highlighted the "seasonal" or monthly affect of dark cutting in these plants using the current data sets. Although the size of the proportion of those carcases that are non-compliant for colour and pH varies between plants, there is a trend where the incidence occurs at a greater rate over the summer/drier months. The major exceptions are that of Plant E and Plant H, where the incidence of non-compliance is considerably higher across most months.

Within the current data set, the occurrence of carcasses that meet MSA pH grades but not colour grades can be scrutinized. This data is almost non-existent in most plants and contributes to well below 1% of the data. Peaks are randomly observed in certain plants which otherwise have zero occurrence (see graphs of non-compliance for meat colour only). This is likely due to a change in grader. This could not be established without grader information being provided for this data set. On the other hand, Plant E had a more frequent and abundant occurrence of this type of non-compliance, and more notably in 2012 and 2013 at a rate of 12.9 and 8.17 % during the winter months. More investigation is required.

The frequency of pH of all plants is shown in a histogram at 0.02 pH intervals (Fig. 4.49). This clearly shows an unexpected drop in the frequency of pH data recorded beyond pH 5.7. Although it is understood that pH data is not normally distributed, as reflected in the data, this drop off is somewhat of a concern. The biology behind such a drop off is unexplainable (especially in such a large data set) and we suggest most likely attributed to human/grader influence. This could indicate that the bulk of carcasses are being graded at a time when their pH is not at ultimate. At this time, any carcases that are classified as DFD are left for a greater length of time and regraded, when their pH is lower, compliant and closer to ultimate. Although this approach to grading/regrading will likely benefit the producers and not penalise them unfairly due to time of grading, it seems as though this may not be consistent throughout all plants. Additionally, this makes this data difficult to use to investigate the occurrence of the "uncoupling" of pH and meat colour.

By observing tables of pH and meat colour frequencies, it is clear that very little data consistently lies in the area of high pH and compliant meat colour (blue shaded area of the tables), with data from Plant I the exception. In fact, for 6 out of the 9 plants, the occurrence of the pH either 5.71 or 5.72 (just above the pH threshold) and a colour score of 3 is very close to zero. In comparison, the average occurrence of carcases per plant with a pH of 5.68-5.7 (just below the threshold) and a colour score of 3 is 4831. This again points towards regrading for pH being a likely influencing factor which is an

Until now, an MSA minimum requirement of meat colour 1B – 3 was in place. There is now no evidence that meat colour has an impact on eating quality. Consumers do not visually discriminate against meat colours (greater than 3) at the point of sale, where pH is an acceptable level. The MSA Beef Taskforce endorsed the removal of meat colour as a specification for the MSA eating quality grading system in December 2016; however, this project reports on the influences of meat colour as contracted prior to 2016. The removal of meat colour as an MSA specification will have minimal impact on the MSA grading process. Other industry standards such as the AUS-MEAT grain fed specifications will still apply (meat colour 1B – 3). For grain fed carcases being MSA graded, this will need to be included as a company specification in the relevant PBR line.

acceptable explanation for this sudden chance in incidence. Plant F has the greatest contrast between colour score 3 data, with 13585 carcases having a pH of 5.68-5.7 to just 1 at 5.71-5.72. More data seems to lie on the other scale (poor meat colour, good pH and shaded pink in the table). Thus data from plants that have very little pH 5.68-5.7 and colour 4 scores is concerning. It is possible that graders are giving these carcases more time to bloom and regrading. It is also possible that this data is not an entirely accurate representation of the association of pH and meat colour.

It seems as though Plant E has the only data set with a clear spread of data. Yet this data set has the highest correlation coefficients for pH and meat colour. In contrast data sets such as Plant C and Plant D which have very little data spread once outside MSA grades have correlations of 0.829 and 0.610. These comparisons make correlations of such data sets difficult to interpret.

4.3.1 Data

Table 4.13 below shows that at most plants when the equation of the line between pH and meat colour is solved for pH 5.7, the meat colour is generally below 3, other than at the 2 plants in SA. This supports the findings from later in the report for these 2 plants where there is a larger proportion of carcasses with a low pH but meat colour is out of specification indicating bloom time issues.

Table 4.14 represents the percentage of carcases from each plant that are graded as MSA and those that are non-compliant for meat colour and pH. The table also shows the occurrence of uncoupling of pH and meat colour. Most plants grade more than 90% of the carcases as MSA, while plant E only graded about 78% of carcases as MSA. This plant had the highest occurrence of dark cutting (19.5%) and 1.5% that fail on meat colour only. The occurrence of carcases being non-compliant on pH alone is typically very low with only one plant (Plant I) having more than 0.5% occurrence (1%).

Table 4.13. Correlation coefficients, R-squared value and root means square of the error (RMSE) for Meat colour and pH on a lots basis, adjusted for by Month and year. The meat colour at a pH of 5.7 was solved for using the intercepts from the model used.

Plant	Average Correlation for lots	Ave Meat Colour Solved for pH 5.7 within a lot	R-Squared	RMSE
A	0.772	2.703	0.609	0.412
B	0.668	2.859	0.49	0.51
C	0.829	2.798	0.714	0.34
D	0.61	2.697	0.433	0.436
E	0.869	3.323	0.804	0.426
F	0.845	3.053	0.73	0.358
G	0.698	2.572	0.521	0.584
H	0.834	2.688	0.728	0.475
I	0.807	2.864	0.689	0.385

Table 4.14: The percentages for each plant which carcases were graded as MSA and the percentages of dark cutting based in being non-compliant by pH only, Meat colour only, and both pH and meat colour. This table illustrates the occurrence of "uncoupling" of pH and meat colour.

		Non Compliance			
Plant	MSA grade	pH only	MC only	pH and MC	Total ungraded
A	94.11%	0.07%	0.05%	5.77%	5.89%
B	92.44%	0.28%	0.17%	7.10%	7.56%
C	93.01%	0.00%	0.00%	6.98%	6.99%
D	97.63%	0.10%	0.03%	2.24%	2.37%
E	78.87%	0.06%	1.50%	19.57%	21.13%
F	93.45%	0.01%	0.08%	6.45%	6.55%
G	89.21%	0.03%	0.10%	10.66%	10.79%
H	90.09%	0.50%	0.51%	8.90%	9.91%
I	93.77%	1.04%	0.18%	5.01%	6.23%

Fig. 4.49 represents the frequencies of pH recorded in the MSA data set from 9 southern beef processors. Columns represent a range of 0.02 pH units. The green line is the current distribution function. It is not expected that pH data will be normally distributed (red line) and the current data is slightly skewed towards a lower pH, as expected. However, there is a large cliff from data ≤ 5.7 to greater than 5.7. This appears to be an irregular representation of the data likely caused due to the MSA pH threshold limit at pH 5.7. It is unclear as to why this cliff occurs, but it is an indication that grading has been influenced by the MSA threshold. This is probably due to regrading, and if so a protocol for such processes should be developed.

There are a number of peaks in this graph, which would be influenced by the individual plants. When referring to the individual histograms for each plant, it is noticeable that plants C, F and H have clear peaks at certain pH measurements which account for over 20% of the carcases from that individual plant. It seems unlikely that the carcases from a single plant will have an occurrence of one pH at greater than 20% but the surrounding pH measurements have a much lower occurrence. This questions the credibility of some of the pH data recorded and thus the associations with pH and meat colour are likely to be inaccurate. The peaks from those individual plants have clearly influenced the overall histogram for pH 5.53, 5.6 and 5.63.

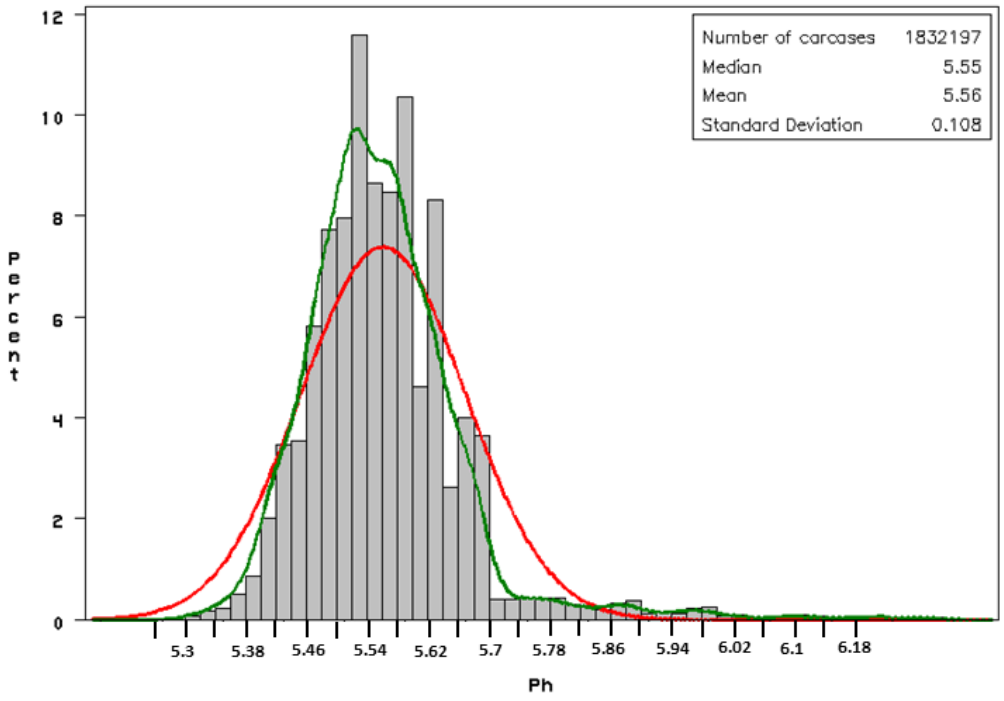

Fig. 4.49: The frequency of pH data for all plant across all years. Each column is the frequency of pH at 0.02 intervals.

******** This information is to help interpret the tables titled "Meat colour versus pH frequency near the MSA threshold of pH 5.7" from all plants below. This table shows the frequency data close to the compliance threshold of pH 5.7 versus the meat colour grades. Data were grouped in pH ranges and represents the number of carcases with that given pH and colour grade. The yellow section of the table demonstrate the data that lies in the MSA grading area. The blue section is that for ungraded carcases that are non-compliant for pH but not meat colour. The pink section are those carcases ungraded for meat colour but not pH. The green section is ungraded for both pH and meat colour. The grey section is the total number of carcases that were graded per respective plant. Most of these tables show very little data in the pH 5.71 -5.73 and good colour range.

Plant A

- 90,326 carcases over 2335 lots
- Seasonal peaks in dark cutting
- Carcasses failing on Meat colour only have been eliminated since 2010 (Fig. 4.51)
- Very little data from pH 5.71 upwards (Fig. 4.52)
- pH data seems to be less frequent from pH 5.6 upwards
- No pH 5.71 and colour 3 at all (Table 4.15).

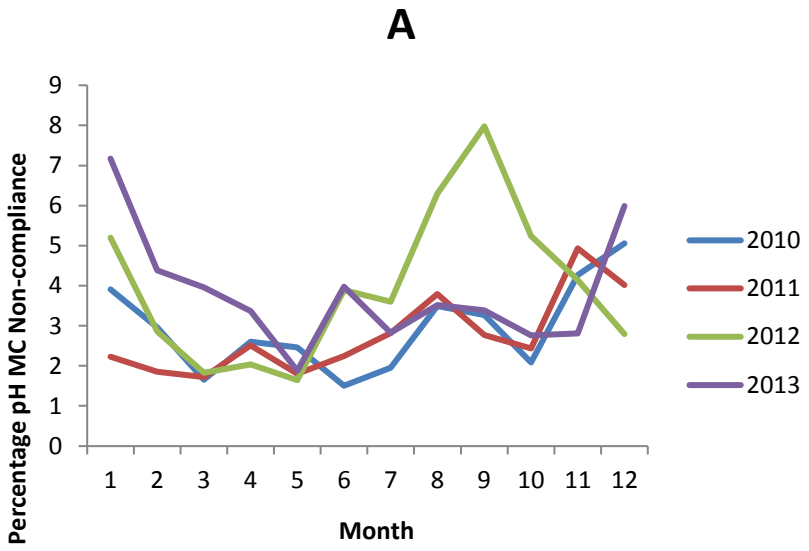

Fig. 4.50: Percentage Non-compliance for pH and Meat colour by month over 4 years

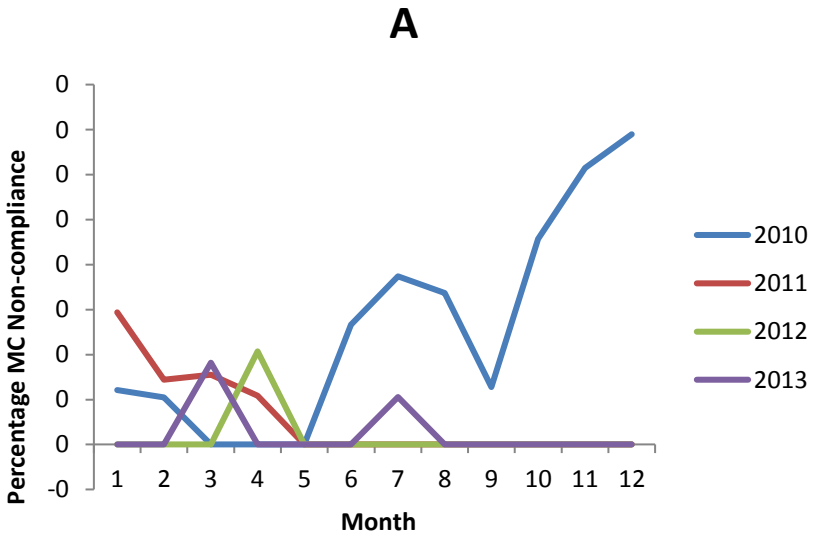

Fig. 4.51: Percentage Fail for Meat colour only by month over 4 years

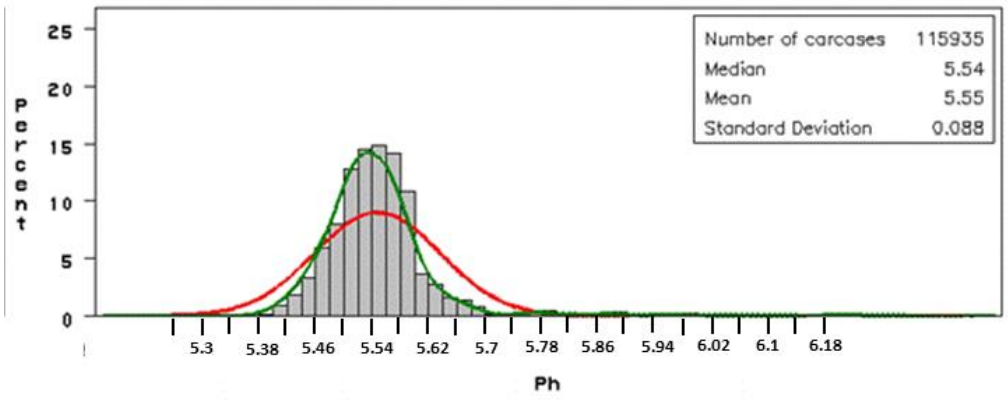

Fig. 4.52: The frequency of pH measurements for all carcasses graded at plant A

Table 4.15: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant A					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	5	2	0	0	7
1B	10939	94	1	1	11034
1C	46157	442	1	1	46600
2	45558	689	7	8	46255
3	7252	1203	34	35	8490
4	22	28	1789	1863	1919
5	5	0	856	861	866
6	5	1	749	750	756
7	0	0	8	8	8
group total	109943	2459	3445	3527	115935

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant B

- 60,992 carcases over 1547 lots
- Seasonal peaks in dark cutting (Fig. 4.53)
- Random peaks in Meat colour non-compliances only (Fig. 4.54)
- Clear data drop off of pH greater than 5.7 (Fig. 4.55)
- No occurrence of pH 5.71 and colour 3 data at all but 54 in the 5.71-5.73 range (Table 4.16).

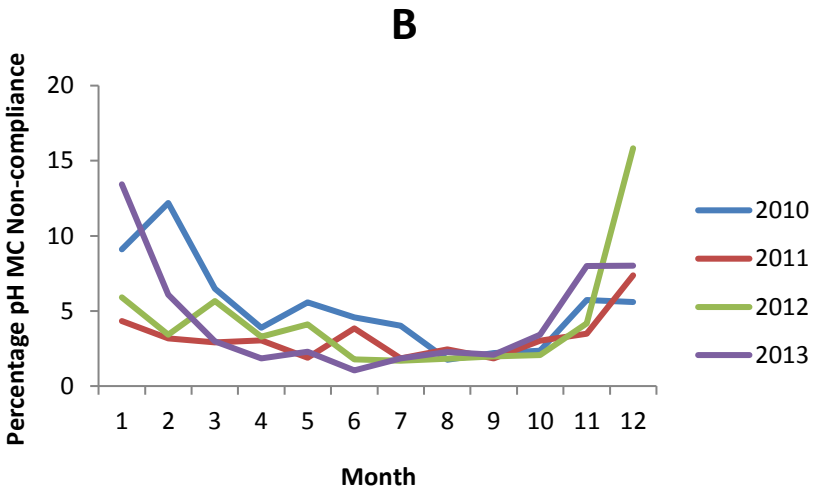

Fig. 4.53: Percentage non-compliance for pH and Meat colour by month over 4 years

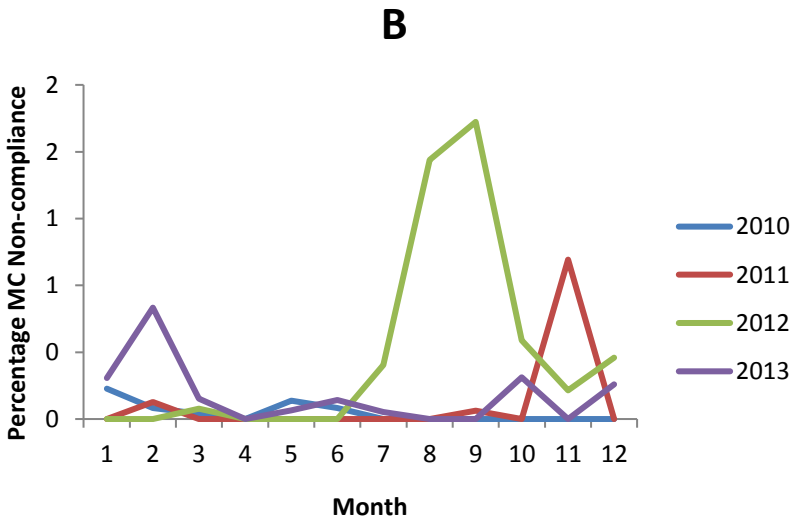

Fig. 4.54: Percentage Non-compliance for Meat colour only by month over 4 years

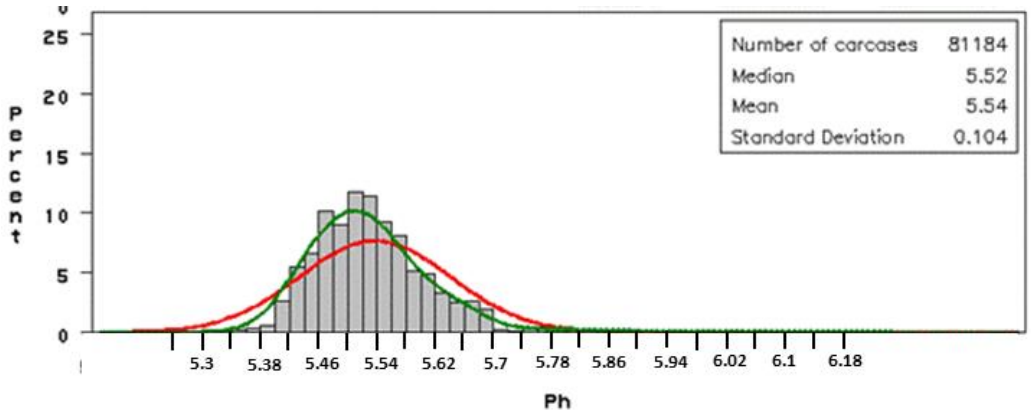

Fig. 4.55: The frequency of pH measurements for all carcasses graded at Plant B

Table 4.16: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant B					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	5	1	0	0	6
1B	1035	50	1	1	1086
1C	33176	1057	21	23	34256
2	28320	1565	40	43	29928
3	11534	1108	54	56	12698
4	107	19	1789	1887	2028
5	10	7	860	872	892
6	2	1	284	285	289
7	0	0	1	1	1
group total	74189	3808	3050	3168	81184

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant C

- 202,622 carcasses over 4260 lots
- Seasonal peaks in dark cutting (Fig. 4.56)
- Only 2 months over 4 years recorded a meat colour only non-compliance (Fig. 4.57)
- Clear data drop off of pH greater than 5.7 (Fig. 4.58)
- Data seems to be randomly distributed with certain peaks which indicates pH not being directly measured (Fig. 4.58)
- No observed mismatch of colour and pH on high pH or low pH side (Table 4.17)

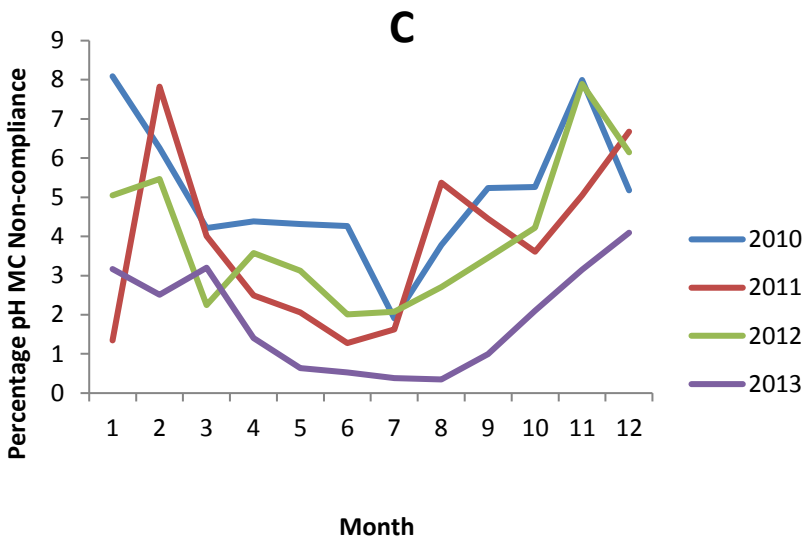

Fig. 4.56: Percentage Non-compliance for pH and Meat colour by month over 4 years

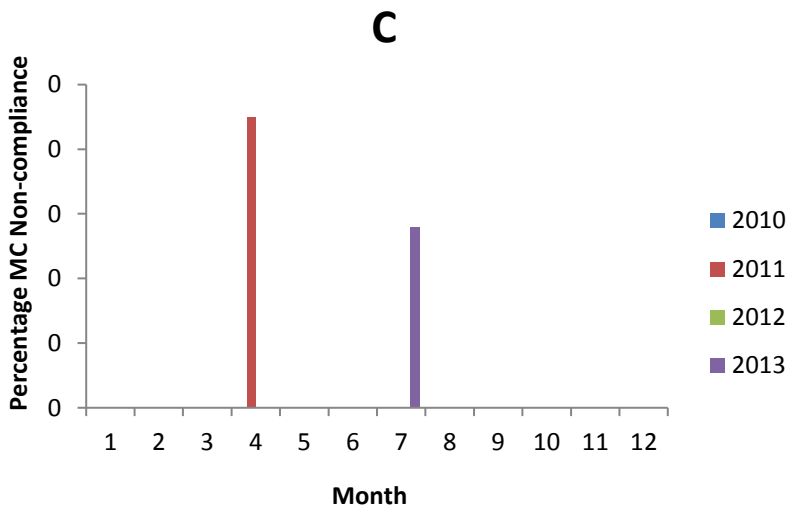

Fig. 4.57: Percentage Non-compliance for Meat colour only by month over 4 years

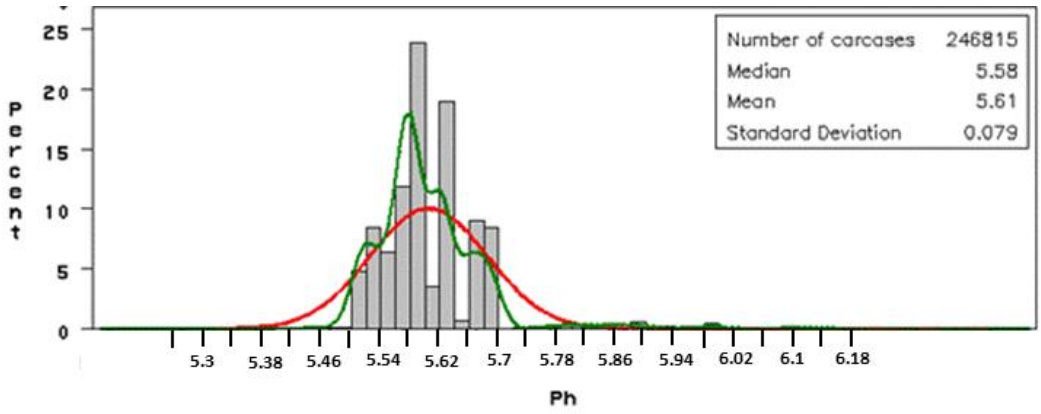

Fig. 4.58: The frequency of pH measurements for all carcasses graded at Plant C

Table 4.17: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant C					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	14094	96	0	0	14190
1C	100401	330	0	0	100731
2	78550	35146	1	1	113697
3	1635	7545	3	3	9183
4	6	0	4061	4178	4197
5	1	0	2991	3004	3005
6	0	0	1787	1788	1789
7	0	0	23	23	23
group total	194687	43117	8866	8997	246815

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant D

- 118,715 carcasses over 2486 lots
- Seasonal peaks in dark cutting late in the year (Fig. 4.59)
- Only a few month over 3 years recorded a meat colour only Non-compliance (Fig. 4.60)
- Data is the most normally distributed data set but the lowest mean (Fig. 4.61)
- Very little pH colour mismatch or data in the 5.71 plus region (Table 4.18)

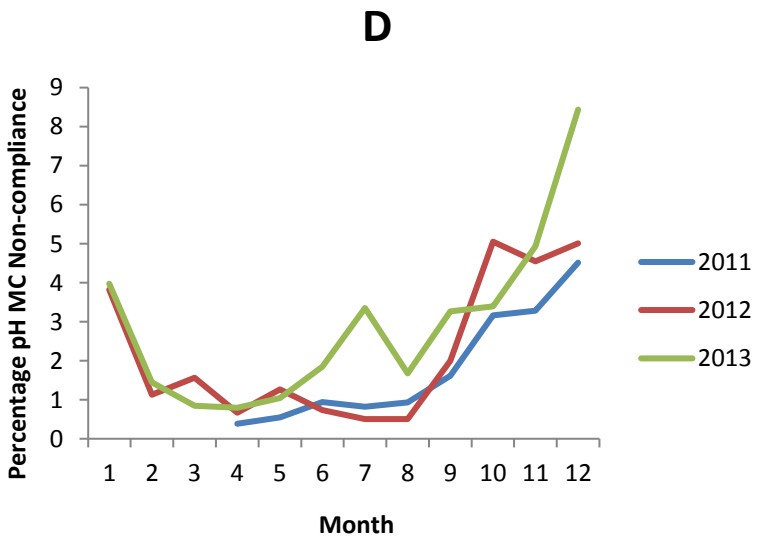

Fig. 4.59: Percentage Non-compliance for pH and Meat colour by month over 4 years

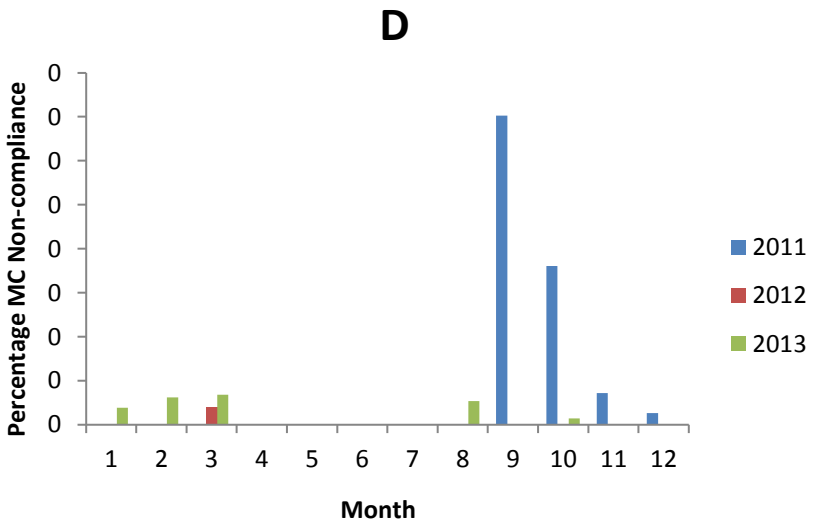

Fig. 4.60: Percentage non-compliance for meat colour only by month over 4 years

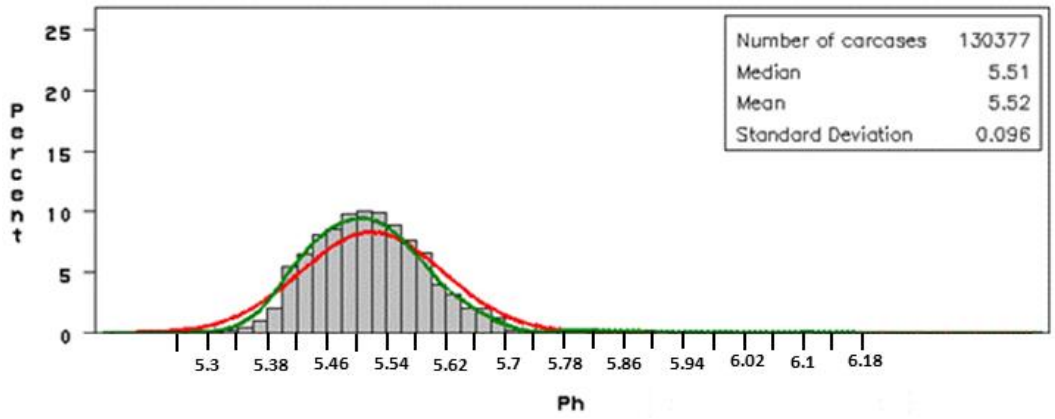

Fig. 4.61: The frequency of pH measurements for all carcasses graded at Plant D

Table 4.18: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant D					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	18194	274	1	12	18481
1C	56115	1116	9	24	57264
2	39098	1272	3	30	40403
3	9413	1804	5	47	11269
4	25	5	21	2216	2267
5	8	1	4	633	646
6	1	0	1	44	46
7	0	0	0	1	1
Total	122854	4472	44	3007	130377

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant E

- 225,153 carcasses over 4095 lots
- Seasonal peaks not observed (Fig. 4.62)
- Consistently higher rates of dark cutting than other plants
- Consistently larger occurrence of meat colour non-compliance only compared to other plants
- Data has a tail beyond pH 5.7 (Fig. 4.64)
- Large number of data with low pH and dark colour. (Table 4.19)
- Large number of pH 5.71 data and colour 4, yet very little with colour 3 (Table 4.19).

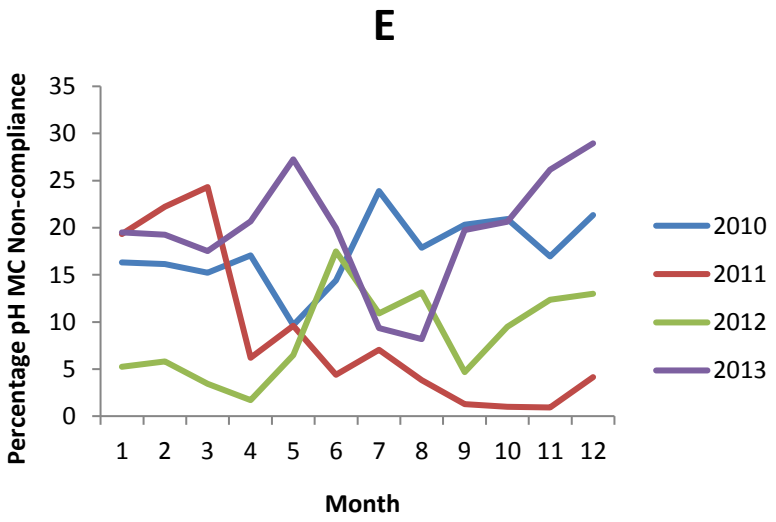

Fig. 4.62: Percentage non-compliance for pH and meat colour by month over 4 years

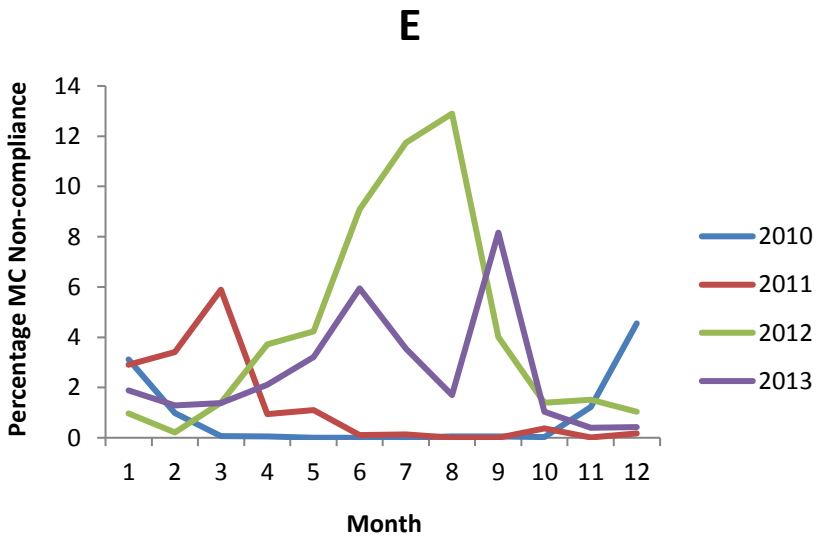

Fig. 4.63: Percentage non-compliance for meat colour only by month over 4 years

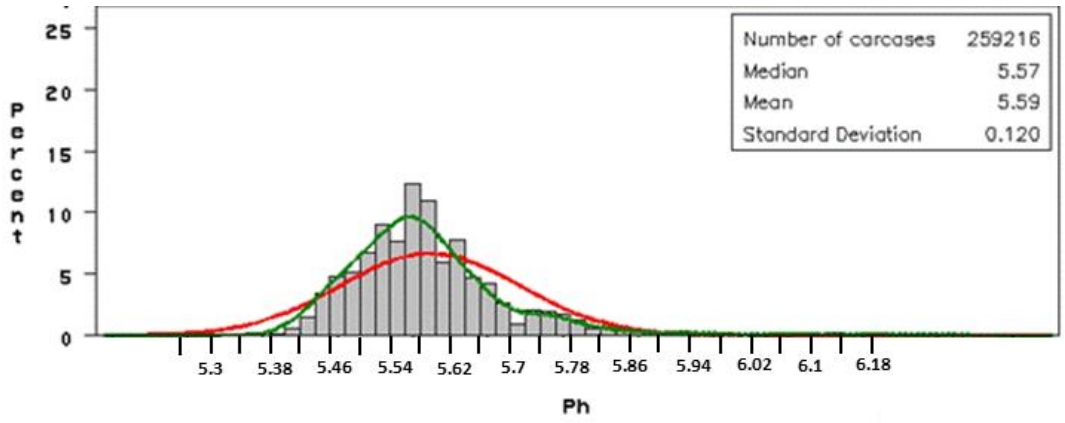

Fig. 4.64: The frequency of pH measurements for all carcasses graded at Plant E

Table 4.19: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant E					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	5796	0	0	0	5796
1C	39897	38	3	3	39938
2	71773	238	10	12	72023
3	90303	14629	50	84	105029
4	961	3012	15406	20659	26485
5	28	157	4339	4371	4560
6	24	55	5203	5281	5382
7	0	0	0	0	0
group total	208782	18129	25011	30410	259213

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant F

- 342,454 carcasses over 4811 lots
- Seasonal effects not observed
- Random and low occurrence of meat colour only Non-compliance (Fig. 4.66)
- Clear data drop off of pH greater than 5.7 (Fig. 4.67)
- Data seems to be randomly distributed but biased towards 5.53 (Fig. 4.67)
- Very little mismatch of colour and pH (Table 4.20)

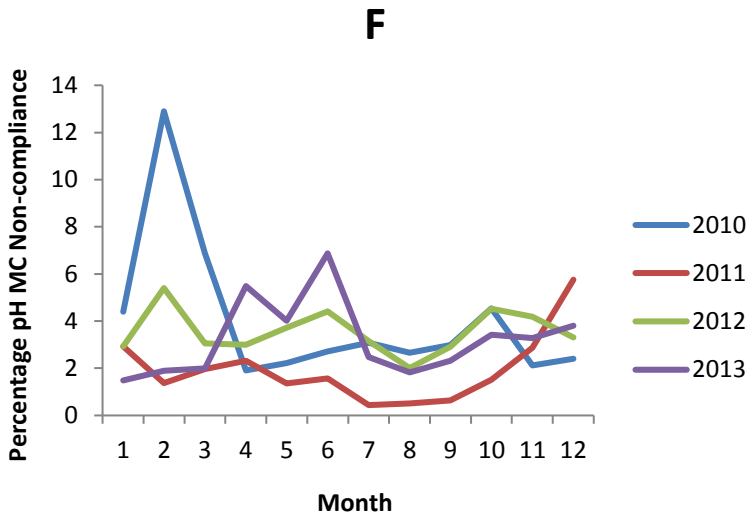

Fig. 4.65: Percentage Non-compliance for pH and Meat colour by month over 4 years

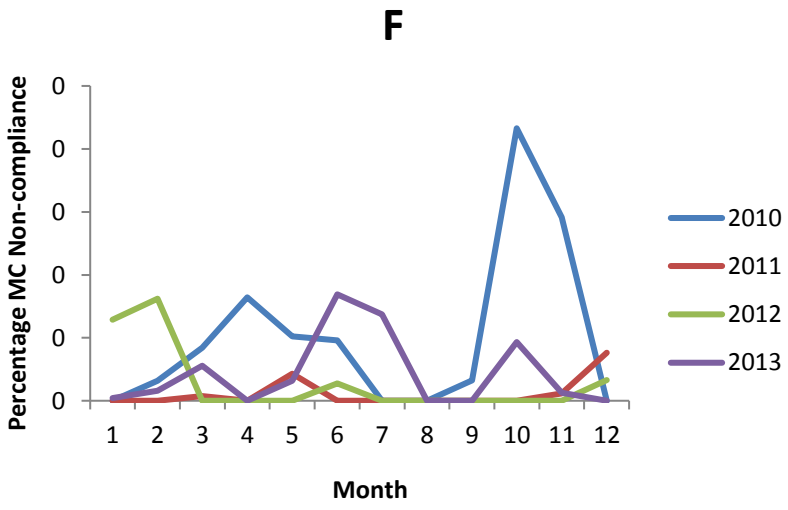

Fig. 4.66: Percentage Non-compliance for Meat colour only by month over 4 years

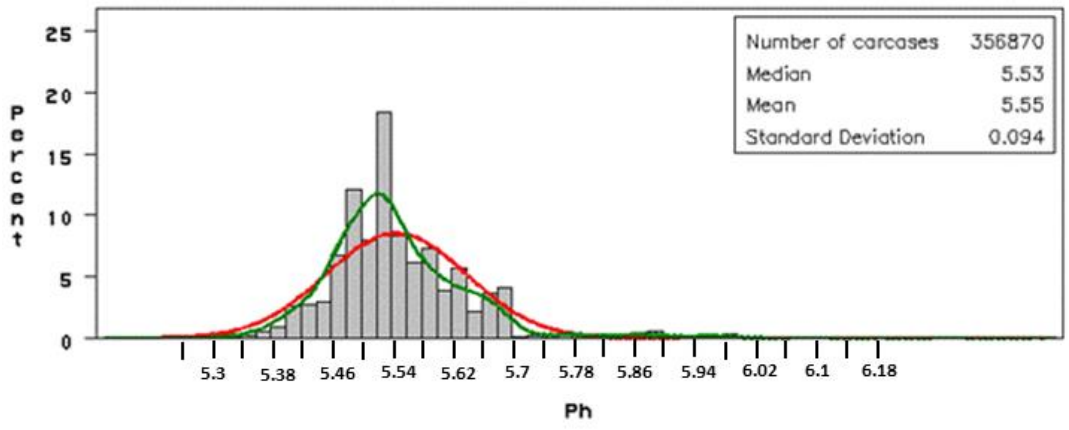

Fig. 4.67: The frequency of pH measurements for all carcasses graded at plant F

Table 4.20: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant F					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	49535	54	1	1	49590
1C	154203	1576	3	3	155782
2	88559	2929	13	14	91502
3	24554	22747	9	9	47311
4	95	143	5738	6330	6725
5	23	29	5468	5542	5611
6	3	1	336	336	340
7	0	0	8	8	8
group total	316972	27479	11576	12243	356869

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant G

- 185,000 carcase over 4162 lots
- No seasonal peaks in dark cutting observed
- Meat colour only Non-compliance seems to be eliminated since 2010 (Fig. 4.69)
- Clear data drop off of pH greater than 5.7 (Fig. 4.70)
- Data seems to be randomly distributed but well spread from pH 5.4-5.7. (Fig. 4.70)
- little observed mismatch of colour and pH (Table 4.21)

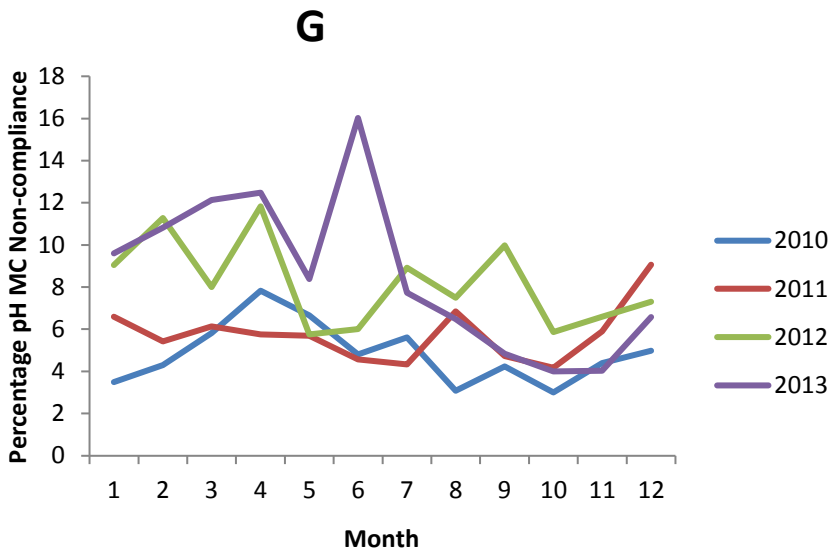

Fig. 4.68: Percentage non-compliance for pH and meat colour by month over 4 years for Plant G

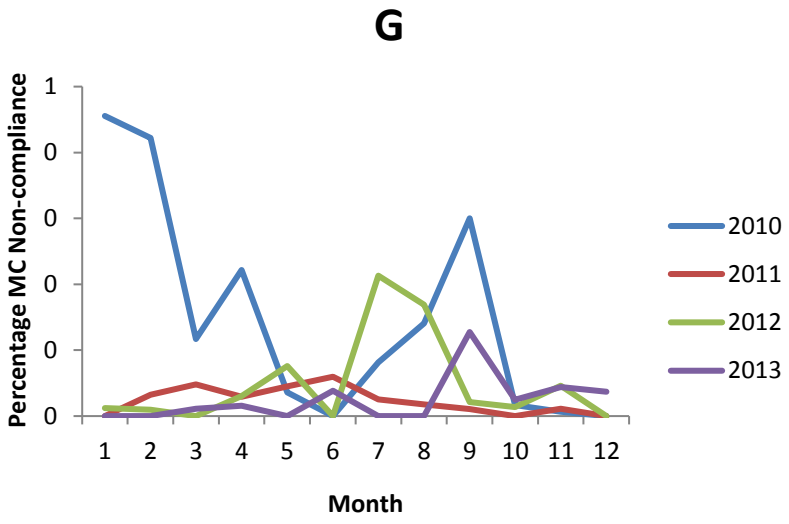

Fig. 4.69 Percentage Non-compliance for meat colour only by month over 4 years

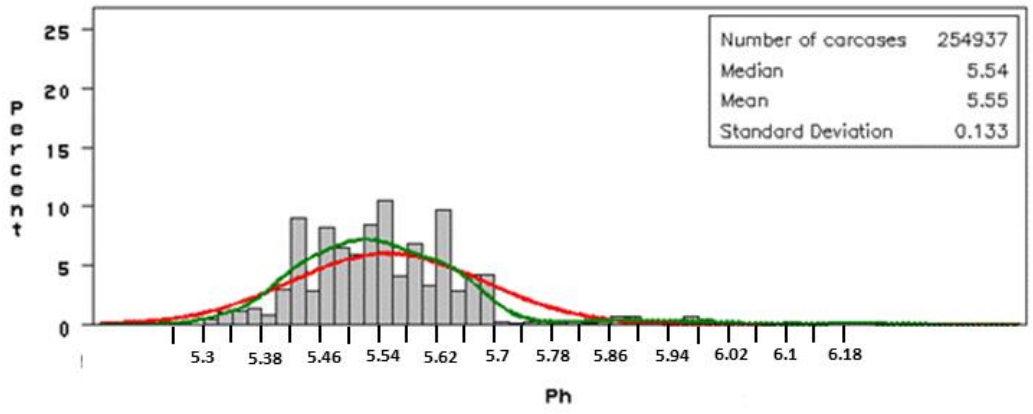

Fig. 4.70: The frequency of pH measurements for all carcasses graded at Plant G

Table 4.21: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant G					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	1	0	4	4	5
1B	6482	137	0	0	6619
1C	77558	4067	3	3	81628
2	105275	8796	12	13	114085
3	28875	8722	20	20	37617
4	151	50	7707	7903	8303
5	50	10	3601	3615	3725
6	19	1	2709	2717	2752
7	0	0	203	203	203
group total	218411	21783	14259	14478	254937

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant H

- 76,534 carcasses over 2204 lots
- No Seasonal peaks in dark cutting
- Meat colour only non-compliance from end of 2012 to early 2013 (Fig. 4.72)
- Clear data drop off of pH greater than 5.7 (Fig. 4.73)
- Data seems to be randomly distributed and biased toward pH 5.53-5.54 and 5.60 (Fig. 4.73)
- Little mismatched in colour and pH observed (Table 4.22)

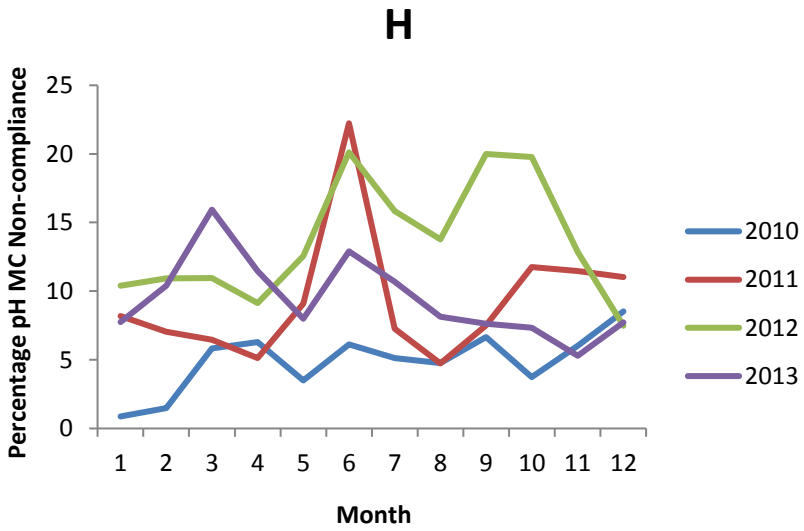

Fig. 4.71: Percentage non-compliance for pH and meat colour by month over 4 years

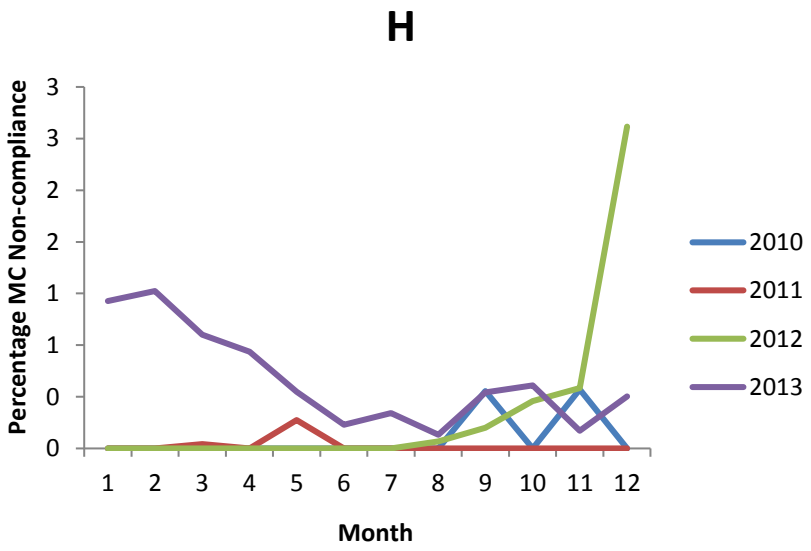

Fig. 4.72: Percentage non-compliance for Meat colour only by month over 4 years

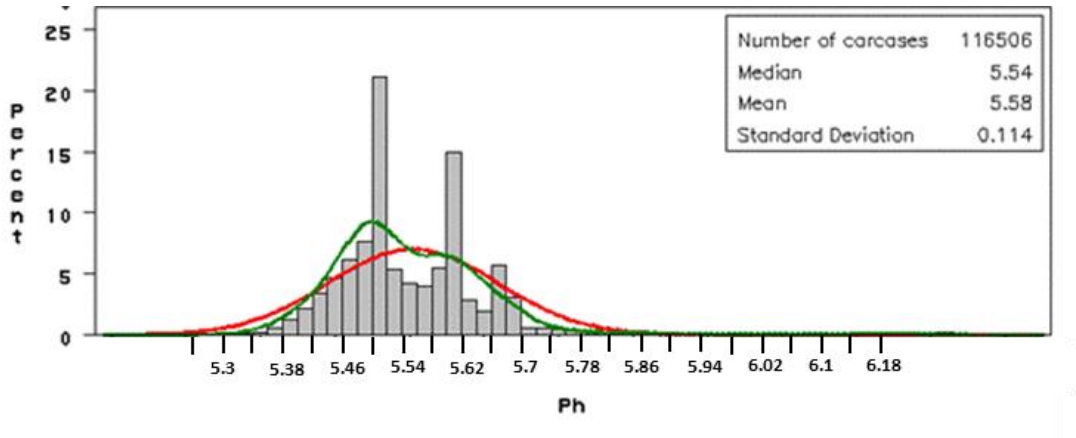

Fig. 4.73: The frequency of pH measurements for all carcasses graded at plant H

Table 4.22: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant H					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	4140	15	2	3	4158
1C	39348	158	26	29	39535
2	44049	638	49	57	44745
3	10184	11167	203	243	21604
4	335	261	3743	4268	5011
5	15	7	945	954	982
6	2	1	453	456	460
7	1	0	10	10	11
group total	98074	12247	5431	6020	116506

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

Plant I

- 242,076 carcasses over 4976 lots
- No seasonal peaks in dark cutting
- Meat colour non-compliance only sparse and random(Fig. 4.75)
- Little data beyond pH 5.7 (Fig. 4.76)
- Reasonable amount of mismatched colour/pH data compared to other plants (Table 4.23).

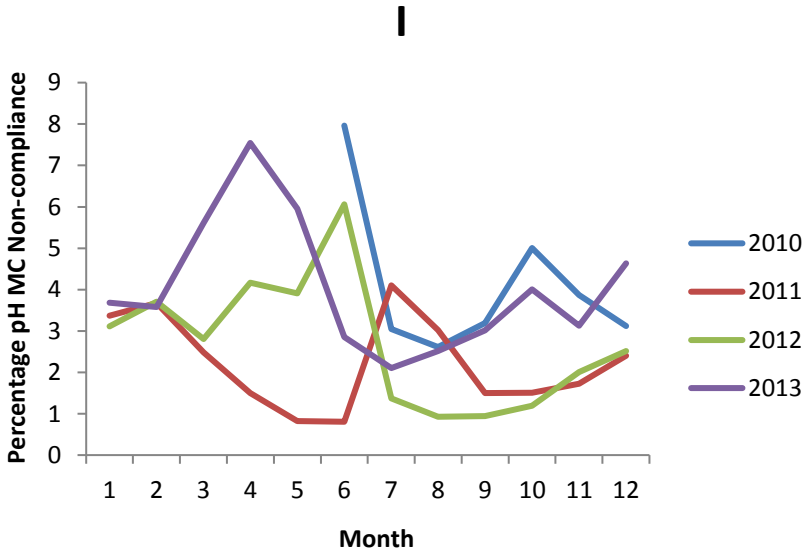

Fig. 4.74: Percentage Non-compliance for pH and Meat colour by month over 4 years

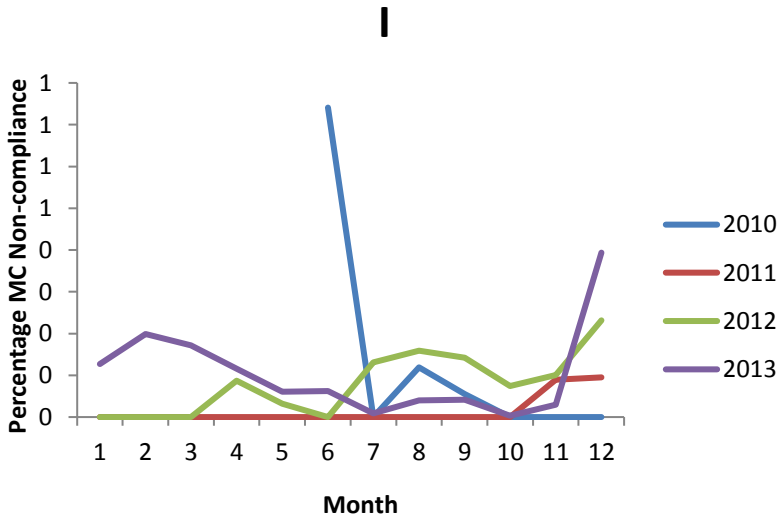

Fig. 4.75: Percentage non-compliance for Meat colour only by month over 4 years

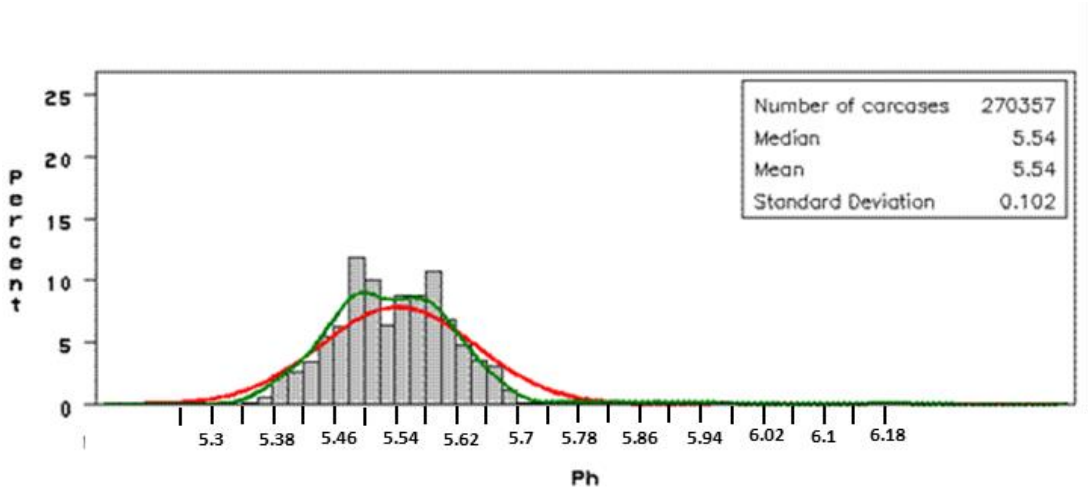

Fig. 4.76: The frequency of pH measurements for all carcasses graded at Plant I

Table 4.23: Meat colour versus pH frequency near the MSA threshold of pH 5.7.

Plant I					
	pH compliant		non pH compliant		
Meat colour	<5.67	5.67 - 5.7	5.71 - 5.73	>5.73	N
1A	0	0	0	0	0
1B	38995	94	2	2	39091
1C	99089	420	23	26	99536
2	97227	3143	236	260	100644
3	14644	7585	1113	1242	23494
4	153	286	3696	3840	4309
5	6	28	836	846	883
6	10	14	2161	2169	2196
7	0	0	204	204	204
group total	250124	11570	8271	8589	270357

MSA compliant
Ungraded for MC and pH
Ungraded for MC only
Ungraded for pH only
total carcases

4.3.2 The time of grading across all plants

Grading interval is the number of calendar days from slaughter to grading. Since there is no time given in the data set for the grading time, the data can only be analysed using calendar date. When the data is broken into these time intervals the apparent lack of carcases with a pH >5.7 is still very prominent in this data set and exists across all time points (Fig. 4.77). Most plants grade carcases on the calendar day after slaughter with a total rate of 69.68% of carcases graded in this time interval, with 12% and 11.4% being graded on the evening the animals were slaughtered and 3 days after respectively (Fig. 4.78; Table 4.25). It is assumed that the three day interval would be carcases from animals killed on a Friday and graded Monday. Plant B grade almost 60% of the carcases on the same day as slaughter, yet there is no stand out in the rate of ungraded cattle from this data.

There is no real obvious trend with time of grading. Grading too early is suggested to be a major influence on compliance rate. The rates were consistent within the plant, with a trend for compliance rates to actually decrease as the grading interval increase. The rates of pH colour mismatch also do not seem to be influenced by the grading interval.

Plants that grade mostly on the same day as slaughter don't have greater rates of dark cutting or colour pH uncoupling than any other plant. It is difficult to understand the mechanism behind the uncoupling of meat colour and pH as it occurs at a rate of only 0.33%, with this level being increased by plant E that has a rate of 1.56%. However since the actual non-compliance rate for plant E is so high (above 20%), the uncoupling rate seems to be a similar proportion of all non-compliant carcases. One hypothesis that is still yet to be tested is to look at the lots that have a high rate of uncoupled pH and meat colour and to test the travel distance. It is plausible that dehydration could cause meat to appear darker, due to the muscle pigment being more concentrated yet the pH remains the same. This could occur in cattle that have travelled a great distance before slaughter.

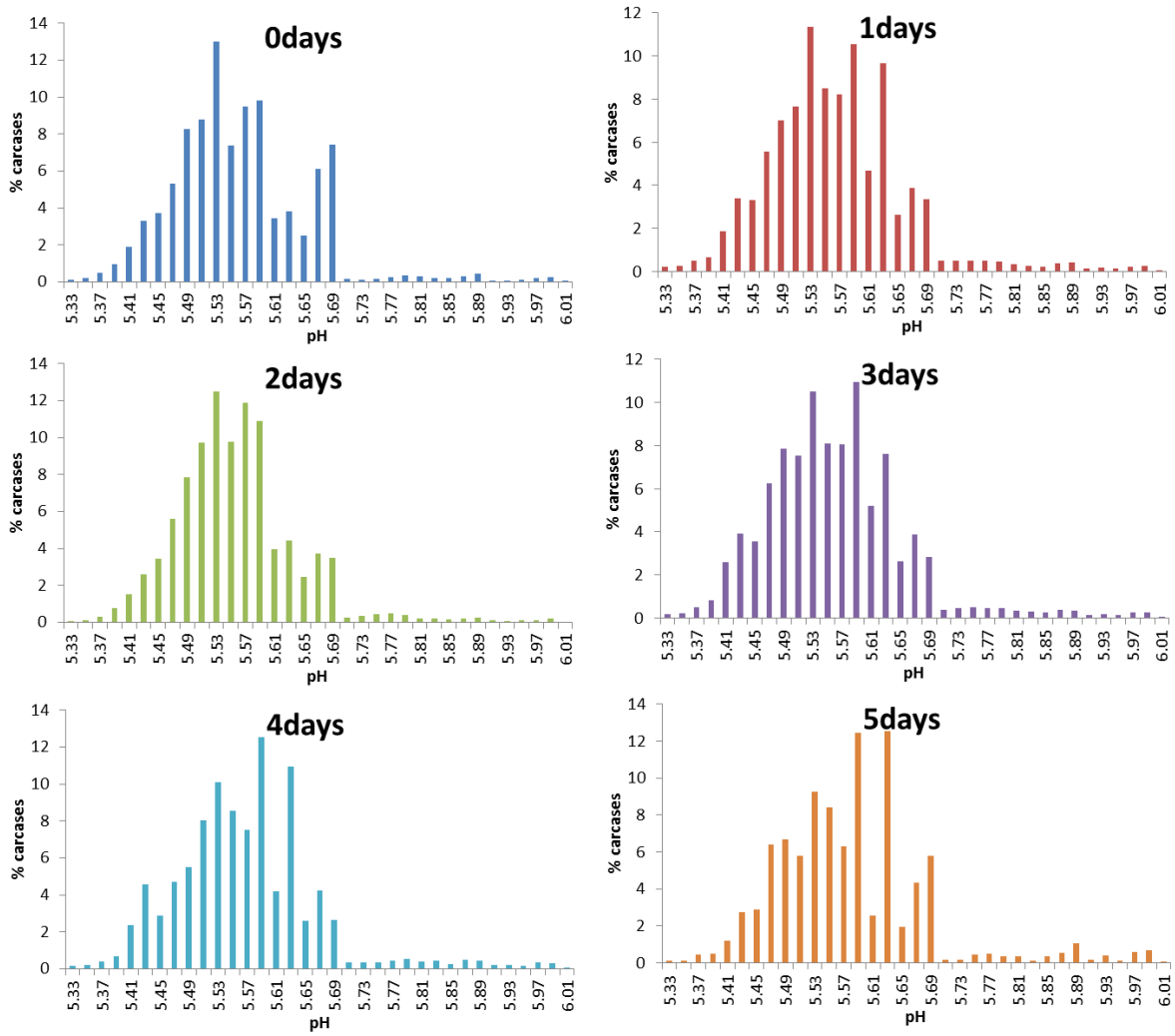

Fig. 4.77. The distribution of MSA pH measurements at different grading intervals in all plants

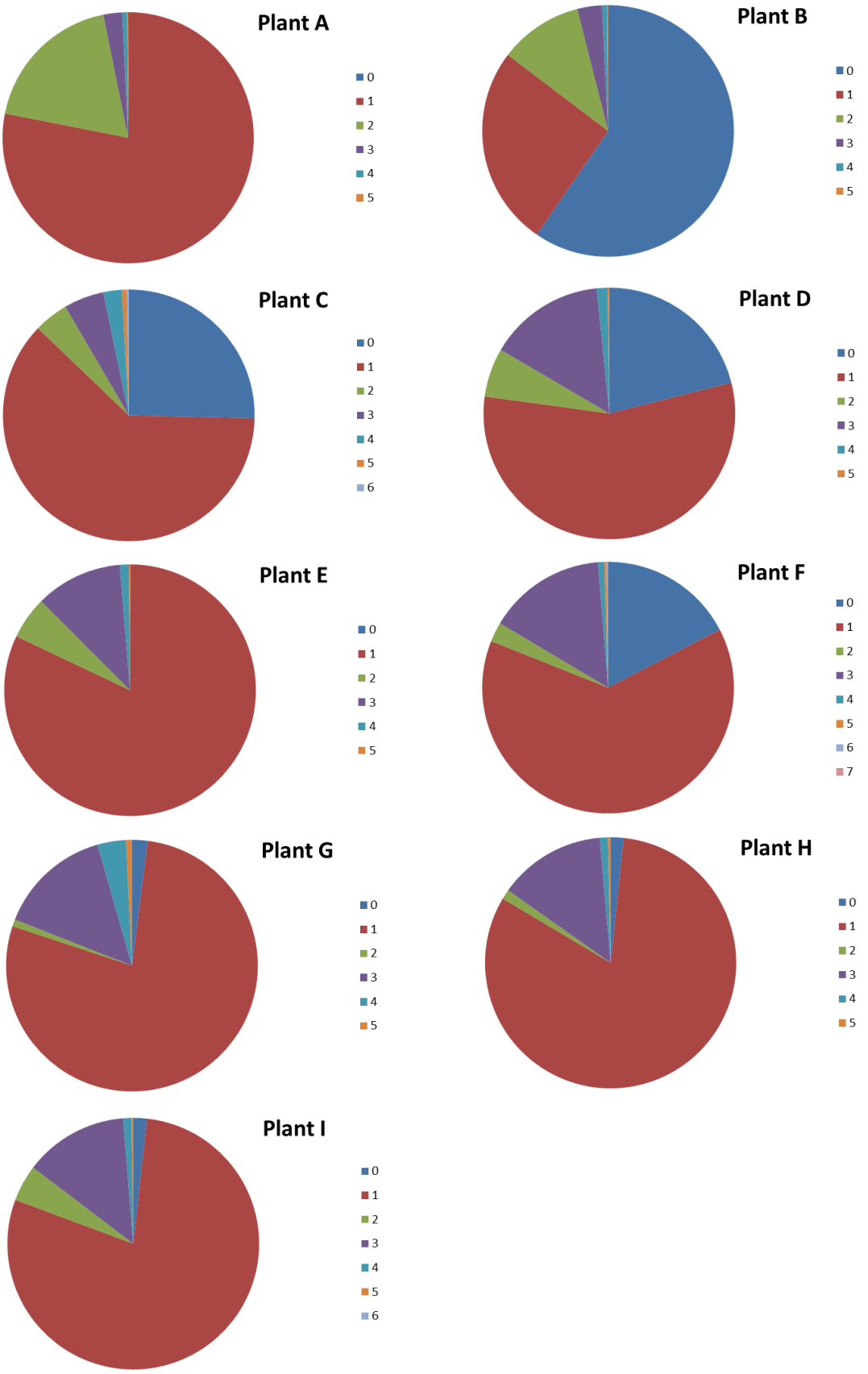

Fig. 4.78 the proportion of carcases graded per time interval per pla

Table 4.24 Total carcase graded per time interval

	Grading interval (calendar days from slaughter)							
Plant	0	1	2	3	4	5	6	7
A	113	89285	21440	2767	745	122		
B	47660	20581	8583	2534	487	130		
C	62095	151245	10798	12619	5821	1489	657	
D	26640	70972	7939	18921	1756	286		
E	101	214212	14292	29216	3025	395		
F	62367	228589	9060	54456	2824	1059	740	2
G	5150	200234	2283	37465	9349	1977		
H	1954	96975	1484	16351	1221	428		
I	2925	132709	7882	22463	1825	361	1	

Table 4.25 Percentage of total carcases graded per plant at each time interval

	Grading interval (calendar days from slaughter)							
Plant	0	1	2	3	4	5	6	7
A	0.10%	78.00%	18.73%	2.42%	0.65%	0.11%		
B	59.59%	25.73%	10.73%	3.17%	0.61%	0.16%		
C	25.37%	61.80%	4.41%	5.16%	2.38%	0.61%	0.27%	
D	21.06%	56.10%	6.28%	14.96%	1.39%	0.23%		
E	0.04%	82.00%	5.47%	11.18%	1.16%	0.15%		
F	17.37%	63.66%	2.52%	15.16%	0.79%	0.29%	0.21%	0.00%
G	2.01%	78.08%	0.89%	14.61%	3.65%	0.77%		
H	1.65%	81.90%	1.25%	13.81%	1.03%	0.36%		
I	1.74%	78.92%	4.69%	13.36%	1.09%	0.21%		
% of total carcases	12.088%	69.680%	4.844%	11.381%	1.565%	0.361%	0.081%	0.000%

Table 4.26 Number of ungraded carcase per time grade

	Grading interval (calendar days from slaughter)							
Plant	0	1	2	3	4	5	6	7
A	0	3080	641	82	26	3		
B	2192	973	323	160	18	8		
C	2093	5566	404	509	255	105	13	
D	618	1938	152	594	44	3		
E	35	30482	1807	5168	622	51		
F	2626	10149	161	1323	53	28	59	
G	375	13596	233	2536	608	173		
H	153	10134	101	2062	162	212		
I	75	5415	376	1226	126	18		

Table 4.27 Percentage of carcase ungraded per plant at each time interval

	Grading interval (calendar days from slaughter)							
Plant	0	1	2	3	4	5	6	7
A	0.00%	3.45%	2.99%	2.96%	3.49%	2.46%		
B	4.60%	4.73%	3.76%	6.31%	3.70%	6.15%		
C	3.37%	3.68%	3.74%	4.03%	4.38%	7.05%	1.98%	
D	2.32%	2.73%	1.91%	3.14%	2.51%	1.05%		
E	34.65%	14.23%	12.64%	17.69%	20.56%	12.91%		
F	4.21%	4.44%	1.78%	2.43%	1.88%	2.64%	7.97%	0.00%
G	7.28%	6.79%	10.21%	6.77%	6.50%	8.75%		
H	7.83%	10.45%	6.81%	12.61%	13.27%	49.53%		
I	2.56%	4.08%	4.77%	5.46%	6.90%	4.99%	0.00%	
% of carcases/grade time	3.91%	6.75%	5.01%	6.94%	7.07%	9.62%	5.15%	

Table 4.28 The percentage of carcases ungraded for meat colour only per plant at each grade interval

	Grading interval (calendar days from slaughter)							
Plant	0	1	2	3	4	5	6	7
A		0.05%	0.05%	0.11%		0.82%		
B	0.22%	0.19%	0.05%	0.00%				
C	0.00%	0.00%		0.02%				
D	0.02%	0.03%	0.03%	0.02%	0.28%			
E	7.92%*	1.59%	1.15%	2.08%	1.65%	1.27%		
F	0.20%	0.10%	0.01%	0.03%				
G	0.08%	0.12%		0.07%	0.11%			
H	0.26%	0.46%	0.13%	0.93%	0.57%	0.93%		
I	0.31%	0.20%	0.19%	0.22%	0.05%			
% of carcases/grade time	0.12%	0.39%	0.24%	0.44%	0.27%	0.16%	0.00%	0.00%

*101 carcase total graded at this time interval

4.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

4.4.1 End of Season nutritional intervention

4.4.1.1 *Weather Analysis*

The Bureau of Meteorology compiled meteorological data throughout the trial period. In Western Australia during September, October, November and December the mean temperatures were above average, +1.72°C, +3.73°C, +1.77°C and +1.02°C, respectively. In South Australia over the same period the mean maximum temperatures were also above average, +0.37°C, +5.61°C, +2.14°C and +2.94°C, respectively (Meteorology, 2015a, d, c, b). In 2015, October had the highest mean maximum temperature on record. In September and October, WA and SA had below average with -67% and -11% in WA and -58% and -82% in SA. November and December had above average rainfall in WA with +53% and+24%. In SA during these months the average rainfall was +23% and-1% (Meteorology, 2015a, d, c, b). In Harvey, the daily temperatures (on the kill days) for each trial ranged between 7.1ºC to 14.8ºC (minimum) and 21.3ºC to 30.1ºC (maximum). A similar range in temperature with a minimum of 8.6ºC to 16.5ºC and maximum 20.3ºC to 32.5ºC on transport days, with no rain was recorded on the day of transport (Table 4.29).

Table 4.29. Minimum temperature (Min), maximum temperature (Max) and rainfall recorded on the day of transport at the weather station closest to the farm and the day of slaughter at the abattoir for Western Australia only.

		Temperature				Temperature		
Trial	Transport Date	Min (°C)	Max (°C)	Rain (mm)	Kill Date	Min (°C)	Max (°C)	Rain (mm)
8	1/10/15	14.2	31.2	0	2/10/15	7.1	22	0
5	7/10/15	8.6	21.1	0	8/10/15	9.3	24.9	0
6	20/10/15	10.1	19.6	0	21/10/15	10.2	24.1	0
7	29/10/15	16.5	20.6	0	30/10/15	13.9	24.8	0
3	2/11/15	13.7	24.5	0	3/11/15	14.5	22.9	1.2
13	2/11/15	13.7	24.5	0	3/11/15	14.5	22.9	1.2
12	10/11/15	11.8	22.6	0	11/11/15	14.8	N/A	0
9	11/11/15	9.1	28.2	0	12/11/15	N/A	26.1	0
10	18/11/15	9.5	20.6	0	19/11/15	13.8	21.3	1
2	30/11/15	12.5	20.3	0	1/12/15	11.4	23.4	0
11	2/12/15	10.9	32.5	0	3/12/15	14.1	30.1	0
1	14/12/15	13.4	24.3	0	15/12/15	13.4	24.3	0
4	14/12/15	12.5	27.1	0	15/12/15	13.4	24.3	0

4.4.1.2 *Pasture Analysis*

The pasture quality and quantity varied between farms and between trials (P>0.05; data not shown). There was no difference in any pasture quality measures or feed on offer (FOO) between treatment and control paddocks in both states (Table 4.30). In Western Australia there was no difference in the FOO between the start and end of the trials however there

was a decrease in metabolisable energy by 0.49 MJ/kg, crude protein by 3.65%, relative feed value by 16.12% and true digestibility by 6.81% DM (P<0.05; Table 4.30). There was also a decline in the levels of several minerals and amino acids including phosphorus, potassium, copper, sulphur, lysine and methionine between the start and end of the trials, while manganese level increased from 70.65 PPM to 87.42 PPM (P<0.05; Table 4.30). There were also increases in acid detergent fibre by 4.26%, neutral detergent fibre by 6.52% and dry matter from the start to the end of the trial (P<0.05; Table 4.30). During the trial period the paddock dry matter increased on average by 11.6%. There were no changes in all other measures taken.

In South Australia there was a significant difference between the FOO at the start and the end of the trial, with a decline of 508.34 ± 126.54 kg DM/ha (P<0.05; Table 4.30). The only other pasture measure that varied between the start and end of the trial in South Australia was the decline in phosphorous by 0.05% (P<0.05; Table 4.30).

In 2016, there was no difference in FOO between the starting and ending point in both WA and SA. Compared to 2015, the FOO higher in both states in 2016 (P<0.05), with SA FOO values being 3771.43± 195.27 and 3385.71 ± 195.27 kg DM/ha (start and end respectively), and the WA Foo Values being 2924.78±187.74 and 2635.77±187.74 kg DM/ha (start and end respectively). There were no differences in dry matter from starting to the ending of the trials in 2016 with WA having a larger increase of dry matter from 29.43 % to 37.04 %, while SA started at 38.44% and finished on 39.94%. There was no difference between the dry matter content between treatment paddocks.

4.4.1.1 *Animal and Carcass Performance*

Out of a total of 1143 carcases, there were only 50 dark cutting carcases with all MSA data across both states giving a rate of dark cutting of 3.17%. In 2015 Western Australian (WA) cattle, there was a rate of dark cutting of 1.75%, 7 dark cutting carcases in the control group and 5 from the treatment (Table 4.31). South Australia (SA) had a higher rate of dark cutting with a total rate of 4.81%, 11 carcases from the control and 11 from the treatment group (Table 4.31). In 2016, Western Australia had a total of 14 dark cutters with a total rate of 5.13% with treatment groups differing only by 2 dark cutters (Table 4.31). In the 2016 south Australian cattle there were only 1 dark cutter per treatment group. Due to the low numbers of dark cutting, the rates of dark cutting between treatments on a lot basis were not compared.

The statistical outputs for the models used are presented in Tables 4.32-4.35. In Western Australia, there was no difference in starting weights, end weights and average daily gain between cattle from different treatments, although 2015 treatment cattle had a higher end live weight of 505.52kg ± 0.69 compared to the control cattle with 503.41kg ± 0.69 when adjusted for stating weight (p<0.05; Table 4.35). The was a significant increase in the hot standard carcass weight (HSCW) between the treatment and control of 2.72kg in Western Australia (P<0.0001; Table 4.36), when adjusted for starting live weights.

Table 4.30. The mean pasture quality measures and Feed on Offer (FOO) at the start and end of the trials in Western Australia and South Australia 2015 ± the standard error (SEM).

Measure	Starting Pasture	SEM	Ending Pasture	SEM	P value
Western Australia					
FOO (Kg DM/ha)	2517.20	164.75	2323.08	144.59	0.35
Energy (MJ/kg)	9.70	0.12	9.20	0.17	0.01
Crude Protein (%)	17.38	0.36	13.73	0.36	0.01
Acid Detergent Fibre (%)	32.25	1.16	36.51	1.16	0.01
Neutral Detergent Fibre (%)	53.72	1.68	60.24	1.68	0.01
Dry Matter (%)	28.90	3.88	40.50	3.88	0.04
Relative Feed Value (%)	112.84	2.50	96.72	2.50	0.01
In Vitro True Digestibility (% DM)	78.73	0.75	71.92	0.75	0.01
Calcium (%)	0.54	0.03	0.48	0.03	0.08
Phosphorus (%)	0.27	0.01	0.23	0.01	0.01
Magnesium (%)	0.23	0.01	0.22	0.01	0.15
Potassium (%)	1.96	0.08	1.69	0.08	0.01
Sodium (%)	0.46	0.04	0.45	0.04	0.84
Iron (PPM)	177.83	18.41	167.91	18.41	0.69
Zinc (PPM)	27.33	1.18	26.98	1.18	0.83
Copper (PPM)	6.49	0.33	5.41	0.33	0.02
Manganese (PPM)	70.65	5.38	87.42	5.38	0.02
Molybdenum (PPM)	1.44	0.51	1.14	0.51	0.67
Sulfur (%)	0.21	0.01	0.18	0.01	0.01
Chloride (%)	1.18	0.05	1.06	0.05	0.10
Lysine (%)	0.67	0.02	0.53	0.02	0.01
Methionine (%)	0.24	0.01	0.19	0.01	0.01
South Australia					
FOO (Kg DM/ha)	2241.67	126.54	1733.33	126.54	0.01
Energy (MJ/kg)	9.45	0.24	9.17	0.24	0.42
Crude Protein (%)	13.98	1.41	12.50	1.41	0.47
Acid Detergent Fibre (%)	33.03	1.92	35.20	1.92	0.43
Neutral Detergent Fibre (%)	51.84	2.97	55.74	2.97	0.36
Dry Matter (%)	54.90	7.31	58.80	7.31	0.71
Relative Feed Value (%)	119.00	8.61	106.75	8.61	0.33
In Vitro True Digestibility (% DM)	N/A	N/A	N/A	N/A	N/A
Calcium (%)	0.63	0.05	0.64	0.05	0.89
Phosphorus (%)	0.27	0.01	0.22	0.01	0.01
Magnesium (%)	0.23	0.01	0.23	0.01	0.78
Potassium (%)	2.21	0.14	1.86	0.14	0.09
Sodium (%)	0.62	0.08	0.71	0.08	0.44
Iron (PPM)	128.42	10.13	115.33	10.13	0.37
Zinc (PPM)	16.67	0.64	15.25	0.64	0.13
Copper (PPM)	6.25	0.59	5.42	0.59	0.33
Manganese (PPM)	43.92	2.91	40.33	2.91	0.40
Molybdenum (PPM)	N/A	N/A	N/A	N/A	N/A
Sulfur (%)	0.22	0.01	0.21	0.01	0.09
Chloride (%)	1.68	0.09	1.66	0.09	0.91
Lysine (%)	N/A	N/A	N/A	N/A	N/A
Methionine (%)	N/A	N/A	N/A	N/A	N/A

Table 4.31. The number and proportion of carcasses not graded due to dark cutting under the Meat Standards Australia grading system

	No. Carcases	Dark Cutters	Rate (%)	No. Carcases	Dark Cutters	Rate (%)	No. Carcases	Dark Cutters	Rate (%)
	2015			2016			total		
Western Australia									
Treatment	340	5	1.47	135	6	4.44	475	11	2.32
Control	346	7	2.02	138	8	5.80	484	15	3.10
Sub Total	686	12	1.75	273	14	5.13	959	26	2.71
South Australia									
Treatment	240	11	4.58	79	1	1.27	319	12	3.76
Control	217	11	5.07	83	1	1.20	300	12	4.00
Sub Total	457	22	4.81	162	2	1.23	619	24	3.88
Total	1143	34	2.97	435	16	3.68	1578	50	3.17

In South Australia, end weights of the cattle were not recorded in 2015. Average daily gain during that year could not be quantitated. In 2016 there were significant difference between treatment groups for starting weights, end weights and average daily gain with the treatment group having higher values for all measures ($P<0.05$; Table 4.36). Carcasses from treatment cattle were 5.21kg heavier than control carcasses when adjusting for starting liveweight ($P<0.001$; Table 4.36), yet the HSCW between treatments across both years was not significantly different despite the difference of means of 1.42kg between treatments.

There was an observed positive effect of treatment on increasing the muscle glycogen in WA only across both years. In WA there was an increase in muscle glycogen of the *M. longissimus dorsi* of 0.13g/100g from 1.22g/100g ± 0.02 in control group to 1.35g/100g ± 0.02 in the treatment group ($P<0.001$; Table 4.36; Fig. 4.79). SA did not have the same observed increase across the 2 years of data and no effect of treatment was observed (Fig. 4.81). There was no effect of treatment on muscle pH in both states (Table 4.36; Fig. 4.80 and 4.82). In SA there was a significant difference in the ossification and Eye muscle area with the control group having a higher ossification score and a lower eye muscle area compared to the treatment group thus indicating, that the control cattle were slightly older and less muscled.

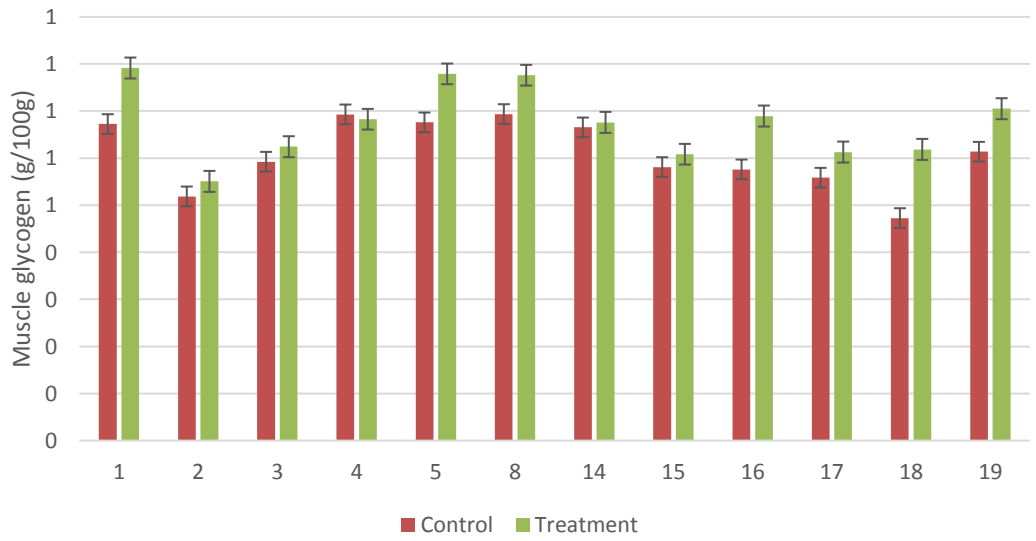

Fig. 4.79. Muscle glycogen In West Australian carcases from control group and treatment group on a per trial

basis. Trials 1-8 are 2015 data and 14-19 are 2016.

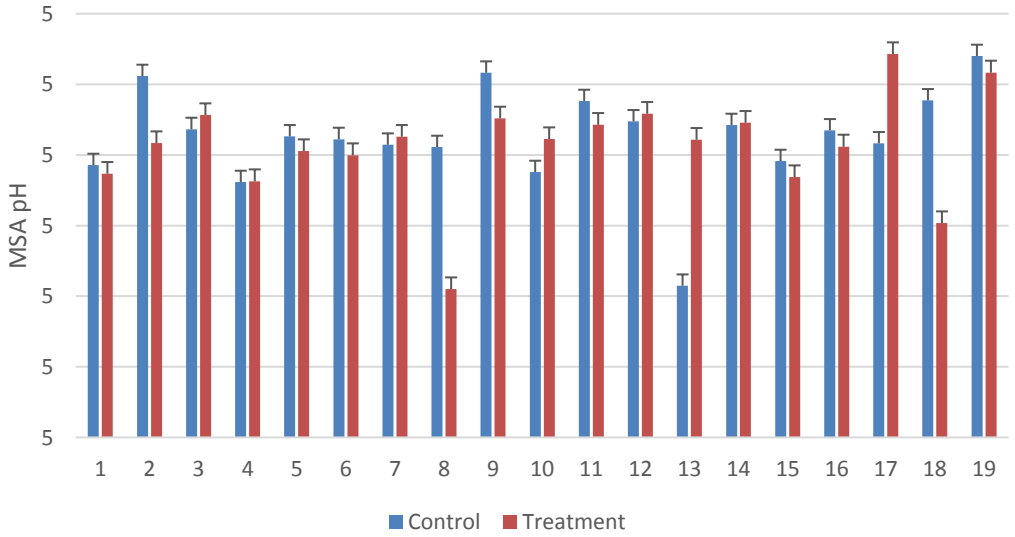

Fig. 4.80. The effect of supplementation of pellets on Muscle pH per trial in Western Australia (P<0.2) ± SEM. Trials 1-13 are 2015 data and trials 14-19 2016 data.

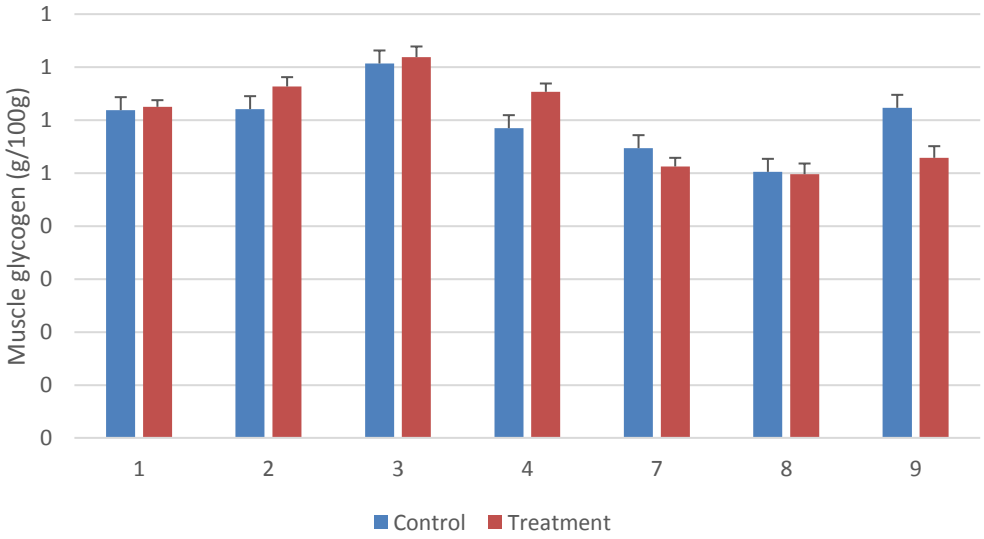

Fig. 4.81. Muscle glycogen In South Australian carcases from control group and Lupin treatment group on a per trial basis. Trials 1-4 are 2015 data and 7-9 are 2016.

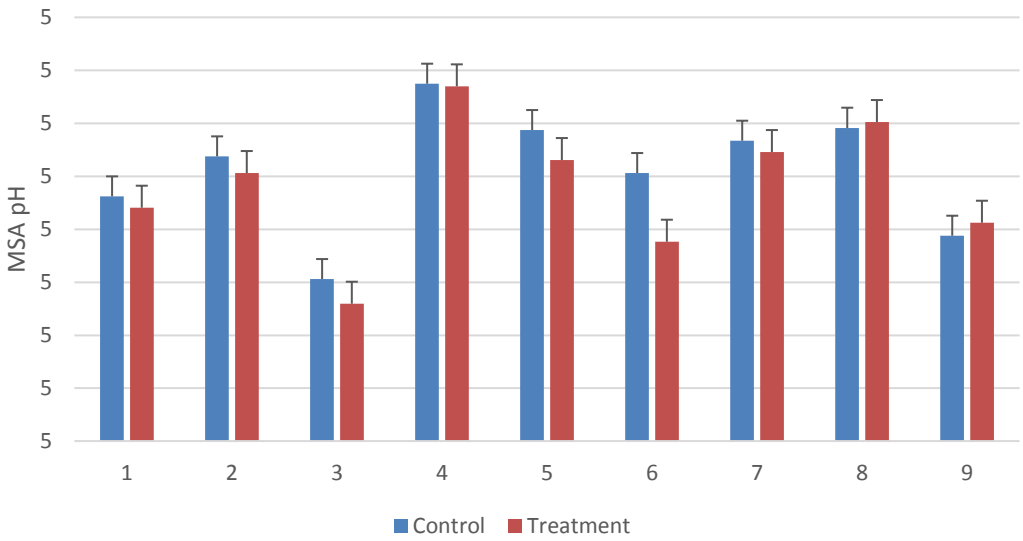

Fig. 4.82. The effect of supplementation of Lupins on Muscle pH per trial in South Australia (P<0.2) ±SEM. Trials 1-13 are 2015 data and trials 14-19 2016 data.

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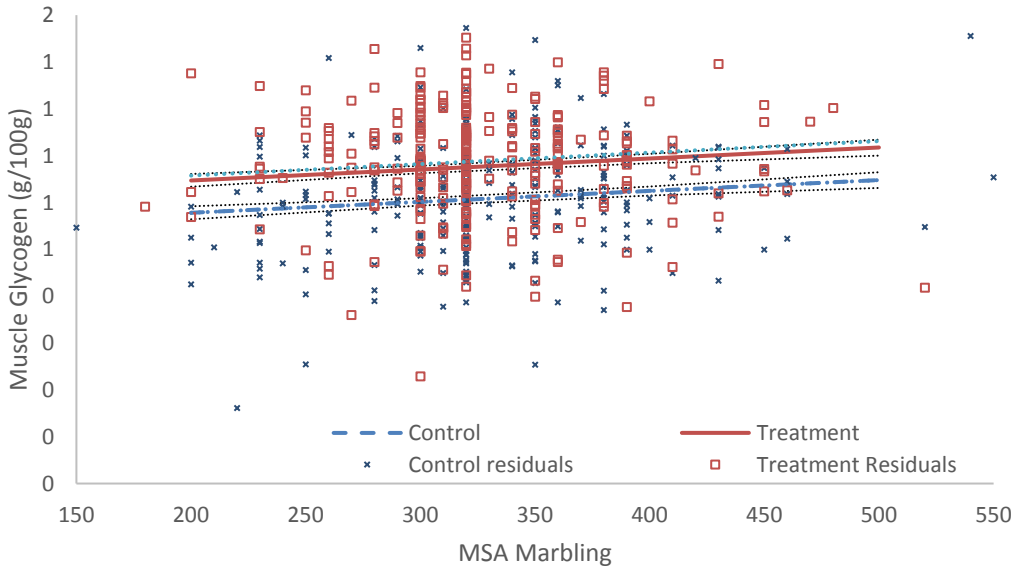


Fig. 4.83. The effect of MSA Marbling scores on the Muscle glycogen (g/100g) in Western Australia (P<0.01) ± SEM.

Treatment did not affect MSA MB score (Table 4.31) but there was an observed positive linear relationship between MSA MB and muscle glycogen in Western Australian cattle (P<0.01). As MSA MB increased from 200 to 500, muscle glycogen in both treatment and control groups increased by 0.14 g/100g across this range (Fig. 4.83).

Table 4.32. Statistical output with F values, numerator degrees of freedom (NDF), denominator degrees of freedom (DDF) and significance for the animal measures and carcass measures in 2015 carcases. Those applicable were also adjusted for starting weight.

	Trial			Treatment			Trial*Treatment			Start Weight		
	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value
Western Australia 2015												
Start Weight (kg)	11;642	30.89	<.0001	1;642	0.30	0.5827	11;642	1.75	0.0588	N/A	N/A	N/A
End Weight (kg)	11;641	55.11	<.0001	1;641	4.75	0.0297	11;641	7.16	<.0001	1;641	4048.05	<.0001
Average Daily Gain (kg)	11;640	52.01	<.0001	1;640	3.14	0.0768	11;640	6.43	<.0001	1;640	0.69	0.4077
HSCW (kg)	11;641	59.46	<.0001	1;641	17.83	<.0001	11;641	3.19	0.0003	1;641	2682.91	<.0001
MSA Index (30-80)	12;647	36.31	<.0001	1;647	0.03	0.8546	12;647	0.68	0.7763	N/A	N/A	N/A
MSA OSS (100-590)	12;660	30.90	<.0001	1;660	0.04	0.8448	12;660	0.85	0.5995	N/A	N/A	N/A
MSA Rib fat (mm)	12;660	28.38	<.0001	1;660	0.58	0.4453	12;660	1.22	0.2659	N/A	N/A	N/A
MSA EMA (cm2)	12;660	10.61	<.0001	1;660	1.49	0.2223	12;660	1.07	0.3861	N/A	N/A	N/A
MSA MC (1-7)	12;660	3.06	0.0003	1;660	1.33	0.2489	12;660	1.71	0.0614	N/A	N/A	N/A
MSA MB (100-1100)	12;660	16.12	<.0001	1;660	0.01	0.9156	12;660	0.72	0.7365	N/A	N/A	N/A
MSA pH	12;660	26.01	<.0001	1;660	1.66	0.1981	12;660	1.34	0.1895	N/A	N/A	N/A
Muscle Glycogen (g/100g)	5;275	21.24	<.0001	1;275	14.78	0.0002	5;275	2.13	0.0626	N/A	N/A	N/A
South Australia 2015												
Start Weight (kg)	5;445	99.01	<.0001	1;445	0.97	0.3262	5;445	6.09	<.0001	N/A	N/A	N/A
End Weight (kg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Daily Gain (kg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HSCW (kg)	5;444	38.93	<.0001	1;444	0.35	0.554	5;444	3.85	0.002	1;444	1774.47	<.0001
MSA Index (30-80)	5;445	8.53	<.0001	1;423	0.31	0.5782	5;445	1.85	0.1025	N/A	N/A	N/A
MSA OSS (100-590)	5;445	4.44	0.0006	1;445	4.05	0.0447	5;445	1.31	0.2587	N/A	N/A	N/A
MSA Rib fat (mm)	5;445	14.87	<.0001	1;445	1.90	0.1684	5;445	4.28	0.0008	N/A	N/A	N/A
MSA EMA (cm2)	5;445	20.44	<.0001	1;445	2.70	0.101	5;445	4.08	0.0012	N/A	N/A	N/A
MSA MC (1-7)	5;445	25.39	<.0001	1;445	3.07	0.0803	5;445	1.00	0.4174	N/A	N/A	N/A
MSA MB (100-1100)	5;445	2.97	0.0119	1;445	1.72	0.1908	5;445	1.41	0.2197	N/A	N/A	N/A
MSA pH	5;445	24.39	<.0001	1;445	4.92	0.0271	5;445	0.59	0.7068	N/A	N/A	N/A
Muscle Glycogen (g/100g)	3;305	9.30	<.0001	1;305	6.09	0.0141	3;305	1.46	0.2255	N/A	N/A	N/A

Table 4.33. Statistical output with F values, numerator degrees of freedom (NDF), denominator degrees of freedom (DDF) and significance for the animal measures and carcass measures in 2016 carcases. Those applicable were also adjusted for starting weight.

	Trial			Treatment			Trial*Treatment			Start Weight		
	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value
Western Australia 2016												
Start Weight (kg)	4;212	168.21	<.0001	1;212	0.48	0.4889	4;212	0.54	0.7087			
End Weight (kg)	3;177	30.73	<.0001	1;177	0.34	0.5592	3;177	8.69	<.0001	1;177	730.19	<.0001
Average Daily Gain (kg)	3;177	26.49	<.0001	1;177	0.26	0.6109	3;177	8.79	<.0001	1;177	0.01	0.9245
HSCW (kg)	4;211	9.9	<.0001	1;211	3.65	0.0574	4;211	2.84	0.0251	1;211	214.5	<.0001
MSA Index (30-80)	5;244	334.42	<.0001	1;244	1.82	0.1787	5;244	4.42	0.0007	NA	NA	NA
MSA OSS (100-590)	5;261	10.43	<.0001	1;261	2.1	0.1489	5;261	16.9	<.0001	NA	NA	NA
MSA Rib fat (mm)	5;261	19.85	<.0001	1;261	0.03	0.8653	5;261	0.38	0.864	NA	NA	NA
MSA EMA (cm2)	5;261	96.48	<.0001	1;261	2.04	0.1546	5;261	0.79	0.5608	NA	NA	NA
MSA MC (1-7)	5;261	15.42	<.0001	1;261	0.22	0.6406	5;261	4.63	0.0005	NA	NA	NA
MSA MB (100-1100)	5;261	9.41	<.0001	1;261	0.15	0.6958	5;261	2.54	0.0289	NA	NA	NA
MSA pH	5;261	2.85	0.016	1;261	0.54	0.4637	5;261	3.39	0.0055	NA	NA	NA
Muscle Glycogen (g/100g)	5;261	7.56	<.0001	1;261	24.84	<.0001	5;261	2.38	0.0391	NA	NA	NA
South Australia 2016												
Start Weight (kg)	2;156	408.68	<.0001	1;156	5.28	0.0229	2;156	0.66	0.5186			
End Weight (kg)	2;155	46.67	<.0001	1;155	23.26	<.0001	2;155	4.99	0.008	1;155	1157.37	<.0001
Average Daily Gain (kg)	2;155	46.67	<.0001	1;155	23.26	<.0001	2;155	4.99	0.008	1;155	3.18	0.0767
HSCW (kg)	2;155	8.27	0.0004	1;155	20.26	<.0001	2;155	4.5	0.0125	1;155	921.47	<.0001
MSA Index (30-80)	2;156	4.33	0.0148	1;156	0.08	0.7744	2;156	0.56	0.5733	NA	NA	NA
MSA OSS (100-590)	2;156	26.95	<.0001	1;156	0.77	0.3821	2;156	1.02	0.3641	NA	NA	NA
MSA Rib fat (mm)	2;156	46.56	<.0001	1;156	0.84	0.3597	2;156	0.23	0.794	NA	NA	NA
MSA EMA (cm2)	2;156	11.38	<.0001	1;156	7.12	0.0084	2;156	2.57	0.08	NA	NA	NA
MSA MC (1-7)	2;156	21.28	<.0001	1;156	0	0.952	2;156	0.22	0.8041	NA	NA	NA
MSA MB (100-1100)	2;156	48.96	<.0001	1;156	1.87	0.1738	2;156	12.85	<.0001	NA	NA	NA
MSA pH	2;156	19.56	<.0001	1;156	0.03	0.8593	2;156	0.22	0.8053	NA	NA	NA
Muscle Glycogen (g/100g)	2;155	16.76	<.0001	1;155	15.75	0.0001	2;155	5.98	0.0031	NA	NA	NA

Table 4.34. Statistical output with F values, numerator degrees of freedom (NDF), denominator degrees of freedom (DDF) and significance for the animal measures and carcass measures in all carcases. Those applicable were also adjusted for starting weight.

	Trial			Treatment			Trial*Treatment			Start Weight		
	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value
Western Australia Total												
Start Weight (kg)	16;834	54.14	<.0001	1;834	0.51	0.4764	16;834	1.45	0.1113	NA	NA	NA
End Weight (kg)	15;799	48.77	<.0001	1;799	2.81	0.0939	15;799	6.58	<.0001	1;799	4856.32	<.0001
Average Daily Gain (kg)	15;798	50.24	<.0001	1;798	1.66	0.1978	15;798	5.93	<.0001	1;798	0.5	0.4791
HSCW (kg)	16;833	57.38	<.0001	1;833	18.19	<.0001	16;833	2.72	0.0003	1;833	2593.35	<.0001
MSA Index (30-80)	18;887	109.14	<.0001	1;887	0.34	0.5613	18;887	1.1	0.346	NA	NA	NA
MSA OSS (100-590)	18;917	26.21	<.0001	1;917	0.34	0.5614	18;917	4.12	<.0001	NA	NA	NA
MSA Rib fat (mm)	18;917	98.79	<.0001	1;917	0.86	0.3531	18;917	0.95	0.5139	NA	NA	NA
MSA EMA (cm2)	18;917	21.55	<.0001	1;917	3.05	0.0813	18;917	0.97	0.4968	NA	NA	NA
MSA MC (1-7)	18;917	9.87	<.0001	1;917	1.61	0.2044	18;917	2.94	<.0001	NA	NA	NA
MSA MB (100-1100)	18;917	14.3	<.0001	1;917	0.04	0.8516	18;917	0.9	0.5836	NA	NA	NA
MSA pH	18;917	12.35	<.0001	1;917	2.08	0.15	18;917	2.46	0.0007	NA	NA	NA
Muscle Glycogen (g/100g)	11;534	16.81	<.0001	1;534	38.71	<.0001	11;534	2.1	0.0189	NA	NA	NA
South Australia Total												
Start Weight (kg)	8;601	143.82	<.0001	1;601	4.13	0.0427	8;601	4.35	<.0001			
End Weight (kg)	2;155	46.67	<.0001	1;155	23.26	<.0001	2;155	4.99	0.008	1;155	1157.37	<.0001
Average Daily Gain (kg)	2;155	46.67	<.0001	1;155	23.26	<.0001	2;155	4.99	0.008	1;155	3.18	0.0767
HSCW (kg)	8;600	35.94	<.0001	1;600	3.44	0.064	8;600	6.18	<.0001	1;600	2563.42	<.0001
MSA Index (30-80)	8;601	8.19	<.0001	1;601	0.14	0.7042	8;601	1.58	0.1276	NA	NA	NA
MSA OSS (100-590)	8;601	6.96	<.0001	1;601	4.31	0.0382	8;601	1.11	0.3552	NA	NA	NA
MSA Rib fat (mm)	8;601	32.87	<.0001	1;601	0.09	0.7692	8;601	2.58	0.009	NA	NA	NA
MSA EMA (cm2)	8;601	21.28	<.0001	1;601	8.09	0.0046	8;601	3.64	0.0004	NA	NA	NA
MSA MC (1-7)	8;601	21.51	<.0001	1;601	2.04	0.154	8;601	0.84	0.567	NA	NA	NA
MSA MB (100-1100)	8;601	15.47	<.0001	1;601	3.5	0.062	8;601	3.99	0.0001	NA	NA	NA
MSA pH	8;601	20.71	<.0001	1;601	2.96	0.0858	8;601	0.64	0.7475	NA	NA	NA
Muscle Glycogen (g/100g)	6;460	30.37	<.0001	1;460	0	0.9511	6;460	4.14	0.0005	NA	NA	NA

Table 4.35. Statistical output with F values, numerator degrees of freedom (NDF), denominator degrees of freedom (DDF) and significance for the animal measures and carcass measures in all carcases with year as a fixed effect. Those applicable were also adjusted for starting weight.

	Year			Treatment			Year*Treatment			Start Weight		
	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value	NDF;DDF	F Value	P Value
Western Australia Total												
Start Weight (kg)	1;864	39.94	<.0001	1;864	0.24	0.6225	1;864	0.01	0.904	NA	NA	NA
End Weight (kg)	1;827	6.13	0.0135	1;827	0.05	0.8164	1;827	1.14	0.2862	1;827	5453.31	<.0001
Average Daily Gain (kg)	1;826	24.33	<.0001	1;826	0.02	0.896	1;826	0.65	0.4217	1;826	0.6	0.4396
HSCW (kg)	1;863	143.64	<.0001	1;863	7.61	0.0059	1;863	0.35	0.5516	1;863	1800.29	<.0001
MSA Index (30-80)	1;921	241.93	<.0001	1;921	1.04	0.3081	1;921	0.6	0.437	NA	NA	NA
MSA OSS (100-590)	1;951	16.25	<.0001	1;951	2.91	0.0886	1;951	1.52	0.218	NA	NA	NA
MSA Rib fat (mm)	1;951	82.22	<.0001	1;951	0.05	0.8256	1;951	0.02	0.8873	NA	NA	NA
MSA EMA (cm2)	1;951	2.67	0.1023	1;951	1.47	0.2264	1;951	0.02	0.8931	NA	NA	NA
MSA MC (1-7)	1;951	22.56	<.0001	1;951	1.45	0.2293	1;951	0.06	0.8096	NA	NA	NA
MSA MB (100-1100)	1;951	0.43	0.5121	1;951	0.45	0.5046	1;951	0.02	0.8877	NA	NA	NA
MSA pH	1;951	9.55	0.0021	1;951	1.63	0.2019	1;951	0.21	0.6462	NA	NA	NA
Muscle Glycogen (g/100g)	1;554	30.85	<.0001	1;554	35.66	<.0001	1;554	1.23	0.2679	NA	NA	NA
South Australia Total												
Start Weight (kg)	1;615	6.37	0.0119	1;615	2.7	0.101	1;615	1.37	0.2425	NA	NA	NA
End Weight (kg)	0;159	NA	NA	1;159	25.09	<.0001	0;159	NA	NA	1;159	3410.06	<.0001
Average Daily Gain (kg)	0;159	NA	NA	1;159	25.09	<.0001	0;159	NA	NA	1;159	28.98	<.0001
HSCW (kg)	1;614	37.64	<.0001	1;614	5.43	0.0201	1;614	20.02	<.0001	1;614	4494.84	<.0001
MSA Index (30-80)	1;615	8.49	0.0037	1;615	0	0.9979	1;615	0.29	0.5882	NA	NA	NA
MSA OSS (100-590)	1;615	3.55	0.06	1;615	2.52	0.113	1;615	0.22	0.6397	NA	NA	NA
MSA Rib fat (mm)	1;615	50.26	<.0001	1;615	0.05	0.8265	1;615	0.92	0.3381	NA	NA	NA
MSA EMA (cm2)	1;615	33.1	<.0001	1;615	7.04	0.0082	1;615	4.2	0.0409	NA	NA	NA
MSA MC (1-7)	1;615	1.6	0.2062	1;615	1.4	0.2378	1;615	1.76	0.1851	NA	NA	NA
MSA MB (100-1100)	1;615	12.73	0.0004	1;615	1.28	0.2591	1;615	0.05	0.8214	NA	NA	NA
MSA pH	1;615	3.12	0.078	1;615	1.63	0.2023	1;615	2.68	0.1019	NA	NA	NA
Muscle Glycogen (g/100g)	1;470	117.64	<.0001	1;470	0.15	0.6996	1;470	12.3	0.0005	NA	NA	NA

Table 4.36. Least squared means ± the standard error of the mean (SEM) of animal and carcass measures from WA and SA in 2015, 2016 and both years combined

	Treatment		Control		Treatment		Control		Treatment		Control	
	Estimate	SEM	Estimate	SEM	Estimate	SEM	Estimate	SEM	Estimate	SEM	Estimate	SEM
	2015				2016				Total			
Western Australia												
Start Weight (kg)	487.91	1.78	486.76	1.76	515.42	2.16	513.28	2.22	495.97	1.44	494.52	1.44
End Weight (kg)	505.52	0.69	503.41	0.69	520.46	1.24	519.55	1.24	508.65	0.60	507.25	0.60
Average Daily Gain (kg)	1.46	0.05	1.34	0.05	1.06	0.07	1.02	0.06	1.34	0.04	1.27	0.04
HSCW (kg)	259.54	0.50	256.60	0.49	279.68	1.02	277.11	1.02	264.74	0.46	262.02	0.46
MSA Index (30-80)	60.87	0.10	60.90	0.10	58.85	0.10	58.65	0.10	60.22	0.08	60.16	0.08
MSA OSS (100-590)	135.20	0.97	134.93	0.96	140.31	1.21	142.79	1.20	136.86	0.77	137.49	0.77
MSA Rib fat (mm)	5.93	0.24	6.19	0.24	7.80	0.22	7.75	0.22	6.44	0.10	6.31	0.10
MSA EMA (cm2)	71.69	0.39	71.02	0.38	72.19	0.38	71.44	0.37	71.84	0.30	71.11	0.29
MSA MC (1-7)	1.85	0.03	1.90	0.03	2.12	0.06	2.16	0.06	1.94	0.03	1.98	0.03
MSA MB (100-1100)	329.46	3.51	329.98	0.35	336.68	3.39	338.56	3.37	331.74	2.68	332.45	2.67
MSA pH	5.55	0.00	5.56	0.00	5.57	0.01	5.58	0.01	5.56	0.00	5.56	0.00
Muscle Glycogen (g/100g)	1.40	0.02	1.28	0.02	1.30	0.02	1.16	0.02	1.35	0.02	1.22	0.02
South Australia												
Start Weight (kg)	553.89	2.63	550.10	2.82	543.03	3.55	531.28	3.68	550.27	2.18	543.83	2.31
End Weight (kg)	NA	NA	NA	NA	564.81	1.42	555.10	1.43	564.81	1.42	555.10	1.43
Average Daily Gain (kg)	NA	NA	NA	NA	2.23	0.09	1.58	0.10	2.23	0.09	1.58	0.10
HSCW (kg)	297.86	0.67	298.43	0.71	301.85	0.82	296.64	0.82	299.81	0.54	298.35	0.57
MSA Index (30-80)	55.10	1.12	56.01	1.20	60.12	0.92	59.74	0.95	56.77	0.87	57.25	0.92
MSA OSS (100-590)	142.33	0.99	145.26	1.06	142.12	1.04	143.44	1.08	142.26	0.79	144.65	0.84
MSA Rib fat (mm)	7.05	0.17	6.70	0.18	9.08	0.37	9.57	0.38	7.73	0.16	7.66	0.17
MSA EMA (cm2)	73.18	0.48	72.02	0.51	78.54	0.70	75.84	0.73	74.96	0.40	73.29	0.43
MSA MC (1-7)	2.54	0.05	2.67	0.05	2.69	0.06	2.68	0.06	2.59	0.04	2.67	0.04
MSA MB (100-1100)	366.07	4.41	374.53	4.72	345.76	7.16	359.85	7.42	359.30	3.80	369.64	4.02
MSA pH	5.58	0.01	5.61	0.01	5.61	0.01	5.61	0.01	5.59	0.01	5.61	0.01
Muscle Glycogen (g/100g)	1.33	0.02	1.27	0.02	1.03	0.02	1.12	0.02	1.20	0.01	1.20	0.01

4.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

4.5.1 MSA regression

The best overall equation for predicting percentage muscle was the most complex model (equation 1, Table 4.37) and contained a 3 way term as shown by the highest R-squared and lowest RMSE. This equation predicted percentage muscle with 73% accuracy. This equation was also the most precise when applied to individual subsets of the data set the equation was derived from (Table 4.38). When the equation was regressed through to containing only 2 way terms (equations 2-6, Table 4.37) only a small amount of precision was lost, with the best performing equations being that of equation 2 (all two way interaction included) and equation 6 (1 two way interaction). A model containing singular terms only (equation 7) seemed to have the worse prediction power of all equations, although this equation still explained 62% of the variation with an RMSE of 3.1 (Table 4.38).

Table 4.39 describes the matrix of the transportation of the seven models into the individual data sets where new co-efficients for each term were derived and then applied to the remaining data sets. This represents the true transportation and robustness of the original derived equations. The one equation that was consistently accurate and precise when transported into other data sets was that of equation 7 (Table 4.39). This equation was the simplest with only single interactions (four single terms; LeftsideHSCW, RFT, OSS and EMA), but proved to be the most robust. Although the most complex model (equation 1, Table 4.39) was shown to have the best accuracy and precision when applied directly to the different subsets of data, the complexity of this model resulted in very poor transportation (Table 4.39) between subsets. Additionally, equations 2 and 6 also had poor transportation (Table 4.39).

When the equation was regressed to the smallest singular interaction terms, the marbling term became insignificant. The remaining 4 terms described body weight (LeftsideHSCW), fatness (RFT), age (OSS) and muscling (EMA). These findings clearly indicate that MSA meat quality measures can be used to develop a prediction equation for percentage muscle in beef carcasses. In the current data set a combination of carcase weight, rib fat, ossification, marbling and eye muscle area was able to predict the CT lean values in different data sets to accuracies above 70%.

4.5.1.1 *Application to retail beef yield data sets*

Equations 1 and 7 were both applied to four retail yield data sets (Table 4.40). The predicted percentage muscle transported into retail yield fairly well, especially considering the limitations and variability in retail beef yield. The first two data sets (also the smallest) transported precisely and accounted for almost 50% of the variation using equation 1. While the accuracy decreased when using equation 7, the relationship was still had low RMSE. The two larger data sets did not transport quite as well (13.5% and 26 .6%) and was also improved using equation 7 (15.4% and 29.7%). The RMSE were both low and thus it is possible to transport the current equations into a retail data set, but will be further improved with more investigation.

4.5.2 Additional carcase measurements for predicting LMY % defined, captured, and analysed, utilising the carcasses being employed for the cut-weight validation of the MSA Index.

This section identifies the additional measurements of feed type, hump, forearm circumference and hind leg circumference as possible additional measurements. A similar analysis was performed to understand if these measurements improved the prediction power of yield equations. However, only three data sets had this information available (muscling, grass and grain) and in this case the grass and grain data sets were combined and thus only two data sets were available for comparison. There are two analysis, firstly the original equations were used and re-derived with feed type included using the smaller data sets (Tables 4.41 and 4.42). These equations were again re-derived in individual subsets of the data (muscling or grass/grain combined) and transported into the other subset (Table 4.43). The second analysis included all the additional phenotypic point measurements, but only in singular interactions (Table 4.44). Equations were re-derived and analysed as above to allow for comparisons (Tables 4.45 and 4.46).

4.5.2.1 *Feed type*

By adding feed type to the model the best performing equation was that of equation 8, containing the 3 way interactions (Tables 4.41 and 4.42). However, much like the original analysis this more complex equation did not transport as well as the simpler equation 12 (Table 4.43). This equation still described 63% of the variation and was quite precise with a RMSE of 2.2. When generated in the grass grain data and transported to the muscling set it had an R-squared of 0.576 and RMSE of 2.33; while when derived in the muscling data set and transported into the grass grain data set had R-squared of 0.612 and RMSE of 2.32.

When comparing these equations to those without “feed type” (equations 13 and 16; Tables 4.41 to 4.46) there was a noticeable improvement in the prediction power. For the more complex model, including feed type only slightly improved the R-squared and RMSE (equation 8 compared to equation 12), while for the less complex model (equation 12) the addition of feed type (equation 16) improved the R-squared from 0.513 to 0.63 and the RMSE from 2.545 to 2.226. Additionally, the simpler equation with feed type included was a lot more robust as shown in the transportation of this equation. Since it was shown above that a simpler equation is generally more robust and that the addition of feed type will improve the accuracy and precision of prediction of yield, more fixed effects need to be tested and are likely to improve prediction models even further.

4.5.2.2 *Other measures*

Adding physiological point measures, such as hump height, forearm and hind limb circumference, to the model improved the prediction power of the more simple model (equation 14 compared to equation 16). By having including all 3 additional terms compared to individual terms (equations 17 to 19) the overall prediction was more powerful, however the equation was less robust and did not transport well (Tables 4.44 to 4.46). The addition of just hump height or hind limb circumference was relatively described the yield quite well while being more robust than equation 14. When feed type was added to this equation, it improved the accuracy, precision and robustness of the prediction equation (equation 15). This equation was slightly different when regressed from all terms (USMB

included and forearm was removed) but described 67% of the variation, stronger than the best term without the additional physiological measures (equation 12).

Table 4.37. F and P values for each term in each equation. R-squared and RMSE are given for each equation.

	Equation 1		Equation 2		Equation 3		Equation 4		Equation 5		Equation 6		Equation 7	
Term	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*
LeftSideHSCW	22.85	<.0001	9.57	0.0022	40.77	<.0001	48.58	<.0001	0.43	0.5129	15.25	0.0001	36.69	<.0001
RFT	2.99	0.0845	8.61	0.0036	65.92	<.0001	14.14	0.0002	12.42	0.0005	80.19	<.0001	57.47	<.0001
USMB	11.25	0.0009	12.13	0.0006	38.18	<.0001			6.39	<.0001		<.0001		
OSS	1.2	0.2751	1.69	0.1947	16.2	<.0001	34.32	<.0001	40.26	0.012	32.49		23.7	<.0001
EMA	43.22	<.0001	25.51	<.0001	50.41	<.0001	78.32	<.0001	26.71	<.0001	109.18	<.0001	32.81	<.0001
USMB*OSS	14.88	0.0001	14.95	0.0001	46.51	<.0001								
RFT*EMA	2.52	0.1134	9.11	0.0028			44.2	<.0001						
LeftSideHSCW*RFT	24.42	<.0001	9.97	0.0017					56.71	<.0001				
LeftSideHSCW*EMA	33.2	<.0001	16.7	<.0001							69.75	<.0001		
LeftSideHSCW*RFT*EMA	16.49	<.0001												

Table 4.38. The transportation of compiled CT data prediction equation to subsets of data.

	All data (minus WA)		Muscle		WA		CRC		Grass		Grain	
Equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
1	0.73	2.68	0.64	2.15	0.51	2.66	0.84	2.75	0.47	2.31	0.23	2.53
2	0.72	2.75	0.61	2.23	0.40	2.94	0.83	2.82	0.47	2.31	0.26	2.49
3	0.68	2.92	0.54	2.43	0.51	2.65	0.80	3.03	0.53	2.17	0.35	2.33
4	0.67	2.94	0.48	2.58	0.39	2.96	0.81	2.96	0.55	2.13	0.22	2.55
5	0.69	2.88	0.44	2.67	0.51	2.66	0.83	2.81	0.56	2.12	0.30	2.42
6	0.69	2.85	0.54	2.41	0.42	2.88	0.83	2.83	0.52	2.21	0.17	2.63
7	0.62	3.14	0.40	2.78	0.51	2.65	0.81	2.98	0.52	2.20	0.28	2.46

Table 4.39. Matrix of the true transportation of equations for the prediction of percentage muscle. Equations were derived in the data set (left hand column) and applied to other data sets (top row).

Data set		**Muscle**		**CRC**		**Grass**		**Grain**		**WA**	
	Equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
muscling	1	0.714	1.986	0.323	5.644	0.475	2.305	0.308	2.404	0.468	2.767
CRC	1	0.342	2.904	0.877	2.507	0.236	2.781	0.093	2.752	0.552	2.541
Grass	1	0.000	3.579	0.481	4.940	0.739	1.861	0.035	2.839	0.051	3.696
Grain	1	0.028	3.529	0.453	5.075	0.026	3.141	0.533	2.290	0.330	3.105
muscling	2	0.697	2.037	0.766	3.315	0.494	2.265	0.224	2.546	0.379	2.990
CRC	2	0.305	2.983	0.872	2.545	0.311	2.641	0.137	2.684	0.511	2.652
Grass	2	0.000	3.579	0.445	5.109	0.739	1.830	0.036	2.837	0.066	3.667
Grain	2	0.078	3.437	0.356	5.503	0.287	2.687	0.531	2.252	0.000	3.794
muscling	3	0.624	2.241	0.662	3.986	0.517	2.212	0.313	2.394	0.432	2.860
CRC	3	0.304	2.986	0.859	2.629	0.487	2.280	0.192	2.598	0.588	2.437
Grass	3	0.063	3.465	0.090	6.543	0.706	1.850	0.212	2.565	0.425	2.876
Grain	3	0.241	3.118	0.423	5.208	0.610	1.988	0.493	2.222	0.328	3.110
muscling	4	0.603	2.293	0.628	4.181	0.520	2.205	0.105	2.734	0.291	3.195
CRC	4	0.319	2.953	0.850	2.702	0.504	2.241	0.137	2.684	0.520	2.628
Grass	4	0.469	2.608	0.783	3.195	0.601	2.124	0.212	2.566	0.548	2.551
Grain	4	0.195	3.212	0.076	6.592	0.503	2.245	0.402	2.373	0.178	3.440
muscling	5	0.596	2.323	0.675	3.912	0.490	2.274	0.165	2.640	0.481	2.732
CRC	5	0.299	2.997	0.863	2.596	0.540	2.159	0.191	2.598	0.528	2.606
Grass	5	0.126	3.347	0.411	5.263	0.698	1.876	0.090	2.756	0.149	3.500
Grain	5	0.068	3.456	0.215	6.078	0.425	2.414	0.499	2.210	0.002	3.790
muscling	6	0.624	2.231	0.744	3.469	0.474	2.308	0.099	2.743	0.367	3.019
CRC	6	0.386	2.805	0.859	2.623	0.503	2.244	0.118	2.714	0.540	2.574
Grass	6	0.120	3.358	0.016	6.805	0.607	2.108	0.331	2.364	0.539	2.576
Grain	6	0.056	3.478	0.248	5.946	0.024	3.144	0.430	2.318	0.176	3.443
muscling	7	0.545	2.445	0.460	5.042	0.493	2.267	0.187	2.606	0.404	2.929
CRC	7	0.259	3.081	0.842	2.763	0.403	2.459	0.136	2.686	0.564	2.504
Grass	7	0.393	2.788	0.605	4.313	0.597	2.105	0.284	2.444	0.468	2.766
Grain	7	0.338	2.913	0.293	5.768	0.518	2.209	0.394	2.352	0.341	3.079

Table 4.40. Transport of equations 1 and 7 into retail yield data sets.

		Equation 1		Equation 7	
	N	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
Retail 1	49	0.489	1.173	0.452	1.215
Retail 2	24	0.499	1.885	0.386	2.087
Retail 3	93	0.135	2.363	0.154	2.337
Retail 4	111	0.266	1.941	0.297	1.899

Table 4.41. F and P values for each term in each equation to test the addition of feed type. R-squared and RMSE are given for each equation for the prediction of percentage muscle.

	Equation 8		Equation 9		Equation 10		Equation 11		Equation 12		Equation 13	
Term	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*
FeedType	5.48	0.0203	11.8	0.0007	38.53	<.0001	29.05	<.0001	61	<.0001		
LeftSideHSCW	6.89	0.0094	5.96	0.0155			6.17	0.0139			13.55	0.0003
RFT	1.25	0.2658	32.07	<.0001	30.2	<.0001	25.64	<.0001	32.79	<.0001	5.19	0.0238
USMB	16.36	<.0001	16.43	<.0001	15.39	0.0001	5.6	0.019			22.81	<.0001
OSS	13.21	0.0004	12.83	0.0004	11.47	0.0009	6.94	0.0091	8.92	0.0032	18.25	<.0001
EMA	31.68	<.0001	47.94	<.0001	124.97	<.0001	39.29	<.0001	136.67	<.0001	60.81	<.0001
USMB*OSS	22.3	<.0001	22.48	<.0001	20.02	<.0001					30.5	<.0001
RFT*EMA	2.88	0.0914									8.86	0.0033
LeftSideHSCW*RFT	2.82	0.0949									8.57	0.0038
LeftSideHSCW*EMA	9.89	0.0019	8.65	0.0037			5.89	0.0162			22.59	<.0001
LeftSideHSCW*RFT*EMA	3.71	0.0556									10.41	0.0015

Table 4.42. The prediction of percentage muscle in data sets containing feedtype.

	all data		muscling		Grass grain	
Equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
8	0.692	2.066	0.698	1.968	0.680	2.108
9	0.684	2.076	0.685	2.009	0.677	2.116
10	0.670	2.112	0.660	2.088	0.680	2.107
11	0.648	2.187	0.635	2.162	0.662	2.167
12	0.630	2.226	0.632	2.171	0.623	2.288
13	0.683	2.090	0.697	1.971	0.663	2.162

Table 4.43. Matrix of the true transportation of equations to predict percentage muscle for data sets including feedtype. Equations were derived in the data set (left hand column) and applied to other data sets (top row).

Dataset		Grass grain		Muscling	
	Equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
Grass grain	**8**	0.750	1.999	0.281	3.035
Muscling	**8**	0.606	2.338	0.715	1.991
Grass grain	**9**	0.727	2.045	0.315	2.962
Muscling	**9**	0.604	2.344	0.702	2.011
Grass grain	**10**	0.725	2.024	0.349	2.887
Muscling	**10**	0.630	2.267	0.672	2.091
Grass grain	**11**	0.722	2.046	0.459	2.631
Muscling	**11**	0.561	2.470	0.662	2.133
Grass grain	**12**	0.636	2.295	0.576	2.330
Muscling	**12**	0.612	2.320	0.637	2.182
Grass grain	**13**	0.742	2.017	0.311	2.970
Muscling	**13**	0.594	2.375	0.714	1.986

Table 4.44. F and P values for each term in each equation to test the addition of phenotypic point measures. R-squared and RMSE are given for each equation for the prediction of percentage muscle.

	Equation 14		Equation 15		Equation 16		Equation 17		Equation 18		Equation 19	
Term	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*	*F Value*	*P Value*
LeftSideHSCW	39.89	<.0001	7.59	0.0064	4.34	0.0384	17.14	<.0001	17.48	<.0001	4.28	0.0398
FeedType			47.01	<.0001								
RFT	50.07	<.0001	22.43	<.0001	83.78	<.0001	70.06	<.0001	75.43	<.0001	74.02	<.0001
USMB			8.06	0.005								
Hump	20.09	<.0001	22.84	<.0001					15.66	0.0001		
Forearm	8.56	0.0038									4.95	0.0272
HindLeg	21.15	<.0001	4.38	0.0376			12.64	0.0005				
EMA	58.63	<.0001	68.38	<.0001	51.08	<.0001	42.92	<.0001	57.38	<.0001	56.98	<.0001

Table 4.45. The prediction of percentage muscle in data sets containing additional physiological point measures.

	Muscling and Grass grain		Muscling		Grass grain	
Equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
14	0.602	2.320	0.567	2.356	0.649	2.208
15	0.670	2.117	0.661	2.085	0.696	2.053
16	0.513	2.545	0.533	2.445	0.526	2.564
17	0.542	2.474	0.517	2.488	0.614	2.314
18	0.549	2.457	0.561	2.373	0.556	2.483
19	0.525	2.521	0.539	2.430	0.506	2.618

Table 4.46. Matrix of the true transportation of equations to predict percentage muscle for data sets including additional physiological point measures. Equations were derived in the data set (left hand column) and applied to other data sets (top row).

data set		**Muscling**		**Grass grain**	
	equation	*R-Square*	*Root MSE*	*R-Square*	*Root MSE*
Muscling	**14**	0.632	2.217	0.205	3.323
Grass grain	**14**	0.055	3.479	0.737	1.978
Muscling	**15**	0.698	2.017	0.583	2.405
Grass grain	**15**	0.468	2.610	0.775	1.841
Muscling	**16**	0.543	2.438	0.472	2.708
Grass grain	**16**	0.398	2.777	0.616	2.340
Muscling	**17**	0.545	2.444	0.500	2.635
Grass grain	**17**	0.333	2.924	0.694	2.103
Muscling	**18**	0.576	2.358	0.488	2.667
Grass grain	**18**	0.410	2.749	0.646	2.262
Muscling	**19**	0.571	2.372	0.238	3.253
Grass grain	**19**	0.004	3.571	0.657	2.227

4.5.3 Further development of a simple equation for the use in industry

Equation 7 accounted for transportability the best and investigated further. An equation was tested with all single terms included and regressed to the best fit. The equation of best fit was

4.5.3.1 *Equation of best fit*

For Steers

Predicted LMY = 62.1109 + (LeftsideHSCW x -0.09244) + (EMA x 0.1645) + (RibFat x -0.4936)

For Heifers

Predicted LMY = 59.3974 + (LeftsideHSCW x -0.09244) + (EMA x 0.1645) + (RibFat x -0.4936)

This equation included a sex effect, with males generally having about 3% more lean than that of females and thus there were two separate equations to manage the addition of the fixed effect. The equation had R-squared value of 0.71 and a RMSE of 2.79, which was a better fit to the data than that of equation 7.

This equation was used to predict CTlean within an MSA database containing 4.4 million animals and this highlighted a number of limitation. Although there was no "actual" CT lean data to compare this against we were still able to scrutinise the predicted output. This generated predicted CT lean values that were well in excess of the data range shown in Fig. 4.84 (ie CTlean of 19-77%, versus the range from Fig. 4.84 which was 66.5 to 40.8 %). Thus, we have assessed the range of HSCW, Ribfat and EMA values that can be entered while still maintaining predictions within the CTlean range of the CT data (shown in Fig. 4.84). As such any combination of HSCW, Ribfat and EMA within the ranges listed below should result in estimated CTlean values that do not extend beyond the upper limit (Ctlean = 66.5%) and lower limit (CTlean = 40.8%) of the training data set. When the MSA data set was constrained within the limits set below this resulted in the elimination of only 9% of the data, thus a further 91% of the MSA data set fitting within these limits.

Left side HSCW – 100kg to 220kg (Thus total carcase weights of 200 to 440kg)

EMA – 50 to 100

Rib Fat – 1 to 20

The industry currently use grids to pay producers and these grids are usually based on HSCW and rib fat or just HCSW. For this reason, 2 equations (HSCW and ribfat; Fig. 4.85, and HSCW only Fig. 4.86) were derived from the CT data sets. As shown in the fihures and the r squared and RMSE values, the equation of best fit resulted in greater accuracy of CTlean, although the only additions in this equation are EMA and sex. For processors that are currently using grids of just HSCW and ribfat, it would be suggested to incorporate EMA and sex to get a more accurate representation of the yield of carcases within the limitation ranges presented.

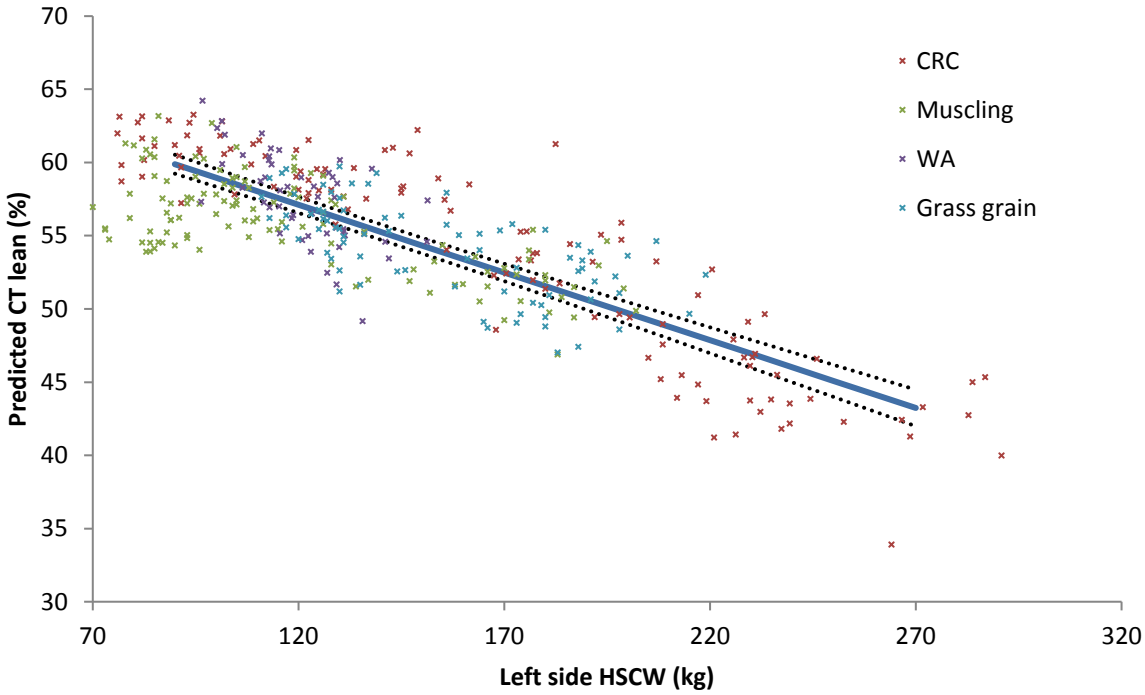


Fig. 4.84. The predicted CT lean in the training data sets versus Left side HSCW. Individual dots are residuals of the prediction model from the response surface. Colours represent data set of origin. R-Squared = 0.71 and RMSE = 2.79.

4.5.3.2 *Equation HSCW only*

Predicted LMY = 66.8777 + (LeftsideHSCW x -0.08037)

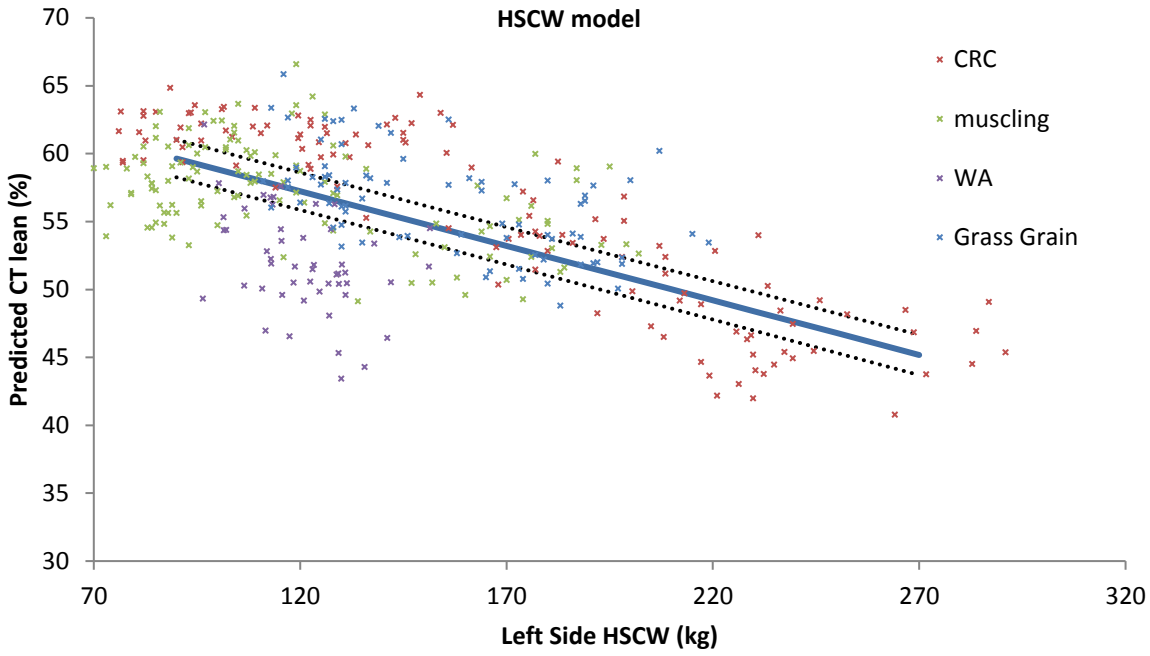


Fig. 4.85. The predicted CT lean using a model with left side HSCW only in the training data sets versus Left side HSCW. Individual dots are residuals of the prediction model from the response surface. Colours represent data set of origin. R-Squared = 0.53 and RMSE = 3.51.

4.5.3.3 *Equation HSCW and Rib Fat only*

Predicted LMY = 64.9926 + (LeftsideHSCW x -0.03094) + (Rib Fat x -0.609)

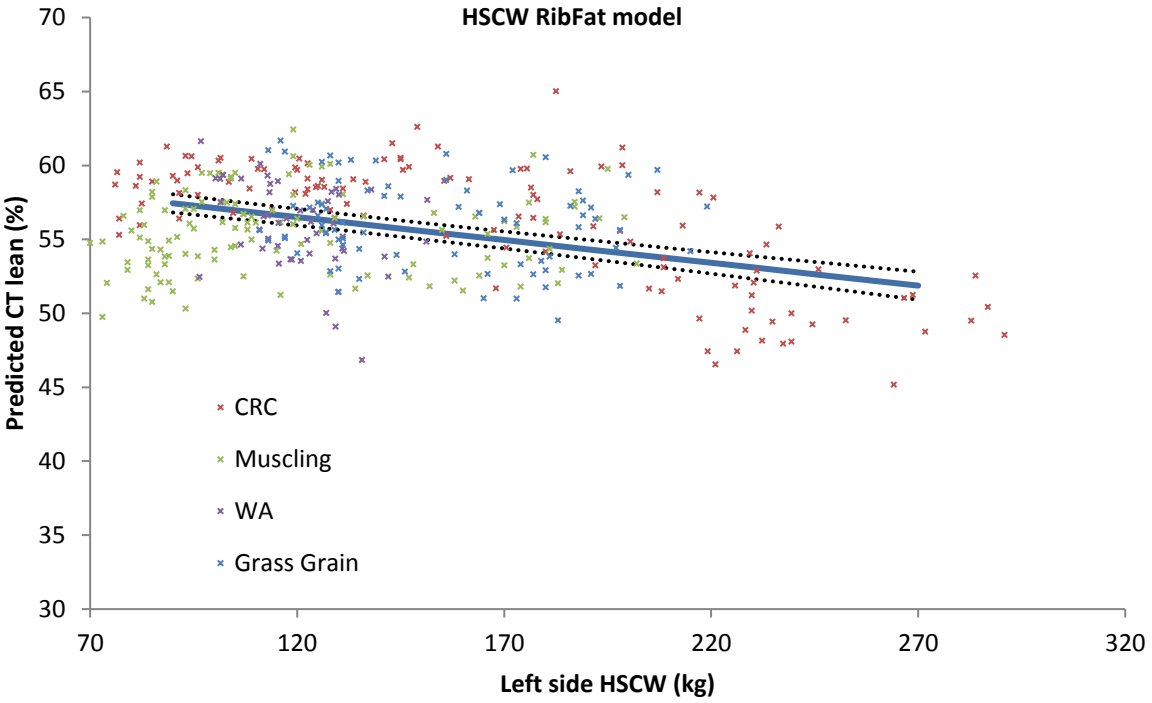


Fig. 4.86. The predicted CT lean using a model with left side HSCW and Rib fat only in the training data sets versus Left side HSCW. Individual dots are residuals of the prediction model from the response surface. Colours represent data set of origin. R-Squared = 0.63 and RMSE = 3.12.

4.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield

4.6.1 Measurement of Yield

The measurement of yield components has attracted a large amount of research over the last few decades. One of the biggest misconceptions is that most of the time, yield is not measured *per se*, but predicted. Unless the carcass has been broken down into the three tissue categories (muscle, fat and bone) or more accurately analysed using Computer Topography (CT) scanning (Kongsro et al., 2008), then the percentage muscle can only be predicted. There are many methods that have been tested throughout the world to predict yield percentages and the most commonly used method is that of multiple regression equations. Research has shown that yield can be predicted well using a combination of technologies such as video image analysis (VIA)(Cross and Belk, 1994; Cross et al., 1983), ultrasound (Forrest et al., 1989; Greiner et al., 2003; Stanford et al., 1998; Tait et al., 2005) and electrical impedance (Forrest et al., 1989; Stanford et al., 1998; Zollinger et al., 2010), however incorporating such systems would need cohesion from all processors involved for consistency throughout Australia. The costs of incorporating such technologies may be beyond reach for a

majority of processors. This literature review will focus on the prediction of yield using equations and visual assessment throughout international markets to give an understanding of possibilities and limitations for the Australian market.

4.6.2 Lean meat yield and saleable meat yield

The collective literature on yield is largely split between the measurement of percentage muscle and that of saleable meat yield (SMY) and has led to some confusion as to what exactly should be measured. The processor typically sells largely boned cuts that are trimmed to a specified fat trim, often 10mm – For the processor this will be saleable meat yield. When a consumer is buying a cut of meat, the cut will contain lean muscle, a small amount of fat and sometimes bone. Much/most of the fat will have been trimmed and what remains is the product the consumer will see and purchase and hence for the retailer this will be the saleable proportion. The presentation of SMY would represent a more significant industry number when compared to lean meat percentages. However, both of these measures do have their merits and limitations. When considering SMY, the total yield is basically the sold product minus the trimable fat for boneless products, which is likely to change on a cut, processor and retailer basis. The measurement of the trimable fat in different cuts gives an indication of the loss per carcass due to fat, but does not give an accurate indication of the percentage muscle. Higher fat percentages would generally mean a greater loss in valuable weight (since carcasses are valued on weight) if producers were paid once the primals are cut and trimmed, however the “loss” in price would not take into account the labour cost to remove such fat. Thus, leaves the industry with the urge to produce higher yielding cattle. However, the industry should also address not only a higher yield but also a reduction in trim. When one carcass is said to be higher yielding then this would generally mean that there is a greater percentage of muscle (NB: It is important to consider this and interpret this data at a constant carcass weight). But since the amount of fat required to be trimmed from one carcass to the next will likely differ and hence the ultimate target should be high muscling and small subcutaneous fat (lowering trim loss and labour costs). This then identifies the question of which should be rewarded on price and do the current measurements of percentage muscle and SMY correctly identify these target carcasses? Currently, because there is no yield grade in Australia, individual companies use proxy grids using carcass weights and fat levels to pay producers premiums. Assuming carcass weight is addressing the amount of muscle possibly available and fat the amount of trim required then, it is possible that both SMY and percentage muscle need to be considered.

4.6.3 International yield grades

Three international grading systems that are different will be the basis of this literature review. Both the USDA and Japanese yield grades use prediction equations, but the target markets are very different, while the EUROP system is primarily a classification of muscling and fatness. This section will give a brief background on how each market grades the carcass.

4.6.3.1 *USDA Yield Grade*

In the USDA grading system, each carcass receives a yield grade and a separate quality grade. Quality grades are based on a grid of the degree of marbling and the degree of physiological maturity. While establishing marbling is reasonably simple, the relative maturity level is a combination of skeletal and lean maturity observations. These observations take into account the ossification score, rib appearance and lean colour and texture. When combined on the grid with the marbling score, carcasses are categorized into “prime”, “choice” and “select” grades for those generally under 30 months of age, while older carcasses are graded as “standard” or “cutter”.

In combination to the USDA quality grades, each carcass is stamped with a USDA yield grade ranging from 1 to 5, with 1 being the highest precent lean. The USDA yield grade is calculated by an equation that was established for the US beef industry in the 1960’s based on the average cattle population (Murphey et al., 1960). The USDA yield grade takes into account deviations from the means of 4 measures including carcass weight, rib fat, kidney/pelvic/heart fat (KPH) and ribeye area in the general population. USDA yield grade is calculated in a series of 4 steps.

1. Calculation of preliminary yield grade (PYG). The grade is initially set at 2.0 and 0.25 is added per 0.1 inch of external fat thickness (Ribeye fat measured three fourths of the length of ribeye from chine bone end).
2. Carcass weight adjusted by deviations from 600 pounds. For each 25 pounds over 600 0.1 is added to PYG, for each 25 pounds under 0.1 is subtracted.
3. Kidney pelvic and heart fat (KPH) adjusted for deviations from 3.5%. A 1% deviation is worth ± 0.2 PYG.
4. Ribeye area (REA) is adjusted for deviations from 11sq inches. Deviations of 1 square inch are worth ± 0.33 PYG.

In summary, the equation for calculating USDA yield grad would be as follows

Yield score = 2.0 +(fat x 2.5)+((HCW-600)(0.004))+((KPH-3.5)(0.2))+((11-REA)(0.33))

Grades are determined by the whole number and not the decimal of the score, for example a score of 2.79 would have a yield grade of 2 and not 3.

4.6.3.2 *Japan*

The Japanese quality grade is primarily based on the extent of marbling. The grades are associated with the Beef marbling score (BMS) and quality grade 3 represents carcasses with a BMS of 5-3; while a grade of 4 is achieved with a BMS 7-6 and a 5 grade with a BMS of 8 or above. The overall Japan beef grade score is a combination of the quality grade and the yield score of A, B or C, with final grades being 1 of 15 possible classes, ie. A5-1, B5-1, C5-1.

Yield scores are calculated as a percentage by multiple equations including four carcass measurements, REA, rib thickness, cold left side weight and subcutaneous fat thickness (similar to rib fat). Like the USDA yield grade, an initial value is given, in this case an estimated percentage of 67.37%. This is added to by the following equations to get the final yield score.

1. + (0.13 x REA cm)
2. +(0.667 x Rib thickness cm)
3. –(0.025 x cold left side weight kg)
4. –(0.896 x subcutaneous fat thickness cm)

Scores above 72% are given a grade A, 69-72% a B grade and under 69% a C grade.

4.6.3.3 *EUROP*

The EUROP classification scheme is the legally compulsory grid used through the European Union to classify carcasses on yield only and not quality. This scheme classifies carcasses based on visual assessment of conformation and the level of fatness. Carcasses are given a letter class to describe the extent of muscling of the round, back and shoulder. These letters are S (superior; although this class is barely used and is associated with strong double muscling), E (excellent), U (very good), R (good), O (fair) and P (poor), and make the basis of the EUROP scheme. There are likely sub classes within each class (see Fig. 4.87). Producers aim for between E-R while O classes and below attract a negative deviation in price. The carcass fatness is graded on a 1 (low) to 5 (very high) level based on the amount of fat on the outside of the carcass and in the thoracic cavity. Leaner carcasses are scored as a 1 and fatter a 5. The target area is between 2 and 3 with 4 acceptable. Finally when describing carcasses using the EUROP scheme, each carcass is given a letter (conformation) followed by a number (fatness) (eg R3). In general the grid will aim for E-R + 2-3; with grids crossing into either or both O and 4 being acceptable. The 1 and 5 fat score are not acceptable and neither is a muscled score of P.

The MLC Classification Grid

	1	2	3	4L	4H	5L	5H
E	E1	E2	E3	E4L	E4H	E5L	E5H
U+	U+1	U+2	U+3	U+4L	U+4H	U+5L	U+5H
-U	-U1	-U2	-U3	-U4L	-U4H	-U5L	-U5H
R	R1	R2	R3	R4L	R4H	R5L	R5H
O+	O+1	O+2	O+3	O+4L	O+4H	O+5L	O+5H
-O	-O1	-O2	-O3	-O4L	-O4H	-O5L	-O5H
P+	P+1	P+2	P+3	P+4L	P+4H	P+5L	P+5H
-P	-P1	-P2	-P3	-P4L	-P4H	-P5L	-P5H

Matrix Key

- Discount prices
- Poorest returns

- Average prices
- Moderate returns

- Premium prices
- Best returns

Fig. 4.87. EUROP grid matrix.

4.6.4 A discussion of the limitations of predicting percentage muscle

The reporting of the accuracy's of different markets yield equations is understandably difficult due to variations likely to occur between producers, processors, boners and animals. The predictability of the USDA equation has recently been shown to account for between 31-50% of the variation in % muscle (Lawrence *et al*., 2010; Lu and Tan, 2004; McEvers *et al.*, 2012). Accuracy of equations will be highly dependent on factors such as breed, fatness, carcass weight/maturity, hormonal additives, point measures used and method of determination of point measures. Thus the point of interest for MSA graded carcasses should be these limitations driven by the variables, to develop a feasible and highly repeatable yield predictor.

4.6.4.1 *Accuracy of point measures and the use of VIA*

The accuracy of point measures used to predict yield may be the biggest determinant for accurate prediction, as this assumes that point measures are correct. It has been shown that human grading (online or not) results in considerably more error than that of instrumental measures such as visual image analysis (VIA) when determining point measures thus decreasing the accuracies of prediction equations (Belk et al., 1998; Cannell et al., 1999). This is understandable since at chain speed, the delivery of yield components is likely to be very difficult. VIA technology has been well studied for use in meat grading (Cross and Belk, 1994; Forrest et al., 1989) and is the most widely used technology already incorporated into many processing plants for quick, accurate and highly repeatable determination of yield components in the US (Cross et al., 1983). For example, the determination of loin muscle area (a point measure used in the USDA equation) using VIA technology accounts for up to 92% of the variation of actual muscle area (Steiner et al., 2003). For a technology to be incorporated at chain speed and replacing online human graders, which are surrounded by error (Belk *et al*., 1998; Cannell *et al*., 1999; McEvers *et al.*, 2012), can only improve the accuracy of yield based equations. However, to incorporate this technology into a market, every processor is required to cooperate and provide capital, something that may be difficult to overcome. Another limitation of VIA technology is the inability to capture all important point measures for accurate yield prediction. Typically a single cross section would be assessed using VIA which can accurately calculate eye muscle area and marbling, however often human graded carcass fat thickness has a more important impact on yield than that which is captured by VIA (Lu and Tan, 2004). Thus a combination of VIA and human grading of cold carcasses can improve overall prediction (Cannell *et al*., 1999) but is not necessary. As MSA grading is performed on cold carcasses and not at chain speed, nor is VIA incorporated in MSA grading so is unlikely to be an issue currently, however this must be taken into account when considering VIA technologies.

4.6.4.2 *Point measures taken during MSA grading and potential new measures*

MSA grading already routinely records a number of point measures of similar value to those used in the USDA and Japanese yield grade equations. Carcass weights, rib fat, eye muscle area and marbling are all recorded are all likely to have a relationship with tissue composition. However, these measurements may not provide the best accuracy for predicting % muscle and different point measures may be required for improved accuracy. Both the USDA and Japanese yield grade equations use different point measures to predict yield but it has also been shown that further or varied point measures can result in more accurate prediction. McEvers *et al.* (2012) used a number of different point measures to improve the accuracy of the USDA yield equation. This work

suggested that new emphasis should be placed on measures at the 12th rib. These measures include Loin width (measured the width at the halfway depth of loin muscle), subcutaneous fat area (measured along the width of the loin muscle) and subcutaneous fat thickness (at the furthest width point of the loin muscle on the rib side) all measured by VIA. By stepwise regressing these values, also adjusting for HSCW, a multiple regression equation was able to account for 71.76% of the variation compared to 39% using the traditional point measures. Farrow et al. (2009) used multiple regressions with HSCW, loin muscle area, subcutaneous fat thickness, ratio of loin muscle area to subcutaneous fat area, and ratio of subcutaneous fat depth to hot carcass weight to improve accuracy of saleable meat yield to about 70%. Lu and Tan (2004), suggest that VIA marbling values contribute significantly to predicting yield, however simply adjusting the multiple regression equation using USDA measures still predicted yield more accurately (76%) than by alternative point measure. Pabiou *et al.* (2011) used VIA measurements plus cold carcass weights to predict total muscle weight to an accuracy of 97%, however predicted tissue weights have little to no meaning on composition (Lu and Tan, 2004). Karnuah *et al*. (2001) used VIA technology at the 6th-7th rib to predict yield in Japanese Black cattle. Using a multiple regression equation containing total cross sectional fat area, area of *M. latissimus thoracis,* and muscle circumference of *M. rhomboideus thoracis*, lean muscle yield was able to be predicted to 57% accuracy. Maeno *et al*. (2014) used only subcutaneous fat thickness, loin muscle area and cold carcass weight to predict lean muscle percentage in Japanese beef to 48%, still higher predictions than that of a more complicated USDA equation with more point measures. Most of these data were in training data sets and the transportability of such equations into the real industry data could be lower. Although this illustrates the benefits of using VIA technologies, which will not always be available, but also that a different combination of point measures will influence the accuracy of equations.

4.6.4.3 *Usefulness of morphometric measurements*

Morphometric measurements have also proven to enhance the accuracy of prediction equations (Conroy et al., 2010; Zembayashi, 1999). These measurements are typically used throughout the EUROP scheme to classify carcasses on the conformation or size and shape of muscling. The differential growth of tissues are likely to be better reflected by morphological changes of carcasses than by cross-sectional features (Busch et al., 1969; Zembayashi, 1999) and thus in these instances the EUROP conformation score could be advantageous. The EUROP system in lambs was shown to poorly predict % muscle and explained only about 40% of the variation (Johansen et al., 2006). However, Zembayashi (1999) showed that a combination of morphometric and cross sectional measurements is beneficial when predicting yield in beef carcasses. A combination of carcass weight, cross sectional measurements at the 12th rib and morphometric measures resulted in an accuracy of 77%. This work did highlight that data had to be grouped by breed types and carcass weights to get the best accuracy. Conroy *et al.* (2010) found similar results when using the EUROP conformation scores to predict % muscle with an accuracy of 73%. These authors again highlighted that the same equations could not be used across all genotypes.

4.6.4.4 *Impact of breed or stage of maturity on yield prediction*

Physiological difference between breeds is likely to be a limiting factor for the prediction of % muscle using multiple regressions. Different breeds have different rates of fat and muscle deposition, and it is likely that a single equation cannot be used across all breeds or maybe fatness levels. Lawrence, Elam *et al*.(2010), showed that that the USDA yield grade equation accounted for

only 1% of the variation in yield in dairy breeds, but 31% in beef breeds. Although this equation is capturing more variation in the target breeds, it still identifies a limitation between physiological differences. Harris *et al.* (1995) used multiple regression equations based on the USDA carcass characteristics to calculate Japanese yield grades in Japanese market weight animals, but this explained only 25% of the variation. Zembayashi (1999) suggested that the data was no longer linear for fat percentage and carcass weight and thus different equations were required between two weight groups. Furthermore, Johnson *et al.* (1997) used different equations for heavy and light weight steers to improve the accuracy of prediction equations. Thus both breed and fat class should be incorporated into any yield prediction equations to improve accuracy (Priyanto *et al*., 1997), an agreement case for classification of carcasses.

4.6.4.5 *Impact of beta agonists on yield*

The recent approval of commercial use of the β-agonist, Zilpaterol hydrochloride, in the USA to increase lean meat yield (Hilton *et al*., 2010) has lead to researchers pushing for changes in the yield grade equations for better prediction of Zilpaterol hydrochloride supplemented cattle (Lawrence *et al.*, 2010; McEvers *et al.*, 2012). By manipulating a yield prediction equation to include an adjustment for Zilpaterol hydrochloride and changing the point measures used, McEvers *et al.* (2012) improved the prediction to account for 71.76% of the variation in actual yield. Zembayashi (1999) suggested that if the industry is to try increase muscling (such as by the use of Zilpaterol hydrochloride) then to improve predictability more point measures to describe muscling are required.

4.7 Genetics of BREEDPLAN carcass traits and meat eating quality

4.7.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality

After data editing to remove extreme within lot variation for HSCW and ossification there were 23,218 lots with 20 or more carcass records representing >1.37M carcasses. Mean lot size was 59 with a range from 20 to 673 (Table), 95% of lots had 125 head or less (Fig.). There were no correlations between lot size and lot mean or variance for any carcass trait (results not presented). Summary statistics for carcass traits are reported in Table . Summary statistics including within lot variation is in Table . There was substantial between lot variations for HSCW indicating groups of cattle were being processed at various end points.

Information on the average variation within lots is presented in Table . The mean within lot standard deviation for Marbling was 62.2 with a standard deviation of 29.8. In some lots there was no variation in Marbling (an SD of 0 indicates all carcasses within a lot received exactly the same Marbling) whereas with other lots there was substantial variation in Marbling SD with the maximum being 257 (indicates range of Marbling within a specific lot was very substantial). The mean SD within lots for HSCW was 21.3, indicating less within lot variation than between lots SD of 51.1, Table).

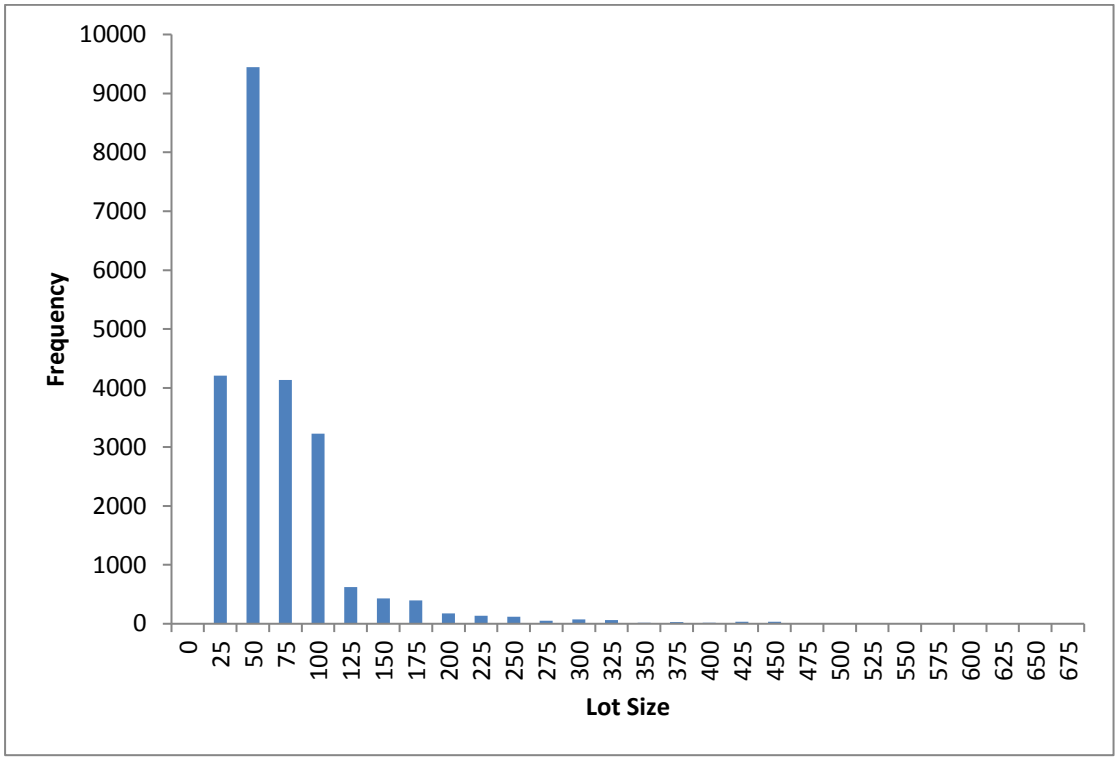


Fig. 4.88. Distribution of lot size. X-axis represents lot size ranging from 25 to 675 head.

Table 4.47. Summary statistics for lot size and carcass traits evaluated during MSA grading

Variable	Mean	Std Dev	Minimum	Maximum
Lot size	59	51.1	20	673
HSCW	273.5	44.0	136.8	474.5
Marbling	344	62.5	124.6	1004
Rib	8.5	2.2	0.2	22.8
EMA	69.5	7.2	24.7	105.7
Oss	145	13.5	100	228
MSA Index	60.1	2.9	46.8	68.8

Table 4.48. Summary statistics for within lot standard deviation for carcass traits evaluated during MSA grading

	Mean	Std Dev	Minimum	Maximum
HSCW-SD	21.3	8.0	4.7	50.0
Marbling-SD	62.2	29.8	0	257.3
Rib-SD	2.5	1.0	0	13.0
EMA-SD	6.1	2.7	0	28.2
Oss-SD	13.5	5.0	0	30.0
MSA Index-SD	1.3	0.4	0.02	4.3

Correlations between lot mean for carcass traits are presented in Table . Increased lot mean HSCW was positively correlated with lot mean Marbling, EMA, Rib, Ossification and MSA Index. Increased lot mean MSA Index was positively correlated with HSCW, Marbling and Rib with low to moderate negative correlations with EMA and Ossification.

Correlations between lot mean and variation in lot mean are also presented. Increased lot mean HSCW was moderately positively correlated with lot SD for HSCW (0.34) and Marbling (0.40). Lower but still positive correlations between lot mean HSCW, Rib, EMA, Ossification and MSA Index were observed (Table). Higher lot mean Marbling was moderately correlated with increased SD in Marbling (0.54) and lowly (<0.25) but positively correlated with all other carcass traits. Increased lot mean Rib was correlated with increasing SD in Rib (0.53). For other traits (EMA, Oss and MSA Index) increasing mean lot performance had low positive correlations with SD in the trait, for example mean EMA with EMA SD (0.00). Increasing lot mean MSA Index was moderate to strongly correlated with increased lot variance in Marbling (0.71) and Oss (0.62) with lower but still positive correlations observed for other carcass traits. A 100 kilogram increase in the lot mean carcass weight (e.g. from 250 to 350 kg) was associated with an increase in marbling by 67 points the standard deviation of marbling by 27 points (almost ½ a standard deviation), and the standard deviation in carcass weight by 6.1 kg with little change in the SD in ossification (Table).

Graphical representation of key correlations between trait average and trait variation at the lot level are presented below. The five Figures all at the lot level are:

- Fig. 4.89 showing the positive relationship (0.47) between mean HSCW and mean Marbling,
- Fig. 4.90 showing the positive relationship between mean HSCW and variation (SD) in Marbling (0.40)
- Fig. 4.91 showing the positive relationship between mean carcass weight and variation (SD) in carcass weight (0.34)
- Fig. showing the positive relationship between mean Marbling and variation (SD) in Marbling
- Fig. showing the close-to-neutral relationship between mean HSCW and variation (SD) in ossification (0.04).

Table 4.49. Correlations between lots for carcass traits (lot mean) and variation (SD) in carcass traits within lot

	HSCW mean	EMA mean	Rib fat mean	Marb mean	Oss mean	MSA Index mean	HSCW SD	EMA SD	Rib SD	Marb SD	Oss SD	MSA Index SD
HSCW	1.00	0.33	0.36	0.47	0.38	0.14	0.34	0.17	0.17	0.40	0.04	0.11
EMA	0.33	1.00	0.09	0.25	0.18	-0.11	0.10	0.00	0.12	0.19	0.07	0.07
Rib	0.36	0.09	1.00	0.39	0.21	0.14	0.08	0.26	0.53	0.26	0.14	0.16
Marbling	0.47	0.25	0.39	1.00	0.33	0.34	0.18	0.19	0.20	0.54	0.11	0.24
Oss	0.38	0.18	0.21	0.33	1.00	-0.31	0.23	0.11	0.17	0.39	0.29	0.16
MSA Index	0.14	-0.11	0.14	0.34	-0.31	1.00	0.04	0.07	0.01	0.23	-0.02	0.16
HSCW SD	0.34	0.10	0.08	0.18	0.23	0.04	1.00	0.20	0.08	0.20	0.12	0.11
EMA SD	0.17	0.00	0.26	0.19	0.11	0.07	0.20	1.00	0.33	0.28	0.30	0.32
Rib SD	0.17	0.12	0.53	0.20	0.17	0.01	0.08	0.33	1.00	0.34	0.42	0.43
Marbling SD	0.40	0.19	0.26	0.54	0.39	0.23	0.20	0.28	0.34	1.00	0.37	0.71
Oss SD	0.04	0.07	0.14	0.11	0.29	-0.02	0.12	0.30	0.42	0.37	1.00	0.62
MSA Index SD	0.11	0.07	0.16	0.24	0.16	0.16	0.11	0.32	0.43	0.71	0.62	1.00

Table 4.50. The change in carcass traits (lot mean) and variation (SD) in carcass traits for 100kg increase in carcass weight.

Trait	Mean	SD
HSCW	100	6.1 ± 0.1
Marbling	67 ± 8	27 ± 0.4
MSA Index	0.93 ± 0.04	0.11 ± 0.01
Ossification	11.6 ± 0.2	0.48 ± 0.07

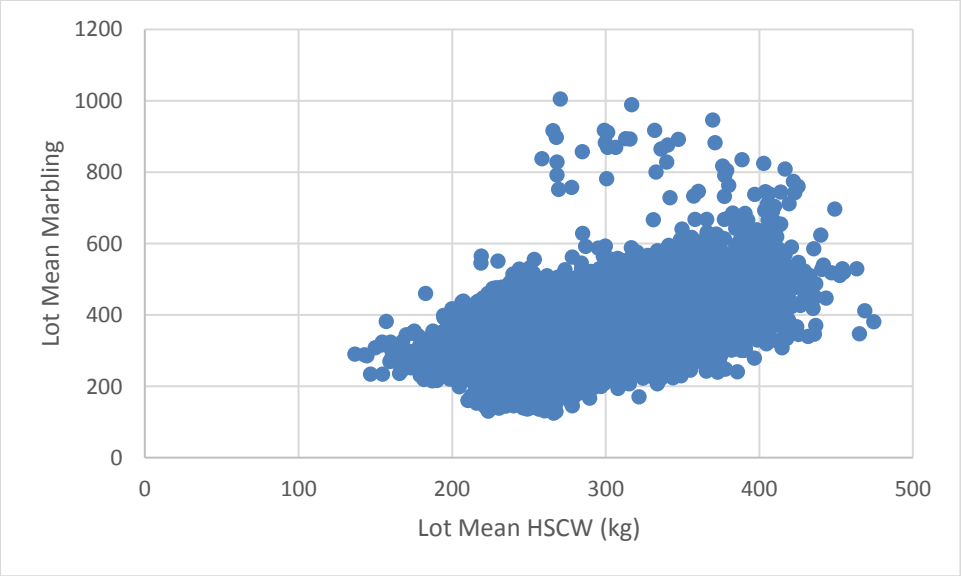


Fig. 4.89. Relationship between lot mean HSCW and lot mean Marbling.

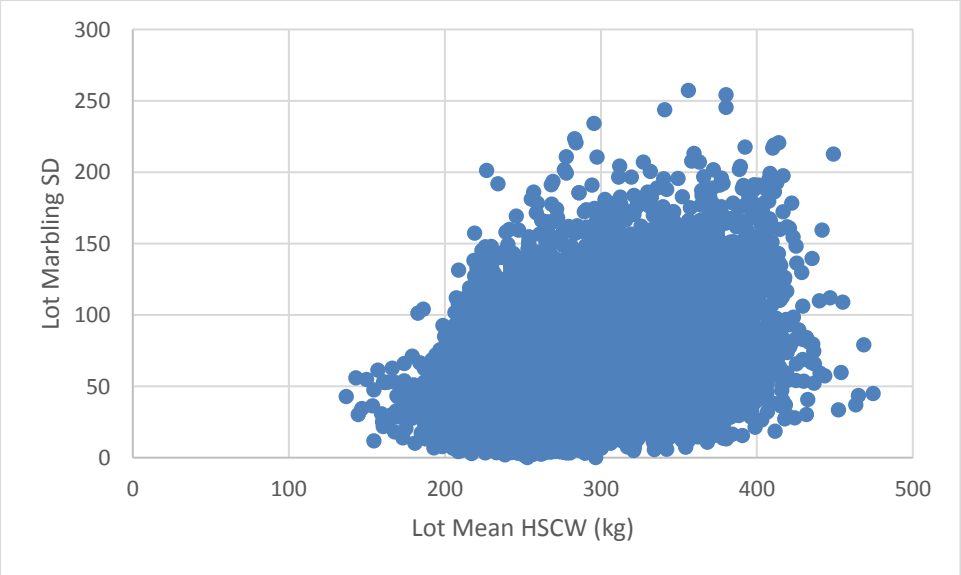


Fig. 4.90. Relationship between lot mean HSCW and variation in lot Marbling (Marbling SD)

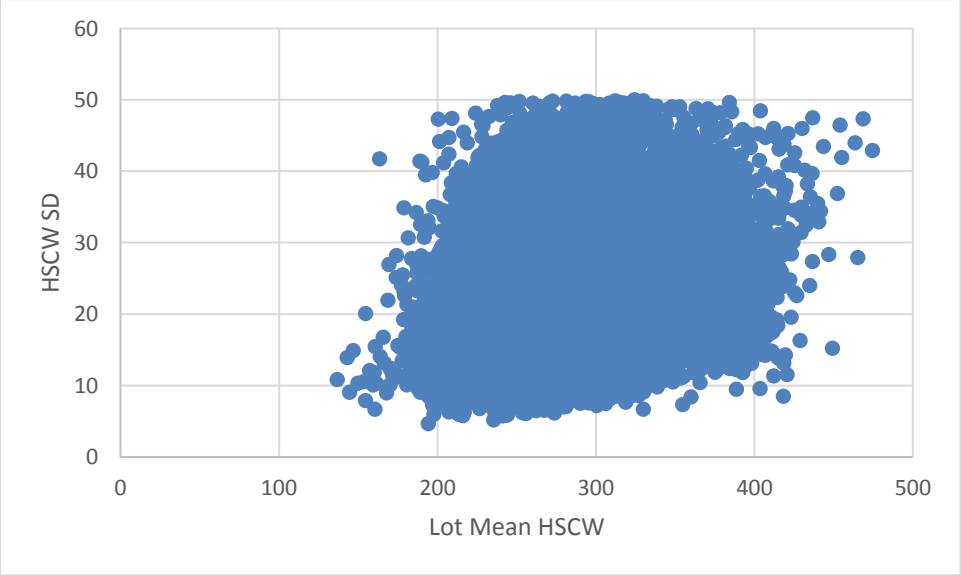


Fig. 4.91. Relationship between lot mean HSCW and variation in lot HSCW (HSCW SD).

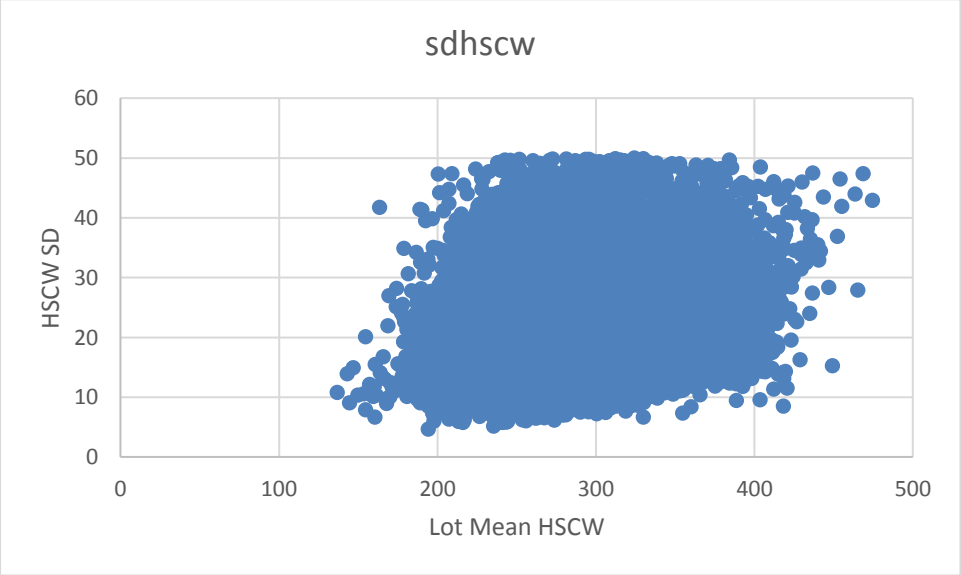


Fig. 4.92. Relationship between lot mean Marbling and variation in lot Marbling (Marbling SD).

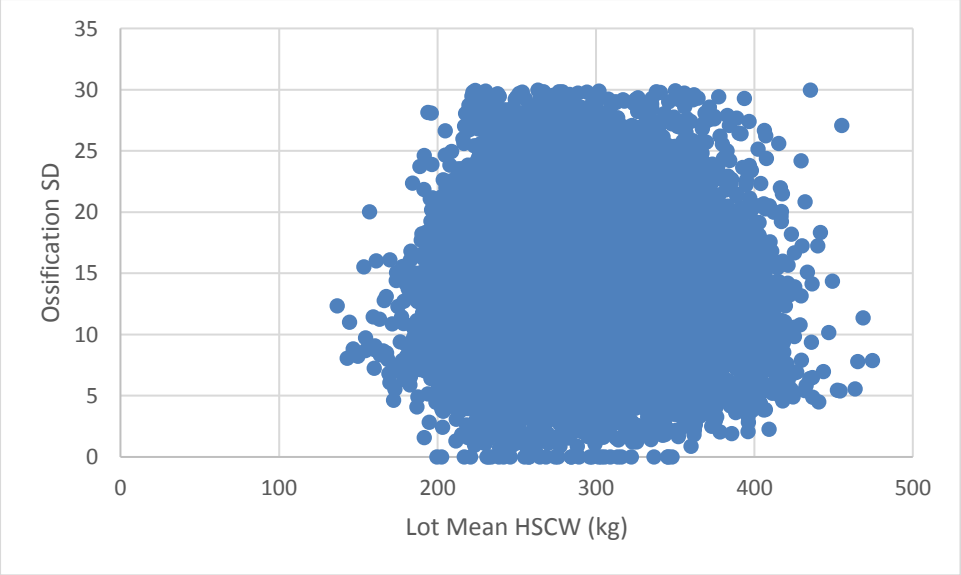


Fig. 4.93. Close-to-neutral relationship between lot mean HSCW and variation in lot Oss (Oss SD).

4.7.2 Relationships between BREEDPLAN EBVs and meat eating quality

4.7.2.1 *Relationship between progeny carcass traits and sire BREEDPLAN EBVs*

The regressions for all carcass traits regressed on their associated EBV were significant. There was a significant interaction demonstrating a different regression coefficient between the finish systems for all regressions except ossification on 600D weight EBV (

Table) and MSA index on 600D weight EBV (Table). In all cases the regression coefficients were greater for the Long-fed cattle than the short and pasture which tended to be similar to each other. The regression coefficient for Rib Fat on sire Rib EBV, IMF% regressed on sire IMF EBV and EMA regressed on sire EMA EBV, was expected to be 0.5 (Table). For each of these regressions the Long finished coefficients were significantly greater than 0.5 and the Short and Pasture finished regression coefficients were significantly less than 0.5. This difference was the greatest when IMF% was regressed on IMF EBV where there was a 6.5 fold difference between the Pasture and Long feeding regimes. The regression coefficients were lower than expected for Short and Pasture fed cattle (0.17 and 0.15) respectively and significantly higher than 0.5 (expected) for the Long-fed cattle (1.08). The effect of selecting for improved IMF EBV was almost 5 fold greater in long grain finished cattle than short for MSA marbling (Table). For every 1 % increase in sire IMF EBV the increase in MSA marbling was 36.7 MSA marbling scores in Long-fed cattle relative to 7.6 in Short-fed cattle. There was no significant relationship between ossification and 600 day weight EBV for each of the finishing systems but there was a significant difference between datasets.

Table 4.51. Tests of significance (F-Prob) for carcass traits regressed on BREEDPLAN sire EBVs

	HSCW on CWT EBV	EMA on EMA EBV	Rib Fat on Rib EBV	IMF% on IMF EBV	Marb on IMF EBV	Oss on 600D Wt EBV
EBV	<0.001	<0.001	<0.001	<0.001	<0.001	0.479
Finish x EBV	0.009	<0.001	<0.001	<0.001	<0.001	0.579
Breed x EBV	0.146	0.066	0.193	0.729	0.067	<0.001
Dataset x EBV	0.453	0.130	0.003	0.529	<0.001	<0.001

Table 4.52. Finishing system regression coefficients for carcass traits on BREEDPLAN sire EBVs (± standard errors)

Finish	HSCW on CWT EBV	EMA on EMA EBV	Rib Fat on Rib EBV	IMF% on IMF EBV	MSA Marbling on IMF EBV	Oss on 600D Wt
Long	0.72^{a} ± 0.03	0.64^{a} ± 0.05	0.75^{a} ± 0.04	1.08^{a} ± 0.04	36.7^{a} ± 1.9	0.02 ± 0.02
Short	0.55^{b} ± 0.06	0.33^{b} ± 0.08	0.21^{b} ± 0.08	0.17^{b} ± 0.13	7.6^{b} ± 2.4	-0.01 ± 0.02
Pasture	0.48^{b} ± 0.06	0.17^{c} ± 0.09	0.31^{b} ± 0.09	0.15^{b} ± 0.13	8.9^{b} ± 2.8	0.02 ± 0.03
P-Value	0.009	<0.001	<0.001	<0.001	<0.001	0.579

Different superscripts indicate significantly different regression coefficients between finishing systems.

Significant differences were observed between the breeds when Ossification was regressed on 600D weight EBV (Table). The regression coefficient for ossification on 600D weight EBV was not significantly different from zero for Angus and Limousin however a 1 kg increase in 600D wt EBV was associated with a reduction in ossification by 0.09 and 0.06 units for Charolais and Hereford respectively. This was statistically significant, but not biologically meaningful. The regression coefficients for IMF% on IMF EBV and MSA marbling regressed on IMF EBV were both significantly greater in Angus cattle than the other three breeds. A 1 unit increase in sire IMF EBV resulted in a 1.66 unit increase in IMF% which is over three times greater than the expected regression coefficient of 0.5.

Table 4.53. Breed regression coefficients for carcass traits on BREEDPLAN sire EBVs (± standard errors)

Breed	HSCW on CWT EBV	EMA on EMA EBV	Rib Fat on Rib EBV	IMF% on IMF EBV	Marb on IMF EBV	Oss on 600D Wt EBV
Angus	0.64 ± 0.04	0.51 ± 0.04	0.59 ± 0.04	0.82 ± 0.04	27.5 ± 1.6	0.02^{a} ± 0.01
Charolais	0.55 ± 0.17	0.30 ± 0.20	0.30 ± 0.18	0.16 ± 0.12	19.9 ± 5.1	-0.09^{b} ± 0.04
Hereford	0.69 ± 0.10	0.57 ± 0.24	0.54 ± 0.18		8.2 ± 3.0	-0.06^{b} ± 0.03
Limousin	0.68 ± 0.43	-0.16 ± 0.35	0.69 ± 0.54	0.14 ± 0.12	5.0 ± 9.8	-0.01^{ab} ± 0.07
P-Value	0.146	0.066	0.193	0.729	0.067	<0.001

4.7.2.2 *Relationship between MSA Index and BREEDPLAN carcass EBVs*

MSA index was most closely related to the IMF EBV (Table and Table *9.14*9.1 Appendix 9.1). A 1 standard deviation increase in sire EBV was greatest for IMF EBV for Long and Short finished feeding systems almost 3 times as great as Pasture. An increase in IMF EBV was associated with a significant increase in MSA Index (Table) with the Long finish almost 3 times greater than Pasture. A 1 % increase in sire IMF EBV was worth 0.28 MSA Index points under a Long feedlot finishing regime relative to a 0.10 unit increase under Pasture (Table 9.2). Similar results were observed for sire Rib and carcass weight EBVs where Long finished regression coefficients were significantly higher than pasture finished.

Table 4.54. Tests of significance (F-Prob) for MSA Index regressed on BREEDPLAN sire EBVs

	600D Wt EBV	CWT EBV	Rib EBV	IMF EBV
EBV	<0.001	<0.001	0.432	<0.001
Finish x EBV	0.308	0.035	0.046	0.020
Breed x EBV	0.073	0.375	0.066	0.989
Dataset x EBV	0.025	0.302	0.648	0.394

Table 4.55. Finishing system regression coefficients for MSA Index on BREEDPLAN sire EBVs (± standard errors)

Finish	600D Wt EBV	CWT EBV	Rib EBV	IMF EBV
Long	0.012 ± 0.003	0.014 ± 0.002	0.003 ± 0.020	0.34 ± 0.03
Short	0.009 ± 0.003	0.010 ± 0.004	-0.085 ± 0.033	0.29 ± 0.06
Pasture	0.005 ± 0.003	0.002 ± 0.004	-0.023 ± 0.036	0.12 ± 0.07
P-Value	0.308	0.035	0.046	0.020

There were no significant (P<0.05) differences between the breeds in their relationship between MSA Index and sire EBVs (Table). The breed by Rib EBV interaction was almost significant (P=0.066) where in Hereford there was a negative relationship and in Limousin a positive relationship (with large standard errors). There was no relationship between MSA index and sire Rib EBV in Angus and Charolais.

Table 4.56. Breed regression coefficients for MSA Index on BREEDPLAN sire EBVs (± standard errors)

Breed	600D Wt EBV	CWT EBV	Rib EBV	IMF EBV
Angus	0.007 ± 0.002	0.011 ± 0.002	-0.009 ± 0.017	0.32 ± 0.02
Charolais	0.008 ± 0.003	0.011 ± 0.009	0.068 ± 0.076	0.22 ± 0.12
Hereford	0.014 ± 0.003	-0.004 ± 0.021	-0.193 ± 0.071	0.15 ± 0.09
Limousin	-0.007 ± 0.011	0.013 ± 0.005	0.320 ± 0.228	0.22 ± 0.60
P-Value	0.073	0.375	0.066	0.989

4.7.2.3 *Relationship between pH and BREEDPLAN carcass EBVs*

Dark cutting or high pH is the major cause of carcasses not making satisfactory MSA grade. When pH was regressed on carcass weight and 600 day weight EBVs, statistically significant but biologically insignificant results were observed for pasture finished animals (Table 4.57 and Table). There was no difference between the datasets in their relationship between pH and carcass EBVs.

Table 4.57. Tests of significance for pH regressed on BREEDPLAN sire EBVs

	600D Wt EBV	CWT EBV	EMA EBV	Rib EBV	IMF EBV
EBV	0.828	0.953	0.584	0.515	0.524
Finish x EBV	0.032	0.028	0.881	0.141	0.315
Breed x EBV	0.054	0.036	0.001	<0.001	0.011
Dataset x EBV	0.205	0.910	0.494	0.269	0.916

Table 4.58. Finishing system regression coefficients (x1000) for pH on BREEDPLAN sire EBVs (± standard errors)

Finish	600D Wt EBV	CWT EBV	EMA EBV	Rib EBV	IMF EBV
Long	0.07 ± 0.16	0.07 ± 0.12	-0.11 ± 0.65	-0.35 ± 1.14	-1.79 ± 1.51
Short	0.19 ± 0.15	0.25 ± 0.23	-0.36 ± 1.05	0.82 ± 1.93	4.37 ± 3.84
Pasture	-0.37 ± 0.17	-0.55 ± 0.23	-0.79 ± 1.20	4.53 ± 2.20	1.50 ± 4.30
P-Value	0.032	0.028	0.881	0.141	0.315

Significant associations were observed for pH on Rib EBV in Limousin where a 1 mm increase in Rib EBV was associated with a decrease in pH by 0.053 units (

Table). Similarly, for IMF where a 1% increase in IMF EBV was associated with a decrease in pH of 0.11 units in Limousin. Statistically significant but biologically insignificant coefficients were observed for 600 day weight, carcass weight and EMA EBVs in Limousin (the coefficient for the three other breeds were not different from zero).

Table 4.59. Breed regression coefficients (x1000) for pH on BREEDPLAN sire EBVs (± standard errors)

Breed	600D Wt EBV	CWT EBV	EMA EBV	Rib EBV	IMF EBV
Angus	-0.06^{a} ± 0.11	0.01^{a} ± 0.11	-0.18^{a} ± 0.54	0.89^{a} ± 0.97	-0.89^{a} ± 1.43
Charolais	-0.44^{a} ± 0.29	-1.00^{b} ± 0.55	1.80^{a} ± 2.87	2.05^{a} ± 4.57	0.47^{a} ± 7.25
Hereford	0.17^{a} ± 0.21	-0.01^{a} ± 0.30	0.28^{a} ± 1.85	-0.95^{a} ± 4.37	1.84^{a} ± 5.55
Limousin	1.62^{b} ± 0.64	3.22^{c} ± 1.28	-19.7^{b} ± 5.0	-52.5^{b} ± 13.8	-113^{b} ± 36.8
P-Value	0.054	0.036	0.001	<0.001	0.011

4.7.2.4 *Sire variances in carcass traits*

Including sire by finishing system and estimating separate sire variance components for each finishing system (i.e. placing a G structure on the data) resulted in a significant improvement to the model for all traits based on the likelihood ratio test statistic. For almost all traits the sire variance under a Long-fed finishing regime was significantly greater than both Short and Pasture (Table). The exceptions were ossification and MSA Index where the sire variance of the Short-fed cattle were higher than both Long and Pasture fed cattle.

Table 4.60. Sire variances for each finishing system (± standard error)

	HSCW	EMA	Rib Fat	IMF	Marbling	Oss	Index
Long	159 ± 27	6.5 ± 1.17	3.03 ±0.56	1.63 ± 0.27	1619 ± 286	21.9 ± 5.3	0.34 ± 0.07
Short	82 ± 21	2.5 ± 0.89	2.05 ± 0.42	0.22 ± 0.07	588 ± 112	32.4 ± 6.6	0.63 ± 0.11
Pasture	39 ± 12	2.4 ± 0.75	0.49 ± 0.19	0.04 ± 0.03	352 ± 107	17.3 ± 5.8	0.07 ± 0.04

Data set mean carcass weight was used as an indicator of target market specifications. Genetic variation in marbling was greater at heavier end points but there was a large range of results (Fig. 4.947). The sire standard deviation in MSA Marbling for the Long-fed Rockdale and Trangie T datasets that had a heavy average carcass weight (414 and 387 kg) was low (14.5 and 14.1). Both the Rockdale and Trangie T animals were selected on net feed intake (NFI) and not IMF like modern Angus cattle. The correlation between average dataset carcass weight and sire SD in MSA Marbling was 0.55, and this was increased to 0.67 when the Rockdale dataset was not included. These correlations are similar to the correlation of 0.40 estimated between lot mean carcass weight and the phenotypic standard deviation in MSA Marbling in the large MSA dataset analysis (4.7.1), confirming that sire variation in MSA Marbling increases with carcass weight. Similar relationships were observed between hot standard carcass weight and sire standard deviations for IMF and rib fat (Fig. and Fig.) with correlations of 0.80 and 0.59 respectively. There was no indication that sire variation in ossification changed with heavier carcass weights (Fig.).

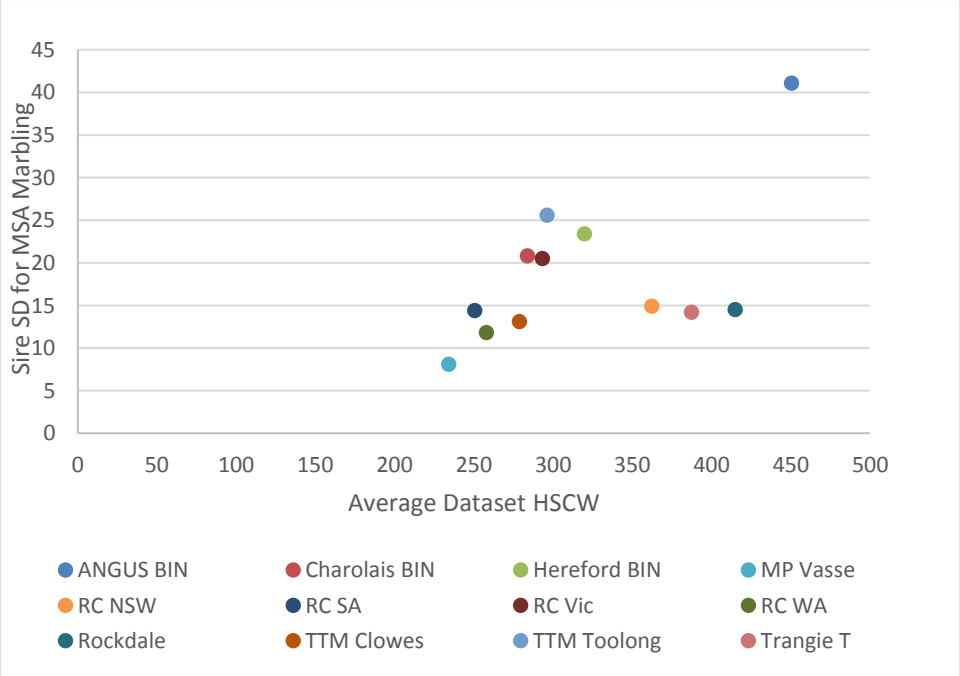


Fig. 4.947. Sire standard deviation for MSA marbling relative to the average hot standard carcass weight for each dataset

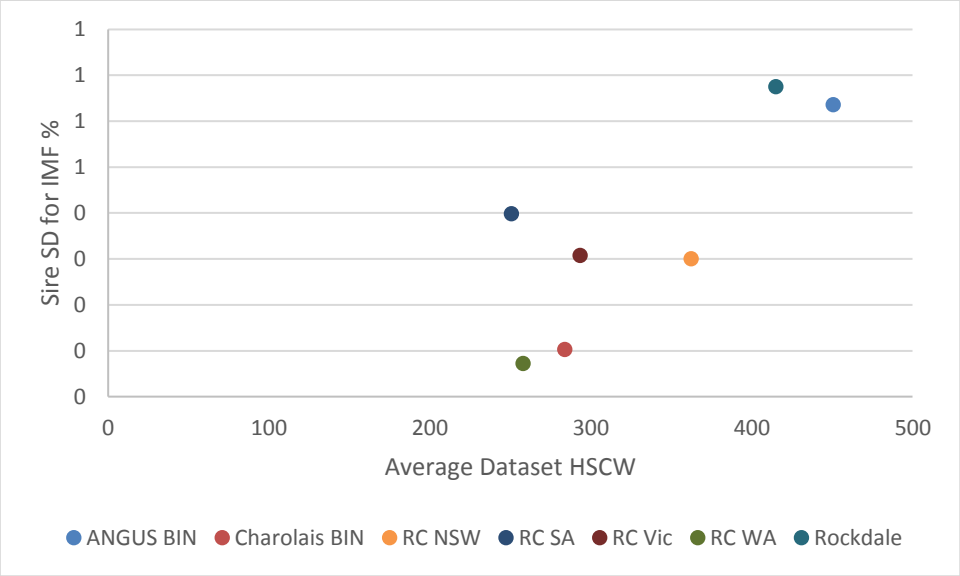


Fig. 4.95. Sire standard deviation for IMF% relative to the average hot standard carcass weight for each dataset

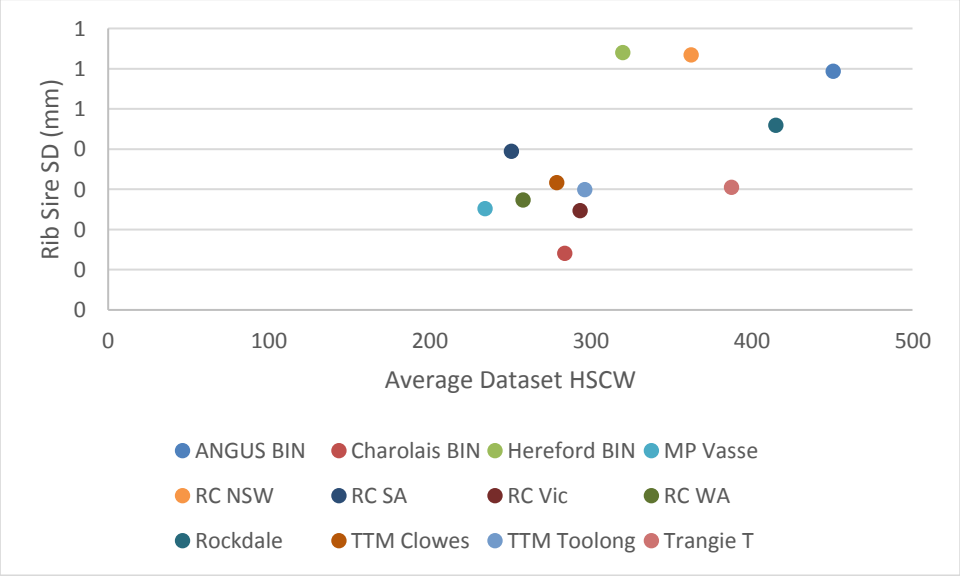


Fig. 4.96. Sire standard deviation for Rib relative to the average hot standard carcass weight for each dataset

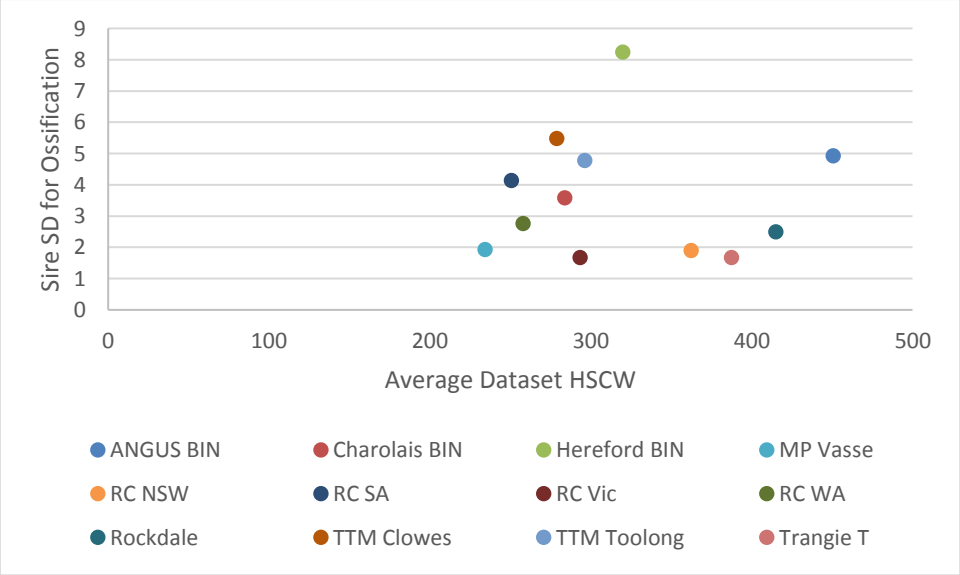


Fig. 4.97. Sire standard deviation for Ossification relative to the average hot standard carcass weight for each dataset

4.7.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits

For the Regional Combinations data set, phenotypic and sire variances and covariances were estimated between short-fed feedlot and pasture finished carcasses. The phenotypic variances were greater for short-fed finishing compared with pasture finishing for HSCW, rib fat and EMA (13-20%, Table). Compared with pasture finished; there was less variation (11-19%) in short-fed carcasses for pH, Marbling, eating quality and MSA index. There was very little difference between the finishing systems for ossification, P8 or IMF.

Based on sire variances, the heritability estimates for ossification and pH were low for both pasture and feedlot fed animals, with very little phenotypic variation observed in pH (Table). For P8, the heritability estimates on pasture were 10% higher than that of feedlot fed animals. The heritability of the MSA Index and eating quality of the striploin was greater in feedlot finished animals relative pasture (0.19 vs 0.11, for MSA Index). The genetic correlations between finishing systems were high (>0.80) for pH, HSCW, Ossification, MSA Index, P8, and EMA (Table). The genetic correlation between finishing systems was less than 0.80 for IMF (0.58) indicating that there was a significant GxE interaction. Both Rib and MSA Marbling had genetic correlations between finishing systems of 0.77 indicating a potential GxE for these traits.

Table 4.61. Phenotypic variance (V_P), heritability (h^2), by finishing system and genetic correlations (sire) between finishing systems for carcass traits

Trait	V_P Short	h^2 Short	V_P Pasture	h^2 Pasture	Difference in SD_P (%)	$r_{G(sire)}$
HSCW	778	0.29 (0.10)	542	0.13 (0.06)	20	0.95 (0.21)
pH	0.015	0.07 (0.06)	0.019	0.08 (0.05)	-11	0.80 (0.51)
Oss	224	0.02 (0.00)	242	0.09 (0.06)	-4	0.99 (0.56)
EMA	55.0	0.14 (0.07)	42.8	0.11 (0.06)	13	0.88 (0.33)
Rib	13.1	0.21 (0.08)	10.0	0.14 (0.07)	14	0.77 (0.28)
P8	18.17	0.20 (0.03)	16.56	0.30 (0.09)	5	0.90 (0.15)
IMF	1.69	0.08 (0.06)	1.51	0.12 (0.06)	6	0.58 (0.45)
Marbling	3083	0.19 (0.08)	3925	0.11 (0.07)	-11	0.77 (0.30)
MSA Index	1.74	0.19 (0.08)	2.63	0.11 (0.06)	-19	0.89 (0.27)
PEQ-sl	4.10	0.21 (0.09)	5.25	0.07 (0.07)	-12	0.83 (0.43)

The genetic (sire) correlations between MSA Index and IMF, and MSA Marbling were very high (0.82 and 0.90 respectively), whilst the genetic correlation between MSA Index and PEQ-sl was 0.99 indicating they are essentially the same trait (Table). The genetic correlation between MSA Index and ossification, pH and EMA were moderate and negative (-0.60, -0.34 and -0.38 respectively). Similarly, the phenotypic correlations between fat traits (Marbling, IMF, and Rib) were positive and moderate to high whilst ossification, EMA and pH with MSA Index were negative. As expected, the trait most highly correlated with MSA index was Marbling and from the current BREEDPLAN traits was IMF. It is assumed that the correlations with P8 and EMA are through their correlation with IMF rather than directly affecting MSA index.

Table 4.62. Phenotypic (above the diagonal) and genetic (below the diagonal) correlations (standard error in brackets) between MSA Index and carcass traits. Note genetic correlations estimated from a sire model.

	PEQ	Marbling	OSS	HSCW	Rib	EMA	IMF	pH	Index
PEQ		0.85 (0.01)	-0.17 (0.02)	0.18 (0.02)	0.30 (0.02)	-0.01 (0.02)	0.53 (0.02)	-0.28 (0.02)	0.88 (0.01)
Marbling	0.97 (0.02)		0.04 (0.02)	0.11 (0.02)	0.20 (0.02)	-0.01 (0.02)	0.54 (0.02)	0.03 (0.02)	0.68 (0.01)
OSS	-0.50 (0.23)	-0.26 (0.26)		0.18 (0.02)	0.05 (0.02)	0.14 (0.02)	0.03 (0.02)	-0.03 (0.02)	-0.45 (0.02)
HSCW	0.30 (0.16)	0.16 (0.17)	0.14 (0.22)		0.19 (0.02)	0.44 (0.01)	0.12 (0.02)	-0.09 (0.02)	0.18 (0.02)
Rib	0.47 (0.16)	0.52 (0.15)	-0.10 (0.26)	0.13 (0.16)		-0.07 (0.02)	0.24 (0.02)	-0.05 (0.02)	0.38 (0.02)
EMA	-0.38 (0.18)	-0.54 (0.16)	0.16 (0.24)	0.47 (0.13)	-0.53 (0.15)		-0.06 (0.02)	-0.02 (0.02)	-0.03 (0.02)
IMF	0.89 (0.08)	0.97 (0.05)	-0.06 (0.29)	0.18 (0.19)	0.58 (0.15)	-0.67 (0.16)		-0.13 (0.02)	0.45 (0.02)
pH	-0.41 (0.25)	-0.34 (0.27)	-0.11 (0.35)	-0.38 (0.24)	0.07 (0.29)	-0.06 (0.28)	-0.42 (0.03)		-0.32 (0.02)
Index	0.99 (0.01)	0.90 (0.05)	-0.60 (0.19)	0.29 (0.16)	0.56 (0.14)	-0.38 (0.18)	0.82 (0.10)	-0.34 (0.26)	

Separate genetic and phenotypic correlations for finish system were estimated for MSA Marbling, IMF and Rib Fat and carcass traits (Table , Appendix 9.1). For MSA marbling genetic correlations were similar in direction and magnitude for all traits except EMA where there was a moderate positive correlation for Pasture finished (0.40 ± 0.24) and moderate negative (-0.48 ± 0.22) for Short Feedlot finished cattle (Fig.). For MSA index, IMF and Rib Fat the genetic correlations were similar in magnitude and direction with reasonably large standard errors (Fig. 4.988, Fig. and Fig. respectively).

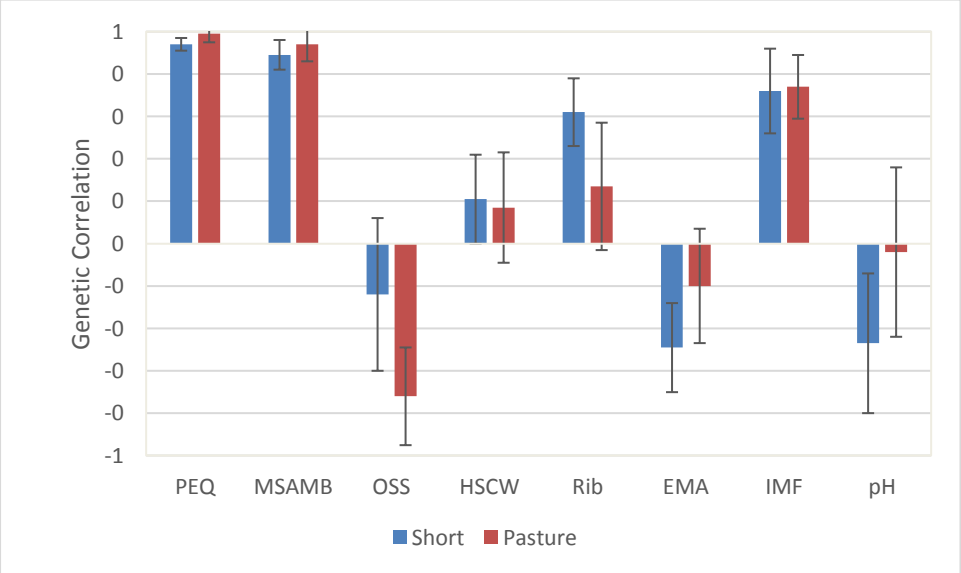


Fig. 4.988 Genetic (sire) correlations between the MSA Index and carcass traits for Short and Pasture finished cattle

Fig. 4.99. Genetic (sire) correlations between MSA Marbling and carcass traits for Short and Pasture finished cattle

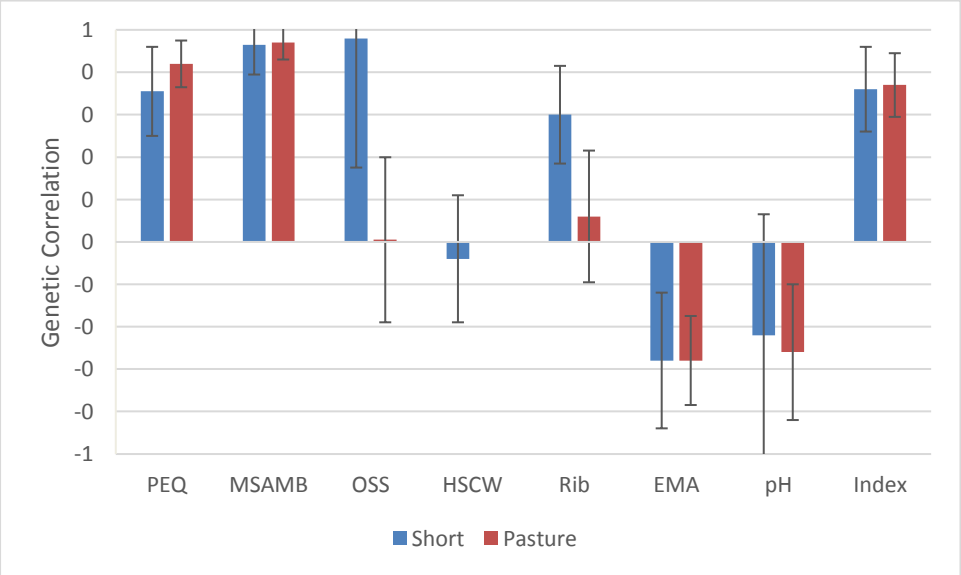


Fig. 4.100. Genetic (sire) correlations between IMF and carcass traits for Short and Pasture finished cattle

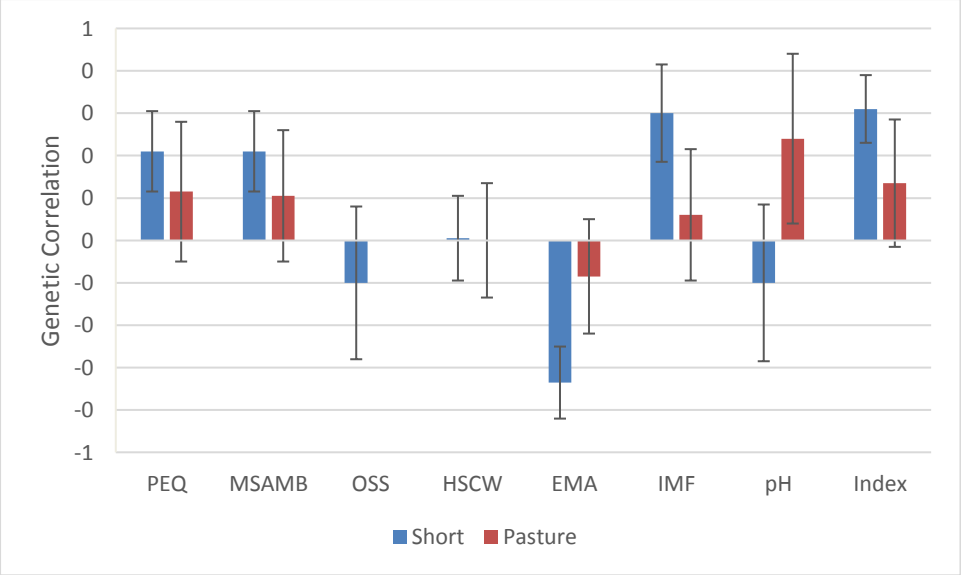


Fig. 4.101. Genetic (sire) correlations between Rib Fat and carcass traits for Short and Pasture finished cattle

5 Discussion

5.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

5.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia

The analysis of the South Australian scoping data set has highlighted risk factors for higher incidences of DC which help explain the overall higher rates and pronounced seasonality observed in South East South Australia. The significant effect of age classification observed is an indication of the growth path of the cattle in this study. All animals involved in this study were from autumn-winter calving cattle herds (typical for South-East South Australia) and thus, only two categories were used to designate whether animals were slaughtered, namely; A) in their second winter/spring (as 12-18 month olds), or B) in their third winter/spring (>24 months old). Although producers aim to slaughter steers in their first season, feed resources may be inadequate (due to poor seasons or overstocking) and a whole cohort of steers may be retained. Alternatively, it is common for a subset of animals that are slower growing and do not make satisfactory weight and/or condition. These are carried over through another spring when they can reach appropriate specification. In situations where sufficient nutrition has been adequately met, this is most likely due to differences in genetic growth potential and thus maturity pattern (Robinson 1996, Englishby *et al.* 2016). Understanding individual growth paths post-weaning allows producers to evaluate not only breeding and feeding systems, but also to identify poor-performing animals that will likely be carried over. This finding highlights the need for autumn-born calves to achieve maximal growth in the first 12-18 months to attempt to reach slaughter weight before the end of their second spring.

Movement to a different paddock within the week leading up to slaughter was undertaken for one of two reasons. Primarily, movements were undertaken to move cattle closer to yard facilities in the lead up to slaughter so as to reduce stress during mustering. Alternatively, movements were made as part of a rotational grazing system where producers were wishing to provide cattle with a fresh, ample feed base so as not to limit feed intake right before slaughter. Studies of dairy cattle grazing homogenous pasture bases show no increase in total feed intake upon movement to another paddock (Abrahamse *et al.* 2009; Pulido *et al.* 2015). However, there was little consistency between the feed bases and thus, a sudden change may have caused clinical or sub-clinical acidosis and altered their feed intake in the lead up to slaughter (Barrett *et al.* 2001). Although no research has been done on the direct effects on intake, rumen health and glycogen metabolism under such management regimes, studies of rotational grazing in dairy cattle show that upon introduction to "new" pasture (of the same botanical composition as animals have been grazing) cattle will increase their feed intake (reference).

The change in environment may also invoke increased activity and excitement, which alone, or in conjunction with altered intake will result in impaired muscle glycogen levels pre-slaughter. The reduced effect from cattle moved at 1-2 or 2-4 weeks slaughter supports this theory. The increase in %DC rates observed from cattle moved greater than 4 weeks out indicates that cattle may have been in a set stocked situation and may have started to run low on feed, or pasture had matured and the intake had decreased (Munoz *et al.* 2016). There is no literature on the effect on intake and behaviour induced by such short term changes in feed base.

The dichotomy in dark cutting incidence between vendor-bred and purchased cattle is not easily explained, other than perhaps an indication that producers who are in the business of purchasing cattle to finish are managing finisher stock requirements more appropriately than those who run breeder/finisher enterprises. Further detailed investigation into the specific cattle genetics, feed base and management differences would help explain this trend.

Minimal curfew protocols, whereby animals were yarded the morning of transport (denoted "No curfew"), or where animals were placed in an adjoining laneway or holding paddock the night before transport ("Partial curfew") resulted in greater incidence of dark cutting. A "Partial curfew" has the potential to invoke stress through a change in environment and feed as per the effects observed for paddock movements, however its similarity to the effect observed for "No curfew" mobs would indicate otherwise. There non-fasted animals will have defecated and urinated considerably more during transport and in lairage (Dickson and Anderson 1992; Gregory *et al.* 2000), leading to a greater chance of slipping and falling. This will ultimately lead to the risk of greater stress and muscle glycogen utilisation. Furthermore, the greater faecal contamination of animal hides will result in greater level of washing pre-slaughter which will also lead to greater amount of stress (Preston 2015).

Animals yarded the day before transport had lower incidence of dark cutting, irrespective of whether they were provided with hay or not. Although the provision of hay may be seen to invoke similar changes as paddock changes and/or a lack of fasting, the higher physical and chemical fibre content will have increased the retention of dry matter in the rumen (Jacobson *et al.* 2002), and maintained satiation during the pre-slaughter period. Reductions in faecal contamination, slipping during lairage and transport and therefore pre-slaughter washing will reduce pre-slaughter glycogen utilisation. However, as measures of faecal contamination, mob activity and washing protocol were not measured on these cattle this cannot be quantified. Despite the presence of recommendations in the "Australian

Animal Welfare Standards and Guidelines – Land transport of Livestock" (Department of Agriculture, Fisheries and Forestry 2012), there appears to be confusion amongst producers and processors as to the appropriate curfew protocols for pasture finished beef. Further verification of fasted/full diets and appropriate supplementation is warranted to determine the effects on animal stress, carcass contamination and resultant carcass quality.

Cattle slaughtered from pure grass pastures had significantly higher levels of dark cutting compared mixed legume/grass pastures. Typically, pure grass stands consisted of Barley grass, Tall Wheat grass, Phalaris and Fescue varieties, with no pure Ryegrass stands observed. Where mixed swards were present there was a legume (Clover or Lucerne) in conjunction with the grass species mentioned. Pastures containing legumes will be higher in protein content, and have been shown to result in increases in intake of 28% compared with grasses of equal digestibility (Minson 1971). Mixed pastures are also less likely to deteriorate in quality as the legumes take longer to reach maturity than many of the grasses, and their ultimate feed quality will not be as poor as that of the grasses.

Feed on offer affected the incidence of dark cutting significantly, with the only significant difference observable when FOO was greater than 3000kg DM/ha. Low FOO will increase grazing activity (Popp *et al.* 1997) and thus energy expenditure (Osuji *et al.* 1974), therefore resulting in impaired muscle glycogen accretion. A meta-analysis of dairy cattle rotational grazing experiments by Perez-Prieto and Delagarde (2012) reported that for FOO estimations based on sward height as measured from ground level, feed intake was increased by 1.7kg DM/day per tonne DM of initial pasture pre-grazing. This resulted in an increase in milk production of 1.23kg per tonne of initial pasture DM Perez-Prieto and Delagarde (2012). Meat and Livestock Australia's guidelines in the "More Beef from Pastures" guide quote 1500kg DM/ha as a minimum FOO, under which pasture:beef conversion will be compromised. However, it appears that the effects of declining pasture quantity, and increased cost-of-harvesting is present at much higher levels of FOO for cattle grazing pastures in South-East South Australia. Further quantification of the effects of FOO on grazing behaviour, intake and energy status at slaughter is required to determine appropriate guidelines.

Despite the effects of feed availability the broad range of feed quality measured, the chemical fibre, protein and energy content of pastures did not have an effect on DC in this study. This is an interesting finding as 75% of the sampled pastures would be unable to sustain growth rates of >1kg/day in a 550-600kg animals as per the requirements recommended by National Research Council (NRC) guidelines for growing cattle (National Research Council 2000). Whilst there is potential for selective grazing behaviour to allow animals to access a higher quality diet than the feed test suggests, the sheer volume of feed available to cattle had a greater effect on DC than the energy and protein content. Given the quality tended to be insufficient to maintain optimum growth rate, the advantages of greater FOO may be purely in reduced energy expenditure to harvest feed, and thus greater retention of energy for growth.

Pasture Magnesium concentration was the only compositional trait with a significant effect on the incidence of DC. Based upon the NRC's recommendation of 0.1% of dry matter intake for Mg, all pastures sampled in this study should have had adequate levels of magnesium (NRC 2000). However, it is quite common for hypomagnesemia to occur as a result of excessive levels of other dietary elements, primarily Potassium (K) (Ram *et al.* 1998; Schonewille *et al.* 1999; Spann *et al*. 2010). It can also be affected by high rumen concentrations of Calcium, Phosphorous (Schonewille *et al*. 1994) and

ammonia (Martens *et al* 1988). None of these potentially inhibitory factors were significantly related to DC when fitted individually, nor when fitted in a model with Magnesium. However, subtle inhibition of already marginal (albeit adequate) levels of Magnesium by these factors may have impaired glycogen accretion long term or led to a heightened stress response and increased glycogen utilisation during pre-slaughter processes. The presence of marginal liver magnesium levels indicates that some form of inhibition was likely occurring. Regardless of the exact mode of action, higher dietary magnesium resulted in a significant decrease in the incidence of DC.

Magnesium supplementation has been conducted in pigs (D'Souza *et al.* 1998; Dunshea *et al*. 2005), where it promoted consistent pH decline and a reduction in Pale, Soft, Exudative (PSE) pork even under stressful conditions. Supplementation of Mg to Merino lambs pre-slaughter has been shown to significantly reduce glycogen loss (Gardner *et al.* 2001). Conversely, Bass *et al.* (2014) supplemented steers and heifers for 14 days prior to slaughter with 0, 0.25, 0.5 and 0.75% dietary Mg and observed no difference in dry matter intake, ADG or carcass grading performance. There is evidently a finite balance between supplementation level and duration in order to achieve effects on either increased pre-slaughter glycogen accumulation and/or the reduction in stress response post-farm.

Copper status of the sampled animals was overall sub-optimal with all excluding one individual exhibiting liver concentrations that were marginal through to clinically deficient. This is not surprising given the extremely low levels of copper observed in pasture samples and the overall lack of additional supplementation by producers (Table 3.1). The effect of copper status on hydrogen ion concentration approached significance, but had no effect on the probability of an animal being a dark cutter in this data set. Nonetheless, such low levels of copper status will be having an effect on energy metabolism through its role in cellular respiration and haemoglobin. Until the carcass grading performance of cattle of adequate copper status can be quantified, the role of this deficiency in growth performance and carcass quality of pasture-finished steers cannot be disregarded.

The significance relationship between liver sulphur and the probability of DC is an unexpected finding. No published reference ranges for liver Sulphur concentration could be found. However, a meta-analysis of Copper status trials by Dias *et al.* (2013) reported the liver Sulphur concentration from 9 separate studies, with values ranging from 900-3000 mg/kg DM. In addition, Richter *et al.* (2012) investigated dietary S effects on beef cattle performance, reporting liver S concentrations of 6920 and 7000 mg/kg DM for yearling steers grazing Brome grass and being supplemented with low (0.2-0.3%) or high (0.5-0.6%) S supplements respectively. Based on the published values from these studies the values measured in this population are on the lower end of the spectrum but commensurate with the moderate dietary levels encountered.

Sulphur is required by many ruminal bacteria, particularly cellulolytic species (Spears *et al.* 1976) and is also a crucial component of the sulphur containing amino acids (cysteine, cysteine, homocysteine and methionine) and B-vitamins (biotin and thiamine) (Drewnoski *et al.* 2014). Cattle grazing forages will ingest sulphur through S-amino acids in forages, or as inorganic sources through water or through soil ingestion. Water mineral concentration was not measured in this study. The moderate levels of sulphur seen in the liver would indicate that levels are not excessive. In addition, soils in the limestone coast region, although variable in type, are generally low in Sulphur (Hall 2009). Supplements such as

dried distillers grains and molasses are also sources of high sulphur levels, however are not commonly used in extensive southern beef systems in Australia (Drewnoski *et al.* 2014).

Increasing dietary sulphur intake from 0.12-0.46% has been shown to linearly increase dry matter intake in steers (Spears *et al.* 2011), presumably due to the promotion of cellulolytic bacteria and the production of methionine. However, when supplemented as inorganic sources of S, intake and average daily gain will decrease by 0.43 and 0.08 kg/day for every 0.1% over 0.2% total diet S (Drewnoski *et al*. 2014).

Little work has been done in the area of carcass quality and Sulphur status, and that which does exist focuses on the effects at higher dietary inclusions. High levels of dietary sulphur have been shown to reduce carcase weight due to its effect on intake (Zinn *et al.* 1997; Loneragan *et al.* 2001; Spears *et al.* 2011). High S diets (>40%) also have an effect on post-mortem proteolysis activity of μ-calpain and thus reduced tenderness in the chilled beef product (Pogge *et al.* 2014). Further investigation of the response to Sulphur supplementation from low (<0.1%) to moderate (<0.4%) dietary inclusion in pastured beef systems is warranted.

5.1.2 Farm management and feed quality factors contributing to dark cutting in King Island

Contrary to our hypothesis, the grass tetany index did not impact the incidence of dark cutting beef, however pasture with Mg concentration above 0.24% did have a moderately reduced risk of dark cutting. The significant increase in dark cutting rate with low pasture Mg suggests that HypoMg may have been occurring in these cattle. HypoMg results from low reticulo-rumen availability of Mg or poor absorption. Dietary Mg on offer is low in grass dominant, short (<1,000kg DM/ha), rapidly growing pastures (Schonewille 2013; Mayland 1988). Solubility of Mg in Rumen rapidly declines as rumen fluid pH >6.5 (Goff 2014). Rumen pH tends to be higher in grazing animals due to high K of pasture, increased saliva production and high digestible protein diets (Goff 2014). The ammonia and ammonium ion end-products of excessive rumen degradable protein can increase the rumen fluid pH >6.5 (Schonewille 2013; Goff 2014). Absorption of Mg across the rumen wall is impaired by high dietary K (>3.0%) (Schonewille 2013). High ruminal K depolarizes the apical membrane of the rumen epithelium and reduces the potential of the Na-linked active transport to drive Mg across the rumen wall (Schonewille 2013; Mayland 1988). Pastures sampled were at mineral levels and grass tetany index consistent with high risk for HypoMg however did not have a significant effect. In contrast to our hypothesis the fact that low pasture Mg increased dark cutting independent of K suggests that reduced Mg intake underpins this finding rather than K-induced malabsorption of Mg.

The significant risk of water source on dark cutting is underpinned by previous research that has demonstrated there is a positive interaction between clean water source and forage intake (Hyder *et al* 1968, Willms et al 2002). Water is critical in forage digestion as rumen microbial attachment to feed particles is largely facilitated by the rumen fluid matrix (McAllister *et al*, 1994). Willms *et al* reported grazing cattle with a dam water source had a 23% reduction in weight gain compared to those with clean trough water access which may also be decreasing glycogen deposition. Water intake directly affects grazing habits (Willms et al 2002). Cattle with clean water trough access have been shown to spend longer time grazing compared to those with a faecal contaminated water

sources such as a dam (Willms et al 2002). Hence water source may impact dark cutting due to the water palatability impacting overall forage intake, weight gain and glycogen storage (Willms et al 2002).

The association between supplementary feeding and dark cutting in this study was not due to increased quality of feed on offer. The quality of the supplementary feed, evaluated by crude protein, water soluble carbohydrates, metabolisable energy, neutral detergent fiber and acid detergent fiber were lower than pasture on offer. The suggested mechanism of action of supplementary feed reducing dark cutting is reduction in stress response from improved human habituation.

The sex effect of heifers having reduced incidence of dark cutting compared to mixed mobs and steers was an unexpected and contradictory finding to other data sets (McGilchrist *et al,* 2014).

Evaluating the impact of pasture mycotoxins in a commercial survey trial presents many difficulties. Random sampling in a paddock may not capture the true mycotoxin exposure present. Further when there is little variability in mycotoxin exposure across the groups it makes it challenging to determine what the true impact on production is. Finally dose response risk levels of low, medium and high need to be interpreted with caution as they consider the effects of a single mycotoxin insult only, not what interactive impacts of multiple mycotoxins on physiology may be.

5.2 Assessed current industry compliance to fat and weight specifications using MSA data

The discussion of the compliance for fat and weight specifications is contained within the results presented in section 4.2. There is considerable discussion around the rates of non-compliance on a per plant basis (4.2.2.1), on a per feeding system basis (4.2.2.2) and the impact of carcase weight on fat depth (4.2.2.3). Please refer to these sections.

5.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

It is understandable that the uncoupling of meat colour and pH is a frustrating situation, however this data analysis indicated that the rates of uncoupling is quite low. Since meat colour does not influence the eating quality of the product, and that MSA is an eating quality guideline, the solution to the uncoupled pH and meat colour would be to remove meat colour from the MSA grading system. Furthermore, the data is observed to be biased against carcases with a pH of 5.7 and above. Its seems too coincidental that very little data is present after the MSA pH threshold, thus the data tested may not likely to be an accurate indication of the pH colour range. Thus the relationship between colour and pH seems to be represented in the industry data set to be correlated at the pH threshold, where a large amount of the data lies in the yellow and green zones in the tables described above and not in the zones where the uncoupling occurs.

To further investigate the occurrence of uncoupled pH and meat colour, a study that was undertaken (See appendix for attached paper) within this project set out to test a line of cattle being slaughtered at Plant E. These cattle in the previous couple of year had a large rate of uncoupled pH and meat colour and thus the opportunity to collect these samples was taken. The cattle travelled 20 hours from Alice Springs. There were very little dark cutters from this consignment nor mismatched cattle. None the less, slaughter blood was taken to test the packed cell volume, an indicator of dehydration, and the dry matter in the muscle was calculated. There were no differences between either of these measures, thus dehydration could not explain the dark cutting in this case.

Until now, an MSA minimum requirement of meat colour 1B – 3 was in place. There is now no evidence that meat colour has an impact on eating quality. Consumers do not visually discriminate against meat colours (greater than 3) at the point of sale, where pH is an acceptable level. The MSA Beef Taskforce endorsed the removal of meat colour as a specification for the MSA eating quality grading system in December 2016; however, this project reports on the influences of meat colour as contracted prior to 2016. The removal of meat colour as an MSA specification will have minimal impact on the MSA grading process. Other industry standards such as the AUS-MEAT grain fed specifications will still apply (meat colour 1B – 3). For grain fed carcases being MSA graded, this will need to be included as a company specification in the relevant PBR line.

Because of the lack of result, the study then sought to investigate if a meat colour 4 product colour be improved to be of similar standard to an MSA graded product through aging. Since aging meat results in less utilization of oxygen by enzymes post mortem and thus allows for a greater bloom on the surface, it is possible that dark graded meat could be within the MSA standard after aging. When dark graded meat was aged for 14 days the same redness, lightness and bloom depth as a 5 day aged MSA product was achieved during retail display. The pH of these dark non-compliant carcases improved during the aging period to become in line with the MSA guidelines. Carcases graded for MSA colour 4 costs the industry $36.7 Million annually and thus aging these products and regrading them could result in a MSA standard product and thus a huge economic benefit.

5.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

5.4.1 Effect of nutritional intervention on dark cutting

The results of this study have demonstrated that there were low levels of dark cutting in both WA and SA trial cattle compared to the previously seen rates (McGilchrist et al., 2014). It was hypothesized in this current study that as pasture quality declines the rates of dark cutting in both WA and SA in cattle offered a restricted grain supplement would halve, from what was historically observed at 10% to 5%. However, due to the unseasonably low rates of dark cutting in both the treatment and control cattle from both states across both years, the current hypothesis was not able to be tested. While dark cutting rates were not improved, the supplementary treatment increased the muscle glycogen levels in WA trials, while SA data was trending towards an increase, resulting in more than adequate glycogen levels to avoid dark cutting, thus proving our second hypothesis.

However, the effectiveness of lupins is questionable. Previous data shows that beef cattle are at risk of dark cutting when the muscle glycogen levels are below 57 µmol/g (Tarrant, 1989) which equates to approximately 1 g of muscle glycogen / 100 g of muscle. Warriss (1990) also indicated that a muscle glycogen level of 0.7 g/100 g is required to reach the MSA required pH_u of ≤ 5.7. Thus the low rates of dark cutting in this study are understandable since even the control animals had an average muscle glycogen concentration greater than this amount and therefore are not in the 'at risk' area of dark cutting.

Glycogen levels are highly correlated with the metabolisable energy content of the feed available (Gardner *et al*., 2001; Knee *et al*., 2004). It has been previously shown that supplementation with hay (approximately 8-8.5 MJ of metabolisable energy/kg DM) was insufficient in replenishing the glycogen stores in beef cattle post exercise compared to higher energy supplements such as barley (approximately 11.3 MJ metabolisable energy/kg DM) over a three day period (Gardner *et al.*, 2001). During the current trial, the pastures available had a higher quantity of metabolisable energy than the hay used to replenish glycogen stores by Gardner et al. (2001). Since the cattle in the current study were not exposed to conditions on farm that would cause the depletion of glycogen, indicates that these pasture levels were sufficient in maintaining the muscle glycogen concentration irrespective of the supplementation. However, there is no evidence that the pasture alone would be sufficient in repleting glycogen stores post exercise, or after a stressful event, as the current ME levels were in between those levels tested by Gardner et al. (2001) in their repletion experiment. An observed increase in muscle glycogen in the treatment cattle is indicative of greater metabolisable energy on offer. Since there was no variation in the quality and quantity between the treatment and control paddocks in either state this increase can be attributed to the addition of the supplementation provided.

In Western Australia, the pasture analysis indicates that the trials were held during the period of pasture decline, as indicated by the increase in ADF, NDF and DM. As DM increases, overall intake decreases as cattle reach their requirement for DM faster, while an increase in ADF and NDF is negatively correlated with digestibility and intake. This reduction in digestibility between spring and summer will impact on ME intake (Watson *et al*., 1980) and subsequently effect stored energy. Although the pasture quantity and quality was on the decline, this did not result in an increase in dark cutting. McGilchrist *et al.* (2014) observed that between 2010 and 2013 WA and SA the highest incidences of dark cutting in February and March, respectively. The current trial was conducted between September and December. The increased incidence of dark cutting later in the summer months may be a result of other factors in combination with pasture quality. Pastures need to be insufficient in quantity and or quality in order to impact on the muscle glycogen concentrations Watson *et al*. (1980), and during times of relative inactivity, may require several months of poor nutrition. This is also evident in the fact that an increased pH compliance is likely to be associated growth and better nutrition (McGilchrist *et al.*, 2012).

It is clear that there are large seasonal impacts on pasture quality, with decreasing amounts of available feed occurring in late spring early summer, especially in Mediterranean climates. It is also well known that extreme weather conditions and fluctuations in daily ambient temperature can induce a stress response in cattle, (Scanga *et al*., 1998) increasing the incidence of dark cutting as

well as having a negative impact on pasture. Intervening nutritionally, with high energy feed has been seen as an effective strategy to limit the loss of muscle glycogen and lower pH_u in cold and hot seasons (Immonen *et al.*, 2000). However, there were no extreme weather conditions throughout the current study and temperatures were moderate, ranging from a minimum of 8.6ºC to a maximum of 31.2ºC, with no rain recorded on the days of transport. There was no additional stress to cattle due to climate during the trial or the transportation process, which may further explain the unseasonably low rates of dark cutting in this trial. Because the historically observed peaks in dark cutting the WA and SA regions are later in the summer, these could be a result of decreased pasture quantity and quality combined with unfavourable weather conditions. However further investigation is required into these effects for the southern regions of Australia.

Acclimatisation of cattle with short periods of human contact can minimise the stress caused and subsequently result in a more docile animal (Le Neindre *et al.*, 1996). Pre slaughter handling practices can attribute to reduction in the stress associated with handling in the pre slaughter period and subsequently have an increased glycolytic potential (Lensink *et al.*, 2001). The cattle in this trial were yarded twice in the lead up to slaughter to measure start and end weights which may have contributed to the acclimatisation of the cattle to people and handling. Pasture fed cattle are not often exposed to this amount of handling, and could be reason the current study had a lower rate of dark cutting than expected.

The resting muscle glycogen of cattle typically ranges from 1.1 to 1.8 g/100 g (Tarrant, 1989). Warriss (1990) demonstrated that a muscle glycogen concentration of approximately 0.7 g/100 g is sufficient to reach an pH_u of ≤ 5.7, however cattle will be at risk of dark cutting when levels are below 1.0 g/100 g (Tarrant, 1989). To deplete the glycogen levels in cattle to 50%, cattle only require to be exercised at an intensity equivalent to 65% VO_2 max for 5 X 15 min periods (Gardner *et al*., 2001). In the case where cattle were exposed to pre-slaughter stressors that resulted in an approximate decrease by 50%, a resting muscle glycogen level of above 1.4 g/100 g would be required make sure the limit of 0.7 g/100 g was not reached. In the current study, glycogen levels taken at slaughter were not representative of resting concentrations. The treatment animals in WA had a mean muscle glycogen of 1.35 g/100 g. Considering the narrow range where carcases will be at risk of dark cutting, an increase in muscle glycogen of 0.13 g/100 g compared to the control animals could be enough to buffer the animal against pre-slaughter stressors, and hence an increase in MSA compliance. None-the-less, it is imperative that stress pre-slaughter should be kept to a minimum and that animals are coming of a high plane of nutrition to reduce the rate of dark cutting.

There was an observed relationship between indicators of fatness and muscle glycogen and pH measurements. As marbling increased, so did muscle glycogen at slaughter in WA cattle, while and an increase in rib fat resulted in lower muscle pH_u in SA cattle. The increase in marbling is associated with fatter cattle, which is usually an indicator that the cattle had access to a high level of nutrition, which would result in increased stored energy. This effect was only seen in WA. In SA carcasses with a higher depth of rib fat had a lower pH_u, thus cattle with a higher depth of fat at the ribbing site are associated with a higher rate of pH_u compliance. The relationship between rib fat and pH_u, like marbling and muscle glycogen is likely to be associated with nutrition, as cattle on a higher plane of nutrition are generally fatter, however there was no relationship between the treatment and control groups in SA on the effect of rib fat on muscle glycogen. Previous studies have suggested that fatter cattle are more adrenalin sensitive and thus utilise glycogen pre-slaughter at a greater rate which

could attribute to the correlation between rib fat and pH_u but not muscle glycogen (McGilchrist et al., 2012). The nutritional intervention in this trial was too acute to impact on the marbling and rib fat thus indicating that the impact of supplementation is maximised on cattle that are already in good condition.

5.4.2 Muscle Glycogen and pH

A cubic polynomial equation was used to describe pH and muscle glycogen data (R-Squared 0.484, RMSE 0.071; Fig.5.1). From this equation, the minimum muscle glycogen requirement for reaching a pH of 5.7 and below is 0.8g/100g. Under this scenario an increase in muscle glycogen of 0.1g/100g would improve the carcass pH by about 0.08 pH units in the pH range of pH 5.78 to 5.70. In the current data set 14 carcases fell into this zone (not all had glycogen measured). However, half of these were already in treatment group, thus only a possible seven carcases from the control groups would likely have a MSA graded pH if glycogen was to be increased by 0.1g /100 g, a total increase of 1.2% in compliance. When applying this logic to the three years of MSA data from the southern plants (2011-2013), then 16,387 more carcases would be compliant for pH (Table 5.1), an improvement of 1.7%, due to the increase in muscle glycogen levels.

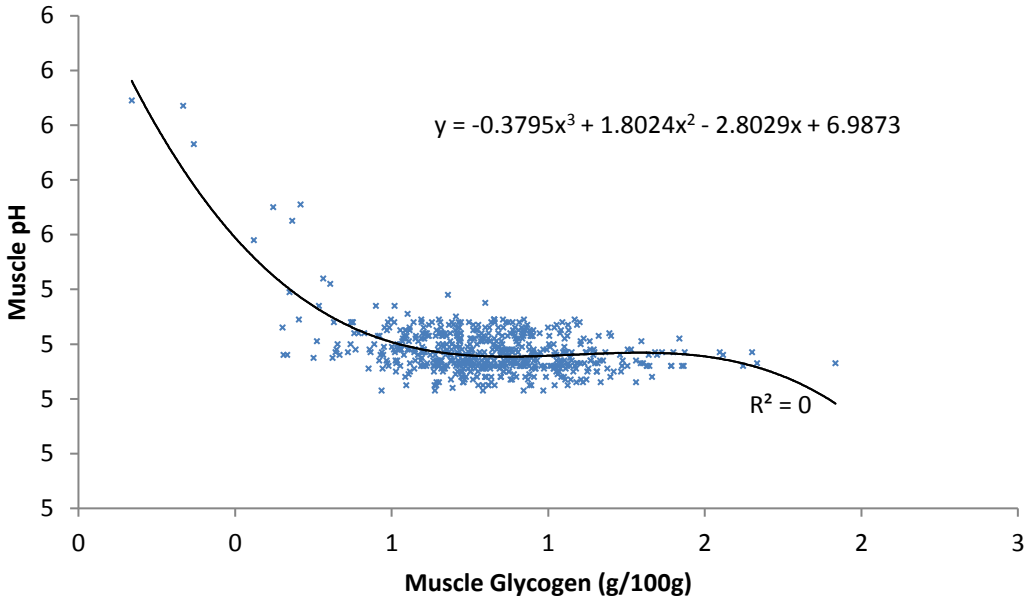


Fig.5.1. The relationship between muscle glycogen and muscle pH at grading. A cubic polynomial equation was fit to predict muscle glycogen in the southern compliance from the MSA pH.

However, when modelling the current data set, it is clear that the carcases with a pH of between 5.84 and 5.71 had a highly variable glycogen concentration that was above the previously published levels of being at risk of dark cutting. The nine carcasses in this pH range had a mean glycogen content of 0.95±0.069 g/100 g with a min and max of 0.67 and 1.29 g/100 g respectively. Either the

at risk zone of muscle glycogen at slaughter has shifted to be higher or that these "darker" or higher pH carcasses have not actually reached ultimate pH at the time of grading, with the likelihood of still having substrate left for more production of lactate. In the case of the latter, this would mean a slower post mortem metabolism, either a genetic effect or a result of faster chilling rates, hence slower metabolism. It is a strong indicator that more research needs to be undertaken to understand the variation of the time at grading for those carcasses within 0.1 pH units of being compliant. Additionally, a greater understanding of the at risk muscle glycogen concentration for non-compliance cattle is needed, with the increased collection of muscle glycogen and pH data to compile into a large data set based on the present day beef cattle.

Table 5.1. Number of dark cutting carcases per year from grass fed cattle in the southern plants based on the state the cattle originated from, that would benefit from an increase in muscle glycogen stores of 0.1g/100g.

State of origin	*2011*	*2012*	*2013*	
NSW	6	51	316	
SA	214	849	6185	
TAS	499	895	2351	
VIC	46	584	1830	
WA	438	871	796	
NT	na	na	423	
QLD	na	na	33	
Total	***1203***	***3250***	***11934***	**16387**

5.4.3 Effect of treatment on HSCW

There was no increase in liveweight in WA cattle, however there was in SA, and thus our final hypothesis that nutritional intervention would increase liveweight gain was partially accepted. However, the increase in liveweight in the SA cattle, although analysis was adjusted for by starting weight, may be biased based on the fact that control animals were older (higher OSS) and less muscled (lower EMA), resulting in a slower growing animal. There was an increase in HSCW of 2.72 kg observed in the WA treatment cattle compared to the control cattle, although this was not seen in SA (trended towards 1.74 kg increase). The large increase in HSCW in WA but not SA may be attributed to the use of different feed types across the treatment groups. In SA lupins provided an additional 22 MJ ME/head/day while the pelleted ration used in WA provided approximately 33 MJ ME/head/day. The pellets used in WA had the addition of 37 ppm of Bovatec®, a rumen modifier that promotes an increased feed efficiency (Lomas, 1982). The increase in HSCW of 2.94kg compared to the control group is the result of feeding the cattle for only 14 days, highlighting the

improved efficiency of Bovatec®. Thus the additional provision of ME along with Bovatec®, could account for the increase in HSCW seen in WA.

5.4.4 Cost benefit analysis of nutritional intervention

This study has shown that restricted supplementation in both WA and SA was effective in increasing the muscle glycogen levels at slaughter, thus can potentially decrease the rate of dark cutting in 'at risk' cattle. Aside from being effective, it is critical that the nutritional intervention is economical for producers to implement.

While the aim of this study was to level out the nutrition of pasture fed cattle in times of pasture decline in order to maintain high muscle glycogen levels and subsequently reduce dark cutting, the cost associated with feeding grain supplements or a total mixed ration is generally uneconomical for producers. This is why the experiment focused on using a restricted supplementation of 25 MJ ME/head/day.

In WA, feeding cattle 2.5 kg of Milne Feeds Vitalize pellets cost producers $AU1.08/head/day. Over a 14 day period this would cost producers $AU15.12 per animal (based on a price of $AU432/t). This price is over estimated due to the additional cost of getting the pellets pre-packaged into 25 kg bags for the ease of producers in the feeding trial. With the increase in HSCW seen in WA of 2.72 kg, a beef price of $AU5.15/kg HSCW would cover costs of purchasing the feed for producers. In order to cover costs, through the reduction in dark cutting, producers would require an increased compliance of 8.5% to cover the feed costs in WA and 7.9% increased compliance in SA (assuming a HSCW of 300 kg with average penalties of $AU0.59/kg for dark cutting). Currently the rate of non-compliance due to dark cutting in southern processing plants is 6.52% for pasture fed cattle. it is unlikely for producers to cover the feed costs from dark cutting alone and thus the added HSCW makes this intervention economically viable.

5.4.5 Further Research

While this project initially aimed to test a large number of lots with an emphasis on capturing data on dark cutting carcasses throughout the change of season, many challenges arose. Due to high winter rainfall and then an early break of season which saw September and October being particularly dry and hot (Meteorology, 2015b, a) producers in the area offloaded cattle early and didn't have pasture fed cattle on hand to capture the numbers initially sought after. As a result we only tested 13 lots in WA and seven lots in SA in 2015. In 2016 the season was described as very good with large amounts of feed on offer and a wet winter and late spring rainfall which helped maintain high pasture levels and most pastoral cattle were sold before pastures turned off. It may also be beneficial to the industry to investigate the greatest peaks of dark cutting towards the end of summer. In the current study it was extremely difficult to locate producers that had grass fed cattle going to slaughter during the late summer that were not from irrigated paddocks. An audit of the grass fed cattle coming in during the summer in the southern regions may be necessary to understand the scope of the dark cutting rates during this period.

There is a requirement for further research based on the preliminary findings of this study. Moving forward analysis on the two treatment types on the same property would be beneficial to see the impact of the treatment on HSCW as this varied greatly between the two states. The increase in HSCW in WA is an important aspect in relation to nutritional intervention being economically viable, thus it would be necessary to see these results on a larger scale.

It has been seen that feeding for three days post exercise is sufficient time to replenish muscle glycogen after exercise (Gardner *et al.*, 2001), and supplement feeding for at least one week can substantially increased the muscle glycogen levels (Pethick *et al*., 1999). However, due to constraints such as adaptation to the feed and the variability of metabolisable energy of different supplement feeds further studies regarding the optimum feed type, quantity of feed required per head per day and the length of nutritional intervention would be required to maximise productivity and profitability for producers.

5.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

5.5.1 Possibilities for MSA yield grade predictions

The above discussions have highlighted a number points in which the Australian beef industry should take into account when developing a yield predicting equation to compliment the MSA quality grade.

Firstly, current point measures available should be regressed to provide the best equation accuracy. Clearly, a greater combination of point measures to represent possible differences in yield to improve accuracy would be beneficial, however currently MSA only have about 4 suitable measures. These being hot carcass weight, marbling, rib fat and eye muscle area. Ultimately, the use of VIA cross sectional measurements would improve consistency and accuracy; however this may not be a possibility.

Secondly, MSA has information available on breed contents, hormonal growth promoters, physiological age and sex, all of which could influence deposition rates of tissues. These should be tested on the effect on the accuracy of prediction equations.

Thirdly, the question remains on whether to grade or classify carcasses or grade then classify. Certainly grading a carcass based on % muscle will be the final outcome and the basis of carcass value, however it is how this grade is obtained that is an uncertain. Currently, different plants will use proxy cut-off values of weight and rib fat to reward or penalize carcasses and in a way is an example of classifying carcasses but in no way is a true representation of % muscle or true carcass value. At present processors and producers are satisfied with this level of classification.

Different equations are required for differing physiologies within cattle. Poor accuracies have been returned between fat and lean carcasses and heavy and light weight. It would seem obvious that carcass classification account for fat and weight groups before a prediction equation is applied.

5.6 Genetics of BREEDPLAN carcass traits and meat eating quality

5.6.1 Investigating relationships between market end point and expression of carcass traits associated with eating quality

The positive correlations observed between lot mean HSCW and lot mean Marbling and between lot mean Marbling and variation (SD) in Marbling (Table) have important implications for the expected magnitude of the regression of carcass traits on BREEDPLAN EBVs. Lots with higher mean carcass weight (finished to a heavier specification) or higher mean Marbling (feedlot-finished or finished to a heavier mean HSCW) would be expected to have higher EBV regression coefficient estimates, for example Marbling on IMF EBV because of the greater variation (SD). This would subsequently flow to varying predicted effects for MSA Index for a 1% increase in IMF EBV.

Some scale effect on the variance was observed for all traits except EMA, i.e. increasing within lot variance with increasing within lot trait mean. This effect was most apparent for Marbling and Rib fat depth. Increasing lot mean for Marbling had a moderate positive correlation with Marbling variation within a lot of 0.54 with a comparable correlation of 0.53 for Rib. Correlations for lot mean HSCW with variation in HSCW (0.34) and mean ossification with variation in ossification (0.29) were moderate. Zero to low correlations were observed for MSA Index and EMA. These correlations are informative as they indicate higher lot-mean for Rib and Marbling appear likely to be associated with increasing phenotypic variance within lot. If heritability remains stable across market end point or finishing regime (see section 1 of this report) but the phenotypic variance increases, then the regression coefficients for EBVs on key traits influencing MSA Index will vary.

The scale effect was also evident for HSCW and ossification but to a much smaller extent. For example, a simple correlation indicated that 29% (or 0.54^2) of the variation in Marbling at the lot level could be accounted for by lot-mean Marbling. This was only 12% for HSCW and 8% for ossification.

The results presented must be considered in the context that the information used to inform grouping of carcasses (lot). Lot was a concatenation of producer, processor, HGP use and kill date with some data editing to remove obvious outliers (where lot variance and minimums, maximum and range in data where beyond plausible for a lifetime contemporary group are not likely truly reflective of phenotypic variance observed in structured trials). Potentially, stock from varying backgrounds may be grouped together resulting in increased variance relative to that which would have been observed had animals been maintained in contemporary groups throughout life. In contrast, larger scale producers may manage and sell multiple lots through a season as animals reach target market specification, for example drafting off animals that have reached market specification for weight. This would reduce variance compared to what would be expected had drafting not occurred. However, despite the shortcoming in not be able to assign ‘true’ lifetime management groups to more accurately quantify the phenotypic variation, the data appear a sound representation of the mean and variation observed (as discussed below). This can provide confidence in interpreting the correlations between trait mean and variance.

The mean standard deviation within a lot for a given trait was very similar to the phenotypic standard deviation for both the Regional Combinations carcasses (see previous section of this report) and also by Reverter *et al*. (2003) for feedlot- and pasture-finished animals (Table). For example, the mean SD within a lot for this data was 21.3 for HSCW compared with a range in phenotypic SD from Reverter *et al.* (2003) and Regional Combinations data of 21.3 – 28.8. For Rib fat, the mean SD within a lot for this data set was 2.5 which is very similar to the phenotypic standard deviation reported by Reverter *et al*. (2003) for both feedlot- (2.80) and pasture-finished (2.17) animals at similar mean carcass weight to that observed in this data set. Similar standard deviation was observed across data set for ossification (13.5 vs. 15 and 16), EMA (7.2 vs. 7.6 and 6.7) and for Marbling (63 vs. 57 and 64). Based on these similar estimates of phenotypic variation at similar mean carcass weights, it appears reasonable to infer likely outcomes for changing EBV regressions based on lot mean HSCW and Marbling. Further research data sets with carcasses finished at higher weight and Marbling specifications will be accessed to provide additional estimates of phenotypic variance across a range of heavier market end points close to the maximum represented in this data set (up to 450 kg carcass and lot mean Marbling of 600).

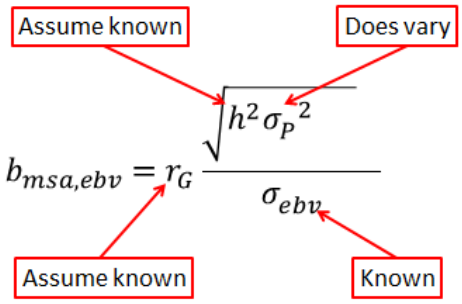
Table 5.2. (Phenotypic) Standard deviation observed in MSA data set compared with feedlot- and pasture-finished animals in southern Australia from two research herd data sets.

	MSA data set	Reverter *et al*. (2003) feedlot	Reverter *et al*. (2003) pasture	Regional Combinations feedlot	Regional Combinations pasture
HSCW	21.3	23.7	21.3	28.8	24.0
Rib	2.5	2.8	2.2	3.7	3.2
Oss	14			15	16
EMA	6.1			7.6	6.7
Marbling	62			57	64

Why is this information important?

To establish the regression between EBVs and MSA Index (& MSA carcass traits) requires knowledge of the genetic correlation between the MSA trait of interest and EBV, the heritability of the MSA trait, the phenotypic variation in the MSA trait and the variation in EBVs (Equation 1). As described in section 1 of this report, it is expected the genetic correlation and heritability of carcass traits are the same whether animals are feedlot- or pasture-finished. However, in each section of the milestone it has been shown that phenotypic variation is associated with finishing system and/or lot mean carcass weight and/or MSA Marbling. If it is assumed the genetic correlation is 1.00 (very high genetic correlations were reported in Table), the heritability of MSA Marbling is 0.32 (average of heritability for feedlot- and pasture-finished in Table) and the SD of IMF EBV is between 0.7 (Lee *et al*. 2017) and 0.81 (Table 9.1 Appendix 9.1), but the phenotypic variance in MSA marbling alters from lot-mean ± 1 SD (Table 5) then the EBV regression changes. The regression at the mean lot SD for Marbling (62.2) is a mean of 49.9 points increase per 1% increase in animal IMF EBV. At one SD lower than average than lot-mean SD for Marbling (32.4) the regression is 26 points / 1% increase in animal IMF EBV. At

one SD higher than lot-mean SD for Marbling the regression is 74 points increase in Marbling per 1% increase in IMF EBV. This has obvious significance for flow on effects to MSA Index change per 1% increase in EBV.



Equation 1. Establishing the relationship between BREEDPLAN EBVs and MSA Index and MSA carcass traits.

5.6.2 Relationship between BREEDPLAN EBVs and meat eating quality

Carcass performance was greater for carcasses from sires with higher BREEDPLAN EBVs although the specific relationships varied between trait and market endpoint and breed in some cases. Higher than expected regression coefficients were observed when IMF% on IMF EBV, Rib Fat on Rib EBV and EMA was regressed on EMA EBV, under a Long feeding regime. Conversely, lower than expected regression coefficients were observed under Short-fed and Pasture finished cattle. An increase in sire IMF EBV of 1% is expected to result in an increase of progeny IMF% of 0.5% given half of the genetics are from the sire. Given that an increase of 50 points in MSA Marbling is associated with an increase in IMF of approximately 1%, it is expected an increase in sire IMF EBV of 1% would be associated with a 25 point increase in progeny MSA Marbling**.** For Angus the regression was not significantly different from expectation however, for Hereford and Limousin the regression coefficient was significantly lower than 25. Further, the Long finished regression coefficient was significantly higher than 25 (36.7 ± 2.4) whist the Short and Pasture coefficients were significantly lower (7.6 ± 2.4 and 8.9 ± 2.7, respectively).

The results for Short finished cattle align with results reported by Barwick et al. (2005) who reported a regression coefficient for MSA Marbling on IMF EBV of 14.3 ± 2.7 for steers that were feedlot-finished for 120 days. There was a large effect of IMF EBV on MSA Index for grain finished and only a small effect for Pasture and Short finished cattle. For Angus, X1 standard deviation (SD) increase in IMF EBV is 0.81% (Table *9.14*9.1 Appendix 9.1). Therefore, X1 SD unit increase in sire IMF EBV was associated with approximately a 30 unit increase in MSA marbling or a 0.28 unit increase in MSA Index for Long feedlot-finished cattle relative to a 6 and 0.08 unit increase in Pasture finished cattle (Table 9.2). These results should be considered in the context of the Australian Meat Industry Strategic Plan (MISP) where the goal is for a two unit increase in MSA Index by 2020 and 5 units by 2030. Single trait selection of bulls from the top 10% of Angus sires for IMF EBV (currently the top 10 % = +2.9 % and breed average is +1.6 %; Angus Australia, 2017), will result in 0.65% superiority in IMF EBV in progeny. This would only deliver a 0.08 (Pasture) and 0.22 (Long) unit increase in MSA Index. Assuming a five-year generation interval, single trait genetic selection for IMF will only get the industry approximately 10% of the way to 2030 target. Notwithstanding the importance of continuous genetic improvement, improvement in MSA index should focus on management than genetic strategies.

As expected, there was a much greater variance for long-fed than pasture fed cattle. The low variance for pasture finished cattle led to carcasses reflecting less sire superiority than expected (0.5). Thus, breeders are not likely to capture the full benefits of buying superior sires unless they retain ownership through to heavier finish weights or are paid a premium by the finishing or wholesale meat sectors where the benefits are captured. While direct comparisons could only be made between Short-fed and Pasture finished carcasses, the results herein demonstrate that the cause of this is not due to major differences in heritability or genetic correlation (Table), rather due to the very substantial change in phenotypic variance as hypothesised.

For most traits the sire variance under a Long-fed finishing regime was significantly higher than Pasture finished cattle (Table 4.49). The exceptions were ossification and MSA Index where the sire variance of the Short-fed cattle were higher than both Long and Pasture finished cattle. For HSCW, EMA, Rib Fat, and MSA marbling, the sire variance for Long-fed animals was between 4 and 6 fold higher than pasture finished cattle. The difference for IMF was even larger, however there were fewer animals with IMF measured. The sire variances were larger than those estimated by Reverter *et al.* (2003) for temperate beef breeds. It was hypothesised that despite genetic correlations for marbling between various end points and finishing regimes being close to 1 the regression may change substantially depending on the variance in MSA marbling. Where there is low variance the regression coefficient of MSA marbling on IMF EBV is expected to be lower, in contrast where there is higher variance the regression coefficient is expected to be higher. There appears to be systematic differences (increases) in variance of traits of interest such as MSA Marbling and IMF for heavier carcass weights or faster growth paths. This highlights the importance of considering higher carcass weight when estimating breeding values.

5.6.3 Genetic parameters between current BREEDPLAN traits and meat eating quality traits

The genetic correlations between Pasture and Short-fed finishing systems were high (>0.80) for pH, HSCW, Ossification, MSA Index, P8, and EMA (Table 4.50). This is consistent with those observed by Reverter *et al.* (2003) in temperate beef breeds. A genotype by environment (GxE) interaction is not considered significant if the correlation between the same trait under different finishing systems is greater than 0.80 (Robertson 1959). There would appear to be a significant GxE for IMF and potentially Rib and MSA Marbling. This is in contrast to Reverter *et al.* (2003) who estimated the genetic correlation between domestic and export market endpoints of 0.92 and 1.00 for IMF and Rib. Estimates between pasture and long feedlot finished cattle were unable to be estimated but it is expected that the difference between these two finishing systems would be even greater given the results from the EBV regressions and sire variance.

The MSA index was very highly genetically correlated with IMF (0.82), MSA marbling (0.90) and PEQ-sl (0.99). Since the weighted proportions of each muscle is constant (i.e. independent of yield) it is not surprising that the index and the predicted eating quality of the striploin (one of the 39 cuts to inform the MSA Index) are genetically the same trait. IMF and MSA marbling were very highly genetically

correlated (0.97) implying that they are almost the same trait genetically. Therefore genetic selection for IMF will increase MSA marbling and MSA index. Ossification and pH were both negatively genetically correlated with the MSA index (-0.60 and -0.34 respectively) despite being lowly heritable. It is well established that there is an antagonistic relationship between animal maturity and meat tenderness (Shorthose and Harris 1990; Schonfeldt and Strydom, 2011, Weston et al. 2002) driven by changes in collagen cross-linkages. The MSA system uses ossification as one of its parameters for prediction of the MSA index (Polkinghorn *et al*. 2008). It was not surprising that the there was a negative phenotypic and genetic correlation between ossification score, an indicator of animal maturity, and the MSA index. Similarly, pH is used by the MSA system to predicted eating quality, where penalties apply when ultimate pH is greater than 5.7.

When the genetic correlations were estimated separately for Short and Pasture finished cattle there were no differences in magnitude or direction except between MSA marbling and EMA. This is not surprising given the regression of MSA indicator traits and carcass traits on BREEDPLAN sire EBVS were similar between Short and Pasture finished cattle. Differences in genetic correlations between carcass traits and meat eating quality traits may have been larger between Long feedlot finished cattle and pasture or Short-fed cattle since the sire variance and EBV regressions were significantly higher in Long-fed cattle. Further pedigreed carcass data is required where sires have progeny that are both Long-fed and Pasture (or Short-fed) to determine if there are any significantly different genetic correlations between BREEDPLAN carcass traits and meat eating quality traits.

6 Conclusions/recommendations

6.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

6.1.1 Farm management and feed quality factors contributing to dark cutting in South Australia

The results of this scoping research have highlighted a number of risk factors for increasing the incidence of dark cutting in pasture-finished beef. The results indicate that to maximise carcase grading performance, animals must be slaughtered in their first spring (under 18 months of age) from a mixed legume/grass pasture which they have been introduced to between 7-14 days before slaughter. Target FOO during the final week pre-slaughter should be a minimum of 2000 kg DM/ha so as not to limit feed intake. Stock may be yarded the night before transport to the abattoir and either completely fasted or provided a source of roughage such as hay.

Although the availability of magnesium in pasture appeared desirable, the reductions in DC observed as its concentration increased suggest inadequate absorption of the mineral, and the need for supplementation regimes. Further investigation into the extent of magnesium deficiencies, its effect on muscle glycogen metabolism, stress response and the required supplementation protocol pre-slaughter is warranted.

Liver mineral status revealed a high prevalence of copper and zinc deficiencies, which although did not have a significant effect on carcass pH in this data set, will be impairing growth performance of cattle significantly. The significant effect of sulphur status on the probability of dark cutting requires further investigation to determine whether it is feed intake, digestibility or post-mortem proteolysis effects that are driving the response in carcase pH observed.

Whilst a number of these contributing factors are known to have an effect on carcass compliance, their presence in this study indicates that further work needs to be conducted educating producers about the effects of management on performance of pasture-finished cattle.

6.1.2 Farm management and feed quality factors contributing to dark cutting in King Island

The results show that the grass tetany index did not impact dark cutting, however increasing pasture Mg above 0.24% decreased the risk of dark cutting. Providing good quality clean water from a trough, free from faecal contamination is important in maximising feed intake and glycogen storage thus reducing the incidence of dark cutting. Further investigation of the mechanism why supplementary feed of inferior quality to available pasture reduces incidence of dark cutting is required. Habituation to humans is important to reduce stress with transport and lairage handling. The optimum preparation type and level is still unknown. Supplementation with lower quality feed may also slow down rumen passage rate or the high fibre might increase the heat of fermentation lowering energy use for heat production. Improving water palatability, providing supplementation and monitoring pasture magnesium can help reduce dark cutting and thereby minimise its large economic impact on the beef industry. Characterising the true impact of mycotoxins consumed by grazing cattle on the incidence of dark cutting is challenging. This survey identified high mycotoxin prevalence in *L. perenne* dominant pastures from commercial beef properties plus highlighted that exposure is impacting dark cutting. Care must be taken interpreting mycotoxin levels as they may not represent the true magnitude of production impact especially when there are multiple toxins present (Lean *et al.* 2016). Further research is required to determine cost-benefit analysis of mycotoxin mitigation strategies in the commercial setting.

6.2 Assessed current industry compliance to fat and weight specifications using MSA data

The MSA system facilitates further understanding on the effects of non-compliance and carcass quality. It is imperative that data in the MSA system is as complete as possible and that any carcass presented at slaughter is included regardless of compliance. The investment that MLA and the stakeholders make into research programs like the southern beef compliance project, allows for the continual improvement to the production of beef cattle by furthering our understanding of what influences compliance rates. The correct collection of MSA data as well as the development of a yield measurement technology, which could remove the human variation in fat measurements, is important and requires:

1. Present rib fat and weight graphs to each processor individually and discuss feedback of this in relation to the company grid.

2. Discuss with Plant 3 the consistency in the rib fat depths which don't mimic bovine biology. This will hopefully result in possibly ways to rectify this issue.
3. Correct collection of data is important for the monitoring of MSA data and further understanding the compliance of fat across the southern region, thus this should be delivered to industry in the form of workshops for graders and producers.
4. Monitor the input of all MSA data, including feeding system at the plant level
5. Continue to monitor the impact of season variation particularly in the pastoral dependent areas. Considering in Tasmania the spike in non-compliance for dark cutting is in different seasons to the spike in fat depth.
6. Further investigation into light weight cattle is required, including the actual rates of these cattle being slaughtered, as it is likely that these cattle have a higher fat non-compliance and dark cutting risk.

6.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

Recommendation 1: Improving the accuracy and consistency of the MSA pH recorded

- The measurement of meat pH requires a rigorous approach. The prescribed pH meters and glass probes currently used by MSA graders are the best available for meat but protein generally accumulates in the porous glass probes (especially at the reference junction and glass membrane) blocking the transfer of hydrogen ions. It is therefore **necessary to ensure probes are cleaned on a regular basis**. Cleaning must be performed with a weak hydrochloric acid/pepsin solution.
- **Calibrate the pH meter correctly and at the correct temperature** (to those temperatures the meat is expected to be - pH buffer standards should be kept chilled). Calibration of pH meters using buffers at office temperatures will cause for inaccurate measurements of pH at 0 to 12 ^{o}C, regardless of the pH measurements taken by the meters being adjusted using Bendalls equation.
- The measurement of pH in meat is not greatly accurate due to variations in temperature and thus accuracy greater than 1 decimal place is not possible (Honikel, 2004). **MSA should re-evaluate the use of two decimal places when recording pH and consider using a value to a single decimal**. This would mean that any carcases with a pH less than 5.75 would be compliant as long as the colour is 3 or less. It has been shown that consumers do not negatively discriminate against high pH meat (Carpenter *et al.*, 2001; Jeremiah *et al*., 1972; Viljoen *et al*., 2002), thus weakening the pH restrictions to 5.74 should not affect the eating quality as long as colour is compliant. However, pH should still be restrictive due to microbiological requirements and the effect of high pH on the degree of doneness.
- **A method should be set for re-grading carcases and used uniformly across all plants**. Re-grading is likely and important way to not penalise producers because carcases were graded too early after slaughter and have not yet reach the ultimate pH. Workshops for AUS-MEAT trainers and MSA graders to explain the influences of pH on meat quality and the impact of stimulation, temperature and time of grading on pH is encouraged**.**

Recommendation 2: MSA consider employing the use of instrumental colour measurement

- For statistical analysis purposes, testing pH to two decimal places against a colour score system (with nine possible scales) is going to result in falsified correlations as the colours are all grouped and not evenly distributed across the colour range. **MSA should consider employing the use of instrumental colour measurement** such as a Minolta chronometer, NIX or Hunter lab or even an App on an apple or android device. Validation of this measurement versus the colour chips would be required. Instrumental grading would reduce the subjectiveness of colour grading.

Recommendation 3: Re-assess time of grading guidelines

- Time of grading is also worth analysing for its effect on non-compliance. Hughes *et al.* (2014) has suggested that extending the time between slaughter and grading will lower the incidence of dark cutting and thus **the regulations on the time of grading for MSA carcasses should be re-evaluated and lengthened**. At present AUS-MEAT has two very crude requirements for the time of grading.
    - Carcasses with electrical stimulation: eight hours minimum between slaughter and grading
    - Carcasses with NO electrical stim: 18 h minimum between slaughter and grading
- In the future, the impact of time after death on the colour and pH grade for each carcass will be analysed following on from the work of Hughes *et al*. (2014). At grading, it is likely that a number of carcases will be yet to reach their ultimate pH and thus could result in some carcases having a higher than expected pH or darker colour. A way to test this in the current data set would be to analyse those carcases that are graded after a weekend compared to those that are graded the next day.

Recommendation 4: Re-assess bloom time guidelines

- Furthermore, the extent and rate at which meat from carcases bloom will vary depending on temperature and even metabolic activity. It is likely that **greater time is required to allow for carcases to bloom at the quartering site** than what is currently allowed in some plants. This could also be re-evaluated in the MSA protocols. Further studies are required to determine the impact bloom time on grading of colour so that producers are not penalised for DFD carcasses when it is only a blooming issue. The time to bloom could be the cause of the observed "uncoupling" of pH and meat colour especially seen at Plant E (Table 4.19). **Carcasses should be also be allowed to be graded for up to 6 h after the loin is quartered.** Current protocols are that after two hours, the loin needs to be resurfaced and bloom again, but it is well known that the loin will continue to get redder for six hours.

Recommendation 5: Analysis of Aussie Blue and Beef CRC data sets

- The Aussie Blue and Beef CRC data sets be utilized to investigate the occurrence of uncoupled pH and meat colour data. The analysis of data sets that have no commercial bias and have consistent grading could indicate the normal occurrence of pH and meat colour uncoupling plus indicate what factors impact on the rate of uncoupling. The commercial MSA data from the southern plants analysed has indicated that the rate of uncoupling is low which needs to be verified by other research data sets of MSA graded carcasses.

Recommendation 6: Non-compliant meat colour and compliant pH

- MSA could also consider treating carcasses with a meat colour scores of 4 differently as long as they are in the correct pH range, ie displayed under MAP to allow for a better bloom development or given longer time to bloom before grading (Regrading). Because high pH meat has a higher incidence of microbial spoilage, the threshold for pH should be strictly adhered to (although adjusted due to a decrease in decimal place measurements), however if the colour of dark meat with good pH could be improved some lenience could be applied. Further investigation into the blooming of such meat is warranted.
- It has been shown that ageing these products will result in improved pH and colour scores. This could eliminate all penalties received from colour 4 carcases and be worth $36M a year.

6.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

The nutritional intervention using commercial pellets rather than lupins was effective in increasing muscle glycogen stores of the treatment cattle at slaughter despite there being no reduction in dark cutting. This result could prove to be beneficial in increasing the compliance of cattle which are at risk of dark cutting. In WA, the increase in HSCW despite no increase in weight gain was important for the nutritional intervention to be economical however this was not seen in the SA lupins treatment. The use of commercial grain based pellets would not be viable in SA due to PCAS regulation. We currently recommend the use of commercial pellets to help cover the shortfall of energy in pasture during early summer to late summer as a possible means to prepare cattle against a risk of dark cutting.

Magnesium supplementation for cattle grazing short rapidly growing lush pastures is considered to be beneficial to maintain high levels of daily magnesium intake. The cattle need to be well trained to consume feed from a trough prior to the 7 day supplementation period pre-slaughter. The supplementation also needs to ensure significant quantities of unpalatable magnesium oxides and magnesium salts can be consumed without consumption issues.

6.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

1. The MSA measurements, left side hot standard carcase weight, marbling, eye muscle area, rib fat and ossification can describe the percentage muscle of a carcass to a high level of accuracy even in data sets that were not specifically set to address a carcass yield equation.
2. Left side hot standard carcase weight, rib fat and eye muscle area in combination with sex can predict CTlean to a high level of accuracy when compared to traditional processor grids of fat and carcass weight
3. CT lean needs to be collected in more serial kills with a purpose to build a more accurate training data set. There needs to be data available on cattle with varying EPBI and therefore hump height; more heifers; cattle which are HGP treated. It would also be beneficial to have retail beef yield in this data set for a more industry comparison of equation prediction power.

4. A consistent accurate method for calculating percentage muscle needs to be in place across all data sets
5. Feed type will likely improve the prediction power of yield equations. Definitions of what is grain fed needs clarification. Other fixed effects; HGP use, sex and breed need to be investigated. These effects may just group animals as being fatter or leaner and thus a further understanding of these effects is required.
6. Additional measurements that describe the physiology of the animal such as hump height, forearm and hindlimb circumference and rib thickness need further investigation in future purpose built data sets. These measurements are likely to improve the accuracy and precision of yield equations as shown in the findings. These measurements are not readily available in all historic data sets.
7. Investigate the impact that classifying carcases based on fat and weight grids would have on the prediction power of derived equations. Using feed type to classify carcases resulted in an improved prediction power and this requires greater focus

6.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield

1. Predict % muscle and not saleable meat yield
2. Evaluate the use of hot carcass weight, marbling, rib fat and eye muscle area along with Bos indicus content, ossification, sex and HGP status in a regression equation to predict % muscle
3. Utilise carcasses that have been CT scanned at UNE and Murdoch University as the training data set for the regression equations
4. Determine if another point measure like rib thickness (also measured on a large proportion of the carcasses that have been CT scanned) adds value for the accuracy of prediction
5. Determine the cost of a VIA system for the quartering site – preferably a new system other than VIAscan
6. Once a prediction equation is generated using the CT scanned carcasses and point measures, sort the predictions for carcasses into classes like A to E. The accuracy of predicting A to E will be far greater than predicting the actual % of muscle
7. Evaluate the possibility for prediction equations within weight and/or fat categories to increase the power of prediction of % muscle
8. Determine at what level of accuracy is sufficient to have a commercial payment system. Statistical and economic inputs need to be analysed to address the financial implications.

6.7 Genetics of BREEDPLAN carcass traits and meat eating quality

This work has quantified the relationship between carcass quality traits and sire BREEDPLAN EBVs and many of the relationships were as expected. The sire EBV of greatest effect on MSA index was IMF. To achieve the targets set in the Meat Industry Strategic Plan 2020 for beef (5 unit increase in MSA by 2030), single trait selection for the top 10% of Angus sires for IMF EBV would result in only 0.5 For the same trait (e.g. IMF), it was expected that half of the sire superiority would be passed on to progeny. However, this was commonly less than 0.5 for Pasture finished and much greater for Long-fed cattle. This affects the premiums that commercial producers should pay for bulls based on EBVs in addition to the issues of being able to capture additional value for superior carcasses.

7 Key messages

7.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

- Maintain growth rates to ensure cattle are slaughtered in under two years – slower growing cattle are at higher risk of non-compliance
- Avoid movement of stock within one week of slaughter – feed quality and quantity changes disrupt intake patterns and alter pre-slaughter glycogen accumulation
- Ensure feed on offer is at least 2000 kg/ha leading up to slaughter to ensure intake and glycogen accumulation is maximised
- Pasture magnesium concentration relates to the incidence of dark cutting. Monitor feed levels and supplement accordingly to counteract negative effects of high potassium and soluble protein in pastures
- Pasture mycotoxin concentration is related to the incidence of dark cutting. Provide animals on old cultivars of rye grass and fescue with mycotoxin binders or renovate pastures
- Providing cattle grazing short green lush pastures with hay or silage supplementation reduces dark cutting. The exact mechanism unknown, but management, habituation, increased heat of fermentation or reduced rumen passage rates of feed may contribute
- Cattle which have access to trough water have lower incidences of dark cutting. Clean water ensures greater intakes of water and feed.

7.2 Assessed current industry compliance to fat and weight specifications using MSA data

- Total non-compliance for fat depth in the southern regions ranged from 0.271% to 0.914% in four years of data (2010-2013)
- Season influences fat depth non-compliance in pastoral regions during the summer.
- Grass fed systems had a fat non-compliance rate of 0.74% while grain fed systems 0.086% of carcases were non-compliant for fat depth
- Carcases under 200 kg are at a higher risk of non-compliance (2.8%) for fat.

7.3 Determine the frequency of uncoupling in the relationship between meat colour and pHu and identify likely causes

- The frequency of uncoupling of pH and meat colour in the nine southern processors is extremely low and is often less than 0.1% of all carcases graded (Non-compliant for pH only, mean 0.15 % ± 0.91; range = 0 to 25%; Non-compliant for meat colour only, mean 0.33% ± 2.01; range 0 to 89.7 %)
- Industry data sets may not be a true indication of normal rates
- Meat colour does not influence eating quality and pH alone is a more useful indicator
- Time of grading needs to be assessed, with guidelines set for regrading of carcases to allow for longer time to reach an ultimate pH and thus compliance
- Bloom time regulations need changing to allow for longer times between quartering and grading

7.4 Evaluated on-farm nutritional options that reduce the incidence of dark cutting (high pH or dark meat colour) by 50% during periods of elevated non-compliance (break of season, winter and the end of season) in pasture-fed cattle

- 25 extra megajoules of energy delivered per day
- No decrease in dark cutting in animals tested
- Supplementation of a commercial pellet increase muscle glycogen concentration 0.13 g/100g in comparison to no supplementation
- Carcase weight increased by 2.74 kg when supplemented with only 2.5 kg/hd/day pelleted feed.
- Lupins as a supplementation method was not effective at increasing glycogen significantly nor carcase weights.
- Palatability of magnesium pellets and training of pasture raised cattle to eat from a trough are key considerations

7.5 Assessed the suitability of MSA carcass measurements, in combination with other measurements, for predicting Lean Meat Yield

- From the current CT data base an equation of best fit was developed (see below) which should be implemented into all carcass feedback systems for MSA graded carcasses.

For Steers

Predicted LMY = 62.1109 + (LeftsideHSCW x -0.09244) + (EMA x 0.1645) + (RibFat x -0.4936)

For Heifers

Predicted LMY = 59.3974 + (LeftsideHSCW x -0.09244) + (EMA x 0.1645) + (RibFat x -0.4936)

- The equation has limitations in carcase weight (200-440kg), EMA (50-100) and Rib fat levels (1-20).
- This equation shows the benefit of a more complex prediction over just carcass weights and rib fats, however more data is required to improve the precision and accuracy of such prediction equations
- More CT data is needed for cattle with HGPs, *bos indicus* cattle, and from various feed types (grass and grain)

7.6 Identified and evaluated appropriate technologies for measuring Lean Meat Yield

- CT is the gold standard of lean meat yield measurement
- It is possible to work on a grid system and incorporate point measures on the carcass to predict yield, but these measures need to be accurately determined

7.7 Genetics of BREEDPLAN carcass traits and meat eating quality

- BREEDPLAN EBVs work very well for Long-fed cattle
- The benefits of selecting EBVs are not as great for pasture-finished cattle. Producers need to carefully consider the premiums payed for bulls based on EBVs
- Selection for increased sire IMF EBV will have the biggest impact on the MSA Index.

8 Bibliography

8.1 Identified key factors associated with high incidences of dark cutting in southern grass-fed beef supply chain systems and quantified the economic impacts

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8.3 Genetics of BREEDPLAN carcass traits and meat eating quality

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9 Appendix

9.1 Genetics of BREEDPLAN carcass traits and meat eating quality

9.1.1 Relationship between BREEDPLAN EBVs and meat eating quality

Table 9.14. Summary statistics for sire BREEDPLAN EBVs

	600D Wt EBV	CWT EBV	EMA EBV	Rib EBV	IMF EBV
Mean	1.08	0.75	0.03	-0.08	-0.02
SD	14.0	12.0	2.26	1.39	0.81
Minimum	-45.5	-50.5	-8.55	-4.56	-3.69
Maximum	63.4	43.3	8.55	8.04	4.01
Count	697	697	697	697	697

Table 9.2. Change in MSA Index per 1 Standard Deviation increase in BREEDPLAN EBV by finishing system.

	600D Wt EBV	CWT EBV	Rib EBV	IMF EBV
Long	0.17	0.17	0.00	0.28
Short	0.13	0.12	-0.12	0.24
Pasture	0.07	0.02	-0.03	0.10

Table 9.3. Change in MSA Index per 1 Standard Deviation increase in BREEDPLAN EBV by breed

	600D Wt EBV	CWT EBV	Rib EBV	IMF EBV
Angus	0.10	0.13	-0.01	0.26
Charolais	0.11	0.13	0.09	0.18
Hereford	0.20	-0.05	-0.27	0.12
Limousin	-0.10	0.16	0.45	0.18

9.1.2 Genetic parameters between current BREEDPLAN traits and meat eating quality traits

Table 9.4. Genetic and phenotypic correlations by finishing system for MSA index and carcass traits. Note genetic correlations estimated from a sire model.

	MSA Index				MSA Marbling				IMF					
	Short		Pasture		Short		Pasture		Short		Pasture		Short	
	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	
PEQ	0.99 ± 0.01	0.01 ± 0.94	0.94 ± 0.03	0.03 ± 0.86	0.96 ± 0.04	0.82 ± 0.11	0.88 ± 0.01	0.99 ± 0.03	0.52 ± 0.02	0.71 ± 0.21	0.54 ± 0.02	0.84 ± 0.11	0.23 ± 0.03	0
Marbling	0.71 ± 0.02	0.02 ± 0.89	0.89 ± 0.07	0.07 ± 0.65	0.06 ± 0.04	0.11 ± 0.38	0.04 ± 0.03	-0.36 ± 0.39	0.54 ± 0.02	0.93 ± 0.14	0.55 ± 0.02	0.94 ± 0.08	0.14 ± 0.03	0
OSS	-0.34 ± 0.03	0.03 ± -0.24	-0.24 ± 0.36	0.36 ± -0.64	0.09 ± 0.03	0.03 ± 0.21	0.13 ± 0.03	0.19 ± 0.25	0.04 ± 0.03	0.96 ± 0.61	0.02 ± 0.03	0.01 ± 0.39	0.05 ± 0.03	-0
HSCW	0.21 ± 0.03	0.03 ± 0.21	0.21 ± 0.21	0.21 ± 0.14	0.14 ± 0.03	0.42 ± 0.19	0.23 ± 0.03	0.21 ± 0.31	0.12 ± 0.03	-0.08 ± 0.30	0.00 ± 0.05		0.16 ± 0.03	0
Rib	0.36 ± 0.03	0.03 ± 0.62	0.62 ± 0.16	0.16 ± 0.37	0.00 ± 0.03	-0.48 ± 0.22	0.01 ± 0.03	0.4 ± 0.24	0.19 ± 0.03	0.60 ± 0.23	0.26 ± 0.03	0.12 ± 0.31	-0.08 ± 0.03	-0
EMA	-0.05 ± 0.03	0.03 ± -0.49	-0.49 ± 0.21	0.21 ± 0.02	0.54 ± 0.02	0.93 ± 0.14	0.55 ± 0.02	0.94 ± 0.08	-0.01 ± 0.03	-0.56 ± 0.32	-0.10 ± 0.03	-0.56 ± 0.21	0.19 ± 0.03	0
IMF	0.45 ± 0.03	0.03 ± 0.72	0.72 ± 0.20	0.20 ± 0.45	0.00 ± 0.03	-0.39 ± 0.41	0.05 ± 0.03	0.25 ± 0.38	-0.11 ± 0.03	-0.44 ± 0.57	-0.15 ± 0.03	-0.52 ± 0.32	-0.01 ± 0.03	-0
pH	-0.34 ± 0.03	0.03 ± -0.47	-0.47 ± 0.33	0.33 ± -0.3	0.71 ± 0.02	0.89 ± 0.07	0.65 ± 0.02	0.94 ± 0.08	0.45 ± 0.03	0.72 ± 0.2	0.45 ± 0.02	0.74 ± 0.15	0.36 ± 0.03	0
Index	0.99 ± 0.01	0.01 ± 0.94	0.94 ± 0.03	0.03 ± 0.86	0.96 ± 0.04	0.82 ± 0.11	0.88 ± 0.01	0.99 ± 0.03	0.52 ± 0.02	0.71 ± 0.21	0.54 ± 0.02	0.84 ± 0.11	0.23 ± 0.03	0

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9.1.3 Investigating relationships between market end point and expression of carcass traits associated with eating quality

ASAP Conference Paper 2016

Drafting cattle for slaughter should not limit use for genetic evaluation

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Summary

Capturing data for genetic evaluation from commercial herds can be problematic. One of the limitations relative to research projects is that in commercial herds it is common for cattle to be drafted prior to slaughter based on carcass price grids. This paper generated an artificial draft factor based on carcass weight and then examined the effect of this on genetic analysis of carcass quality traits. Compared to fitting carcass weight as a covariate for carcass quality traits, the impact of drafting was negligible. Thus, this should provide confidence for greater use of commercial data for genetic evaluation. Even a small proportion of MSA graded carcasses utilised would increase the amount of carcass data in BREEDPLAN enormously.

Introduction

Increasingly applied livestock research is being conducted in commercial productions systems. This has advantages of working closely with those that will adopt the outcomes and for researchers to understand more fully commercial drivers of innovation adoption and farm profitability. With the exception of well designed progeny test programs, it can be difficult to capture data of sufficient quality for genetic evaluation.

The impact of genomics (Meuwissen *et al.* 2001) means that large numbers of single nucleotide polymorphism (SNP) markers can be tested on animals. A limitation for conducting genetics research and development on commercial properties used to be lack of pedigree. However, SNP chips can be used to effectively reconstruct pedigree on commercial animals. In addition, if the property has been using bulls with high genetic merit, then their animals will likely be genetically related to leading animals in the breed. Thus, commercial performance can be integrated into genetic evaluation programs like BREEDPLAN (Graser *et al.* 2005) and can provide valuable information which is currently difficult for studs to record. Examples of such traits are days to calving of heifers and cows where synchronising oestrus masks genetic variation and marbling of steers especially those for markets with large premiums for marbling.

A problem often encountered with commercial data is maintenance of contemporary groups. However, increasingly cattle are grazed in large mobs (>100) and this is becoming less of an issue.

Another common problem is that of drafting cattle for sale where cattle are weighed and the heaviest potentially grazed in a separate mob for 1-4 weeks, then transported to a feedlot or abattoir for slaughter. The common number of cattle would be a semi-trailer or B-double load in southern Australia (e.g. 50 x 640kg) and a 6 deck road train in northern Australia. Thus, these cohorts are still quite large but the problem of drafting remains and is the subject of this paper.

Materials and Methods

The "Southern Crossbreeding Project" was conducted at Struan Research Centre, Naracoorte SA and various feedlots in southern Australia (Pitchford *et al.* 2006). Mature Hereford cows (637) were mated to 97 sires from 7 breeds: Jersey, Wagyu, Angus, Hereford, South Devon, Limousin and Belgian Blue. There were 1201 carcasses from heifer and steer calves born 1994-97. Cattle were slaughtered when the majority of heifer carcasses were >200 kg (average 16 months) and steer carcasses >300 kg (average 23 months) at various commercial abattoirs. With 4 years and 2 sexes, there were 8 slaughter groups. They were assessed for hot standard carcass weight (HSCW, kg), and carcass traits of eye muscle area (EMA, cm^2) and P8 rump fat depth (mm). Chemical extraction of intramuscular fat (IMF, %) was conducted subsequently in the University laboratory.

The data was analysed with an animal model including fixed effects of management group and sire breed in all models (Gilmour *et al.* 2009). Management group was a function of year of birth (1994-97), birth location (Struan or Wandilo) and sex (heifer, steer) with a total of 16 combinations. Birth month (March or April) was not included because it was not significant for any of the four carcass traits herein.

There was no drafting of carcasses, but a factor was developed to simulate cattle being drafted on weight and slaughtered on different days. This was simply done by sorting carcasses by HSCW and then within each of the 8 year x sex cohorts assigning a 1 to the heaviest 50, 2 to the next 50 and 3 to the remaining carcasses. The size of the third group varied substantially between year x sex cohorts.

Three models were fitted:

1. Unadjusted for carcass weight;
2. Carcass weight included as a covariate as is done in BREEDPLAN for carcass traits (Graser *et al.* 2005); or
3. Draft included as a factor (1-3 within each of the 8 year x sex cohorts, so 24 groups).

Results and Discussion

Breed differences

While not the primary focus of this paper, the breed means do demonstrate the difference between the three models. There were large differences between breeds in carcass weight with the Jersey (12%) and Wagyu (9%) much lower than purebred Hereford and the other crossbreds were 3-8% heavier (Table 1). The Belgian Blue sired calves were 22% heavier than Jersey and the difference in eye muscle area (EMA) was even greater (32%). However, fitting carcass weight as a covariate had a big effect so that the difference in EMA between Belgian Blue and Jersey reduced to 19%. Given that carcasses were "drafted" on carcass weight, it is not surprising that the means for the drafted model (3) were similar to fitting carcass weight as a covariate (Table 1).

Table 1. Sire breed means for carcass weight and eye muscle area.

Sire breed	Carcass weight (kg)	EMA Unadjusted (cm^2)	EMA Covariate (cm^2)	EMA Drafted (cm^2)
Jersey	238	62.4	67.1	66.1
Wagyu	245	67.0	70.7	69.3
Angus	285	69.6	67.8	67.6
Hereford	270	66.8	67.1	66.9
Sth. Devon	286	74.1	72.3	72.4
Limousin	278	76.7	75.9	75.6
Bel. Blue	291	82.4	80.0	80.3
SED	4.6	1.36	1.23	1.22

Genetic parameters

The heritability of carcass weight was 50% (Table 2) with ample phenotypic variation (SD=$712^{0.5}$=27kg), slightly more than that reported by Reverter *et al.* ($511kg^2$, 2003). It doesn't make sense to report an analysis of carcass weight with itself fitted as a covariate. The draft factor accounted for 73% of the variance in carcass weight so the SD within draft was only 14kg and the heritability only 9%. The drop in heritability demonstrated the draft factor removed a greater proportion of genetic variance than residual or environmental.

The variances of EMA, P8 fat and IMF from the drafted model were similar to fitting carcass weight as a covariate (Table 2). The heritabilities were also very similar and the results are similar to those reported by Reverter *et al.* (2003). This demonstrates that if drafting is done on weight alone, it should not affect genetic evaluation of carcass quality traits. Indeed, IMF is the trait most related to eating quality and MSA Index and the variance and heritability in IMF hardly changed at all (Table 2). Furthermore, the correlation between EBVs for IMF from the Covariate and Drafted models was 0.99. Thus, it is assumed the impact on MSA marbling score would also be negligible.

As demonstrated by the effect of fitting carcass weight as a covariate on breed means (Table 1) and variances (Table 2), carcass weight was most strongly correlated with EMA (r_P=0.41, r_G=0.54; Table 3). It was also moderately correlated with P8 and IMF. However, in BREEDPLAN, evaluation carcass quality traits are reported at a constant carcass weight which is equivalent to model 2 herein.

When carcass weight was included as a covariate, phenotypic correlations between the carcass traits were low but genetic correlations were moderate with the strongest being with P8 fat depth. Fitting the drafted effect changed the correlations a little, but not significantly. Given in BREEDPLAN even when drafted, they would be adjusted to a constant carcass weight, this is not expected to be a concern.

Table 2. Phenotypic variance for eye muscle area.

Trait	Unadjusted	Covariate	Drafted
Phenotypic variance			
Carcass weight (kg)	712	-	193
Eye muscle area (cm^2)	76.4	63.6	63.4
P8 fat depth (mm)	17.0	15.3	15.7
Intramuscular fat (%)	2.31	2.30	2.29
Heritability (%)			
Carcass weight (kg)	50	-	9
Eye muscle area (cm^2)	32	28	25
P8 fat depth (mm)	20	22	17
Intramuscular fat (%)	15	17	14

Table 3. Phenotypic (above diagonal) and genetic (below) correlations.

Trait	HSCW	EMA	P8	IMF
Unadjusted				
HSCW		0.41	0.32	0.08
EMA	0.54		0.00	0.00
P8	0.30	-0.16		0.18
IMF	-0.33	-0.40	0.22	
Covariate				
EMA			-0.16	-0.09
P8		-0.40		0.16
IMF		-0.27	0.41	
Drafted				
EMA			-0.08	-0.09
P8		-0.24		0.17
IMF		-0.34	0.25	

This paper has modelled drafting on carcass weight and demonstrated that the effect on genetic evaluation of carcass weight is substantial, but on carcass quality traits (EMA, P8, IMF) is negligible. In reality, commercial mobs would be drafted on live weight rather than carcass weight. Given that final weight is highly genetically correlated with carcass weight (Crews *et al.* 2004), this is almost equivalent to what was modelled herein. The results of Jopson *et al.* (2007) are encouraging in that even the effect on genetic evaluation of later weights of drafting on an earlier weight is not as severe as may be expected.

In addition to the drafting information herein, the effect of birth month was only just significant for carcass weight and not for any of the three traits when carcass weight was a covariate. Thus, it is concluded that genetic evaluation for weight can be conducted on the final liveweight before cohorts are drafted and that as long as cattle are drafted on weight alone (not including condition), there should be ample opportunity to conduct genetics projects with commercial collaborators. As stated in the introduction, the limitation for this work used to be lack of pedigree but genomic tests have

overcome that and allow a new paradigm of livestock genetics research and development. Even a small proportion of MSA graded carcasses utilised would increase the amount of carcass data in BREEDPLAN enormously.

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