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Report Title: Summary of yearly, monthly, daily and between and within lot variation in MSA carcase data

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Acknowledgements

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Abstract

This project arose from questions raised with previous research into beef carcase pricing regarding the variation of the dataset and whether it was representative of variation experienced by processors on any given day, month or year. There is very little research covering commercial carcase variation, so there is very little documentation to compare against to determine if any given dataset has sufficient variation. The dataset used for this research covers 35 variables over four years, derived from over 1.7 million carcases. A number of different summary statistics were completed on the data to cover the different time periods of interest, as well as a mixed model regression to understand where some of the variation may stem from. The variation determined here could be used going forward to determine if a smaller dataset has sufficient variation in specific traits to be comparable to the variation a processor experiences. The variation experienced by processors in eating quality is greater than that from specific trials, almost by definition given that genetics trials are aimed to evaluate animals born and raised together.

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Executive Summary

Increasingly, beef processors are able to extract more value from higher quality carcasses. This will likely increase demand for quality and be reflected in price. Pitchford et al. (2020) examined various pricing strategies based on yield and quality and concluded that the majority of variation in price/kg was associated with yield, even when high premiums were placed on quality. However, concerns were raised by processors that the dataset used had less variation in quality than they commonly experienced. There is very little research covering what is the expected variation for all carcase traits for any given processor on any given day at any given location. Therefore, there was a need to try and capture this variation and reflect what is experienced by industry, and to allow comparison to research datasets so they can be deemed to be representative of industry reality or not.

The current study involved analysis of a subset of the Meat Standards Australia database. The dataset included 1,731,075 individual carcases which cover four years, ranging from 4 Jan 2010 to 31 Dec 2013 in kill date. There were 1,159 individual dates covered within the four years, as well as 35 variables recorded for each carcase. Some of these variables included location details, saleyard or direct consignment, kill date, grade date, hang method, HGP treatment, meat colour and loin temperature, Hot Standard Carcase Weight (HSCW), Eye Muscle Area (EMA), Rib and P8 fat depth, Ossification score (Oss), MSA Marble Score and MSA Index, to name a few. A number of summary statistics were completed on the dataset to cover multiple time periods, as well as detailed graphs captured, a mixed model linear regression completed, and determination of variation sources. The results have a presentation of the overall dataset, year as a factor, and month as a factor to cover the different time periods. These time periods have results presented in a number of tables, as well as the results for a mixed model regression and variation partitioning. The daily summary results were compiled into a number of different graphs due to the magnitude of days present, as well as the inconsistency of numbers of individuals seen on each day. A number of graphs were also generated to show the change over time in the mean and standard deviation values for the key variables of interest. The histograms which covered daily variation covered a range of distributions, with no consistent shape across all variables of interest. There were only a few variables which had a slight correlation ($r \leq 0.5$), while the sources of variation were different for each variable tested, with HSCW having the greatest variation between plants.

Pitchford et al. (2020) reported results from a bone out trial with animals from a genetics trial that were born and raised together. Thus, there was minimal variation in age and all animals had been managed the same. The animals herein had similar carcass weight, eye muscle area and fat depth to Pitchford et al. (2020) but, as expected, the variation in quality experienced by processors was much greater. Processors have large variation in ossification whereas in the bone out trial it was assumed there was none as the animals were not MSA graded in plant. Processors also have much greater variation in marbling so that on a daily basis the standard deviation was 77 relative to 39 scores. The combination of ossification and marbling meant that the standard deviation in MSA index experienced by processors was 2.3 compared to only 0.8 in the bone out trial. Thus, even though it was not measured directly in the MSA dataset herein, it appears that while the bone out trial had representative variation in yield, the variation in quality was far smaller than commonly experienced. The implication of this is that the conclusion about the relative importance of yield and quality should rightly be questioned and will be the subject of further work.

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Contents

1 Contents

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2 Introduction

Previous research into beef carcase pricing signals (Pitchford et al. 2020) came to the conclusion that yield was the major driver for carcase price paid per kilogram. However, questions were raised about the transferability to commercial processing systems in that industry feedback was that the dataset, and therefore the conclusions, were not representative of the variation that processors commonly experience, and there should be more emphasis on eating quality. There is very little research covering what is the expected variation for all carcase traits for any given processor on any given day at any given location. There are a number of papers which quote their range, mean and standard deviation of the data for the variables studied such as those by Reverter et al. (2003); Piao and Baik (2015); Bonny et al. (2016a); Bonny et al. (2016b), but these studies did not cover datasets that are of comparable magnitude or did not use MSA grading. These studies also do not cover comparable time periods and some have been designed to try to minimise the variation. For example Reverter et al. (2003) had mean carcase weights by design to meet market requirements, and genetics trials, by definition, are designed to compare performance of animals that have been born and raised together. A large number of the published studies are also only reporting variation of the dataset as a by-product of the study rather than it being the focus of the project. Therefore, there was a need to try and capture this variation and reflect what is experienced by processors. This study utilises data from four years of the Meat Standards Australia (MSA) database covering a wide range of variables, particularly those which can be used to determine yield and eating quality, so that an estimate of variation could be determined for various time periods. Once this variation has been quantified, it will allow comparison with future datasets to determine if that dataset is capturing a realistic processing time period and its variation.

3 Methods

3.1 Description of dataset

The analysis for this project was carried out using R. The dataset comprised 1,731,075 MSA graded carcases over four years, from 4 Jan 2010 to 31 Dec 2013 in kill date. There were 1,159 individual dates covered within the four years, as well as 35 variables recorded for each carcase. There were five classes of variables: location, date, carcase, miscellaneous, and the variables of primary interest.

3.1.1 Location variables

Within the location class of variables were plant, postcode, town, state, saleyard and lot, which all covered a wide range. There were nine different plants covered, with each one having a differing number of carcases ranging from 80,029 to 261,100. Carcasses were sourced from 761 postcodes, which again range in the number of carcases from each postcode, from one to 100,852. These postcodes are representative of 1,747 towns within each state of Australia. The vast majority (1,751,512) were direct consignment with just 9,563 from saleyards. There were 4,429 different lots coming from 6,851 vendors.

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3.1.2 Date variables

Within the date class of variables there were kill date, grade date, month, year, and grade interval. There were 1,159 kill days, 36 kill months and 4 kill years. Kill date is the day the cattle were slaughtered on and is the variable used to sort the dates when looking at the variation per year, month and day (covered later in the methods). Month and year match up with the month and year of kill and grade date, and are used as categorical (factor) variables.

3.1.3 Carcase variables

This dataset has the majority of carcase variables for eating quality measurement required to calculate a MSA index score. Hang method is a categorical variable with the options of Achilles Tendon or Tender Stretch methods, of which the majority of the carcases were Achilles hung. Hormone growth promotants (HGP) is either a yes or no option, with majority of the carcases not hormone treated, and 468,013 being hormone treated. Hump height, measured in gradient of 5mm at the greatest point of the hump, averaged 50mm for this dataset. Fat colour is a numeric categorised variable with a mean of 1.63, but a score range of 0 to 9 covering the full scale covered by MSA. pH ranged from 5.25 to 7.25, with mean of 5.57 and standard deviation of 0.13 units. This also corresponds to the range and mean seen for meat colour (MC), with a mean of 2.16, and range of score 1 to score 7.

3.1.4 Additional variables

The variables within this group are useful variables and important for the MSA index score calculation and MSA database, however for this project they served minimal purpose and have been put into this group because of that. Within this class are variables such as loin temperature (loin temp.), and grader identification. Loin temperature had a mean of 6.8 degrees and a standard deviation of 1.6 degrees. Grader identification is a number-letter code, with 51 graders within the dataset and grader 4C alone grading 219, 234 carcases. The other variables within this dataset cover areas like grade code, pH by MC interaction and MC class.

3.1.5 Key variables of interest

The key variables of interest within this study are variables which are used by industry to estimate yield and eating quality, which can then be related back to previous pricing studies (e.g. Pitchford et al. 2020). The variables are Hot Standard Carcase Weight (HSCW), Eye Muscle Area (EMA), Rib fat which was used to calculate P8 fat, Ossification (Oss), MSA Marble Score (Marb), and MSA Index score (MSA). P8 fat was calculated based on unpublished data (ALMTech, n.d.), and has been estimated as being 20% more than the Rib fat measurement. Summary data is provided (Table 1).

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Table 1: Range, mean and standard deviation (SD) for Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm^2), Rib Fat depth (mm), P8 fat (mm), Ossification score (Oss), MSA marbling score (Marb), MSA Index score (MSA), and pH level (units).

	HSCW (kg)	EMA (cm^2)	Rib fat (mm)	P8 fat (mm)	Oss (score)	Marb (score)	MSA (index)	pH (units)
Minimum	59	20	0	0	100	100	37.46	5.25
Maximum	689	150	60	72	590	1190	74.05	7.25
Mean	275.4	70	8.5	10.2	155	349	59.77	5.57
SD	50.0	10.1	3.6	4.3	56	94.6	3.33	0.13

Within the dataset there were 116,267 (6.72%) carcases that did not receive an MSA index score, therefore are considered to be 'ungraded'. As expected, the majority were due to an out of specification pH level with pH over 5.7 or not meeting minimum rib fat requirements of over 3mm.

3.2 Variation across years

The dataset was summarised by year (Table 2), using the Year variable, to determine the variation year-on-year. Carcasses were very consistent across years with the possible exception of higher variation in ossification in 2013.

Table 2 Raw minimum, maximum, mean and standard deviation (SD) for each year across four years for Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm^2), Rib Fat depth (mm), Ossification score (Oss), MSA marbling score (Marb), MSA Index score (MSA), and pH level (units).

	HSCW(kg)	EMA(cm^2)	Rib fat (mm)	Oss (score)	Marb (score)	MSA (score)	pH
2010							
Minimum	72	21	0	100	100	38.44	5.30
Maximum	593	150	60	590	1150	72.84	7.20
Mean	276	72.2	8.61	153	363.6	59.31	5.58
SD	52.4	9.66	3.45	30.8	99.4	3.32	0.14
2011							
Minimum	100	20	0	100	100	40.28	5.26
Maximum	689	150	60	590	1190	74.05	7.14
Mean	277.7	69.5	8.87	151	346.4	60.00	5.57
SD	53.7	12.5	3.41	34.0	94.8	3.11	0.13
2012							
Minimum	74	20	0	100	100	42.52	5.30
Maximum	648	150	60	590	1190	73.42	7.09
Mean	275.3	69.8	8.52	151	341.5	59.78	5.57
SD	49.6	9.57	3.47	48.8	94.4	3.29	0.14
2013							
Minimum	59	25	0	100	100	37.46	5.25
Maximum	660	150	60	590	1190	72.81	7.25
Mean	274.1	69.3	8.28	160	349.2	59.83	5.57
SD	47.4	9.10	3.75	75.3	91.5	3.47	0.13

Across the four years, between 5.3-7.9% of the carcases were classed as ungrades and were removed to calculate standard deviation as they are classed as NA's. Each year had a differing number of carcases, with the most seen in 2013 at 635,448, growing from 288,280 in 2010 following the increase in uptake of MSA grading system.

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3.3 Variation across months

Trends within years were examined (Table 3). Carcasses were lighter and with less variation in the winter months. Eye muscle area and fat depth did not reflect this, but ossification was greater in winter. Marble score was lower in mean and variation during late spring and early summer, assuming this reflects more grass-fed carcasses during this period. MSA index was also slightly high at this time.

Table 3 Range, mean and standard deviation (SD) for each month for Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm^2), Rib Fat depth (mm), Ossification score (Oss), MSA marbling score (Marb), MSA Index score (MSA), and pH level (units).

		HSCW(kg)	EMA(cm^2)	Ribfat (mm)	Oss (score)	Marb (score)	MSA (score)	pH (units)
Jan	Mean	277.56	69.99	8.42	151.20	346.79	60.22	5.57
	SD	52.73	10.62	3.47	47.07	95.87	3.29	0.14
Feb	Mean	279.02	71.00	8.59	154.25	353.57	59.62	5.57
	SD	52.41	10.15	3.52	51.03	99.75	3.23	0.15
March	Mean	275.57	70.94	8.60	155.66	350.30	59.34	5.57
	SD	51.53	9.76	3.41	61.82	99.75	3.28	0.14
April	Mean	273.27	70.66	8.61	157.57	352.54	59.24	5.57
	SD	48.24	9.34	3.41	65.48	97.67	3.34	0.13
May	Mean	273.20	70.29	8.68	160.88	354.06	59.10	5.56
	SD	46.82	9.30	3.58	73.41	96.84	3.40	0.13
June	Mean	273.06	70.72	8.88	160.18	357.74	59.25	5.56
	SD	49.16	9.34	3.99	65.33	95.45	3.31	0.14
July	Mean	270.48	70.27	8.61	155.14	354.07	59.51	5.56
	SD	46.47	8.95	3.72	57.25	92.08	3.30	0.13
Aug	Mean	270.84	70.08	8.38	152.37	353.41	59.29	5.56
	SD	45.86	8.86	3.52	43.75	91.60	3.26	0.11
Sept	Mean	274.42	69.55	8.30	153.10	346.98	59.38	5.57
	SD	49.18	9.24	3.50	46.01	91.26	3.26	0.11
Oct	Mean	278.83	69.07	8.31	153.28	341.88	60.08	5.58
	SD	50.77	10.43	3.52	48.75	92.64	3.15	0.13
Nov	Mean	279.38	68.35	8.51	152.25	340.83	60.59	5.58
	SD	52.06	12.02	3.61	52.22	91.22	3.30	0.13
Dec	Mean	275.43	69.52	8.35	152.27	342.92	60.81	5.58
	SD	51.68	10.67	3.49	56.10	92.46	3.32	0.13

3.4 Data summary within day

The data was also summarised per day to determine the variation a plant may see on any given day of the year. This data is too lengthy to tabulate so is displayed in graphs in the Results section. Day was applied as a categorical variable to allow analysis of the variables of interest on a particular day, in a particular month, and in a particular year. The results of the daily mean and standard deviation are presented in histograms to show distribution of the data, and the mean and SD are graphed against each other in scatter plots to show relationship between the values.

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3.5 Mixed Model Regression

A linear mixed model was fitted to the data, utilising a nested structure, to quantify sources of variation. Predominately the LMM was utilised to try quantify the daily variation in a different way, which is the variation of most interest. There were a number of different random effects fitted to each variable of interest. These random effects were year, month within year, day within month lot within day and residual variation. The variables of interest were also compared to each other, producing a covariance value, which enable calculation of an SD value, and a correlation between traits.

$$correlation_{XY}\ (r) = \frac{covariance\ of\ relationship}{((variance\ of\ X)\ x\ (variance\ of\ Y))^{0.5}}$$

4 Results

4.1 Overall summary

Carcasses averaged 275.4kg HSCW, 70cm^2 EMA, 8.5mm and 10.2mm Rib and P8 fat respectively (Table 1). The mean ossification was a score of 155, while marble score had a mean of 349, and eating quality measured by MSA index had a mean of 59.77. There were 6.72% of the carcases that did not have a MSA index score due to either being out of specification for either pH or minimum fat requirements. There was a very wide range in the data for all variables, with variables like ossification and marble score spreading from the lowest possible score to the highest possible score within the AUSMEAT scales. There were also some very small and very large carcases within the dataset, with a minimum carcase weight of 59kg with a minimum EMA of 20cm^2 or a maximum carcase weight of 689kg and an EMA of 150cm^2 (Figure 1).

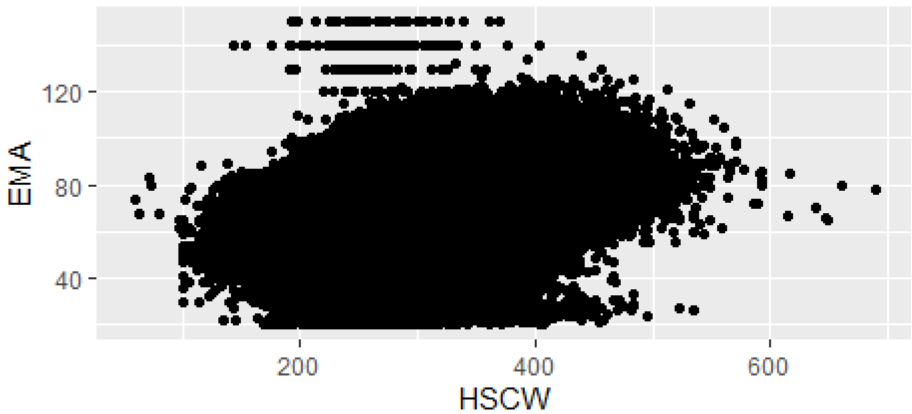

Figure 1: Scatterplot of Hot Standard Carcase Weight (HSCW, kg) against Eye Muscle Area (EMA, cm2)

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There were also high fat measurements of 60mm for Rib fat depth, while there were some that didn't meet minimum requirements [<3mm](Figure 2). Majority of carcases in both Figure 1 and 2 seem to be falling within certain market requirements.

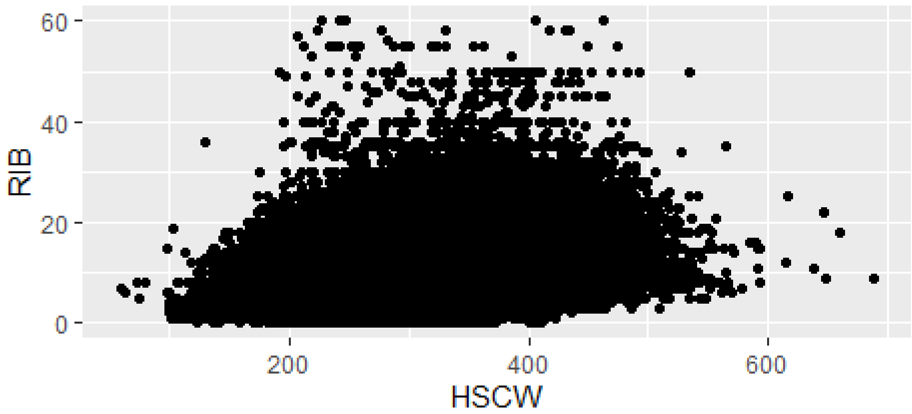

Figure 2: Scatterplot of Hot Standard Carcase Weight (HSCW, kg) against Rib fat depth (RIB, mm)

Carcase weight had a SD of 50kg, which could be the difference between price grid levels, for example changing from optimum weight category of 200 – 249.5kg, to below or above optimum weight and a loss of some money. Ossification had an SD of 56 score units, and Marble score had a SD of 94.6 score units (Table 1). EMA presented a SD of 10.1cm^2 and MSA index score showed a SD of 3.33 score units. Ossification score has distinct bands at above a score of 250, which may be reflective of certain markets or certain periods and types of cattle (Figure 3). There is a large number of carcases below a score of 250 which have a large amount of spread across the different carcase weights, reflective of the majority of young stock processed.

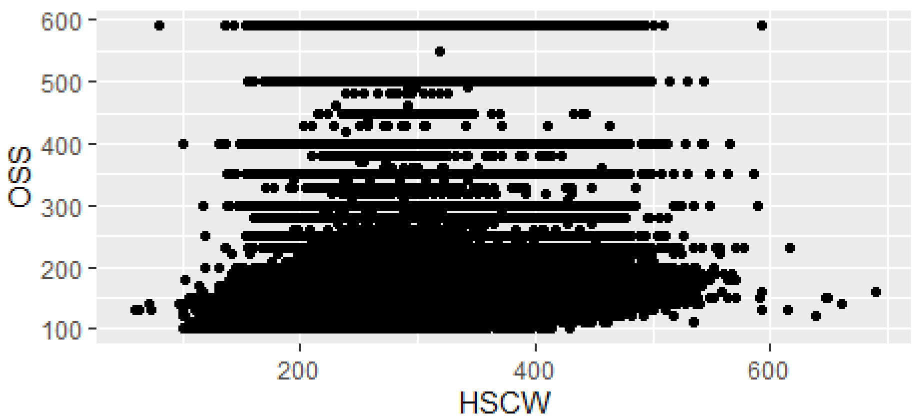

Figure 3: Scatterplot of Hot Standard Carcase Weight (HSCW, kg) against Ossification score (OSS, out of 590)

There is no discernible trend between HSCW and Marble score, with a wide spread of data at all levels of marble score (Figure 4). The lower levels of marbling have a greater amount of spread in carcase weight, with a smaller number of carcases reaching the highest levels of marbling.

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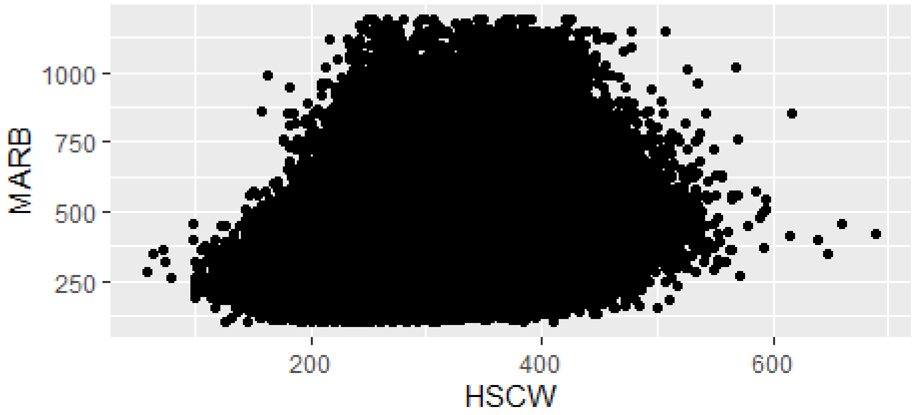

Figure 4: Scatterplot of Hot Standard Carcase Weight (HSCW, kg) against MSA Marbling Score (MARB, out of 1190)

The shape of the relationship between HSCW and MSA has an increasing amount of variation from a point of an MSA of 35 and a HSCW of 200kg, with the most amount of spread at the highest levels of MSA score (Figure 5). There are a number of small outliers which are present at lower end of the graph that are distinctly separate from the main group, where the carcase weight is very small and various MSA scores above 40.

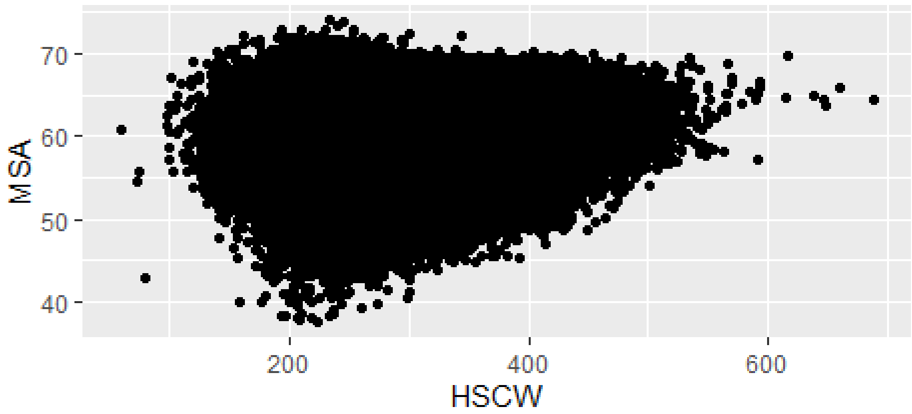

Figure 5: Scatterplot of Hot Standard Carcase Weight (HSCW, kg) against MSA Index score (MSA)

4.2 Yearly summary

The summary and comparison of the yearly results (Table 2) had interesting changes in the values between the years for each of the variables of interest. There is no one particular year that stands out as the best for all variables in terms of mean, SD or range in data, with 2012 the most consistent in mean and SD when compared with overall results. Notably, 2013 shows a very high inconsistency in OSS, with an extremely high SD value compared to the other years and the overall results.

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4.3 Monthly summary

The monthly summary results for mean and standard deviation are presented in Table 3. From this point on the maximum and minimum will not be included, due to the overwhelming amount of data to be included in one table and the variation is better described by the standard deviation. Carcases were lighter and with less variation in the winter months. Eye muscle area and fat depth did not reflect this, but ossification was greater in winter. Marble score was lower in mean and variation during late spring and early summer, assuming this reflects more grass-fed carcasses during this period. MSA index was also slightly high at this time. Ossification also appears to be slightly higher from the end of autumn/start of winter, as well as being more variable.

4.4 Monthly and yearly summary

4.4.1 Year by month graphs

Figures one to six show scatterplots of the mean [(a) graphs] and standard deviation [(b) graphs] values across each 12-month period, with each year corresponding to a different colour, completed for each key variable as labelled at the top of the graphs. The variation for HSCW presents a clear trend across most months with a drop occurring from mid-autumn to mid-winter and picking up over spring and summer (Figure 6). Each year follows slightly paths of the main trend, with 2013 in the lower part of the graph for standard deviation and shows the most consistent path for the mean values.

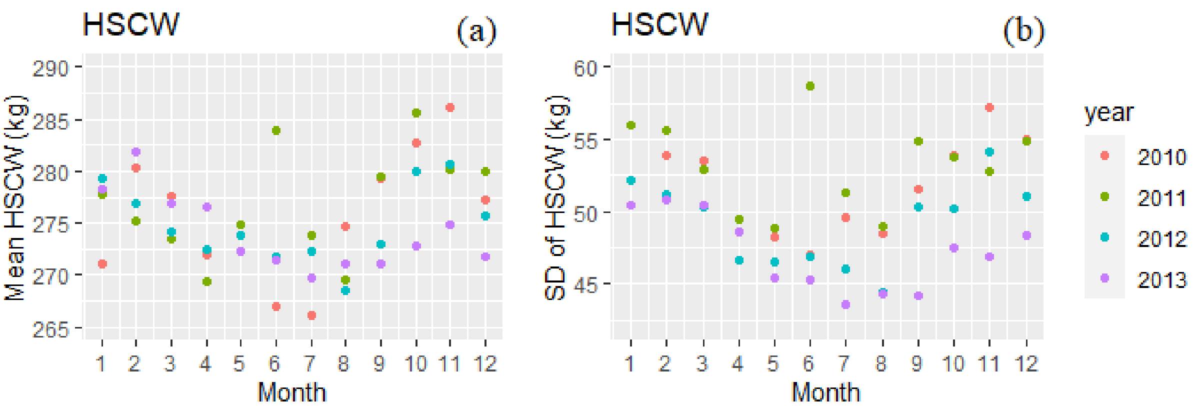

Figure 6: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for Hot Standard Carcase Weight (HSCW, kg).

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The variaton in EMA and fat depth was consistent across most months (Figures 7 and 8). There was also consistent variation between most years for both variables, with a few select outliers which strayed from the overall trend.

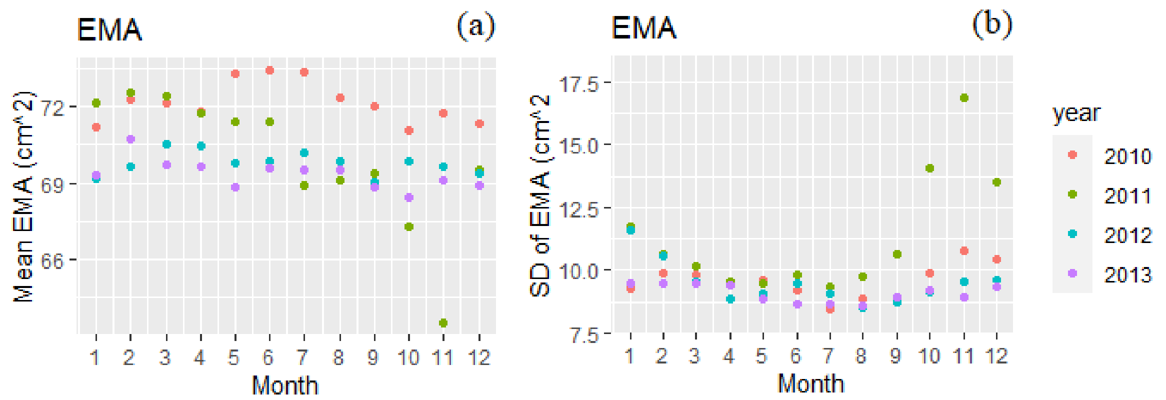

Figure 7: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for Eye Muscle Area (EMA, cm²).

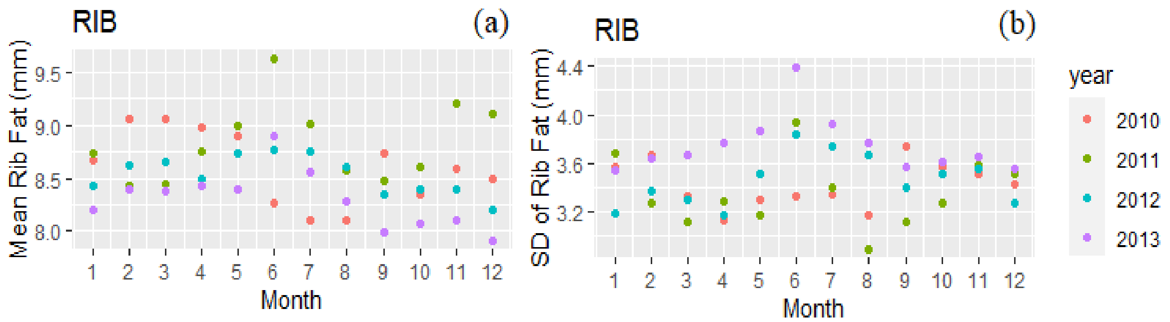

Figure 8: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for Rib Fat Depth (RIB, mm).

Both ossification graphs (Figure 9) show a large amount of variability between the different years, which may indicate some seasonal effect. The first three years of the study show similar mean values; however, this trend is disrupted by the increased values seen throughout the first half of 2013. These increased values also occurred for the same time period in the SD values, however there were also high values in the latter half of 2013 and 2012.

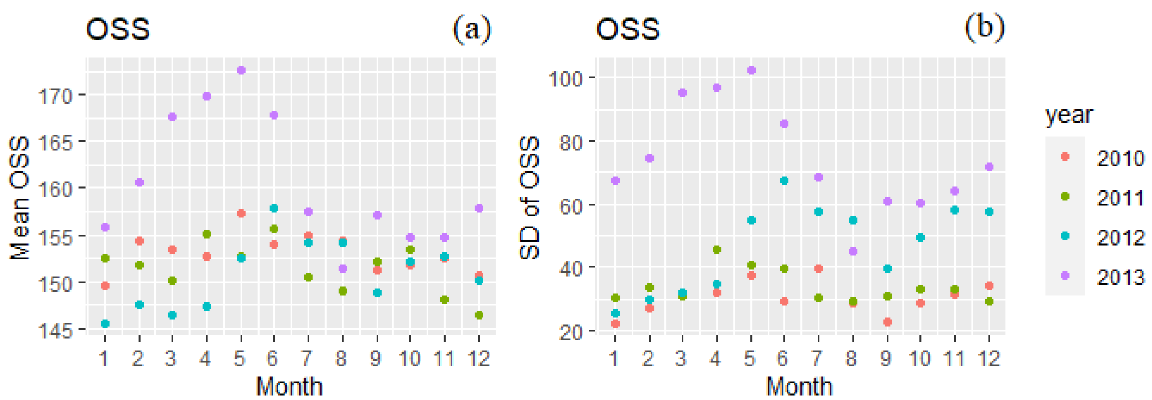

Figure 9: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for Ossification score (OSS, out of 590)

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There was a large amount of variability in both mean and SD values for Marble score (Figure 10) with no consistent increase or decrease in the same time periods or multiple years with similar values.

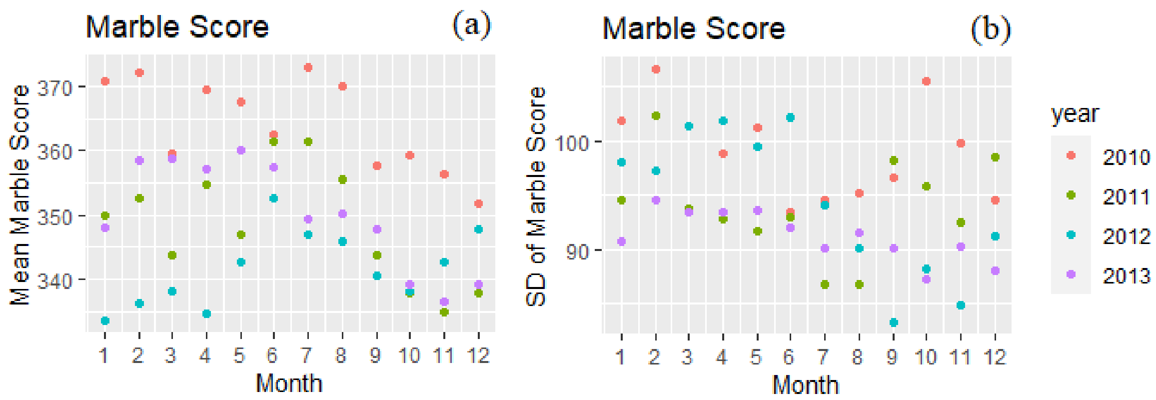

Figure 10: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for MSA Marble score (MARB, out of 1190)

There was a clear trend across all years and most months for the mean values of MSA Index score (Figure 11), however this was not corroborated within the standard deviation graph. The trend in mean values shows a clear spike from late spring with a steady decrease from early summer to winter.

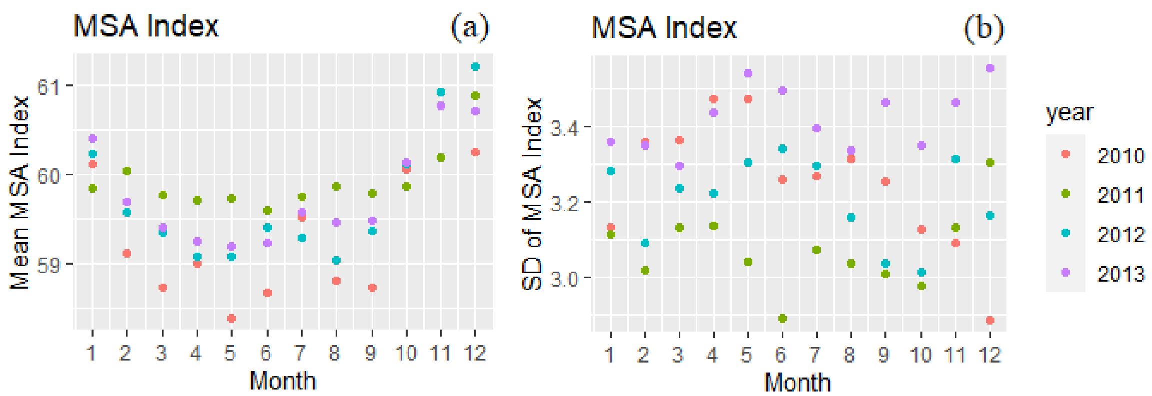

Figure 11: Scatterplot showing mean (a) and standard deviation (b) values across each 12-month period (colours in key) for each month along the x-axis for MSA Index score (MSA)

4.5 Daily Summary

4.5.1 Daily graphs

Figures 12 to 17 cover the daily mean [(a) graphs] and standard deviation [(b) graphs] values for each of the variables of interest, covering 1,159 different days, with some days having one carcase and others having up to 3,700 carcases. The graphs show the distributions of mean and SD where each day has a value for mean and SD for each trait, thus SD represents the variation in the trait within a day. HSCW (Figure 12) is the only variable that is truly normally distributed for the daily mean values, with the median and mean values presenting as the same (275.3kg), however the daily SD values show slight negative skewing with the median (47.76kg) being greater than the mean (47.38kg).

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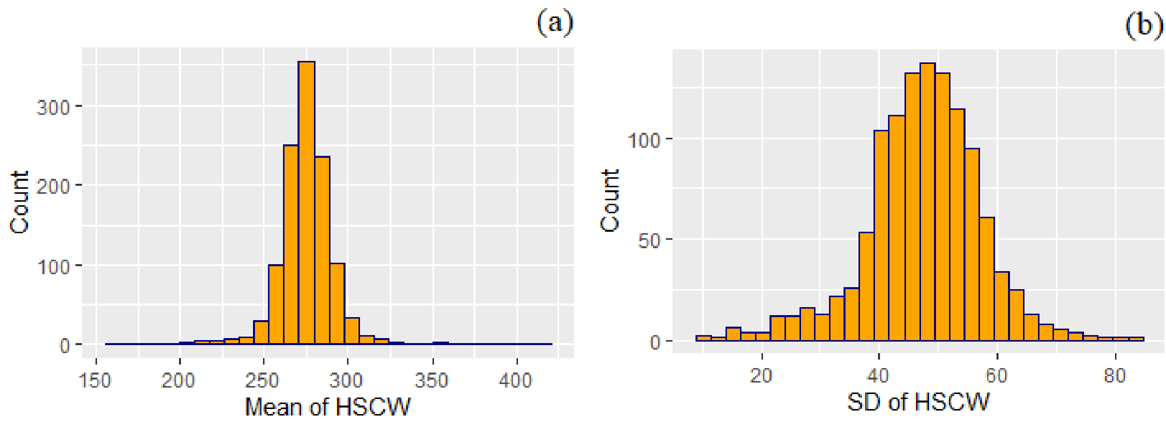

Figure 12: Histogram of daily mean (a) and standard deviation (b) values for Hot Standard Carcase Weight (HSCW, kg)

Daily mean and SD of EMA were close to normally distributed, albeit with some quite low and some quite high values (Figure 13). The daily mean values present a mean of 69.92cm^2 and a median of 70cm^2, with an even smaller difference seen for the SD values (mean of 9.16cm^2, and median of 9.11cm^2). This is not evident in the shape of the graphs, with each showing an irregular bell shape.

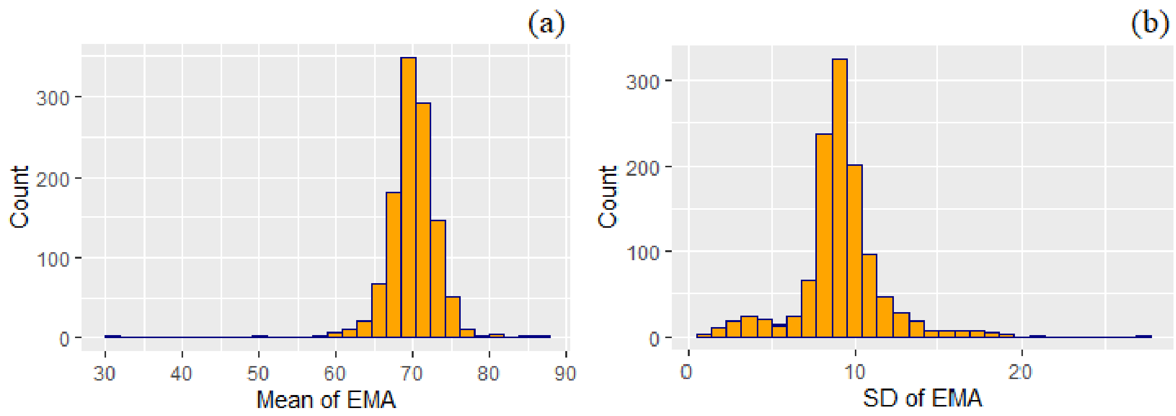

Figure 13: Histogram of daily mean (a) and standard deviation (b) values for Eye Muscle Area (EMA, cm^2)

Rib fat depth (Figure 14) had a relatively normal distribution with very little difference between mean and median values for both mean and SD, requiring multiple decimal places to distinguish the minor difference. The shape of the histograms does not show this closeness to normal, with both graphs appearing slightly skewed with a secondary small grouping at the low end of the graph.

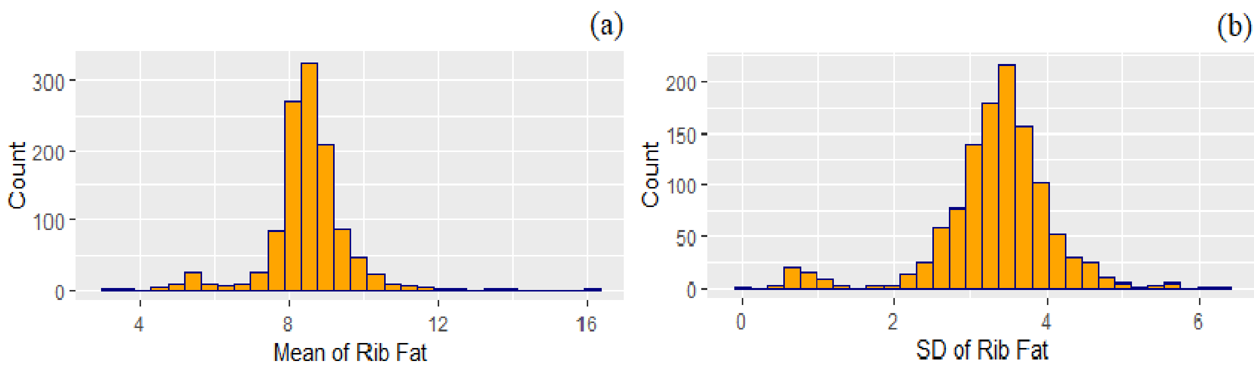

Figure 14: Histogram of daily mean (a) and standard deviation (b) values for Rib Fat Depth (RIB, mm)

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Daily mean ossification score was close to normally distributed, but SD was skewed with many days having high variation reflecting diverse ages being processed (Figure 15). The graphs appear to have a negative or left skew; however, the values show a significant positive or right skew with the mean being greater than the median. The difference between mean and median values for the daily SD values is the greatest, with a mean SD of 41.31 and a median SD of 32.30 (a difference of 9.01). The difference between the mean and median values for the daily mean values is also quite large, with a mean value of 154.3 and a median of 152.3 (a difference of 2).

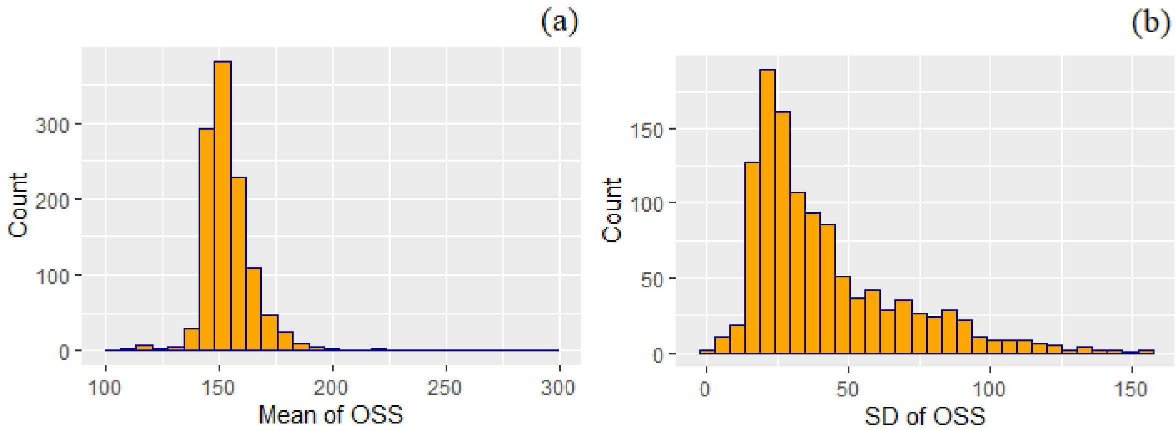

Figure 15: Histogram of daily mean (a) and standard deviation (b) values for Ossification score (OSS, out of 590)

The Marble score results had relatively even distributions overall for both mean and SD values, however the SD histogram does appear slightly left skewed (Figure 16). However, the mean and median results reveal a positive skew. The mean value for the daily mean values was 352, while the median value was 350.4 score units, but the SD values show a greater amount of skew presenting a mean value of 92.08 and a median value of 90.05 (a difference of 2.03).

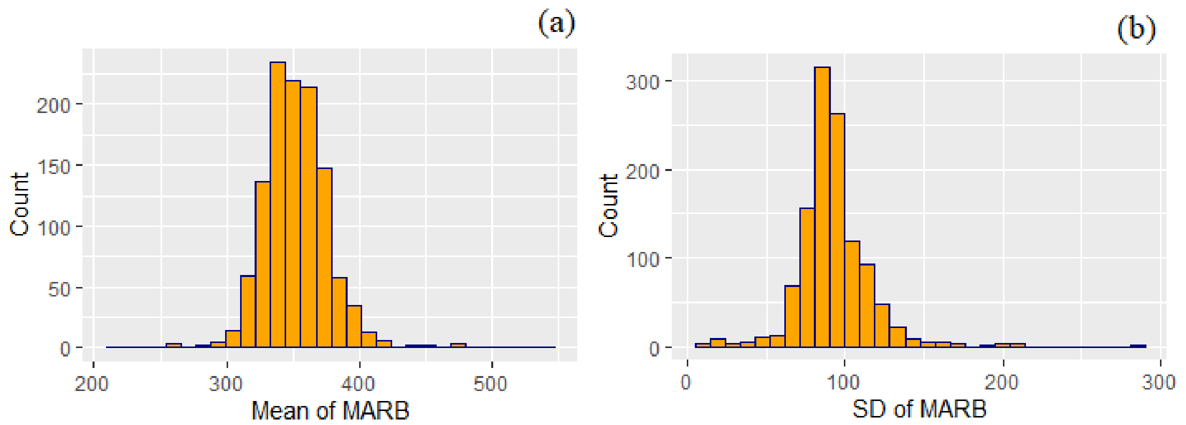

Figure 16: Histogram of daily mean (a) and standard deviation (b) values for MSA Marbling Score (MARB, out of 1190)

MSA Index score had the most normal distribution (Figure 17) in both shape and values, with differences between mean and median values under 0.1 for mean and SD values. The shape of the SD values histogram does appear to be right skewed; however, the values for mean (3.02) and median (3.10) show a slight left skew. The skew of the mean values is less evident, with mean value of 59.74 and median value of 59.73, showing minimal impact of the outliers appearing in the histogram.

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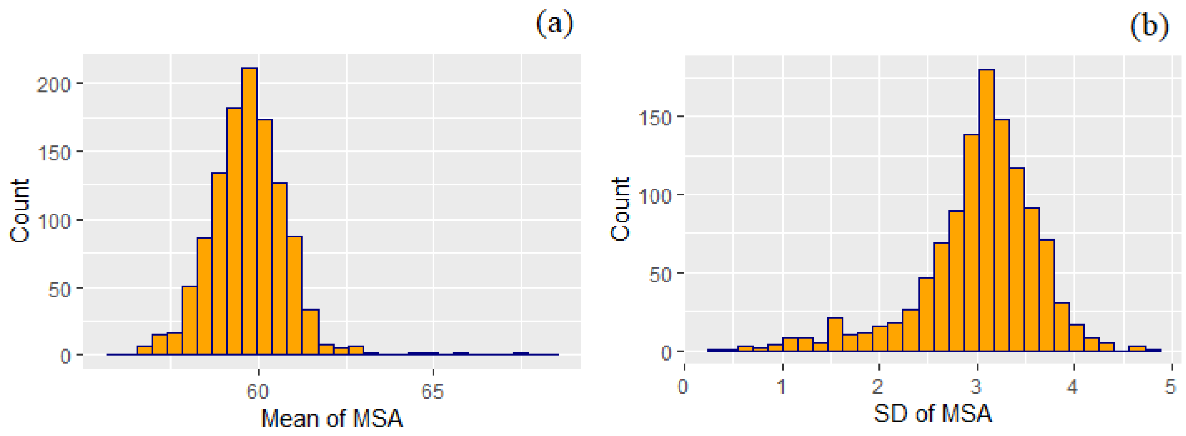

Figure 17: Histogram of daily mean (a) and standard deviation (b) values for MSA Index Score (MSA)

4.6 Scale effects on variation

It is common in biological traits that there is more variation when the mean is higher. This is termed a scale effect and is demonstrated in Figures 18 to 23. The positive relationship of the scale effect for HSCW (Figure 18) shows a majority of values between 225 to 325kg in mean and filling most of the y-axis SD values.

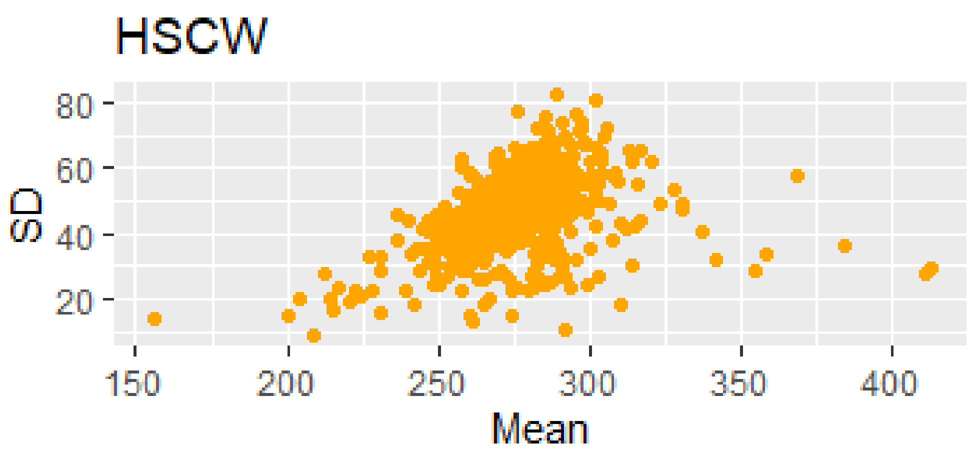

Figure 18: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for Hot Standard Carcase Weight (HSCW, kg)

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There appears to be a positive relationship between the x and y values for EMA (Figure 19), with majority of the data ranging from 62.5 to 77.5cm^2 in mean and an SD of 0 to 15cm^2. However, the scatterplot has an interesting shape, which may indicate some inconsistencies within the data.

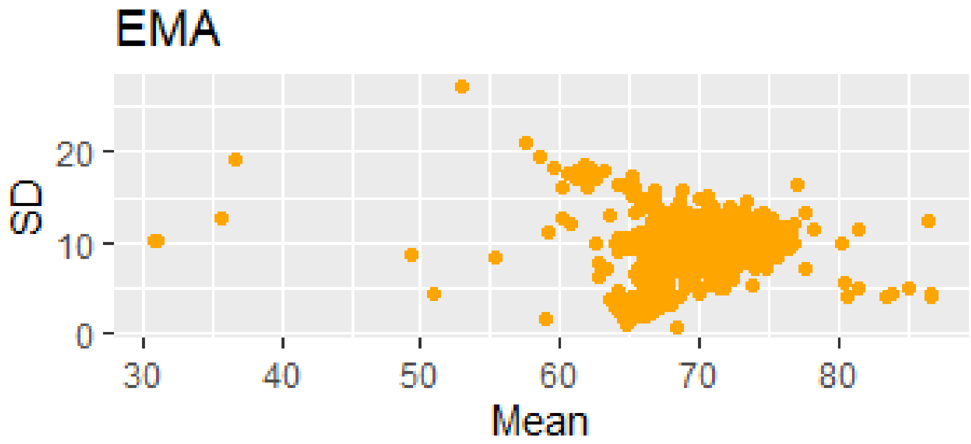

Figure 19: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for Eye Muscle Area (EMA, cm^2)

The scaled effect for Rib Fat Depth had a very strong positive relationship (Figure 20) with majority of the points sitting between 6 and 11mm, with a small secondary group following a flat trend at an SD of 1mm.

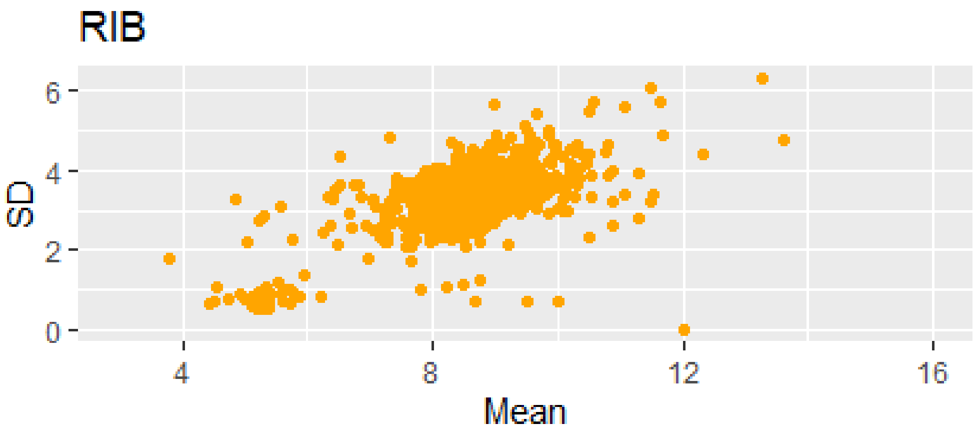

Figure 20: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for Rib Fat Depth (RIB, mm)

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The majority of the data for ossification score follows a curved trend (Figure 21), replicating a rough parabolic shape with the high mean values having SD values nearly as high in value. There is a large amount of data between a mean of 150 and 175 under an SD of 100, with the values over SD of 100 following the curved shape more closely.

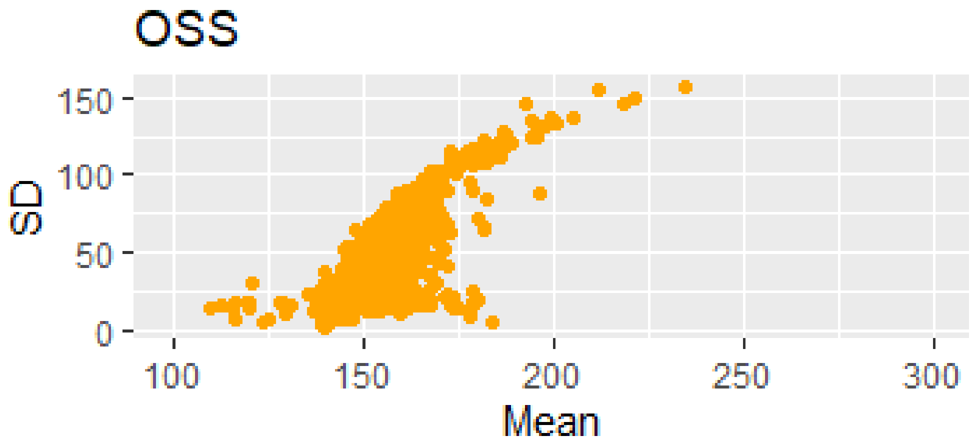

Figure 21: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for Ossification Score (OSS, out of 590)

There is a subtle relationship between daily mean and SD for marble score (Figure 22), with a positive linear trend in the tightly grouped data. Majority of the data ranges from 300 to 400 in mean value and is centred around an SD of 100.

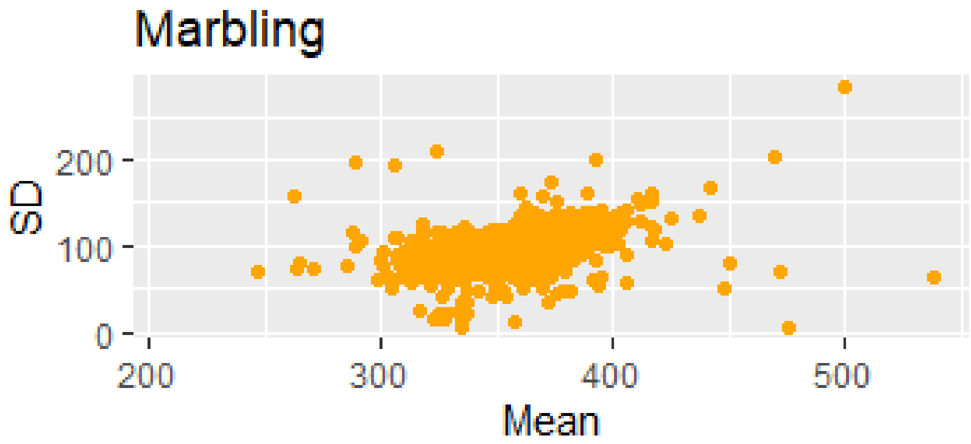

Figure 22: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for MSA Marbling Score (MARB, out of 1190)

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The scatterplot relationship for daily mean and SD values for MSA Index Score (Figure 23) has a slightly negative trend in the data, with the small mean values having high SD values. This relationship is not overly strong, with a large amount of data outside of this overall trend, with some mean values around a mean of 60 and SD under 2, as well as a number of data points over a mean of 62.5 points.

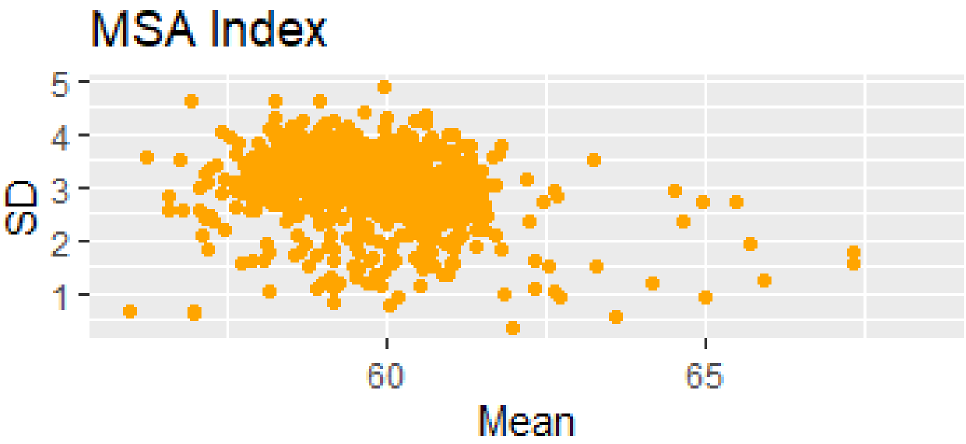

Figure 23: Scatterplot of daily mean values (x-axis) against daily standard deviation values (y-axis) for MSA Index Score (MSA)

4.7 Mixed Model Regression

A linear mixed model was utilised to partition the variation across the four years into sources, i.e. explain where the variation is coming from, for a number of different time frame combinations. This was completed using the ASREML package in R, and was completed on a mixed sample of the dataset (4700 individuals), due to the package unable to run a dataset of such a large magnitude. The variables tested were HSCW, Rib fat, pH, EMA, Hump, and Marbling score, due to their ability to have significant impacts on yield and eating quality. The values at the top of Table 4 were used to determine the correlation values for the between trait relationship, following the equation listed in the methods.

Table 4: Variance (diagonals) and correlations (off-diagonal) for Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm2), Rib Fat depth (mm), Ossification score (Oss), MSA marbling score (Marb), Hump height (Hump, mm) and pH level (units)

	HSCW	Ribfat	pH	EMA	Hump	Oss	Marb
HSCW	2105.61	0.30	-0.04	0.34	0.40	0.11	0.28
Ribfat		12.184	-0.03	0.01	0.09	0.14	0.31
pH			0.01432	-0.0332	-0.06	0.08	-0.05
EMA				88.861	0.16	0.03	0.23
Hump					169.29	-0.03	0.10
Oss						2770.61	0.13
Marb							7716.01

The strongest positive correlation values are under 0.50 for the relationships of Hump & HSCW (0.40), EMA & HSCW (0.34), RIB & HSCW (0.30), HSCW & Marb (0.28), and Marb & RIB (0.31).

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4.8 Partitioning sources of variation

The different levels of combinations of the full set of processor and date variables for each carcase variable resulted in a mixture of effects as judged by the percentage (Table 5, Figure 24). The majority of the variables had the most variation within a lot, whereas HSCW and OSS had the most variation between lots.

Table 5: Variance and proportions (%) for various sources for the carcase variables of interest [Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm²), Rib Fat depth (mm), P8 fat (mm), Ossification score (Oss), MSA marbling score (Marb), and MSA Index score(MSA)]

	HSCW	%	EMA	%	OSS	%	MARB	%	MSA	%	P8	%	RIB	%
Plant	488.4	19	7.81	8	356.7	8	866.7	10	1.04	9	0.923	5	0.641	5
Year	662.4	7	16.4	8	290.3	0	1229	4	1.58	5	3.05	11	2.12	11
Month	660.7	0	25.1	9	428.9	3	1608	4	3.41	17	3.35	2	2.33	2
Day	1124	19	34.9	10	1156	18	2701	12	5.70	21	4.95	9	3.44	9
Lot	2118	40	58.6	23	3622	60	5386	30	8.30	23	8.93	22	6.20	22
Within Lot	2506	15	101.6	42	4118	11	8945	40	11.12	25	18.3	51	12.7	51

The variation in MSA is affected nearly equally between months, between days, between lots and within lot, as well as some impact between plants (Figure 24). The greatest variation between plants was in HSCW and least for fat depth.

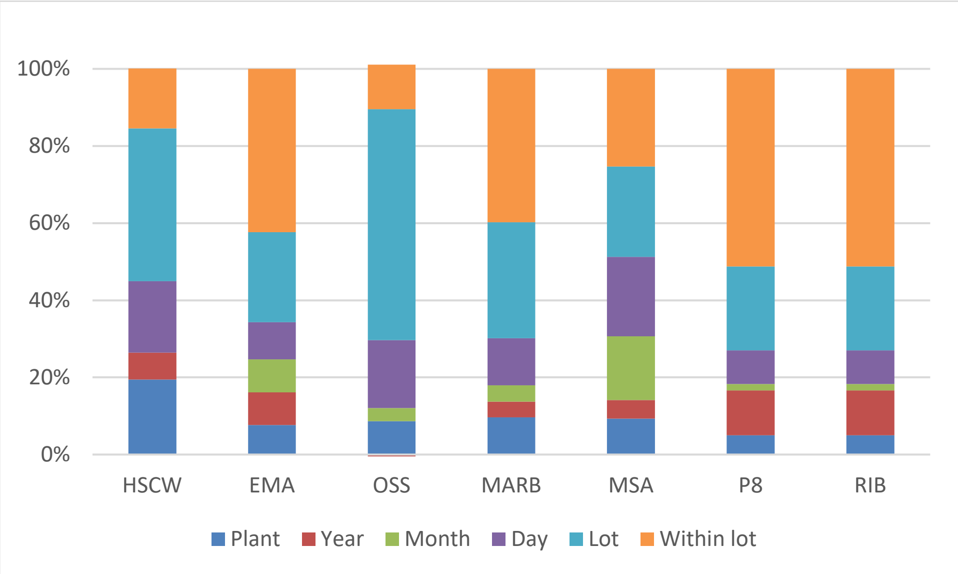

Figure 24: Sources of variation (as a percentage) for each carcase trait based on each processor and date combinations (colours in legend at the bottom) [Hot Standard Carcase Weight (HSCW, kg), Eye muscle Area (EMA, cm²), Rib Fat depth (mm), P8 fat (mm), Ossification score (Oss), MSA marbling score (Marb) and MSA Index score (MSA)]

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5 Discussion

5.1 Comparison of mean and variation

The main driver of this study was to determine the expected variation of a dataset due to most research datasets being formed to test a hypothesis, and variation is often controlled, hence may not accurately represent industry variation. The results from a select few studies were compiled into Table 6 for comparison where possible to the current study and the previous study completed by Pitchford et al. (2020). Some studies did not have all the carcase variables presented (has been left blank), and some have used alternative measures (indicated), as well as different numbers of carcases for each variable (also indicated). There is some consistency in mean and SD values between the different studies. However, there are also some large differences. SD for HSCW seems to be the most consistent across the multiple studies, with five studies presenting values between 50kg and 55kg. Unsurprisingly, the mean and SD values for pH are similar, having come from studies utilising the MSA grading system. EMA also presents some consistent values in mean, ranging from 70 to 72.5cm^2, and scattered SD values between 9.5 and 19.5cm^2.

Table 6 Comparison of mean and standard deviation (SD) values for the carcase variables of interest for the current study, the previous study (Pitchford *et al*, 2020), and a selection of other studies with various numbers of carcases and other conditions [Hot Standard Carcase Weight (HSCW, kg), Eye Muscle Area (EMA, cm^2), Rib Fat Depth (RIB, mm), pH level, Ossification score (OSS), MSA Marbling score (MARB), MSA Index score (MSA)]

		Current study	Pitchford *et al* (2020)	Reverter *et al* (2003)	Piao and Baik (2015)	Bonny *et al* (2016a)	Bonny *et al* (2016b)	Walmsley et al. (2021)
Carcase Numbers		1.7 million, over 4yrs	153	Temperate, Indicated with mean	2.2 million, over 8yrs	Indicated with mean	482	23 (High muscle)
HSCW (kg)	Mean	275.4	323.0	269.13 (3852)	410	327 (521)	329	298 (cold)
	SD	50.0	37.2	54.87	12.7	53.0	53.9	51.6
EMA (cm^2)	Mean	70	71.4	81.59 (length by width,1635)	87.5	72.1 (439)	72.3	72.5
	SD	10.1	12.0	15.90	2.37	19.0	19.4	9.86
RIB (mm)	Mean	8.5	15.6 (P8)	8.21	12.6			7.90
	SD	3.6	5.5 (P8)	4.45	0.64			3.64
pH (units)	Mean	5.57				5.60 (521)	5.60	
	SD	0.13				0.19	0.20	
OSS (score)	Mean	155				190 (521)	195	
	SD	56				99.5	102	
MARB (score)	Mean	349	363			331 (521)	334	358.7
	SD	94.6	39			113	115	55.5
MSA (score)	Mean	59.77	65.1					62.2
	SD	3.33	0.8					1.58

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When taking into consideration the overall results of the current study, and comparing it to the results obtained by the previous study of Pitchford et al. (2020), there are large differences in most of the variables, with only EMA having mean and SD values which are of similar values (Table 6). The previous study has mean values which are predominantly larger for the eating quality variables of MARB and MSA, as well as smaller SD variables. That is, the dataset and analysis completed in the Pitchford study is potentially overestimating eating quality through marbling and MSA score. It also appears to be underestimating variation in carcase weight, and overestimating variation in carcase fatness, affecting the overall conclusion of the research.

5.1.1 Hot Standard Carcase Weight

The mean HSCW was 275.4kg, with an SD of 50.0kg (Table 1). There is a lack of consistency across years and months, which may be reflective of seasonality and climatic conditions (described by BOM, 2021). This may be due to how the animals partition energy and nutrients depending on environmental conditions, which will affect their productivity and performance when conditions are not ideal (Piao and Baik, 2015). The distribution of the daily SD values (Figure 12) had a relatively consistent normal distribution shape, meaning the variation between and within days could be considered as consistent also. This is supported by the narrow spread of the mean value distribution, which predominantly covers a typical weight range that would be seen in a variety of pricing grids (250kg to 300kg). Therefore, if a future dataset is to be considered as accurately representing a kill day at any abattoir in Australia the mean must be within 250-300kg, with a standard deviation in a range of 40-60kg.

5.1.2 Eye Muscle Area

The overall mean result for EMA was 70cm^2, with an SD of 10.1cm^2 (Table 1). The graphs in Figure 2 had reasonably consistent values across the years and months, with a few select outliers occurring in spring of 2011. These greater values of mean, and corresponding high values of SD across September, October and November may be due to the early wet weather in 2011, causing an increased vegetative load in spring (BOM, 2021). Research by Piao and Baik (2015) presented a greater yield grade in spring and summer, with decreased yield grades in winter, which was thought to be due to the occurrence of cold stress. Yield grades were affected positively by eye muscle area, but there was no direct relationship between climatic temperature and EMA (Piao and Baik, 2015). Therefore, it could be considered that a dataset must have a mean between 60 to 80cm^2 and an SD of between 5 and 15cm^2 so that it may be considered representative of a standard kill day.

5.1.3 Rib and P8 fat depth

The overall mean result for Rib fat was 8.5mm, and an SD of 3.6mm, while P8 fat had a mean of 10.2mm and an SD of 4.3mm (Table 1). Piao and Baik (2015) found a strong negative relationship between backfat thickness and yield grade, with higher measures of backfat seen in winter as it serves as insulation. One of the factors which may determine the level of fat deposited is when nutritional intake is greater than the energy used for maintenance and normal productions requirements (Pethick et al., 2004). This will have potentially occurred with grass-fed cattle with the larger vegetative loads in the spring, after the early rains and La Nina events in 2010 and 2011, while the dry springs of 2012 and 2013 (BOM, 2021) may account for less fat on carcasses due to lack of green feed around. The results

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from the histograms (Figure 14) had a mean between 6 and 11mm and a SD of between 2 and 5mm, therefore if Rib fat depth meets these targets a future dataset could be considered a comprehensive dataset.

5.1.4 Ossification score

There is a large amount of research around the different factors which can affect the rate of ossification and physiological age of a carcase, such as hormonal status of the animal, which can be affected by gender or use of hormonal growth promotants for example (Bonny et al., 2016b). Ossification is able to capture the age and maturity of the animal, which is important as meat becomes tougher as the animals mature due to increased collagen crosslinks that survive the cooking process (Bonny et al., 2016b). The overall mean result for ossification score was found to be 155, with a SD vale of 56. There is also a potential seasonal effect with a consistent trend of high mean and SD values in 2013 for most months. This may be due a number of factors, including the dry seen throughout 2012 and 2013 causing producers to destock potentially slightly older heifers and young cows to lighten the demand for feed on-farm pre-empting drought conditions (Steffen et al., 2010). Ossification score showed the greatest spread of daily SD values (Figure 15), with a large number of values covering 0 to 150. These higher values of SD may indicate days where processors are seeing an increased number of older animals which tend to have the higher ossification score, so causing more variation on those days. Even though this variation seems overt, it would appear as though it is representative of production day as there are no obvious outliers in either mean or SD graph, and not every day is going to feature the 'optimum' cattle all day. Therefore, it may be considered a dataset is representative of a processing day if the mean ossification score is under 200, and will be more accurate and precise if the SD value is under 100.

5.1.5 Marbling score

The overall mean result for MSA marbling score was determined to be 349, and a SD of 94.6. This combination of values was not matched in any standalone year or month, and had no clear trend, which is corroborated by the scatterplots in Figure 5, with the only detail discernible being 2010 having the highest mean values consistently. Several factors can affect an animal's propensity to lay down intramuscular fat to create marbling, including genetics and nutritional factors, with intramuscular fat generally being the last area for fat deposition to occur within an animal (Pethick et al., 2004; Park et al., 2018). There are a few outliers present for the daily values of mean and SD histograms (Figure 16), however most of the data lies within 100 points (around one score grade). There are a number of mean values which have quite high counts either side of 350, which could show some of the subjective nature of this measure. This average is also slightly higher than the overall mean seen in 2019, however the graph presented in the 2019 Australian Beef Eating Quality Insights report (Meat & Livestock Australia, 2019) shows a very similar shape. Therefore, it could be assumed that a mean score of between 300 and 400, and a SD score value of between 50 and 150 within a future dataset will be representative of a single processing day.

5.1.6 MSA Index score

The mean MSA Index score was 59.77 units, and a SD value of 3.33 units. The overall score for this dataset is quite a bit higher than that seen for the national average seen in the latest MSA report, with a

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score of 57.62 (Meat & Livestock Australia, 2019), however the same number of carcasses are not covered in this dataset (report covers 6.6 million from 2017 to 2019). The daily mean values (Figure 17) does have a similar overall shape to the graph presented in the latest MSA report [top of page 8] (Meat & Livestock Australia, 2019), with a high peak around 60 points and a sharp decrease into the higher values. The Pitchford et al (2020) study may have underestimated the variation in eating quality, as judged by SD value for MSA (Table 6), particularly when compared to the results of this study. This study had an SD of 3.33 score units overall (Table 1), with yearly and monthly SD values varying between 3.10 and 3.50 units (Table 2 and 3). When these results are compared to Pitchford et al (2020) result of 0.8, it is easy to determine that the bone-out trial incorrectly assumed that the variation in MSA, and hence eating quality, was not a driver of carcase price per kilogram and carcase value.

The daily SD values (Figure 17) also tend to favour the higher values, displaying that as the mean value increases so does the amount of variation. Given the clear trend in mean values occurring across the months, it may need to be investigated further what month these high daily values have come from as this may be skewing the data, as there may be more high-quality cattle processed during certain months. Depending on the results of this investigation, it may be safe to assume a future dataset should have a mean of between 57 and 62.5, and an approximate SD between 2 and 4, but under 5 at most, for that dataset to cover sufficient daily variation.

5.2 Evidence of scale effects

When the variation measured as SD increases with the mean, this is termed a scale effect and is expected for traits such as marbling. The relationships between mean and standard deviation daily values (Figures 18 to 23) have a variety of different shapes across the variables of interest. There are also a number of days which have values that appear to be outliers on all graphs, however it is hard to know if it is the same days occurring for each variable. For HSCW (Figure 18) there appears to be a strong positive linear relationship between the values, so that as the average mean weight increases the amount of variation present also increases, as described by the SD value. There were a number of values at the lower SD values which do have higher mean values, however they are not unrealistic, as there may be days where particular large lots are processed that tend to be heavier and more consistent, for example large amounts of feedlot cattle come to mind. These values may also be reflective of different brands or markets favoured by the different processors covered in this dataset, as they can tend to have very strict carcases specifications. There also may be some drive coming from processor grids, with the different levels paid according to weight driving producers to meet that demand.

This could also be responsible for the shape of the graph for Rib Fat depth (Figure 20). The two distinct groups may be representative of two distinct weight or grid categories, so the small group would be the carcasses sent domestically with minimum fat while the major group are the heavy domestic to export type carcasses which require more fat. The outliers in all the plots could also potentially be some seasonality effect, when there is not enough supply of direct consignments processed, so abattoirs must rely on saleyard cattle which would likely be more variable in type, and therefore cause increased variability overall on that day. The plot for EMA values has (Figure 19) one of the most interesting shapes out of all the scatterplots, appearing to form an arrow shape point to the right side of the graph, with a large amount of spread along the y-axis at around x = 65cm^2, before tightening up at around x = 76cm^2. This shape represents an interesting relationship between the SD and mean values, with SD values above 10cm^2 decreasing as the mean increases, while SD values below 10cm^2 increasing as the mean increases. If the values above SD of 10cm^2 are ignored, EMA has a strong positive linear

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relationship like that seen for HSCW, therefore as the carcase weight increases, so does the muscularity, and so the variation level increases too.

The next variable with a distribution of interesting shape is ossification (Figure 21), following a strong positive curved trend at the top edge of the plot and a bit of spread under this edge, with the largest spread along the x-axis at the lower SD values. Ossification is one variable that has a high impact on the MSA Index , causing a 0.6 point decrease for each 10-point increment increase (Meat & Livestock Australia, 2019). That is, ossification has a greater impact on eating quality due to its effect on meat tenderness, causing large decrease in MSA Index score. This strange shape does not occur in the MSA Index score plot (Figure 23) however, which may be due to these higher ossification score days potentially having a large amount of ungraded cattle so will not have been given a MSA score. MSA Index score shows very little definite shape, with a slight negative linear trend appearing through the middle of the large grouping. The MARB graph (Figure 22) has a very slight positive linear trend, with quite a few various outliers, with those days showing SD values over 200 of some concern. There are also two days which had very high means of over 500, which does seem unrealistic, unless there was a large number of purebred Wagyu or F1 crosses with scores of 900+ processed on those days for example. The overall positive trends for EMA, RIB and MARB show some of the consistency in type of carcases processed, as there is the same general shape and slope in the scatterplots. This may show the market requirements that Australia has very strongly, as well as the type of cattle that are predominant; that is cattle that have moderate EMA and muscularity, well covered in fat, and a moderate degree of marbling.

5.3 Relationships between traits

The mixed model regression results (Table 4) had moderate correlation values between some of the traits, while others had very little correlation at all. The traits which present with correlations over 0.25 are those which make sense, those being HSCW with fat, EMA, hump height, and marble score. That is, HSCW is slightly affected by level of fat, size of EMA, size of hump, and degree of marbling in the carcase and vice versa. This result makes sense logically, for example the more hump present on an animal, the more weight is going to be present in the forequarter across the neck and shoulders, so there will be more weight in the carcase overall, and consequently the bigger the animal is overall, the heavier their carcass will be. Surprisingly though the correlation values for these relationships are not higher. The other relationship where $r > 0.25$ was between the two different fat measures of Rib fat depth and marble score, however it is surprising that this was not a higher correlation. The other sets of variables had a variety of different values for covariance, which may indicate the presence of outliers and other large values skewing the magnitude of the relationship, eg the correlation between HSCW and MARB (Table 4). Therefore, the value itself is not of interest but whether the value is positive or negative. Unsurprisingly, the relationships covered in the other sets of variables appear to be realistic and logical if only viewed as a positive value and the magnitude of the value is ignored.

5.4 Partitioning sources of variation

The tests of variation occurrence had some potentially unexpected results, mostly the lack of variation that could be attributed to the different processor or time effects for the different variables. The research conducted by Pitchford et al (2020) was identified as not capturing enough eating quality variation, with majority of the carcase value in the pricing work driven by yield. The data utilised for the Pitchford et al (2020) study was from a genetics trial, which try to evaluate animals born and raised together, so by

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definition should have limited variation. However, the results of the variation tests (Table 5, Figure 24) of eating quality, as determined by MSA index score, had relatively consistent variation between months, days, lots, and within lots, showing the assumptions made by previous research may be sound. This must be viewed cautiously though, as there is a large amount of variation in HSCW between plants and lots, which may explain the differing opinions of carcase value drivers from processors.

The research by Pitchford et al (2020) also assumed that ossification was approximately the same for the lot of cattle analysed (data collected was pre-MSA, and pre-OSS measurement) as all animals were raised and slaughtered together well under 2 years of age. This assumption is supported by these results (Table 5, Figure 24), where OSS is showing minimal variation within lot. This between lot variation may also be having an impact on the overall eating quality variation a processor may see, due to its impact on MSA score as discussed previously. MARB also had similar levels of variation between and within lot, again affecting the overall perceived eating quality variation. Due to the inconsistencies between these results and those found in the previous research, it can be determined that more research is needed into the drivers of price and carcase value. This further research needs to be conducted in a way that it ensures the reality of processors is captured, as well as produce an effective, workable pricing system that appreciates carcase yield and eating quality.

6 Conclusion

Pitchford et al. (2020) reported results from a bone out trial with animals from a genetics trial that were born and raised together. Thus, there was minimal variation in age and all animals had been managed the same. The animals herein had similar carcass weight, eye muscle area and fat depth to Pitchford et al. (2020) but, as expected, the variation in quality experienced by processors was much greater. Processors have large variation in ossification whereas in the bone out trial it was assumed there was none as the animals were not MSA graded. Processors also have much greater variation in marbling so that on a daily basis the standard deviation was 77 relative to 39 scores. The combination of ossification and marbling meant that the standard deviation in MSA index experienced by processors was 2.3 compared to only 0.8 in the bone out trial. Thus, even though it was not measured directly in the MSA dataset herein, it appears that while the bone out trial had representative variation in yield, the variation in quality was far smaller than commonly experienced. The implication of this is that the conclusion about the relative importance of yield and quality should rightly be questioned and will be the subject of further work.

This study was completed using a subset of the MSA database, covering a four-year period and with details on 35 different variables. A number of different results were generated for the key variables of interest over a number of different timespans, as well as showing the market demand and seasonal effects which may influence data. These various results could potentially be used for comparison of future datasets; however, the magnitude and details of this dataset must also be considered to ensure accurate comparison. The results achieved here will be utilised in further research as a way to capture processor variation. There was also a number of inconsistent results in terms of variation of carcase traits found between this study and previous research, which raises further questions about realistic results found therein. These questions are namely around yield driving carcase value; however, this study shows that eating quality should be having more of an impact than previously found. Further research will be conducted to determine the level of impact, to more accurately capture the yield and eating quality drivers of carcase value, and present to industry a pricing system that effectively uses both measures.

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