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Report Title: The value of precise cut weight prediction in the optimisation of lamb carcase processing

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Abstract

The Australian beef industry is focused on improving the objective measurement of lamb carcase yield to improve the valuation of lamb carcases. However, the value that technologies such as DEXA, that have improved the precision of cut weight prediction, represent to plants in the processing of carcases needs clarity. This project thereby assesses the value of using DEXA cut weight predictions in a processing scenario in the lamb Optimisation tool compared to using hot carcase weight (HCWT) and GR cut weight predictions. 191 lambs representing a wide range in HCWT and fatness were measured for GR, DEXA scanned and comprehensively boned out to weigh a wide selection of retail cuts and associated lean trim and fat. A scenario was then developed in the Carcase Optimisation Tool with 2 to 3 cut options available for each section of the carcase, with cut weight thresholds applied limiting the carcases that could be assigned to the different cut options based on their cut weights. The costs of processing the lambs were input and well as the market value of each retail cut available and the associated fat and trim. The cut weights of the lambs were then entered into the optimiser to determine the optimal processing of the lambs. The optimiser scenario was then repeated using HCWT, GR, DEXA and DEXA image component predicted cut weights to determine the most profitable processing of the carcases. The profits and cut allocations output by the optimiser models were then assessed to determine the difference in profit using cut weight predictions compared to the actual cut weights and examining the number of misallocations caused by imprecise cut weight predictions. Using DEXA variables to predict cut weights resulted in optimised profits closer to those achieved using actual cut weights, and les cut option misallocations in the rack, loin and hindquarter sections of lamb carcases.

Contents

Acknowledgements 2

Abstract 3

Contents 4

1 Introduction 5

2 Methodology 5

  2.1 Lamb selection and data collection 5

  2.2 DEXA scanning and image analysis 6

  2.3 CT scanning 7

  2.4 Lamb bone out 7

  2.5 Statistical analysis 7

    2.5.1 Data transformation and adjustment 7

    2.5.2 Linear modelling to predict cut weights 8

    2.5.3 Assigning trim and fat weights to predicted cut weights 9

  2.6 Carcase Optimisation Tool scenario development 9

    2.6.1 Lambs available 9

    2.6.2 Costs 9

    2.6.3 Cut options and thresholds 9

    2.6.4 Returns 10

    2.6.5 Cut weights 10

  2.7 Carcase Optimisation Tool outputs 12

3 Results and discussion 12

4 Conclusions 16

5 References 16

1 Introduction

Lean meat yield (LMY) is an important trait driving profitability in the lamb industry, as carcases of the same weight can vary substantially in the amount of lean meat they contain and thereby the weight of saleable meat cuts procured from a carcase. Current Australian industry standards for measuring lamb carcase fatness and thereby estimating LMY are via subjective palpation for fat class or measurement of tissue depth at the GR site (Anonymous, 2005). The GR site is located 110mm from the midline of the carcase along the lateral surface of the 12th rib on either side of the carcase. However, this single site fat depth measure has poor precision predicting the composition of lamb carcases (Williams et al., 2017) and thereby predicting retail cut weights.

In recent years a dual energy absorptiometry (DEXA) system has been successfully developed in the Australian lamb industry to predict the CT composition of lamb carcases scanned at abattoir line speed (Gardner et al., 2018). By predicting composition with high precision and accuracy, this lamb DEXA system can also predict retail cut weights in lamb with higher precision than existing carcase weight and GR predictions (Gardner et al., 2021). However, the value of improved precision of cut weight prediction precision to processors has not yet been clearly demonstrated. The lamb optimisation tool has been developed to allow processors to examine the most profitable means of processing available lambs based on their carcase weight and fatness; the cutting plans available to different animals and the value of these markets and the costs of processing the lambs into the different cut options available. We hypothesise that using more precise cut weight predictions informed by DEXA measures will allow for the optimiser to process the lamb carcases most closely to what can be achieved knowing their actual cut weights, as will be reflected in the optimiser profits and allocation of carcases to certain cutting plans.

2 Methodology

2.1 Lamb selection and data collection

Genetically diverse lambs (n = 191) were selected from the MLA Resource Flock to represent a wide phenotypic range in carcase weight and fatness for this study. The lambs were a mixture of sexes and a combination of Maternal, Merino and Terminal sired lambs. The lambs were slaughtered at a commercial abattoir where an AUS-MEAT accredited employee measured GR tissue depth on hot carcases using a GR knife. All carcases were dressed to a hot standard carcase before weighing for hot standard carcase weight (HSCW), chilling overnight and DEXA scanning at abattoir line speed the following day.

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2.2 DEXA scanning and image analysis

X-ray images were generated using a single emission from a 140 kV and 27 mA X-ray tube, with a set of 2 images captured on a detector comprised of 2 photodiodes separated by a copper filter (Scott Automation and Robotics). The first photodiode used ZnSe as the scintillant, and the second used CsI as the scintillant, with these scintillants selected due to their specificity for low and high energy photons (Ryzhikov et al., 2005).

Initially all images acquired were calibrated by scaling the pixels corresponding to un-attenuated regions (scans of air) to a value of 4095. The ratio of the photon attenuation between carcase pixels in the low and high energy images was then used to calculate an R-value for each pixel (Pietrobelli et al., 1996) according to the following formula:

R value = ln (ILow/AirAtten)/ ln (IHigh/AirAtten);

where:
ILow represents the pixel value in the low energy image (ZnSe Photodiode)
IHigh represents the pixel value in the high energy image (CsI Photodiode).
AirAtten represents the pixel value corresponding to the un-attenuated photons within each image that have passed through air only (adjusted to 4095).

The average R-value for all pixels in the carcase image was then calculated, setting a threshold with pixels above this value removed, thereby eliminating predominantly bone-containing pixels. Although this step is imperfect (Gardner et al., 2015), the aim is to reduce the image to a two-part mixture consisting mainly of fat and lean. Pixel R-values were then converted to a chemical fat % and weighted by their estimated tissue thickness based on values established from DEXA scanning tissue calibration blocks of varying composition (ranging from 100% lean/0% fat to 0% lean/100% fat) and thicknesses (ranging from 12.5 to 280 mm thick). Finally, the mean of these pixel values was calculated, and this percentage figure was subtracted from 100 to arrive at the final “DEXA value” representing carcase lean. Subtracting the percentage figure from 100 was undertaken to give it a positive alignment with CT lean% which aids in reporting feedback to industry-stakeholders.

In addition to the mean DEXA value, a further two values were extracted from DEXA images that corresponded to the dimensions of the carcases. The first was the total pixel number which corresponded to cross-section area of the carcase, and the second was the average of the negative log (pixel value) for the low energy image which corresponds to average thickness of the carcase image. These DEXA image values combined with the mean DEXA value are referred to as ‘DEXA image components’ when used to predict cut weights.

2.3 CT scanning

Lamb carcases were CT scanned at Murdoch University using a Picker PQ 5000 spiral CT scanner according to a defined protocol (AUSMEAT) for CT determination of CT lean, fat and bone %. Carcasses were split into three components for weighing and CT scanning, the fore-section, saddle and hind section, enabling the estimation of percent lean (CT lean%), fat (CT fat %), and bone (CT bone%) within these regions. Scanning methodology, and CT image analysis was undertaken in the same way as described in Gardner et al. (2018). Pixels within CT images were defined as fat, lean or bone on the basis their Hounsfield unit values, with pixel values of − 235 to 2.3 allocated as fat; 2.4 to 164.3 allocated as lean; and >164.3 allocated as bone.

2.4 Lamb bone out

Following CT scanning, all carcases were boned out according to a detailed protocol to determine the weights of a series of key commercial cuts. At each boning step in this protocol, the weights of the commercial cuts, bone, lean, and fat trim were reconciled against the original primal weight from which they were dissected. In this way full recovery of this original weight was ensured and errors in procuring commercial cut weights was ensured.

Cuts were dissected by a team of 4 boners operating at two separate tables, with each table dissecting an entire carcase. The same boners operated at the same table throughout the bone-out procedure. The table at which each carcase was dissected was recorded, enabling us to identify the team of 2 boners responsible for dissecting each cut and thereby to adjust each cut weight for boner ID as described below.

2.5 Statistical analysis

2.5.1 Data transformation and adjustment

Huxley’s allometric equation (y = axb) was used, where x is the independent variable, a is the proportionality coefficient and b the growth coefficient of y relative to x (Huxley & Teissier, 1932). By transforming the cut and carcase weight values to natural logarithms, the data is linearised (loge y = loge a + b loge x) and can be solved by least squares regression, where loge cut weight (y) is predicted by loge carcase weight (x). There are three key advantages of this approach. Firstly, it enables maturation rate of each cut to be interpreted. The value of the b coefficient describes the relative growth rate of the component (y) to the whole carcass weight and will be either: early maturing ($b < 1$), late maturing ($b > 1$) or maturing at the same rate as that of x ($b = 1$). Secondly, using the log form of the equation homogenises the variance over the entire range of sample data, handling the scale effect on variance which is inherent in growth modelling. Thirdly, it also allows for the direct comparison of the differences in loge y values as percent differences in weight (Cole, 2000), and it is on this basis that the data in this paper has been interpreted.

After transformation, cut weights were adjusted to account for consistent variation due to the boners who procured the cut. For each cut this was done by fitting a linear mixed effects model in SAS, using loge cut weight as the dependent variable, and loge of the component weight that the cut was dissected from as the independent variable (ie for the Rump, loge weight of the hind section was used), along with the CT fat% and CT lean% of that section. In each of these models the fixed effect of table ID was fitted as a random term. The magnitude of these random effects represented the consistent variation caused by the boner procuring cuts on each table. Therefore, the last step in this process was to add these values back to the loge cut weight data according to the boning table that procured that cut, correcting it for boner ID variation. CT is utilised to provide these corrections as it has also been used to train the predicted fat% values from the DEXA system (Gardner et al., 2018), thus we are aligning the cut weight and DEXA prediction datasets using the same consistent gold-standard fatness indicator.

2.5.2 Linear modelling to predict cut weights

For each cut, general linear models were trained in SAS to predict the corrected loge cut weight from loge hot standard carcase weight using different carcase variables:

a) HSCW
b) HSCW and GR
c) HSCW and mean DEXA values
d) HSCW, mean DEXA values and DEXA image component data (pixel number and mean negative log of low energy pixel values)

The models predicting lamb cut weights using variables a) to d) were all trained and validated using a five-fold cross-validation procedure. This was achieved by randomly dividing the data into 5 groups (though balanced for carcase weight and fatness), training predictions in four groups or 80% of the data and validating this prediction in the remaining group or 20% of data. This process was repeated

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a further 4 times so that each group and thus individual animal had a validated prediction of each cut weight.

2.5.3 Assigning trim and fat weights to predicted cut weights

The trim and fat weights associated with every cut were also measured in the bone out. The trim and fat weights associated with each predicted cut weight was worked out based on the proportion of trim produced relative to the commercial cut weight in the bone out. For example, if the Shortloin cap on no tail, 6mm fat cap in an individual animal was associated with 107g of lean trim and 87g of fat tissue and this equated to 52.7% of recovery being lean trim and 42.8% being fat, then these % values were applied to the ‘recovery’ of each of the predicted cut weights to obtain an approximate fat and lean trim value for every cut weight prediction associated with lean or fat trim.

2.6 Carcase Optimisation Tool scenario development

The data captured from these lambs was then input into the Lamb Carcase Optimisation Tool to examine the optimised processing output for these lambs when several cut options are available and different cut weight inputs are used (actual versus predicted cut weights).

2.6.1 Lambs available

The 191 lambs boned out in this data set were input into the optimiser available for processing based on their individual HSCW and GR fat measurement.

2.6.2 Costs

Each lamb was attributed a fixed slaughter charge of $12 per head, covering the slaughter and production of a hot standard carcase, and a fixed boning room charge of $25 per head. This estimated boning room charge was then spread across each cutting plan available for each lamb carcase, attributing an exact cost to each potential cut. The charge is spread across available cuts on a per kg basis, meaning that the heavier cuts attributed a larger portion of the boning expense. A fixed packaging charge of $5.40 was also applied to each carcase, that was again spread across the potential cuts in each processing option, however on a per piece or cut rather than per kg basis.

2.6.3 Cut options and thresholds

The cut options available to cut the lamb carcase sections into are shown in Table 1, along with the cut weight constraints applied to each cut option (Table 1). The approximate HSCW represented by the cut weight constraint is also shown, given that current boning room allocation is based on carcase weights.

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The cut options were designed to mimic common commercial scenarios. For example, the hind section can be processed into a whole chump on leg, with smaller carcases (<18kg) generally assigned to produce this larger roasting leg; could be boned into a smaller chump off leg; or could be boned out into individual primals, generally using larger carcases to ensure primals of a certain weight are procured.

2.6.4 Returns

Each commercial cut available in the Optimiser was designated an approximate wholesale value per kg, as shown in Table 1. Trim and fat were also designated values of $6/kg and $0.4/kg respectively.

2.6.5 Cut weights

The above inputs into the Carcase Optimisation Tool remained fixed, with only the predicted Cut weights, and their associated predicted trim and fat weights differing between each Optimisation scenario model. Five Lamb Carcase Optimisation models were run using different cut, trim and fat weight inputs:

1. Actual cut weights
2. HSCW predicted cut weights
3. HSCW + GR predicted cut weights
4. HSCW and mean DEXA value predicted cut weights
5. HSCW, mean DEXA value and DEXA image component predicted cut weights

The variables predicting cut weight predictions are ordered in line with their average precision of predicting cut weights – HSCW is the least precise; followed by HSCW and GR measures; followed closely by HSCW and DEXA mean values; while using DEXA image component predicted cut weights produces generally the most precise predictions of cut weights (Gardner et al., 2021). However, the level of cut weight prediction precision of varies substantially between different retail cuts (Gardner et al., 2021) and the improved precision from GR to DEXA image components for example also varied between cuts (Gardner et al., 2021).

Actual trim and fat weighs measured in the bone out were input into model 1, while approximations of trim and fat weights were input into models 2 to 5 based on the cut weight predictions as previously described in section 2.5.3.

Table 1: Carcase cutting options input into the optimiser. All cuts included in each option are listed as well as cut weight thresholds (kg) for the option where applied and the market value assigned to all cuts ($/kg). Cut options for each carcase section (HQ, shortloin, rack and FQ) are available for optimisation independent of the other sections of the same carcase. Meaning for example an individual carcase could be cut into HQ3, SL1, Rk2 and FQ1.

Cut specification	Cut weight threshold (kg) {~ equiv. carcase weight*}	Market value	Cut specification	Cut weight threshold (kg) {~ equiv. carcase weight*}	Market value	Cut specification	Cut weight threshold (kg) {~ equiv. carcase weight*}	Market value
Hindquarter (HQ)								
Option 1 (HQ1)			Option 2 (HQ2)			Option 3 (HQ3)		
Leg chump on, shank on, tip off , 6mm fat cap	≤ 2.75 {< 18 kg}	$9.60/kg	Chump BO (6mm)		$16.80/kg	Leg chump off, shank on, tip on, 6mm fat cap	nil	$9.00/kg
Hind Shank Tipped		$8.40/kg	Butt tenderloin		$29.40/kg	Chump BO (6mm)		$16.80/kg
			Round	≥ 0.55 { > 27 kg}	$15.60/kg			
			Rump		$16.80/kg			
			Silverside fat cap on		$13.20/kg			
			Topside Fat Cap On		$15.60/kg			
			Hind Shank Tipped		$8.40/kg			
			Heel Muscle		$9.00/kg			
Shortloin (SL)								
Option 1 (SL1)			Option 2 (SL2)			Option 3 (SL3)		
Shortloin eye	0.58 – 1.5 {17 – 40kg}	$25.20/kg	Shortloin cap on no tail, 6mm fat cap	≤ 0.85 { < 24 kg}	$19.20/kg	Shortloin cap 50mm tail, 10mm fat cap	≤ 1.4 {< 17 kg}	$15.60/kg
TDR Butt off/Side Off		$29.40/kg						
Rack (Rk)								
Option 1 (RK1)			Option 2 (RK2)					
French rack, 8x100mm rib, 50mm Fr., Capoff, False capoff	≥ 0.75 {> 32 kg}	$27.60/kg	Rack, 8x100mm rib, CFO, scap in, 6mm fat, cap on	≤ 1.4 { < 33 kg}	$9.60/kg			
Forequarter (FQ)								
Option 1 (FQ1)			Option 2 (FQ2)			Option 3 (FQ3)		
Square Cut Shoulder 10mm Fat Cap, St. Cut (4Rib)		$8.40/kg	Best End Shoulder Chops 6mm Fat Cap	1- 2.2 {17 – 32kg}	$6.00/kg	Boneless Shoulder 6mm fat cap, chuck roll out	≥ 0.22 {> 31 kg}	$12.00/kg
Breast		$4.20/kg	Neck off Cut, St. Cut		$1.80/kg	Chuck roll		$18.00/kg
ForeShank Tipped		$8.40/kg	Round Bone Piece BO, 6mm Fat Cap		$7.79/kg			

* no carcase weight thresholds were input into the optimisation models. These values give an indication only of approximate equivalent carcase weights for each cut weight threshold defined.

2.7 Carcase Optimisation Tool outputs

Two key outputs of the lamb Carcase Optimisation Tool were examined in this experiment- the profit of each model and the detailed allocation of cuts output. The overall profits and profit per carcase were compared between models directly, while the detailed allocation of models 2 - 5 were compared to the model 1 – considered the ‘correct’ allocation of cuts into markets given this optimisation model is underpinned by actual cut weights. Differences in cut allocations between models 1 and models 2 -5 (using predicted cut weights) were counted and assessed to determine if misallocations were due to imprecise cut weight predictions causing cuts to exceed or fall short of the cut weight threshold applied (Table 1).

3 Results and discussion

The scenario developed ran successfully in the lamb Carcase Optimisation Tool, outputting the results shown in Figure 1 when run using the actual cut weight data for all lambs (model 1). The Optimiser gives a summary of the number of each cut procured with optimised processing; the profits relating to each cut; the costs of processing the lambs; the overall profit ($3552.24) and the average profit per carcase ($18.60).

The relative overall profit of processing the 191 lambs using predicted cut weights compared to the profit using actual cut weights is shown in Figure 2. In line with our hypothesis, the more precise predictions of cut weights (DEXA image component models) produced an overall profit closest to the profit produced using actual cut weight values, differing by $191.91, than less precise cut weight predictions such a HSCW and GR, that differed in overall profit by $234.65 and $202.87. Given that costs and income inputs in the optimiser scenario remained unchanged between models, these differences in profit relate only to differences in lamb carcase allocation based on their cut weights meeting or not meeting the thresholds applied to the different processing options. Therefore, profits closer to those anticipated using actual cut weights reflect that these DEXA cut weight predictions produced an optimised solution most similar to the solution based on actual weights.

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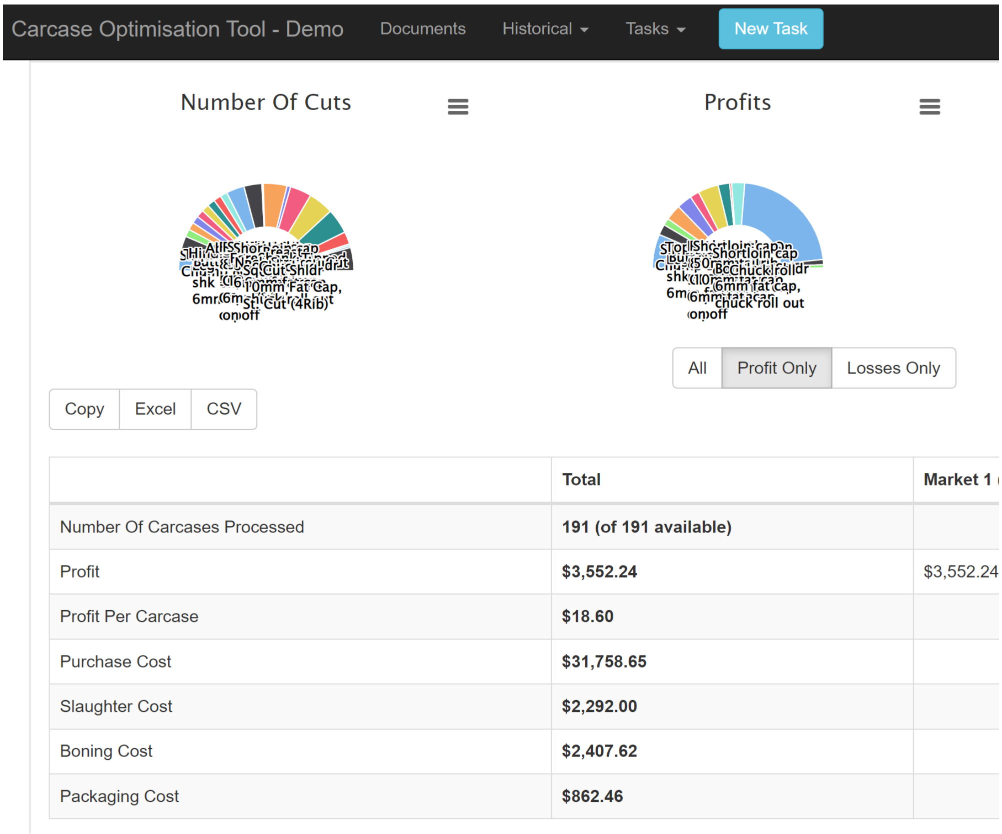
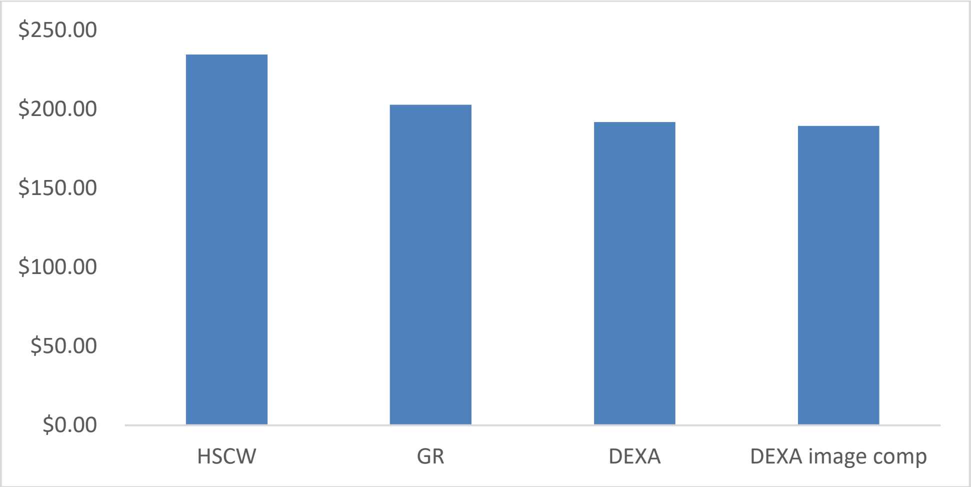
Figure 1. A picture of the Carcase Optimisation Tool output based on the optimised processing of all lambs in this scenario using their actual cut weight data (model 1).



	Total	Market 1
Number Of Carcases Processed	**191 (of 191 available)**	
Profit	**$3,552.24**	$3,552.24
Profit Per Carcase	**$18.60**	
Purchase Cost	**$31,758.65**	
Slaughter Cost	**$2,292.00**	
Boning Cost	**$2,407.62**	
Packaging Cost	**$862.46**	

Figure 2. The difference in profit ($ total) in the lamb Carcase Optimisation Tool using cut weight predictions compared to using actual cut weights. Cut weight predictions are informed by hot standard carcase weight ('HSCW') only; GR measures and HSCW ('GR'); mean DEXA values and HSCW ('DEXA') and by DEXA image components, mean DEXA values and HSCW combined ('DEXA image comp.').



This is also reflected in the number of cut option misallocations identified in the models using predicted cut weights compared to the optimised allocation using actual cut weights (Table 2). The misallocations represent the number of carcases within each section which were allocated to a cut option (see Table 1) that differed from their optimised allocation using actual cut values. These misallocations were caused by cut weight predictions that exceeded or did not meet a threshold, preventing their allocation to the most profitable option as determined using the actual cut weights. The exception to this was seen in the shortloin section, where the majority of cut misallocations were caused by the cut options have very similar levels of profitability, meaning that small shifts in cut weight predictions caused differences in the most profitable cutting plan for the shortloin, irrespective of the cut weight thresholds. The second row in Table 2 shows the number of these shortloin cut option misallocations that related to cut weight thresholds and thereby imprecise cut weight predictions.

These results align with our hypotheses, with the less precise predictors of cut weights (HSCW, GR) producing more cut option misallocations (6.54% and 5.76%) compared to the most precise cut weight predictions made using DEXA image component data (4.97%). The exception to this was seen in the forequarter section, where model 2 using HSCW and GR to predict cut weights led to less cut allocations (10 errors) than the other 3 models (11 errors). This likely relates to the lack of substantial improvement using DEXA image component data to predict the relevant forequarter cuts – the square cut shoulder (Graham et al., 2021), the boneless shoulder and the best end chops.

Table 2. The number of cut option misallocations in the forequarter (FQ), rack, Shortloin and hindquarter (HQ) sections using cut weight predictions informed by 1. HSCW, 2. HSCW and GR, 3. HSCW and DEXA values and 4 HSCW, DEXA values and image components. Cut misallocations are defined as cut allocations differing from their optimised allocation using actual cut weights.

		Number of cut option misallocation			
Carcase section	Cut options produced of those available	Model 1 HCWT	Model 2 GR	Model 3 DEXA	Model 4 DEXA Image Components
FQ	2 of 3	11	10	11	11
Rack	2 of 2	15	15	14	12
Shortloin	3 of 3	43	43	44	41
		6*	6*	5*	4*
HQ	2 of 3	18	13	12	11
Total misallocations		50^	44^	42^	38^
Total carcase sections		764	764	764	764
% errors		6.54	5.76	5.50	4.97

* Misallocations caused by cut weight predictions exceeding or falling short of cut weight thresholds.

^ Sum of misallocations caused by cut weight predictions exceeding or falling short of cut weight thresholds.

The price differentials of the two rack cut options in this optimisation scenario and expense of misallocating this product are shown in Table 3. Racks that were incorrectly allocated as French Racks (due to predictors incorrectly estimating the French Rack > 750g, Table 1) instead of cap on racks were thus assigned a market value $18/kg higher than the value of the actual cut procured. Imprecise cut weight predictors led to a total of 9.75 to 11.21 kg of racks being overvalued as French racks in this optimiser scenario, resulting in an apparent extra $176 to $202 of value. Conversely, lamb racks that were incorrectly allocated to cap on racks as their predicted weights did not meet the French racks threshold were undervalued by $69 to $97.

Table 3. The number of cut option misallocations in the forequarter (FQ), rack, Shortloin and hindquarter (HQ) sections using cut weight predictions informed by 1. HSCW, 2. HSCW and GR, 3. HSCW and DEXA values and 4 HSCW, DEXA values and image components. Cut misallocations are defined as cut allocations differing from their optimised allocation using actual cut weights.

Cut	Rack cap on (misallocated at French Rack)				French Rack (misallocated as Rack)			
Price differential	$18/kg				-$18/kg			
Cut weight predictor	HCWT	GR	DEXA	DEXA I.C.	HCWT	GR	DEXA	DEXA I.C.
Number misallocated	8	8	8	7	7	7	6	5
Mass misallocated (kg)	11.21	11.21	11.21	9.75	5.38	5.38	4.57	3.81
Mass*price diff.	$202	$202	$202	$176	-$97	-$97	-$82	-$69

The cost of these misallocations relates to processors procuring cuts that do not actually meet their market specifications, potentially incurring a penalty and/or undermining market confidence in their product. Or, if the error if detected before the product reaches the market then the cost to the processor is associated with cutting the product to a different spec if possible or downgrading this product to whatever market is available for this cut spec, as well as the cost of repackaging the product.

4 Conclusions

These results demonstrate that the improved precision with which DEXA can estimate cut weights can improve the optimised processing of lamb carcases. The higher precision cut weights leads to less cut weight misallocations, that is to less cuts being assigned to a different market as the true cut weight. Less cut misallocations with more precise cut weight information leads the optimiser to follow a cutting plan more like the ideal cutting plan (using actual cut weights data), and therefore a more accurate estimation of profits from processing a set group of lambs. Additionally, the misallocation of cuts with less precise cut weight measures will cost processors in terms of supplying cuts that do not actually meet their market specifications, eroding their reputation with markets; or in preventing this there is a cost associated with diverting the product to another market.

Though the number of cut misallocations and differences in profit using different cut weight predictors in this study are not large, the number of misallocations depends on the number of markets available and thresholds applied to these markets, and are substantial when considered over an entire day, week or month's kill. This study therefore demonstrates the value for processors in using more precise measures of lamb cut weights to improve their ability to forecast slaughter floor procurement and to apply optimisation of their processing for profit.

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