DEVELOPING A DUAL X-RAY ABSORPTIOMETER FOR ESTIMATING CARCASE FATNESS IN BEEF AT ABATTOIR CHAIN-SPEED.

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A prototype DEXA system was purpose-built to exactly match the dimensions of a similar system installed in a lamb abattoir in South Australia. Hind and forequarter sections from 51 beef carcases that had been spray chilled or chilled conventionally were scanned using computed tomography (CT) to determine CT fat%, and then DEXA scanned to establish a DEXA value that was used to predict CT fat%. The prototype DEXA system demonstrated good potential for predicting carcase fatness, describing 88% of the variation in whole carcase CT fat%, with RMSE values of 3.21 CT fat% units. When predicting specifically within the forequarter and hindquarter regions, the precision was similar to whole carcase levels in the forequarter, but reduced in the hindquarter, describing about 10% less of the variation in composition. Spray-chilling had little impact on the DEXA prediction of CT fat %. Given the precision and robustness to processing factors this system shows good potential for industry-wide adoption.

Key Words – DEXA, Computed Tomography.

I. INTRODUCTION

The current beef industry standard for determining carcase composition is based on carcase weight and a measurement of fat depth either on the hot carcase at the P8 site [1], or on the cold carcase at the rib quartering site [2]. However, these measurements are prone to operator and processing errors [3] hence there is a perception within the Australian beef industry that they are inaccurate and lacking precision. On this basis a more accurate system is required. One alternative technology for determining carcase composition is dual x-ray absorptiometry (DEXA), with numerous studies demonstrating the application of medical DEXA systems to production animals including cattle [4]. Recent work within the lamb industry has seen the development of an on-line dual x-ray absorptiometer (DEXA) that can match the fastest abattoir chain-speeds [5]. This has been adapted to a prototype beef system, with this paper detailing its precision for measuring carcase fatness.

II. MATERIALS AND METHODS

A prototype DEXA system was purpose-built in a shipping container to exactly match the dimensions of a similar lamb system installed at an abattoir in Bordertown, South Australia, with some modifications to facilitate handling of beef carcases. This hardware was used to capture dual energy images of 51 beef carcases selected across a broad range in weight (159kg - 472kg) and fatness (1mm - 50mm P8 fat depth) from animals that had been slaughtered 1-2 days prior, and stored at 2˚C. During the chilling process half of each carcase, hung as a side, was spray-chilled and the other chilled conventionally. These carcase sides were then cut below the 12th rib and each of the quarters DEXA scanned using the prototype hardware. Quarters were then CT scanned using a Seimens Sensation-64 spiral computed tomography (CT) scanner to enable estimation of percent fat (CTfat%), using previously defined scanning protocols [6].

DEXA images were generated using a single emission from a 140kV X-ray tube, with a set of two images captured using two photodiodes separated by a copper filter. The first photodiode used a scintillant that was more responsive to low energy photons, and the second used a scintillant that was more responsive to high energy photons enabling the acquisition of high and low energy images of each carcase quarter which were then used to calculate an R-value for each pixel within these images [7] according to the following formula:

$(R = \ln(I_{Low}/Air_{Atten}) / \ln(I_{High}/Air_{Atten}))$;

Where: I_{Low} represents the pixel value in the low energy image
I_{High} represents the pixel value in the high energy image
Air_{Atten} represents the pixel value corresponding to the un-attenuated photons (I_0) in the white part of each image.

The average R-value for all of the pixels in the carcase quarter image was calculated, setting a threshold value with pixels above this value coresponding to bone containing pixels, which were removed from the image. Pixel R-values were then converted to proportion of lean tissue and weighted based on thickness, and then averaged to reflect an average "DEXA-value" for each carcase quarter. To enable the conversion of R-values for each pixel into the corresponding proportion of lean tissue and associated thickness, tissue phantoms were constructed consisting of varying proportions of lean and fat ranging from 100% lean/0% fat, to 0% lean/100% fat and at a range of thicknesses of 10mm, 80mm, and 160mm. These carcase DEXA-values were then used to predict CT fat%, which was also determined directly on these same carcase quarters.

Separate general linear models were constructed using the DEXA-value to predict CT fat% within the spray-chilled and non spray-chilled fore and hindquarters. This was then repeated wih the inclusion of weight of that quarter in the model. Covariates were tested as curvelinear terms but were not significant. To test the effect of spray chilling on the DEXA prediction of CT Fat%, a single linear mixed effects model was used to predict CT fat% within carcase quarters, with fixed effects for spray chill (Yes/No) and carcase section (forequarter/hindquarter), DEXA-value included as a covariate, and animal identifier used as a random term. Covariates were also tested as curvilinear terms but were not significant. Finally, in order to model a potential industry application, and because spray chilling was shown to have minimal impact on carcase composition, the CT fat% data from both the spray-chilled and non spray-chilled fore and hind quarters were reconstructed into one whole carcase. This measurement of whole carcase CT fat% was then predicted using separate DEXA-values from the four carcase quarters and hot carcase weight as covariates in a general linear model.

III. RESULTS AND DISCUSSION

Spray-chilling had no impact on the DEXA estimated carcase composition. Furthermore, the precision of estimating CT fat% varied little between spray-chilled and non-spray chilled sections in the forequarter (Table 1), suggesting that this system will be robust against processing variation linked to carcase shrinkage. Simple correlations of DEXA values between carcase sections were high, with the forequarter sections correlating at 0.99 and the hind quarter sections showing a correlation of 0.93. This provides some evidence of repeatability of this measurement, albeit confounded by potential differences between carcase sides.

Table 1. Models predicting CT Fat % in forequarter and hindquarter carcase sections for both the spray chilled and non-spray chilled sides. F-value, intercept and coefficients are reported for each model, as well as estimates of precision (R^2, root-mean-square-error (RMSE)).

	Non-Spray Chill		Spray Chill	
	Coefficient	F Value	Coefficient	F Value
	Forequarter			
Intercept	43.9		44.0	
DEXA-value	-0.329	205.5*	-0.341	257.8*
R^2	0.81		0.84	
RMSE	3.836		3.539	
	Hindquarter			
Intercept	27.8		28.6	
DEXA-value	-0.3	157.6*	-0.3	86.6*
R^2	0.763		0.648	
RMSE	4.25		5.19	

*P<0.05; DEXA dual energy x-ray absorptiometry

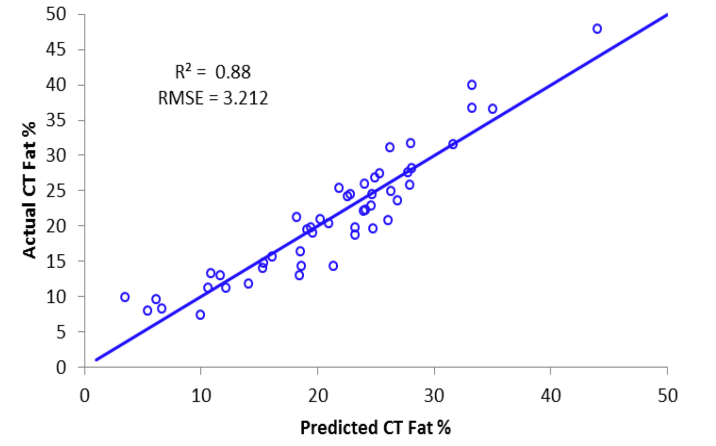

Figure 1. Association between CT fat% in the whole carcase and DEXA-predicted CT fat% with the prediction derived from forequarter hindquarter sections and hot carcase weight. Icons represent raw data, and lines are depicted on a 45degree angle where the data would fit if the prediction was perfect.

The prototype DEXA demonstrated good precision for estimating CT fat% in the forequarter (see Table 1), with RMSE values of 3.53 and 3.84 CT fat% units (R^2 = 0.85 and 0.81). Within the hindquarter precision was lower with RMSE values of 4.25 and 5.19 CT fat% units (R^2 = 0.76 and 0.65). In all cases when carcase weight was included in the prediction model it was not significant. The lower precision within the hindquarter likely reflects the greater tissue depth of this section leading to increased attenuation of x-rays and decreased sensitivity for differentiating fat from lean tissue [5].

When the reconstructed whole-carcase CT fat% value was predicted using DEXA-values from each carcase quarter and carcase weight there was an improvement in precision. The RMSE of the model was 3.21, and it described 88% of the variation (R^2 value) in the data. Thus the prototype DEXA system has demonstrated excellent capacity to describe variation in carcase fatness within this study, however it should be noted that the precision is somewhat lower than that demonstrated for lamb, with this same DEXA system demonstrating RMSE values approximately half that evident in this study [5]. As with the differences in precision between carcase sections, this difference is likely due to the greater tissue depth of beef carcases compared to lamb.

IV. CONCLUSION

The prototype DEXA system demonstrated good potential for predicting CT fat%, although this was more precise in the forequarter section of the carcase than the hindquarter. High correlations of DEXA values between carcase sections are an early demonstration of repeatability, and spray chilling had little impact on DEXA prediction of CT fat% demonstrating that processing factors linked to carcase hydration are unlikely to impact the accuracy of the system. Therefore the prototype DEXA system appears to be an excellent method for determining carcase composition in beef.

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