ASSESSMENT OF LAMB CARCASS COMPOSITION BY X-RAY COMPUTER TOMOGRAPHY (CT) AND IMAGE ANALYSIS

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Introduction

Lean, fat and bone content are not uniformly distributed in lamb carcasses. Carcass composition is used as a reference for grading systems world-wide. The purpose of grading of carcasses is usually split in two parts:

- Sorting of carcasses into groups of similar values
- Communicating needs and demands among all segments of the meat industry, from farm to fork

To assess carcass composition, one needs to know the total distribution of lean, fat and bone throughout the whole carcass. Traditionally, this has been done by full dissection, which is a costly, invasive and a time-consuming method. Therefore, less expensive, more cost-effective and non-invasive methods are required for assessment of carcass composition. X-ray computer tomography (CT) was developed by Cormack and Houndsfield, for which they received the Nobel Price Award in Medicine (1979). Since then, several applications have been tested within various fields of science, such as animal and food science. CT scanning has shown promising results as an alternative method for dissection of pork carcasses [2].

Objectives

The main objectives of this study were to:

1. study lean, fat and bone content distribution in lamb carcasses using X-ray computer CT
2. test the predictive ability of X-ray CT on lamb carcass composition using multivariate statistical methods

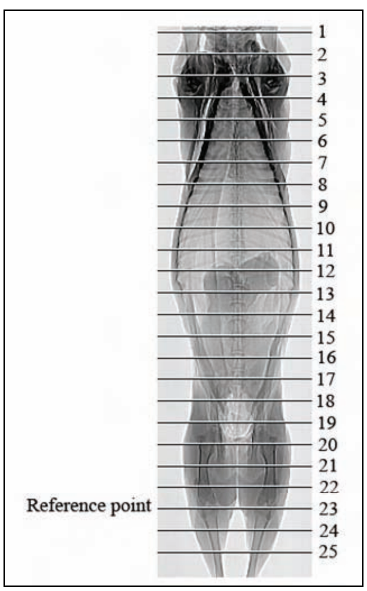
Methodology

Sampling

A total of 140 lambs were sampled randomly from one Norwegian abattoir during autumn 2004. The abattoir is one of the largest abattoirs in Norway and is located in the central part of southern Norway. Lambs are supplied from mountain pastures (inland). Crossbred was the dominant breed (56%) and ram was the most numerous sex in our samples (63%).

Scanning

The carcasses were scanned using a Siemens Somatom Emotion CT scanner [3]. Images were obtained by operating with a “Spine” algorithm [3], using the following set-up: voltage 130 kV, mAs 120, 512x512 pixels per scan, FOW 400 mm, pixel size 0.78 mm, slice thickness 3 mm and scan time 1s. The images were produced in DICOM format, 12-bit grayscale (2^{12}) with a range from 0 to 4,096, where 0 is total black and 4,096 is total white. This corresponds with the Houndsfield (HU) scale by an offset of -1,024 to 3071 [3], where 0 is the value of water. The total number of images per lamb varied from 25 to 27, according to carcass length, resulting in a [4 cm x n] grid, where n is number of images according to carcass length.



a.


b.

Fig. 1. CT scanning of lamb carcass.

1. **Fixed scanning sites, starting point 1. Reference point (23) at distal femur.**
2. **Scan at 12th vertebra. Lean area is highlighted in red color.**

Starting point was cranial end of carcass (neck). Distal point of leg bone (femur) was used as a reference point for each carcass (fig.1). The reference point was used to aim the [4 cm x n] grid.

Image analysis

The images from the CT scanning were pre-processed and analyzed using Image J 1.31v [4]. The various tissues in each scan slice were segmented into fat, lean and bone according to their gray value range (fig.2).

Gray value ranges were [830, 1001] for fat, [1002, 1170] for meat (lean) and [1171, 4096] for bone, according to their corresponding HU ranges: [-194, -23], [-22, 146] and [147, 3072], respectively [5].

The area of each tissue segment was obtained from the images, using the integral of pixels to calculate fat, lean and bone content from each image:

$$\text{Fat area} = \int_{830}^{1001} f(x)\,dx$$

$$\text{Lean area} = \int_{1002}^{1170} f(x)\,dx$$

$$\text{Bone area} = \int_{1171}^{2747} f(x)\,dx$$

$$\text{Total area} = \int_{830}^{2747} f(x)\,dx$$

where f(x) is a function of the number of pixels per gray value range.

For the entire carcass, the sums of the images 1 through 27 were calculated:

$$\text{Total lean content, entire carcass} = \sum_{27}^{1} \int_{1170}^{1002} f(x)dx$$

$$\text{Total fat content, entire carcass} = \sum_{27}^{1} \int_{1001}^{830} f(x)dx$$

$$\text{Total bone content, entire carcass} = \sum_{27}^{1} \int_{2747}^{1171} f(x)dx$$

The total tissue contents for each lamb were estimated and given as sum, mean, standard deviation, minimum and maximum variables.

Cutting

The carcasses were cut at the pilot plant of the Norwegian Meat Research Centre. Lean, fat and bone were separated visually and weighed according to EU regulations for pig dissection [1]. Fat content in trimmings and cuts were measured using a Scanalyzer, Scanio, Denmark. Measuring error (MSE) for Scanalyzer was 1.0% for fat [6]. Saleable meat content was calculated using weight of saleable meat, including saleable subcutaneous, inter- and intramuscular fat [7]. In this trial, cutting error was not estimated. This source of error will inevitably add to the error of prediction.

Statistical Data Analysis

Statistical data analysis was performed in The Unscrambler®v9.1 [8]. Prediction models were calculated using the partial least square (PLS) regression routine with full leave-one-out cross validation [8]. Fat, lean and bone contents from cutting were used as dependent variables, while total tissue content estimations from image analysis were used as independent variables. Two samples had to be left out due to obvious cutting and measuring errors. For PLS-modelling, 138 samples were used. Validation, uncertainty testing and selection of most important variables were estimated using full cross validation with jack-knifing and stability plots [8].

Results & Discussion

Table 1. Descriptive statistics, carcass characteristics (dependent variables)

Dependent variable	n	Mean	Median	St.dev	Min	Max
Carcass weight (kg)	140	19.77	19.40	3.49	9.20	29.60
Lean content(per cent)	140	61.19	61.35	2.72	50.73	67.51
Fat content(per cent)	140	13.04	12.39	3.24	7.36	26.09
Bone content(per cent)	140	22.09	22.21	2.16	16.54	30.04
Saleable meat (kg)	140	12.98	12.63	2.55	4.80	20.48
Saleable meat content (per cent)	140	65.46	65.38	2.69	52.19	75.44

Table 2. Correlation coefficients (Pearson) and significance test for correlation, carcass characteristics (dependent variables)

	CCW[a]	Lean[b]	Fat[c]	Bone[d]	SM[e]	SMY[f]
Carcass weight[a]	1					
Lean content[b]	-0.17*	1				
Fat content[c]	0.51**	-0.72**	1			
Bone content[d]	-0.59**	0.05ns	-0.69**	1		
Saleable meat[e]	0.99**	-0.05ns	0.45**	-0.64**	1	
Saleable meat content[f]	0.48**	0.62**	-0.05ns	-0.54**	0.60**	1

ns no significant correlation $p > 0.05$
* $0.01 < p < 0.05$
** $p < 0.01$

The fixed position images [4 cm x n] were not sampled from the same anatomical sites due to variation in carcass length. Only the reference site (distal end, femur) was anatomically accurate each time. By plotting tissue contents from image analysis, a systematic skewness depending on carcass length was detected, causing small dissimilar changes over short distances. Therefore, sums of images for the entire carcass were used for modeling, which is independent of carcass length. Anatomical site selection or denser fixed grids may lead to more accurate prediction in future trials.

The distribution of lean, fat and bone varied throughout lamb carcasses:

- For lean, the largest content (per cent) occurred in the shoulder and leg region
- For fat, the largest content (per cent) occurred in the shoulder and belly region
- For bone, the largest content (per cent) occurred in the belly region

Table 3. Results form regression analysis. Cutting variables as dependent, CT variables as independent

Dependent	R^2	RMSEP*	Important CT image variable	Number of PC's (PLS-modelling)
Lean content	0.85	1.42	Mean lean area	4
Fat content	0.91	1.36	Median fat area	4
Bone content	0.84	1.16	Median lean area	4
Carcass weight	0.98	0.66	Sum lean area	2
Saleable meat	0.98	0.48	Sum lean area	2
Saleable meat content	0.81	1.50	Mean lean area	5

* Prediction error, RMSEP (Root Mean Square Error of Prediction)

Explained carcass composition variation (R2) spanned from 81.2 to 90.8 (saleable meat content and fat content, respectively) (tab. 3). The fat predictions were more accurate than the other carcass components. Prediction errors for lean, fat, bone and saleable meat content were 1.42, 1.37, 1.16 and 1.50 percent. For carcass weight and saleable meat weight, the prediction errors were 0.63 kg and 0.48 kg. The results showed that CT scanning could be used as a predictor of carcass composition, with further improvement of accuracy by adjusting imaging techniques.

The number of principal components (PC) in table 3 shows the complexity of source of variation in the model. Originally, 18 independent image variables were used to model 5 dependent cutting variables. Due to collinearity and the need to reveal data structure, latent variables or PC's were estimated by the PLS-procedure. Weight of saleable meat and carcass has low complexity, and may be modeled by 2 PC's. Saleable meat content has higher complexity, and may be modeled by using 5 PC's. 4 PC's could model the tissue contents (lean, fat and bone).

Lean image variables were the most important variables for modeling 5 of 6 cutting (dependent) variables. Only for modeling fat, fat image variables were most important.

Conclusions

Computer Tomography (CT) is a versatile method for visualizing and assessing lamb carcass composition, especially for carcass + tissue weights and fat content. For lean, bone and saleable meat content, CT showed promising results, but needs to be improved. A further study of optimal scanning sites is necessary to achieve more accurate prediction models.

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