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*Full Length Research Paper*

# Artificial neural network analysis of ultrasound image for the estimation of intramuscular fat content in lamb muscle

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**The purpose of the study was to evaluate the effectiveness of ultrasound image analysis of sections of the longissimus dorsi muscle in lambs using artificial neural networks to estimate intramuscular fat content. Ultrasound images of the musculus longissimus dorsi cross-sections on the right flank behind the last rib were collected from 169 live lambs of both sexes prior to slaughter at the age of approximately 4 months. The analyses were conducted using a Pie Medical 100LC ultrasound scanner with an 8.0 MHz linear probe. On recorded ultrasound images using the MultiScan® ver. 12.05 software (Computer Scanning Systems Ltd.), measurements were taken for the thickness of subcutaneous fat, as well as the depth and cross-section area of the muscle. Further, on each ultrasound image, 10 frames of 1 × 1 cm were marked, which were converted to the ASCII format using the scale from 0 – a black pixel, to 255 – a image pixel of maximum brightness. After slaughter the content of extraction fat was determined using laboratory analyses in samples of the longissimus dorsi muscle collected on the site of ultrasound examinations. The data analysis was performed using a simulator of artificial neural networks implemented in the Statistica ver. 7.1 software package. The multi-layer perceptron proved to be the neural model with the best validation parameters (correlation = 0.858, mean prediction error = 0.151). All the tested network models resulted in an overestimation of the estimated fat contents. Despite that fact, obtained results are promising and more accurate than the previously applied regression method.**

**Key words:** Sheep, intramuscular fat, neural network, ultrasonography.

## INTRODUCTION

The ability to meet consumers' expectations by providing high quality product is an important goal for both animal breeders and the meat industry. Intramuscular fat content is one of the important quality attribute and an indicator of culinary value and processability of meat, particularly beef and pork, but also lamb meat, so it can influence the meat price (Heylen et al., 1998; Wood et al., 1999). For this reason, methods are being developed to estimate this attribute both on carcasses and in live animals example for selection purpose (Crews et al., 2003). In recent years, we observe the dynamic development of non-invasive techniques presenting the structure of animal tissues. This includes ultrasound technique accompanied by a computer analysis of ultrasound images of muscle cross-sections as a source of information (Hassen et al., 2001; Newcom et al., 2002; Mörlein et al., 2005; Aass et al., 2006). Studies are also conducted on the suitability of advanced analytical procedures for different types of images using artificial

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**Table 1.** Description of the data sets.

| Trait | Mean | S.D. | Minimum | Maximum |
|---|---|---|---|---|
| Live weight before slaughter (kg) | 31.61 | 4.64 | 23.80 | 40.30 |
| Age before slaughter (days) | 117.04 | 12.53 | 98.00 | 137.00 |
| Backfat thickness over loin „eye(mm) | 1.82 | 0.76 | 0.63 | 4.00 |
| Muscle depth (mm) | 28.03 | 4.13 | 20.01 | 36.00 |
| Loin „eye" area ($cm^2$) | 12.44 | 2.65 | 8.84 | 18.77 |
| Extractable fat content in LD sample(%) | 3.06 | 1.09 | 1.02 | 6.16 |

neural networks (Brethour, 1994; Shiranita et al., 2000; Chandraratne et al., 2007; Qiao et al., 2007).

The study evaluated the effectiveness of ultrasound image analysis for cross-sections of the longissimus dorsi muscle in lambs with the use of artificial neural networks for the estimation of intramuscular fat content.

## MATERIALS AND METHODS

Analyses were conducted in 4 consecutive years on 169 slaughter lambs (94 ram lambs and 76 ewe lambs), which were slaughtered at random at the age of approximately 4 months. On the day before slaughter, lambs were weighed and the image of a cross-section of the longissimus dorsi muscle (LD) was monitored on the right flank behind the last rib with the use of a Pie Medical 100LC ultrasound scanner with an 8.0 MHz linear probe. After slaughter and 24 h cooling of the carcass, samples of LD muscle were collected between the 1st and the 3rd lumbar vertebra and extraction fat content was determined in the laboratory according to Soxhlet.

Ultrasound images were recorded in the BMP format in a computer and further, they were analysed in the MultiScan® ver. 12.05 software (Computer Scanning Systems Ltd.). The thickness of the subcutaneous fat layer, as well as the depth and cross-section area of the muscle was measured on the images. Moreover, 10 frames (subimages) of 1 × 1 cm were marked on each ultrasound image, covering uniformly the entire muscle cross-section area. Each subimage comprised 40 × 40 = 1600 image pixels, distributed into 4 × 4 pixel-blocks, which were converted into the ASCII format according to the scale from 0 - a black point to 255 - a pixel of maximum brightness (the 8 bit grey-scale), with the value of each point after conversion being equal to the mean value of entire pixel-block (16 adjacent image pixels). Finally, according to described procedure, 10 subimages × 100 pixels from each ultrasound image were analysed and each subimage was treated as a separate set of data in subsequent part of the study, thus the total number of analysed cases was 1690.

The SAS ver. 9.1. software package was used for the statistical analysis of the obtained data. Due to the non-orthogonal data design to estimate the influence of fixed effects (sex, and year of birth) on the investigated traits, the method of the least square multivariate analysis of variance was applied. Moreover, Pearson linear correlations were estimated between analysed traits.

For the purpose of neural network analysis of data, the simulator implemented in the Statistica ver. 7.1 software package was used. The "automatic network design" option was applied for preliminary analyses and further, a series of simulations was performed aiming at the generation of an optimal network. The intended topology of the neural network should solve the regression problem, consisting in the identification of a numerical continuous variable (intramuscular fat content) based on the set of input data including age and body weight of lambs at slaughter, sex and type of birth, subcutaneous fat thickness, as well as the depth and cross-section area of the longissimus dorsi muscle and also variables containing converted information about the level of brightness of 100 pixels of the probe for the given image – according to the description given previously. The set of data collected in the first 3 years of the experiment, covering 1430 cases, was used for training purposes and for the preliminary validation of the network. In turn, data collected in the previous year before the study (260 cases) comprised a testing set, used to evaluate the effectiveness of previously generated neural models.

## RESULTS

Table 1 presents basic data characterising slaughter value of examined lambs. Mean body weight of approximately 32 kg at the age of 117 days indicates a good growth rate of lambs and it is typical of the analysed breed (Ślósarz et al., 2004). At the same time, a relatively high variation was maintained in terms of the investigated traits, which in view of the methodological character of the conducted study needs to be considered advantageous. The level of most slaughter performance traits was similar in lambs of both sexes (P>0.05), except for the difference in body weight and subcutaneous fat thickness, which seems to be natural (Table 2). Male lambs had slightly bigger dimensions of the LD muscle cross-section; however, the differences were statistically non-significant. No effect was found on the level of analysed traits by the year of birth of lambs or interactions in this study, which indicates stable experimental conditions in the consecutive years (Table 2). Extractable fat content in samples of the LD muscle of examined lambs was averagely 3.06%, ranging from a minimum of 1.02% to a maximum of 6.16% (Table 1). The lack of significant differences in this respect, found in the LD muscles of examined lambs (Table 2), was advantageous, since it made it possible for the model neural networks to estimate this trait in the entire group of lambs jointly, without dividing these groups into male and female lambs. This opinion is also justified by the results presented in Table 3. Linear correlation coefficients between the analysed slaughter performance traits of lambs and extraction fat content in samples of the LD muscle were very similar in lambs of both sexes.

The multi-layer perceptron (MLP) network with 17 hidden layers, learning by the Back Propagation and

**Table 2.** Description of the data sets (continued).

| Factor | Live weight (kg) | Backfat thickness (mm) | Muscle depth (mm) | Muscle area ($cm^2$) | Extractable fat (%) |
|---|---|---|---|---|---|
| Sex | ** | * | ns | ns | ns |
| Male | 32.27 | 1.72 | 28.54 | 12.65 | 2.98 |
| Female | 30.38 | 1.94 | 27.02 | 12.07 | 3.14 |
| Year | ns | ns | ns | ns | ns |
| Interactions | ns | ns | ns | ns | ns |

* – P<0.05; ** – P<0.01; ns – no significant difference.

**Table 3.** Correlation between slaughter traits and intramuscular fat content.

| Slaughter trait | Whole group of lamb | Ram-lamb | Ewe-lamb |
|---|---|---|---|
| Live weight before slaughter | 0,001 | -0.007 | 0.063 |
| Age before slaughter | 0.305** | 0.335** | 0.252* |
| Backfat thickness over loin „eye” | 0.190 | 0.142 | 0.231 |
| Muscle depth | -0.064 | -0.056 | -0.087 |
| Loin „eye” area | -0.127 | -0.134 | -0.123 |

* – P<0.05; ** – P<0.01.

**Table 4.** Parameters of selected best network models generated in teaching part of experiment (n = 1430).

| Ranking position | NN model | Correlation | Mean prediction error |
|---|---|---|---|
| 1 | MLP | 0.858 | 0.151 |
| 5 | Linear | 0.920 | 0.202 |
| 6 | RBF | 0.855 | 0.862 |

Conjugate Gradient Descent methods, turned out to be a neural model with the best parameters. In the course of the validation process of this model, the correlation coefficient was 0.858, while the mean prediction error for intramuscular fat content was 0.151 (Table 4). For further evaluation of the effectiveness of generated models, performed on the testing set (260 cases), additionally the best linear model was selected (from among the obtained models), being 5th in the ranking of generated networks, and the radial basic function (RBF) network (ranking 6th), table 4.

Table 5 presents statistics describing intramuscular fat content determined analytically in the testing set, as well as results of prediction of this value using three selected neural network models. Values closest to the correct results were generated by the MLP network, that is, one with the best validation parameters. Intramuscular fat content estimated with this method was by only 0.22 units higher than the reference values (P>0.05), with the maintenance of the range of variation for this trait similar to the reference values. The least accurate results were generated using a linear network, despite the fact that it was evaluated as superior in the preliminary analysis than the RBF network (Table 4). This may indicate that analysed dependencies are not linear in character. Table 6 presents correlation coefficients between intramuscular fat content determined analytically and values estimated using the artificial neural network method for the entire group of examined lambs and separately for the group with a fat content higher and lower than the mean. In reference to the MLP network, these correlations in all cases were relatively high (0.867 for the whole group of lambs) and markedly higher than in the other analysed models. There is need to stress here that in case of each of the tested models, correlations in the group of lambs with fat contents higher than the average were markedly higher than in the group of lambs with lower fatness. This indicates an effect of the level of fat content on the accuracy of its estimation in muscle samples.

## DISCUSSION

In this study, a low correlation was found between body weight of lambs before slaughter and the intramuscular fat content at a moderate level, although, there was a significant correlation in relation to the age of lambs. This result is generally consistent with those of similar studies

**Table 5.** Results of final testing of selected NN models in prediction of intramuscular fat content (n = 260).

| Statistics | Test value of IMF content | IMF content predicted by selected NN models | | |
|---|---|---|---|---|
| | | MLP | Linear | RBF |
| Mean (%) | 2.71 | 2.93 ns | 3.36 ** | 2.97 ns |
| Min. | 1.27 | 1.74 | 1.91 | 2.01 |
| Max | 3.18 | 4.43 | 4.77 | 4.20 |
| S.D. | 0.49 | 0.47 | 0.43 | 0.44 |

** – P<0.01; ns – no significant difference.

**Table 6.** Correlation between predicted and test value of intramuscular fat content.

| NN model | Whole group of lamb | Group with IMF content higher than average | Group with IMF content lower than average |
|---|---|---|---|
| MLP (1) | 0.867 ** | 0.873 ** | 0.768 ** |
| Linear (5) | 0.683 ** | 0.582 ** | 0.449 ** |
| RBF (6) | 0.574 ** | 0.748 ** | 0.407 ** |

** – P<0.01.

conducted on dairy cattle (Yang et al., 2006). However, the authors cited here pointed to other studies, in which a linear dependence was shown between meat marbling and body weight of cattle before slaughter. The described discrepancies may result from differences between breeds in terms of the age of finish and the generation of a relationship between body weight and fat deposition. In this study, body weight and age of lambs were relatively varied and some lambs could be slaughtered before the aforementioned relationship was reached. The correlations between subcutaneous fat content and the dimensions of loin eye area on the one hand and intramuscular fat content on the other, recorded in this study, were also low. Similar results were reported by Yang et al. (2006), both in reference to this study and when citing those of other authors. The limited suitability of individual parameters of ultrasound images for the estimation of intramuscular fat content was also shown in relation to pigs (Ville et al., 1997; Mörlein et al., 2005). This could have been caused by the numerous artefacts of the ultrasound echo, resulting from the internal histological structure of muscles, the presence of the connective tissue, blood vessels, etc. (Harper and Pethick, 2004; Yang et al., 2006). However, detailed analyses indicate a considerable potential of ultrasound methods, provided many different parameters of the acoustic echo are included in the analysis and advanced statistical methods are used (Mörlein et al., 2005). For this reason, in this study, collection of data was done for the analysis of data by the artificial neural network method, apart from the digital recording of brightness of individual points of the ultrasound image, in addition to the contained data concerning the age and body weight, sex of lambs, as well as linear measurements of loin eye area.

A multifaceted comparison of suitability of regression methods and artificial neural networks for the estimation of carcass quality of lambs was presented in a study by Chandraratne et al. (2007). These investigations indicated a markedly higher accuracy of analysis conduced by the neural network method, particularly when using multilayer perceptrons. Similarly, a high suitability of multilayer perceptrons for the analyses of meat colour in pork was shown by Lu et al. (2000) and in relation to the carcass quality classification, including marbling, of beef (Shiranita et al., 2000). Moreover, in the investigations conducted by these authors, the best validation parameters were found for this model of the neural network. In the case of all neural networks analysed in this study, the forecasted values of intramuscular fat content were overestimated by approximately 0.22 units to 0.65 in comparison to these values determined in the laboratory analyses. However, the accuracy of estimation of fat content using the neural network method, measured by the power of correlations, was higher than that of the regression methods, used previously on a similar material, and based on the basic analysis of brightness of ultrasound image points (Ślósarz et al., 2001). Thus, it seems justified to conduct further modelling of neural networks, including the modification of the set of input data and the analysis of a larger number of ultrasound image points for muscle cross-sections in lambs.

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