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Comparison of Innovative and Non-Invasive Methods in Estimating the Fat Content in Pork Trimmings

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Abstract

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The purpose of research was to determine a possibility of application of computer vision systems (CVS) for estimation of fat content in pork trimmings in comparison with methods based on DXR (dual energy X-ray) and NIR (near-infrared reflectance spectroscopy). Research was conducted on 232 samples of pork trimmings. In order to verify the fat content determined by CVS, DXR, and NIR methods, fat content was also determined by the Soxhlet reference method. It was found that CVS can be used to estimate fat content in pork trimmings with a standard error of prediction between 4.9 and 5.6%. In order to achieve higher efficiency, it seems advisable to grind and standardise meat in a meat grinder with a kidney shaped plate.

Keywords: CVS; DXR; fat content; NIR; pork trimmings

Pork trimmings are the basic material for sausage production. They are characterised by a high variability of fat content which is dependent e.g. on the part of the carcass from which they were obtained. Diversity of fat content in the initial material translates into diversity of the quality of products and plays a significant role in economic and legal aspects of production (Brienne *et al.* 2001; Hansen *et al.* 2003). Classification of pork trimmings is most often done by workers on the basis of visual evaluation and experience. Visual evaluation used in the meat processing plant does not guarantee standardisation of the raw material. Therefore, it is necessary to use rapid and objective quality evaluation of pork trimmings. In the industrial practice, modern tools for the evaluation of chemical composition of meat, including fat content determination, such as near-infrared reflectance spectroscopy (NIR) and roentgen radiation (X-ray, DXR) methods are becoming more and more popular (Hansen *et al.* 2003; Savenije *et al.* 2006; Gaitán-Jurado *et al.* 2008; Wold *et al.* 2011). Dual energy X-ray solutions have been used in on-line systems to determine the fat content directly on the cutting and fabrication line. This method is objective and accurate but expensive. Whilst using NIR spectroscopy, it is necessary to obtain a representative meat sample and then comminute it. Devices based on NIR are used in small, medium, and big meat plant laboratories. A drawback of this kind of device is that it cannot be used on-line directly on the processing line (the analysis is periodic).

To satisfy the needs of the industry it is necessary to develop new methods for determination of basic chemical composition, including fat content. Computer vision systems (CVS) belong among the methods of estimating fat content in pork trimmings. Their advantages are: objectivity, non-invasiveness, rapidity, and possibility of application in constant production

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lines with various production capacities, without a necessity of bearing considerable costs (Zheng *et al.* 2006; Jackman *et al.* 2009; Rius-Vilarrasa *et al.* 2009; Valous *et al.* 2009; Girolami *et al.* 2013). In the meat industry, the CVS method is currently employed as a classification and evaluation tool of the carcass conformation of large slaughter animals and poultry (Mollah *et al.* 2010; Pabiou *et al.* 2011; Chmiel & Słowiński 2013). Other studies show that the CVS might be used to detect PSE and DFD of pork meat obtained from *m. longissimus lumborum* and it classification into quality groups (Chmiel *et al.* 2011b). The usefulness of the computer vision systems in grading the pork or beef quality including the evaluation of fat (marbling) content was reported in the studies of Jackman *et al.* (2010) and Sadkowski *et al.* (2014).

The purpose of the present study was to determine a possibility of application of innovative and non-invasive methods for the estimation of fat content in pork trimmings. The CVS method was compared with methods based on DXR and NIR. In order to verify the fat content determined by CVS, DXR, and NIR methods, it was determined by the Soxhlet reference method.

MATERIAL AND METHODS

Test material. The test material consisted of pork trimmings (approx. 5 × 4 × 5 cm) taken by cutting and trimming of hams from randomly industrial lines of meat plants in Poland. The samples were obtained successively in eight batches on eight various slaughter days from different pig carcasses. The weight of slaughtered fattener pigs (crossbreds of meat pigs × Polish Large White) ranged between 95 and 110 kg. The animal slaughtering was conducted in industrial settings. The carcasses were allowed to cool for 24 h in a two-step chilling process: 1st step – ambient temperature –10°C, time 1–2 h; 2nd step – ambient temperature 0–4°C, time approx. 22 h, to reach an internal temperature not higher than 4°C in the muscle. About 90% of carcasses was classified into E and U meatiness grades. Totally, research was conducted on 232 samples of pork trimmings. Temperature of samples was not higher than 7°C, and weight of each sample was not lower than 20 kg.

Fat content determination

Dual energy X-ray (DXR). Fat content was determined with the use of a DXR device (MeatMaster; FOSS Analytical, Poland) located in a meat plant hall. Analyses were done on meat samples placed in the containers (approx. 20 kg of pork trimmings/container). According to the device producer, the measurement range was 2–85% of fat content at determination accuracy of 1%. After analysing meat samples, with the use of DXR device, containers including meat were transferred to the computer vision system (CVS) measurement station.

Computer vision systems. Images were taken in a white matt chamber with a green background. The construction of a measurement station guaranteed standard conditions for taking images. During the acquisition of images, constant lighting conditions were guaranteed by the use of 4 frosted halogen lamps with the power of 35 W each, colour temperature of 2800 K, and colour rendering index (CRI) characterising the light source at the level of 90–100. Distance between the lens and photographed meat surface was 500 mm. Five minutes before the acquisition of images, lighting was switched on in order to stabilise it. Images were taken with a Canon EOS 350D digital camera. Images were saved in JPEG format (Chmiel *et al.* 2011a). Before taking images, the CVS system was calibrated on a white plate (L^* 99.18, a^* –0.07, b^* –0.05). Acquired images were read into CARNE 2.2. (2008) analysing software. First, the background was deleted from researched images. Then the software divided images into parts related to particular objects visible on them, which means areas representing meat tissue, fat, and connective tissue. This process was conducted each time for all images. At this stage, the CARNE 2.2. (2008) software established the form of a function segmenting the image according to information about colour and saturation of particular areas. The software dynamically created a matrix in which dimensions were constituted by values of colour and saturation of defined pixels, and the values were constituted by information whether a pixel is included in a particular segment or not (separated matrixes for meat and fat tissue). On this basis, databases were created which included information about the colour and saturation of meat and fat tissue. Next, the analysis was conducted with the use of established bases. The software determined a percentage content of white spots (related to fat and connective tissue) and red spots (related to meat tissue). Unrecognised points were defined as unrecognised area. Images were taken in three series. The first series was taken on meat samples

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directly from the cutting line (trimmings – without grinding). Next, the meat from each container was ground in an industrial grinder with a kidney shaped plate. After grinding and replacing the raw material in a container, the second series of photos was taken. Then each sample was ground again in an industrial grinder using orifices of 4 mm in diameter, placed in a container, and the third series of photos was taken.

After taking images of the researched material, representative meat samples from each container (approx. 450 g) were taken to estimate fat content using near-infrared reflectance spectroscopy (NIR) and Soxhlet method. Each sample was ground in a laboratory grinder using orifices 3 mm in diameter.

Near-infrared reflectance spectroscopy (NIR). Determination of fat content was done by the method of near-infrared reflectance spectroscopy (NIR) (FoodScan apparatus; FOSS Analytical, Poland) according to PN-A-82109 (2010). Each sample of an approximate weight of 250 g was evenly placed in a glass circular scale and inside the apparatus. The principle of operation of the apparatus consists in 16-fold measurement of fat content with a monochromator with movable diffraction grating which analyses the near-infrared spectrum in the range of 850–1050 mm. According to the device producer (FOSS Analytical), the measurement range of the analyser was 1–43% of fat content at the average root mean squared error of prediction (RMSEP) ≤ 0.5.

Soxhlet reference method. The fat content was determined by Soxhlet extraction (Büchi Extraction System B-811, Donserv, Poland) according to AOAC (2000).

Statistical analysis. Obtained results were subjected to statistical analysis with the use of STATGRAPHICS 4.1. PLUS software by conducting one-way analysis of variance (One-way ANOVA). Significance of differences between features was verified by Tukey's HSD test at the level of significance α = 0.05. Moreover, the relationships between determined parameters were established by means of Pearson's (linear) correlations. The correlation coefficients were determined and the regression equations between fat content determined by the Soxhlet reference method and fat content determined by the other methods were established. In order to determine the assessment accuracy of fat content on the basis of CVS, DXR, and NIR the standard error prediction (SEP) was calculated.

RESULTS AND DISCUSSION

The analysed meat was characterised by high diversity of fat content. Its amount determined by the Soxhlet reference method was in the range of 11.7–47.0%, at the average content of 29.4% (Table 1). At this level of diversity of the initial raw material, it is very difficult to produce meat products of standard quality. Therefore it is necessary to control the content of this ingredient in relation to every production unit which is a partitioning container. Standardisation of pork trimmings in a meat plant, apart from a technological aspect, also has an economic dimension related to the price diversification of lean meat and trimmed fat (Dasiewicz *et al*. 2008). Methods based both on NIR and DXR are practically used in the meat industry. The application of CVS for estimation of fat content in pork trimmings is still being developed. Therefore it is advisable to determine the degree of grinding of the analysed meat at which the accuracy of fat content estimation is highest. In the present studies CARNE

Table 1. Average fat content (%) determined with the use of Soxhlet, computer vision systems (CVS), dual energy X-ray (DXR), and near-infrared reflectance spectroscopy (NIR) methods (N = 232)

	Soxhlet	CVS*			DXR	NIR
		trimmings	kidney shaped plate	Ø 4 mm		
$\bar{x}$	29.4[a]	30.0[a]	29.3[a]	30.1[a]	29.7[a]	30.3[a]
SD	8.6	6.5	6.7	7.1	8.5	8.9
min	11.7	18.7	18.7	17.9	12.1	13.2
max	47.0	47.0	46.6	52.4	48.4	49.7

*fat content determined on a basis of regression equations between the content of white spots determined by CVS in pork trimmings pictures and fat content determined by Soxhlet method; $\bar{x}$ – average value; SD – standard deviation; min – minimum value; max– maximum value; [a,b]average in row marked with different letters differ significantly ($P \le 0.05$)

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Table 2. Correlation coefficients (r) and regression equations between content of white spots determined with the use of computer vision systems (CVS) and fat content determined by Soxhlet reference method

CVS	Soxhlet	
	r	equation
Trimmings	0.81*	$y = 0.833x - 2.563$
Kidney shaped plate	0.86*	$y = 0.815x + 1.018$
4 mm	0.83*	$y = 0.661x + 10.345$

*significant coefficient ($P \leq 0.05$); y – fat content, x – content of white spots

2.2. (2008) software enabled to determine the content of white spots in raw material images. Determined content of white spots for unground meat was on a level of 19.8 to 59.5%, for meat ground with the use of a kidney shaped plate – from 21.2% to 55.9%, and for meat ground in a grinder with orifices of 4 mm in diameter – from 11.4% to 63.6% (data not showed in Tables). In order to determine a possibility of using CVS in estimating fat content in pork trimmings, it is necessary to define a relationship between the content of white spots and the real fat content determined by the Soxhlet reference method. In spite of the degree of pork grinding, significant relationships were found between the content of white spots determined by CVS and fat content determined by the Soxhlet reference method (Table 2). The highest correlation coefficient was calculated for pork trimmings ground a kidney shaped plate (Table 2). The coefficient was lower for meat ground in a grinder with orifices 4 mm in diameter and unground meat (Table 2). On the basis of obtained regression equations (Table 2) between the content of white spots determined by the CVS method and fat content determined by the Soxhlet method, the fat content in meat samples was calculated (Table 1). Fat content calculated by the CVS method for trimmings, kidney shaped, and 4 mm plates was on average level 30.0, 29.3, and 30.1%, respectively (Table 1). The statistical analysis did not show any significant influence of the used method of fat content determination on its level in raw material (Table 1). The average fat content predicted by the CVS method was 30.0, 29.3, and 30.1% for trimmings, kidney shaped plate, and 4 mm plate, respectively (Table 1), compared with the actual fat content in meat determined by the Soxhlet method (29.4%). In order to verify the accuracy of the methods used in research, the analysis of correlations between the fat content determined by the Soxhlet reference method and CSV, DXR, and NIR methods was conducted (Table 3). The highest correlation coefficient was calculated between fat content determined by the Soxhlet reference method and DXR and NIR methods. Considering the fact that the device based on NIR spectroscopy is also used for determination of water, protein, and fat content and a short time of determination, it was found to be highly useful in determining the basic chemical composition of meat during the production process. Periodicalness of action, necessity of taking representative samples, and grinding them is a difficulty in terms of device use.

The values of SEP show the assessment accuracy of fat content based on the DXR and NIR was 1.6 and 1.4%, respectively (Table 3). SEP values for CVS were higher and reached 5.6, 4.9, and 5.2% for trimmings, kidney shaped, and 4 mm plates, respectively (Table 3). Slightly lower values of correlation coefficients between fat content determined with the use of CVS and Soxhlet method (Table 3) could be a result of difficulties in analysing images of the moist meat surface. Moreover, too strong and focused light can cause reflections from the moist surface of meat and lead to distortions in a form of white discolorations visible in the analysed image. The randomness of arranging parts of meat in a partitioning container can also be a factor which has an influence on the values of correlation coefficients. The surface of the container can contain parts of material including a high level of fat tissue, whereas the bottom of the

Table 3. Correlation coefficients (r), regression equations, and standard error of prediction (SEP) between fat content determined with the use of Soxhlet and computer vision systems (CVS), dual energy X-ray (DXR), and near-infrared reflectance spectroscopy (NIR) methods

		Soxhlet		SEP (%)
		r	equation	
CVS	trimmings	0.81*	$y = 0.999x - 0.002$	5.6
	kidney shaped plate	0.86*	$y = 1.000x + 0.004$	4.9
	4 mm	0.82*	$y = 0.940x + 1.596$	5.2
DXR		0.98*	$y = 0.946x - 0.747$	1.6
NIR		0.99*	$y = 0.993x - 0.114$	1.4

*significant coefficient ($P \leq 0.05$); y – fat content; x – content of white spots

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container can contain parts of lean meat with no fat nor connective tissue. However, the results of other research conducted by the authors show that there is no influence of meat 'arrangement' in production containers on the accuracy of fat content estimation (Dasiewicz *et al*. 2010).

Diversity of correlation coefficients calculated for meat with different degree of grinding can also be determined by other factors than the content of white spots. It can be assumed that the low correlation coefficient for pork trimmings not ground in a grinder can be a result of large pieces of meat covered by the perimysium (white membrane which reflects light), which can contribute to significant overestimation of the fat content determined by the use of CVS method. In case of meat ground in a grinder with orifices 4 mm in diameter, it could be a result of the indeterminate limit between fat and meat tissue caused by a high degree of meat grinding. In spite of the fact that there was a low temperature of the grinding process (well cooled meat, low temperature in the production hall), the effect of fat 'smearing' was observed, which as a result, made it difficult to threshold and determine the content of white spots which characterise the fat content determined by the CVS method. Therefore it seems reasonable to standardise meat by grinding it in a grinder with a kidney shaped plate, which will decrease the area covered by the perimysium in relation to the whole analysed meat area.

CONCLUSIONS

Conducted research showed that computer vision systems (CVS) can be used for the estimation of fat content in pork trimmings. There is a possibility of applying this method in constant production lines of meat plants and operation costs would be significantly lower. In order to achieve the higher accuracy of fat content estimation by this method, it seems advisable to grind meat in a grinder with a kidney shaped blade.

It was also found that the devices based on DXR and NIR are efficiently used for the estimation of fat content in industrial conditions. This fact is confirmed by high coefficients of correlation between fat content determined by the Soxhlet reference method and fat content determined with the use of devices. However, it can be too expensive for small and medium-sized meat processing plants.

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