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PREDICTION OF PORK BELLY COMPOSITION USING THE COMPUTER VISION METHOD ON TRANSVERSE CROSS-SECTIONS*

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Abstract

The objective of this study was to identify the pig belly characteristics and to develop regression equations predicting its composition. Based on video image and chemical analysis of 216 bellies, the predictive variables were selected according to their relation to chemically determined belly lipid contents. To estimate the belly fat percentage (BF%), the two best equations constructed were: Equation 1: *BF% = 49.960 – 0.7174 × SHME2 + 0.5047 × HE2A (*R^2 *= 0.66, RMSE = 3.22)*; Equation 2: *BF% = 43.888 – 0.6014 × SHME2 + 0.4769 × HE2A + 0.0014 × ARTO2 – 0.2697 × HE3A* (*R^2 *= 0.70, RMSE = 2.25*), where: *SHME2* = lean meat percentage area of the belly 2 from total cut area, HE2A = the Belly2 height at point 1, *ARTO2* = the Belly2 total cut area, *HE3A* = the Belly3 height at point 1. Compared to lean meat, the percentage of belly fat (BF%) appears to be a more appropriate criterion for the objective evaluation of belly composition due to the simplicity and accuracy of the final regression equation (higher R^2**).**

Key words: pig, pork belly, belly composition, image analysis

The market value of pigs is traditionally determined by the carcass lean meat percentage (Tholen et al., 2003). An efficient method to achieve its increase is to focus on reducing the fat content in different parts of the pig carcass. In terms of meat and fat contents, the belly part and its quality appear to be quite interesting. In the North American context, the belly (most of which is processed into bacon) and the loin, including the tenderloin and the side ribs, are the cuts that fetch the best prices (Marcoux et al., 2007). Also in Europe, especially in grilling season, the pork belly is one of the most valued parts. Belly accounts for about 18% of the carcass weight. Due to continuous intensive selection for an increased lean meat proportion, the belly is now considered as one of the major meat-yielding cuts in the pig carcass

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(Stupka et al., 2004; Pulkrabek et al., 2006). The paramount importance of the belly with respect to its quality has been pointed out in the studies by Schwerdtfeger et al. (1993) and Uttaro and Zawadski (2010). Grading pig carcasses based on lean yield is a common practice in a number of countries (Marcoux et al., 2007). Although some authors state that the belly composition should be estimated from the carcass lean meat percentage (Bahelka et al., 2011), others have reported that this estimate is not accurate and it is necessary to evaluate the belly part directly (Uttaro and Zawadski, 2010; Person et al., 2005). Unlike other carcass primal cuts, the muscle and fat percentages in the belly vary considerably (Valis et al., 2005; Stupka et al., 2008). Because muscle and fat layers overlap in the belly, its evaluation is quite complicated (Baulain et al., 1998). The principle of estimating the fat (or lean) content in the belly primarily consists of finding and measuring suitable anatomical dimensions which are highly correlated with the total fat content in this carcass part. For this purpose, different techniques for determining these predictor variables are used, from directly measuring the width and the height of the belly (Person et al., 2005; Uttaro and Zawadski, 2010), using a planimeter (Pfeiffer et al., 1993), ultrasound (Kolb and Nitter, 1993; Seifert et al., 2002; Tyra et al., 2011), video image analysis (VIA) (Schwerdtfeger et al., 1993; Tholen et al., 1998; Sonnichsen et al., 2002), and magnetic resonance imaging (MRI) (Baulain et al., 1998). The predictor variables and dissection or chemical analysis data (belly lipid content) are then employed in a regression equation able to predict with a reasonable accuracy the amount of fat in a given carcass primal (Pulkrábek et al., 2006). There are also other methods of estimating the belly composition that are, however, less accurate and are primarily used for the belly classification in the food industry. For the highly accurate determination of belly composition and its use as a selection criterion in breeding programs, it is necessary to use the more sophisticated methods.

Based on previous studies, we hypothesize that image analysis can be used to produce an objective and accurate evaluation of pork belly composition. The aim was to find suitable predictor variables and, based on them, to develop linear regression equations for the accurate estimation of the pig belly fat content.

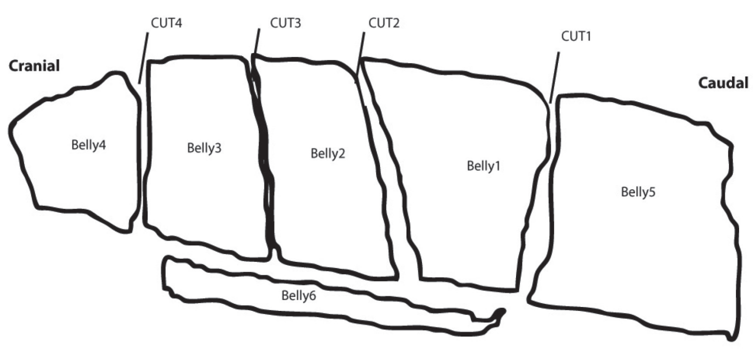
Material and methods

Data were obtained from a pig performance testing station. The animals included in the study were 24 purebred Large White (LWD) pigs, 24 F1 hybrids of Large White × Landrace (LWD×L), 24 three-breed crosses sired by Pietrain (PN × (LWD×L)), and 144 crossbred pigs of either (Large White x Pietrain) × (Large White × Landrace) (LWS×PN) × (LWD×L) or (Duroc × Pietrain) × (Large White × Landrace)(D×PN) × (LWD×L) genotypes.

The pigs with a balanced sex ratio (gilts/barrows) were fattened from the initial live weight of 25.0±2.0 kg and their initial age ranged from 60 to 80 days. The selection of animals was made so that the tested sub-groups corresponded with the current breed structure in the Czech Republic.

The weaners were divided into pens in pairs. They were allowed *ad libitum* access to water and feed. The diet included three major components (wheat, barley, soybean meal) and a vitamin-mineral premix. The diet nutrient composition was 160 g/kg protein, 13.2 MJ/kg of metabolizable energy (MEp) and 0.924 lysine/methionine ratio.

The pigs were slaughtered in a commercial slaughterhouse at approximately 107±5.4 kg of live weight. Up to 45 minutes postmortem the lean meat percentage measured using optical Fat-O-Meater – FOM (Carometec A/S, Herlev, Denmark), backfat thickness 1 (over the first thoracic vertebra), backfat thickness 2 (over the last thoracic vertebra), and backfat thickness 3 (over the 5th lumbar vertebra) were determined. Carcasses were chilled at 2°C for 24 h. Then the right half of each carcass was cut using the methodology of Walstra and Merkus (1995). The belly was divided into pre-defined parts according to the method modified from Tholen et al. (2003). Compared to this report, three additional cuts (CUT2, CUT3, CUT4) were used in this study (Figure 1). The cranial end of the belly (Belly4) was removed with a cut between the 4th and 5th ribs (CUT4; Figure 1). The caudal end of the belly (Belly5) was removed by an incision starting 40 mm caudal to the last rib (CUT1). The mammary glands (Belly6) were removed from the remaining part of the belly with a straight cut just above the line of the glands. The middle of the belly was then divided into three parts. A cut between the 7th and 8th ribs (CUT3) produced Belly3, and a cut between the 10th and 11th rib (CUT2) created Belly2 and Belly1.

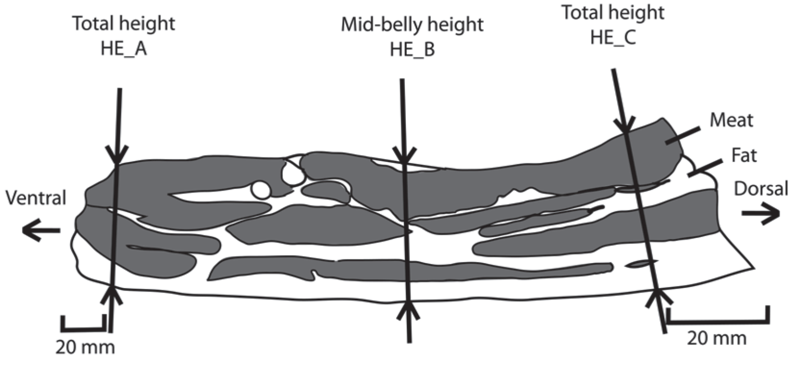


CUT1: the caudal part of the belly was separated by an incision starting 40 mm caudal to the last rib; CUT2: between 10th and 11th rib; CUT3: between 7th and 8th rib; CUT4: between 4th and 5th rib.

Figure 1. Scheme of belly dissection

A digital camera (Canon EOS Rebel XSi, 12 megapixel with 18–55 mm lens; Canon Ltd., Japan) was placed 700 mm from the belly cross-section, and the zoom was set at approximately 20 mm. The belly was placed skin side down and photographed together with a one-millimeter grid used for calibration. Digital images of the caudal surface of CUT1, CUT2, and CUT3 were captured. The images were analysed with the image analysis software NIS-Elements AR 3.2 (Laboratory Imaging Ltd., Czech Republic). The following areal dimensions were measured (Figure 2):

total surface area of cut (mm²; ARTO1, ARTO2, ARTO3) and total muscle area of cut (mm²; ARME1, ARME2, ARME3). The proportion of the muscle area from the total area was then calculated (%; SHME1, SHME2, SHME3). For each belly, average values for the above mentioned measurements were also calculated (ARTOM, ARMEM, SHMEM). Three height measurements were made on each cut: 20 mm from the ventral edge (mm; HE1A, HE2A, HE3A), in the middle of the belly (mm; HE1B, HE2B, HE3B), and 20 mm from the dorsal edge (mm; HE1C, HE2C, HE3C).



CUT1: HE1A, HE1B, HE1C; CUT2: HE2A, HE2B, HE2C; CUT3: HE3A, HE3B, HE3C. Additional measurements: full area of cross section: ART_; Area of meat only: ARME_; Percent of meat area: SHME_ = (ARME_/ARTO_)*100.

Figure 2. Scheme of measurements made on images of the caudal surface of Cuts 1, 2, 3 from Figure 1, using a generic cross-section

Based on the above methodology, a total of 24 length, area and weight predictor variables were used to estimate the belly fat content. Primal and dissected bellies were weighed, deboned, parts Belly1, Belly2, Belly3 were ground, homogenized and sub-sampled (10 g) for the compositional chemical analysis. The contents of water and triglycerides were determined in accordance with current standard AOAC method 960.39 (AOAC, 2000). The water content was ascertained from the difference of the sample weight before and after drying with sea sand and subsequently the fat (all triglycerides) was extracted from the parts Belly1 (FB1), Belly2 (FB2), Belly3 (FB3) and belly total (FB) gravimetrically after extraction with petroleum ether in the solvent extractor (SER 148, VELP Scientifica, Usmate, Italy).

SAS V9.2 (SAS Institute Inc., Cary, NC, USA) was used to calculate means and standard deviations. Simple correlations among variables were calculated and regressions were performed. When evaluating the applicability of regression equations, the emphasis was placed on using the predictive variables with as simple determination as possible. A total of 24 carcass characteristics were used as potential predictor variables to construct regression equations. The backward elimination technique was used. This method first uses all of the embedded values and in every subsequent step the variable with the lowest impact on the entire regression equation (using the F statistics) is discarded.

Table 1. RAW means and standard deviations (SD)

Variable	Mean	SD
Live weight (kg)	113.4	9.3
Hot carcass weight (kg)	90.1	7.7
Carcass lean meat proportion (FOM) (%)	56.9	2.5
Belly weight (kg)	8.4	0.7
Belly1		
FB1 (%)	29.7	8.8
ARME1 (mm^2)	4883	657
ARTO1 (mm^2)	8010	1176
SHME1 (%)	61.4	6.9
HE1A (mm)	42.4	4.1
HE1B (mm)	37.3	3.9
HE1C (mm)	43.8	5.7
Belly2		
FB2 (%)	35	8.9
ARME2 (mm^2)	6129	773
ARTO2 (mm^2)	11205	1493
SHME2 (%)	55.2	7.3
HE2A (mm)	48.9	5
HE2B (mm)	47.8	5.6
HE2C (mm)	51.9	7.3
Belly3		
FB3 (%)	38	10.5
AREME3 (mm^2)	7111	861
ARTO3 (mm^2)	12155	1480
SHME3 (%)	58.9	6.4
HE3A (mm)	57.9	5
HE3B (mm)	53.1	5.7
HE3C (mm)	57.2	5.9
Belly average		
FB (%)	34.2	7.7
ARMEM (mm^2)	6106	596
ARTOM (mm^2)	10427	1095
SHMEM (%)	58.9	5.8
HEMA (mm)	41.2	3.1
HEMB (mm)	49.5	5.4
HEMC (mm)	56.0	4.5

FOM – Fat-O-Meater; Belly1 – between 11th and last rib; Belly2 – between 8th and 10th rib; Belly3 – between 5th and 7th rib; Belly average = average of belly1 + belly2 + belly3; FB1, FB2, FB3, FB – chemically determined belly fat contents in %; ARME1, ARME2, ARME3, ARMEM – total muscle area in mm^2, ARTO1, ARTO2, ARTO 3, ARTOM – total surface area in mm^2; SHME1, SHME2, SHME3, SHMEM – proportion of muscle area from total area in %; HE1A, HE2A, HE3A, HEMA – height measurements at the ventral belly side; 20 mm from its edge in mm; HE1B, HE2B, HE3B, HEMB – height measurements in the middle of the belly in mm; HE1C, HE2C, HE3C, HEMC height measurements at the dorsal belly side; 20 mm from the belly edge – in mm.

Table 2. Correlation coefficients between the belly fat content determined by petroleum ether extraction and measured indicators

Indicator	r	Indicator	R
Chemical analysis		Belly area	
Belly1 dry matter content	0.85	ARME1	0.06
Belly2 dry matter content	0.70	ARME2	–0.16
Belly3 dry matter content	0.39	ARME3	0.02
average dry matter content	**0.77**	ARMEM	0.10
Belly1 fat content	**0.83**	ARTO1	**0.51**
Belly2 fat content	**0.78**	ARTO2	**0.40**
Belly3 fat content	**0.84**	ARTO3	0.32
		ARTOM	0.39
Selected indicators of the carcass value		SHME1	–0.58
carcass lean meat proportion (FOM)	–0.69	SHME2	–0.56
backfat thickness 1	**0.59**	SHME3	–0.35
backfat thickness 2	**0.64**	SHMEM	–0.45
backfat thickness 3	0.67	Belly height	
average backfat thickness	**0.71**	Belly1	
Belly weight		HE1A	0.20
weight of the Belly1	**0.48**	HE1B	0.30
weight of the Belly2	**0.64**	HE1C	0.56
weight of the Belly3	**0.50**	HE1M – average height	**0.55**
total belly weight	**0.64**	Belly2	
Belly proportion from the carcass	**0.59**	HE2A	**0.52**
		HE2B	**0.70**
		HE2C	**0.76**
		HE2M – average height	**0.75**
		Belly3	
		HE3A	0.19
		HE3B	**0.60**
		HE3C	**0.54**
		HE3M – average height	**0.56**

Bold r values with $P<0.05$.

Backfat thickness 1 (over the first thoracic vertebra), backfat thickness 2 (over the last thoracic vertebra), backfat thickness 3 (over the 5th lumbar vertebra). Abbreviation description – see Table 1 footnotes for explanation.

Results

The results given in Table 1 suggest that different parts of the belly have different tissue composition. The lipid content determined by chemical extraction in individual belly parts increased cranially from FB1= 29% to FB3= 38%. The same trend was shown for the surface area measurements. The total area increased cranially from ARTO1= 8 010 mm^2 to ARTO3 = 12 155 mm^2, whereas the muscle area increased from ARME1= 4 883 mm^2 to ARME3= 7 111 mm^2. However, the relative muscle area (SHME) decreased cranially from 61.4% to 58.9%, apparently due to the increased areas of other tissues, especially fat.

Table 2 shows the values of correlation coefficients between the total lipid content in the belly determined by chemical analysis and various independent variables that were used for belly evaluation. It is appropriate to collect the measurements from digital images taken at different cross-sections of the belly and to select those with the highest correlation coefficients and, in addition, those located in places where they are easily measurable, for example at standard carcass cutting lines. The variables selected in this way are then included in the regression equation. The CUT 2 cross-section appeared to be the most suitable for the prediction of relationships between belly height measurements and belly fat content. The highest correlation coefficients r = +0.70 ($P<0.01$) and r = +0.76 ($P<0.01$) were observed for HE2B and HE2C, respectively. The correlation coefficients between muscle area and fat content ranged between r = –0.16 ($P<0.05$) and + 0.06 ($P<0.05$), whereas the correlation coefficients between the proportion of muscle area from the total area and fat content ranged from r = –0.35 ($P<0.01$) to –0.58 ($P<0.01$). Thus, the total area of the cut increased with increasing fat content whereas the muscle area decreased. The belly fat content was positively correlated with backfat thickness (from (r = +0.59 ($P<0.01$) to +0.71 ($P<0.01$)) and negatively correlated with the carcass lean meat content (r = –0.69 ($P<0.01$)). Regression equations were constructed using the regression analysis (Table 3). The two equations selected on the basis of their accuracy (R^2 = 0.65 and 0.70 and RMSE = 3.21 and 2.24) are given in Table 3.

Table 3. Regression equation parameters for predicting the fat content in the belly

Parameter	Regression value – equation 1	Regression value – equation 2
Intercept	49.95979	43.88841
SHME2	–0.71737	–0.60143
HE2A	0.50473	0.47692
ARTO2		0.00141
HE3A		–0.26967
R^2	0.6585	0.7029
RMSE	3.2182	2.2477

R^2 – coefficient of determination; RMSE – root mean square error. Abbreviation description – see Table 1 footnotes for explanation.

Discussion

The fat content in the pork belly differs depending on the anatomical location (Trusell et al., 2011), and therefore it is necessary to define accurately the sampling sites or cuts used for the digital image analysis. The use of VIA for pork carcass evaluation has been previously evaluated by Branscheid and Dobrowolski (1996) and Branscheid et al. (2004). When evaluating the belly composition, however, the authors were not able to achieve satisfactory results. Tholen et al. (2003) used for the belly evaluation the images taken between the 13th and 14th rib, whereas Branscheid and Dobrowolski (1996) used the images taken between the 6th and 7th rib.

For the accurate assessment of the belly by the VIA method, it is necessary to monitor the effect of the time between slaughtering and image collection. The influence of classification time on the prediction of carcass composition was investigated by Branscheid et al. (1994). They reported the fat content deviation of up to 2% in 80% carcasses when the classification was performed on chilled compared to warm carcasses. It is assumed that the evaluation of the belly is carried out only after the dissection of chilled carcasses, i.e. approximately 24 h postmortem. Backfat thickness and belly weight are easily (quickly and reproducibly) measurable and can be used as additional indicators increasing the accuracy of prediction. In this study, moderate to high correlations were observed between these indicators and the belly fat content (from r = +0.48 ($P<0.01$) to r = +0.64 ($P<0.01$)). Similar correlations between backfat thickness and fat content ranging from +0.85 ($P<0.01$) to +0.71 ($P<0.01$) have been reported previously (Hermesch, 2008). The magnitude of the correlation coefficients found in this study suggests the possibility of using the video image analysis (VIA) method for the objective evaluation of the pig belly composition. The use of carcass weight as a predictive variable for the lean meat content determination has also been recommended by Goenaga et al. (2008). The observed reliability values corresponded with those calculated for new equations predicting the lean meat content reported by Goenaga et al. (2008). Equation 1 is simpler than Equation 2 but its RMSE slightly exceeded the limit given in the EU Regulations 1249/2008 (RMSEP <2.5). The advantage of this equation is the use of a single belly image taken on the cut between the 10th and 11th rib. The lower RMSE value was calculated for the more complicated, but also more accurate, equation 2. This equation uses the images of the cut between the 10th and 11th rib as well as the cut carried out behind the last rib.

The equations with similar R^2 values were constructed by Uttaro and Zawadski (2010). However, they also obtained unfavorably high RMSE values (3.18 to 3.34) when using a markedly higher number (4 compared to 2) of predictor variables.

Nevertheless, in spite of the slightly higher RMSE value we consider the equation 1 also applicable for belly composition evaluation due to its simplicity and sufficient accuracy of the fat content prediction.

The accuracy of the regression equations obtained validates the suitability of the selected predictor variables for the objective belly evaluation. If the VIA systems will be commercially used for the classification of individual carcass parts including the belly, this method can be applied as a classification method in accordance with EU Regulations. According to Engel et al. (2003), it is necessary that a new classification method (equipment) works correctly and its reliability is verified. Further refinement of regression equations at the expense of their simplicity can be made when the effect of gender or genotype is added to the regression (Engel et al., 2012). However, as suggested in the study by Zelenak et al. (2004), using separate equations for the different sexes is useless as only a slight improvement in accuracy can be gained. Moreover, inserting additional regressors (sex, genotype) into equations will result in undesirably reduced simplicity and thus in less applicability for classification.

The content of fat determined by a simple reference method (petroleum ether extraction) as the reference method for the evaluation of belly composition appears to be more appropriate than the determination of lean meat requiring difficult detailed dissections. Some simplification can also be gained through the use of computed tomography (Judas et al., 2006). The importance of accurate, reliable and simple reference methods was described by Goenaga et al. (2008).

Abbreviations

VIA = video image analysis; MRI = magnetic resonance imaging; LWD = Large White; LWD×L = Large White × Landrace; (LWS×PN) × (LWD×L) = Large White × Pietrain) × (Large White × Landrace); (D×PN) × (LWD×L) = (Duroc × Pietrain) × (Large White × Landrace); MEp = metabolizable energy; LYZ = lysine; CUT1 = cut 40 mm caudal to the last rib; CUT2 = cut between the 10th and 11th rib; CUT3 = cut between the 7th and 8th rib; CUT4 = cut between the 4th and 5th rib; ARTO1, ARTO2, ARTO3, ARTOM = total surface area in mm^2 of the cut 1, 2 and 3; ARME1, ARME2, ARME3 = total muscle area in mm^2 of the cut 1, 2 and 3; SHME1, SHME2, SHME3 = proportion of muscle area from total area in % of the cut 1, 2 and 3; ARTOM, ARMEM, SHMEM = cut 1, 2 and 3 averages; HE1A, HE2A, HE3A, HE1B, HE2B, HE3B, HE1C, HE2C, HE3C = height measurements at the cut 1, 2 and 3 in mm; FB1, FB2, FB3 = petroleum ether extracts of belly 1, 2 and 3.

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