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Selected measurements of pork carcass geometry and association with slaughter value

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Abstract: The aim of the research was to use a vision technique to assess the relations between anatomical pork carcass traits, carcass geometry and slaughter value. The measurements in the experiment were performed on 128 selected pork carcasses. The 3D image of the carcass was assessed, especially its shape. Based on the carcass curvatures the correlation coefficients for these surfaces and slaughter value traits were calculated. The possibility of using the external dimensions and geometry of pork carcass for the accurate estimation of meatiness and the share of primal cuts using the technique of acquiring carcass images in a 3D configuration was confirmed. This can be useful in improving the classification methods of the SEUROP system. In the fattener breeding process the ham size increased whereas the carcass front decreased. That was probably why the carcass width or surface size correlation with the meat content were positive on the carcass back and negative on the shoulder.

Keywords: 3D image; lean meat content; pigs; pork carcass assessment; primal cut assessment

Pork belongs to the most commonly consumed meats on most continents. The latest change in perceiving pork as an unhealthy food as a result of scientific research performed in this field has proved that pork consumption does not increase the risk of civilization diseases due to the fat content and unfavourable fatty acid content is of great importance. Therefore, pork can also be included in the group of high-quality meat food products (Wood et al. 2008; McAfee et al. 2010; McNeill and Van Elswyk 2012; Janiszewski et al. 2016). Pork is a much leaner meat now and due to feed additives like oils, antioxidants or modern hybrid rye varieties the fatty acid profile has improved and is in accordance with the WHO recommendations (Janiszewski et al. 2016).

Introducing the EUROP classification (currently called SEUROP) into the EU the pork carcass grading system which is strictly based on carcass lean meat content and rewarding the carcasses with the highest lean meat content and the lowest fat content was significant for the process of improving pork slaughter and nutritional values. The grading scale in this system has been enhanced with

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the S class (60% of lean meat content or more) and has been implemented with the following EU Regulation: 1308/2013. All of the facts presented above brought the necessity to adapt pig production to obtain the most desirable meatiness classes (Janiszewski et al. 2019).

The carcass grading within the classification system is based on the estimation of lean meat content in the carcass. Carcass lean meat content is a parameter of great significance for estimating the marketable carcass quality (Font i Furnols and Gispert 2009). Using instruments to perform measurements makes the assessment objective although in the case of hand-held instruments there is a risk of error made by the person performing the assessment. That is why Gispert et al. (2000) predicted the development of automatic pork carcass assessment methods. In order to assess the lean meat content with the most commonly used equipment the following measurements are taken: backfat thickness and longissimus dorsi muscle thickness at the precisely chosen points on the left carcass. The next step is the calculation of the obtained results for the estimated carcass lean meat content by using the regression equation approved by the European Commission individually for each instrument.

Olsen et al. (2017) underlined that an ideal carcass grading system should be based on the whole carcass. The current grading system is a statistical model based on measurements performed at chosen points on the carcass (Causer et al. 2003). Olsen et al. (2017) also indicated X-ray or magnetic resonance imaging as promising future techniques but they also stated that on-line methods are not commonly available although certain instruments such as automatic ones, also applied in Poland, have the potential to be used for whole carcass conformation assessment (Fortin et al. 2004; Knecht et al. 2016). The Estimeat video instrument was used in this research. Estimeat is a very precise instrument which has been developed by the research team of this paper. The research team also approved that the new version of the Estimeat instrument could be used in the Polish meat industry.

Due to many years of using the SEUROP carcass grading system the top European pig producing countries have observed the constant growth of average pork carcass lean meat content until it reached a stable and unchanged level. In Denmark 95% of pork carcasses have been classified as S class for several years.

The average lean meat content in Poland is about 58.5% and has increased by 10 p.p. in the last few years (Lisiak and Borzuta 2014; Borzuta and Lisiak 2016; Janiszewski et al. 2019). The average carcass weight in Poland has also increased and has now reached 90 kg (Borzuta and Lisiak 2016). It has already been proved in scientific papers that the slaughter value of carcasses classified to the same class may be different (Lisiak et al. 2015; Janiszewski et al. 2019). In the carcasses of the same class the share of basic cuts determining the carcass market value may be different. So the carcass class does not provide the full information on the carcass market value due to insufficient measurements (Borzuta et al. 2010; Knecht et al. 2016). According to Ho et al. (2019) the precise and optimal use of the most valuable carcass cuts is becoming increasingly important. However, it seems that the EUROP grading, in the form based on these kinds of measurements, will become less important in the future of the European meat industry (Fortin et al. 2003; Kristensen et al. 2014).

A question has arisen about the future of the pork carcasses in the EUROP grading system and there is a need to search for further indicators that can diversify the carcass slaughter value.

The aim of the research was to use a video/vision 3D technique to assess the relation between anatomical pork carcass traits, parameters of the carcass geometry and the slaughter value, using them to improve the SEUROP grading system.

MATERIAL AND METHODS

Research material

The animal population was chosen for the research according to Regulation (EC) No. 1249/2008. The entire process, beginning from setting the selection conditions for the research material, proper carcass selection on the slaughter line and partial dissection (substantive supervision), was performed by a research team from the Institute of Agricultural and Food Biotechnology (IBPRS). The measurements in the experiment were performed on 128 selected pork carcasses from a mass population. In order to provide a reliable research sample and to properly choose the experimental material a statistical analysis of the mass population in Poland was done. The biological variability of pigs slaughtered

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Table 1. Structure of the studied population of pigs and mean values of the selected slaughter value traits

	Carcass weight range (kg)	Group 1	Group 2	Group 3	Total
Gilts	60–95	8	16	8	32
	95.1–120	8	16	8	32
Castrates	60–95	8	16	8	32
	95.1–120	8	16	8	32
Mean of backfat thickness (mm)	–	10.4	16.1	24.7	–
Lean meat content (%)	–	62.09	57.21	52.87	–
Total	–	32	64	32	128

Group 1 = backfat thickness from 1 to 11 mm; group 2 = backfat thickness from 12 to 22 mm; group 3 = over 23 mm

in Poland, based on sex, backfat thickness at the point (groups: 1, 2, 3, see the explanation in Table 1) measured using the optical probe IM-03, and hot carcass weight, was analysed in the first quarter of the year 2017 and based on 47 915 carcass measurements. The measurements were taken in the 7 biggest slaughterhouses representing the average national population of fatteners. Based on the above-mentioned statistical analysis, carcasses, ranging from 60 kg to 110 kg hot weight, were selected on the slaughter line (gilts and castrates 1 : 1). Table 1 presents the structure of the population of fattening pigs selected for the study, from the mass stock of the western part of Poland.

Carcass selection and dissection

The dissection trial was carried out at the Company "Waldi Zakłady Mięsne". The pigs were slaughtered according to the applicable provisions after several hours of resting using the Koma electric stunning system with standard electric parameters (1.3 A; 250 V; 50 Hz). Only the carcasses with the proper cutting in half were the subject of further dissection. Thanks to that procedure, the effect of carcass cutting on the weight of carcass primal cuts and errors in any further analysis were eliminated. The carcasses were selected on the slaughter line not later than 45 min after sticking. All carcasses were automatically measured with the vision device.

In the next step the warm carcasses were transported to the industrial cooler. Chilling was done by the one-step method, at a temperature of about 4 °C. After 24 h of chilling to the temperature of 6 °C, the left carcasses were cut into the main primal cuts according to the Walstra and Merkus (1996) method. The weight of the most valuable carcass cuts, i.e. belly, ham, loin, neck and shoulder, was measured to the nearest 100 g. After that, the cuts were dissected by 5 experienced butchers who were employees of the slaughterhouse. The butchers were trained and were familiar with the working conditions. Dissection was performed under the scientific supervision of employees from IBPRS-PIB. The tissues obtained in the process of dissection were weighed to check the share of these tissues in each cut.

Video technique

Lean meat content and slaughter value measurement. The instrument used in the experiment was approved for use in Poland and can be found in the EC Implementing Decision No. 252 of 11 February 2019. It functions based on three-dimensional carcass scanning using the optical measuring equipment – depth cameras. The three-dimensional image of the carcass is assessed, especially its shape, and based on that assessment the lean meat content is determined as well as the weight of all cuts – ham, loin, shoulder, belly and tenderloin. Based on the carcass curvatures determined after analysing the carcass image with the standard graphical software used in the analysis, the correlation coefficients for these surfaces and slaughter value traits were calculated. The lean meat content of the carcass was calculated according to the following formula, contained in the above-mentioned EU Regulation, as a regression equation for the "ESTIMEAT method" for grading pig carcasses:

$$\begin{aligned} LMC = {} & 38.39317497 + 508.24 \times X1 - 148.557 \times \\ & \times X2 - 3.63439 \times X3 + 2.481331 \times X4 + \\ & + 8.353825 \times X5 + 2.75896 \times X6 + 268.8835 \times X7 \end{aligned} \quad (1)$$

RMSEP = 1.698 and R^2 = 0.86

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where:

LMC – estimated lean meat content as percentage of carcass weight;

X1 – E_sf_66 – summary error of fitting the cross section points to the circle with R_sf radius at point P-66;

X2 – Z_80 – outside convexity of carcass between maximum convexity of ham and shoulder at point Z-80;

X3 – (E_58/E_67) – summary error of fitting the cross section points to the circle with R radius at point P-58/summary error of fitting the cross section points to the circle with R radius at point P-67;

X4 – (E_sf_103/E_sf_111) – summary error of fitting the cross section points to the circle with R_sf radius at point P-103/summary error of fitting the cross section points to the circle with R_sf radius at point P-111;

X5 – (H_49_3/H_49_5) cross section partial depth at point P-49 in 3/10 of the section width/cross section partial depth at point P-49 in 5/10 of the section width;

X6 – (H_max_18/H_max_49) cross section maximum depth at point P-18/cross section maximum depth at point P-49;

X7 – X_72_4 – partial error at the cross section points to circle with R radius at point P-72 in 4/10 of the cross-sectional area.

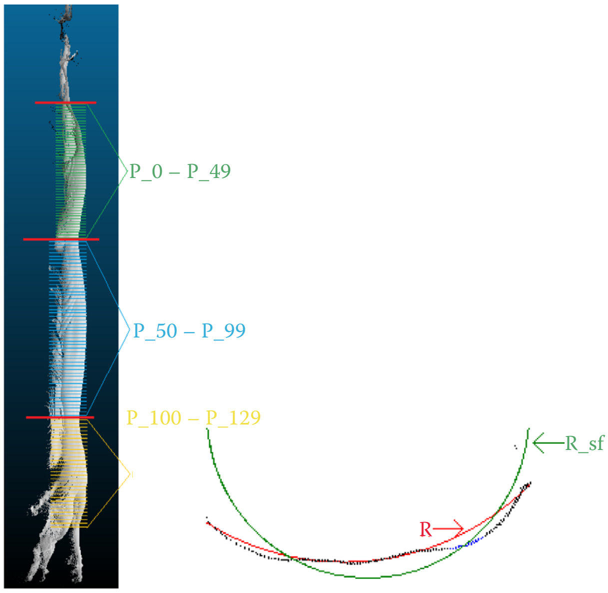

Figure 1. The method of creating a 3D model of pork carcass and graphical characteristics of the principle of collecting measurements to determine the half carcass geometry

Video/vision measurement of carcass curvature and its geometry

After measuring the carcass with the video instrument, the three-dimensional carcass model was obtained in the case of the scanned carcass still hanging or continuous collecting of carcass models was performed in the case of the automatic slaughter line. Next, the data in the form of the 3D cloud of points was analysed. Distortions i.e. outlier points were rejected as they might distort the results. Carcass position was determined – the 3D model was rotated so that all of the carcasses were lined up in the same direction. Next, the characteristic carcass points were set like inner heel and waist line. The carcass was virtually separated into individual cut – ham, shoulder, belly, loin and neck. The parameters were calculated for individual cuts as well as for the whole carcass. The cross and longitudinal sections were then also determined. For each section the following parameters were determined: section size, circumference or curvature so that the distances from the carcass cutting section were visible. Also, the parameters describing the carcass shape (R) were calculated e.g. the proximity of the section to the circle (R_sf). In order to estimate the carcass geometry parameters based on the carcass 3D image using special graphical software, the points from the available cloud were connected and the parameters were the most useful for further analysis (Figure 1).

Statistical analysis

Analysis of the lean meat content. The regression equations for lean meat content and prediction of primal cut share in pig carcasses were derived using the PLS-PCR procedure (Partial Least Squares-Principal Components Regression) in SAS v9.2 (Causer et al. 2003). This method is useful in this analysis because it aims at the minimization of the prediction error by using the function and predictors, which explain variation in the sample and in the linear regression model in the fullest way. The accuracy of prediction was evaluated using the RMSEP (root mean squared error of prediction) factor calculated from the PRESS statistics,

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using the leave-one-out cross-validation method according to the regulations of the European Union (Causer et al. 2003). The RMSEP estimation error will be calculated for the tested device.

Correlation coefficients for carcass geometry and slaughter value traits. Pearson's correlation coefficient are a statistical measure of the strength of the relationship between the tested traits i.e. the measurements of the outer surface of the carcass and the traits of slaughter value. The Statistica v6.1 software was used to calculate the linear correlation coefficients and to make the correlation matrix. The significance of the correlation allows to determine the influence of a given parameter on the examined feature and confirm the direction of the relationship between the interactions.

RESULTS

The results are presented in Tables 2 and 3 and in Figures 2–6.

The chosen slaughter value traits of carcass can be seen in Table 2: the average weight of carcass primal cuts, i.e. ham, loin, shoulder, belly dissected from the carcass, their lean meat content and their share in the carcass. In order to precisely describe the research material for each average value the standard deviation was calculated and the minimum and maximum values are presented. It was confirmed that carcasses had the high lean meat value reaching 57.39%, which is close to the national average in Poland. The analysed average carcass weight was 46.97 kg.

Significant correlation coefficients were determined for several carcass geometry parameters, based on the performed statistical analysis. Some measurements on the carcass surface were found more suitable for lean meat content estimation whereas others were more suitable for carcass weight estimation. The average correlation coefficients for the described traits are presented in Table 3. The highest average correlation coefficients range from 0.57 to 0.62 depending on the trait were observed in the correlation between the whole carcass lean meat content as well as the lean meat content of carcass cuts and the carcass convexity on the ham and concavity in the carcass waist area i.e. on the ham curvature and anatomical belly concavity. It confirmed the high suitability of these parameters to estimate carcass lean meat content and lean meat content of the primal cuts e.g. a significantly high correlation was found between the ham curvature and lean meat content in the anatomically distant cuts like the shoulder and the belly.

Table 2. Characteristics of selected parameters of half carcasses of the studied fatteners (n = 128) determined by slaughter value assessment and dissection

Trait	Mean	Minimum	Maximum	SD
Ham (g)	11 409.8	9 134	15 154	1 208.16
Loin (g)	8 837.6	6 044	13 247	1 256.91
Shoulder (g)	5 809.0	4 667	7 582	608.70
Belly (g)	3 851.3	2 400	5 180	520.60
Lean meat content (%)	57.39	44.8	66.5	4.635
Lean meat content in ham (%)	71.78	58.1	80.0	4.286
Ham share in carcass (%)	24.30	21.6	27.3	1.074
Lean meat content in loin (%)	55.26	38.3	67.5	6.632
Loin share in carcass (%)	18.77	15.7	22.9	1.290
Lean meat content in shoulder (%)	66.15	53.9	75.6	4.645
Shoulder share in carcass (%)	12.38	10.5	14.0	0.673
Lean meat content in belly (%)	56.09	38.1	70.7	6.996
Belly share in carcass (%)	6.76	3.9	10.6	1.083
Hot carcass weight (kg)	46.97	38.3	59.3	4.794

These two parameters, i.e. concavity and convexity, were completely useless in the carcass and carcass primal cut weight estimation. In order to determine the weight, the parameters like circumscribed circle and radius of curvature were statistically more important because statistically significantly higher values were observed even though they were slightly lower and ranged from 0.40 to 0.51. The complete lack of a statistical correlation between the carcass thickness and the tested parameters was surprising.

It is worth noticing what is clearly visible on the graphs in Figures 2–6, which present the cross and

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Table 3. Correlation coefficients between geometry traits from the carcass surface and the slaughter value

Mean value of geometry traits from the half carcass surface	Weight of element (kg)					Lean meat content (%)					Share in the carcass (%)			
	ham	loin	belly	shoulder	carcass	ham	loin	belly	shoulder	carcass	ham	loin	belly	shoulder
Convexity														
Ham	0.33*	0.13	0.20*	0.19*	0.23*	0.62*	0.56*	0.53*	0.57*	0.60*	0.24*	−0.09	−0.15	−0.08
Belly	−0.07	−0.19*	−0.03	−0.02	−0.15	0.17	0.20*	0.17*	0.03	0.17*	0.20*	−0.16	−0.11	0.23*
Shoulder	−0.03	−0.15	−0.05	−0.06	−0.09	0.14	0.17*	0.11	0.21*	0.17	0.11	−0.17*	−0.12	0.03
Radius of curvature														
Ham	0.37*	0.33*	0.28*	0.35*	0.39*	−0.13	−0.11	−0.12	−0.06	−0.11	−0.03	0.11	0.30*	−0.05
Belly	0.38*	0.35*	0.29*	0.36*	0.40*	0.09	0.05	0.08	0.19*	0.09	−0.01	0.14	0.20*	−0.04
Shoulder	0.21*	0.24*	0.19*	0.21*	0.24*	−0.12	−0.13	−0.06	−0.02	−0.10	−0.04	0.13	0.22*	−0.03
Described circle														
Ham	0.34*	0.34*	0.28*	0.19*	0.33*	0.22*	0.16	0.25*	0.26*	0.21*	0.06	0.20*	−0.25*	0.12
Belly	0.38*	0.51*	0.39*	0.27*	0.47*	0.00	−0.08	0.01	0.13	−0.03	−0.16	0.33*	−0.35*	0.33*
Shoulder	0.31*	0.35*	0.31*	0.25*	0.36*	0.04	−0.02	0.02	0.08	0.01	−0.09	0.16	−0.17*	0.25*
Circuit														
Ham	0.27*	0.27*	0.24*	0.13	0.26*	0.23*	0.18*	0.25*	0.27*	0.22*	0.05	0.16	0.08	−0.24*
Belly	0.31*	0.43*	0.33*	0.20*	0.39*	0.02	−0.06	0.02	0.13	−0.01	−0.14	0.29*	0.27*	−0.33*
Shoulder	0.27*	0.31*	0.27*	0.21*	0.32*	0.04	−0.02	0.01	0.08	0.01	−0.09	0.14	0.22*	−0.17*
Thickness														
Ham	0.01	0.02	0.04	−0.08	0.00	0.26*	0.22*	0.26*	0.27*	0.25*	0.05	0.03	−0.11	−0.16
Belly	−0.01	0.07	0.07	−0.08	0.02	0.01	−0.02	0.01	0.03	−0.01	−0.06	0.08	0.05	−0.20*
Shoulder	−0.01	0.02	0.03	−0.05	0.01	0.08	0.05	0.02	0.03	0.05	−0.05	0.01	−0.01	−0.10
Width														
Ham	0.54	0.54	0.43	0.39	0.55	0.14	0.09	0.19	0.21	0.13	0.04	0.28	0.27	−0.26
Belly	0.44	0.59	0.44	0.37	0.56	−0.11	−0.18	−0.07	0.00	−0.13	−0.23	0.37	0.43	−0.31
Shoulder	0.35	0.32	0.33	0.27	0.36	0.11	0.06	0.10	0.22	0.10	0.00	0.11	0.22	−0.15
Surface														
Ham	0.16	0.17	0.18*	0.04	0.15	0.29*	0.22*	0.29*	0.32*	0.27*	0.04	0.10	−0.01	−0.22*
Belly	0.17*	0.29**	0.20*	0.06	0.23*	0.03	−0.03	0.02	0.12	0.00	−0.10	0.23*	0.15	−0.30*
Shoulder	0.07	0.12	0.10	0.03	0.10	0.09	0.04	0.03	0.07	0.05	−0.06	0.07	0.05	−0.13
Concavity														
Belly	0.13	−0.11	0.00	0.10	0.04	0.60*	0.54*	0.46*	0.58*	0.58*	0.20*	−0.28*	−0.31*	0.10

*$P \leq 0.05$; **$P \leq 0.01$

longitudinal sections of the carcass surface and the correlation coefficients. The correlation coefficients between the curvature and lean meat content of the measured anatomical region, and their variability are presented in Figure 2. It was found that carcass convexity on the ham was the most correlated with the lean meat content, and was statistically insignificant on the belly whereas on the shoulder at measuring point No. 1 the correlation coefficient changed its sign from "positive" to "negative".

The average values of the correlation coefficient varied from 0.60 to 0.17 depending on the measurement point. The ham convexities on the whole

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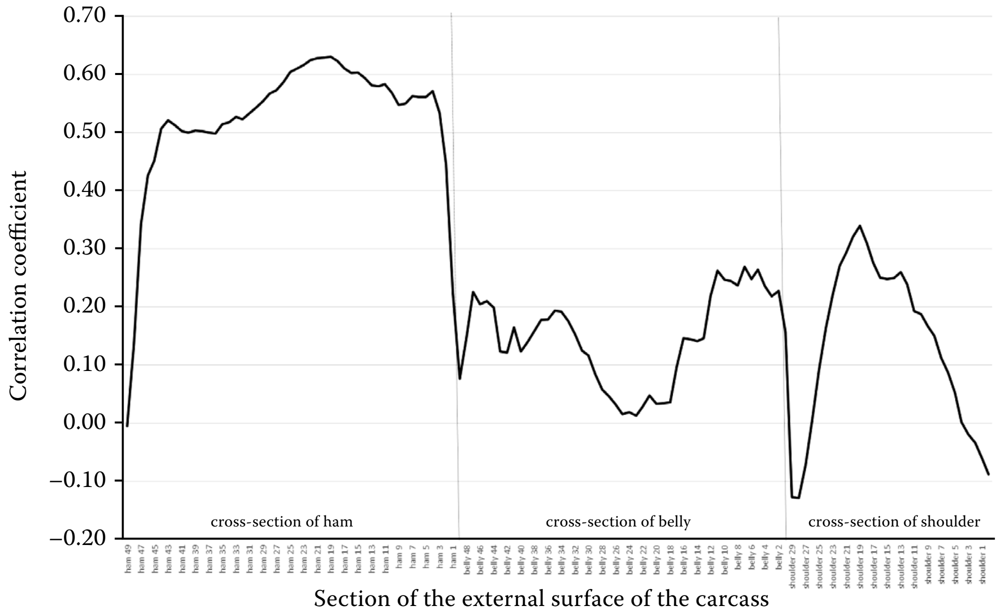

Figure 2. Correlation coefficients between the convexity of the outer surface of the half carcass and the lean meat content in the carcass

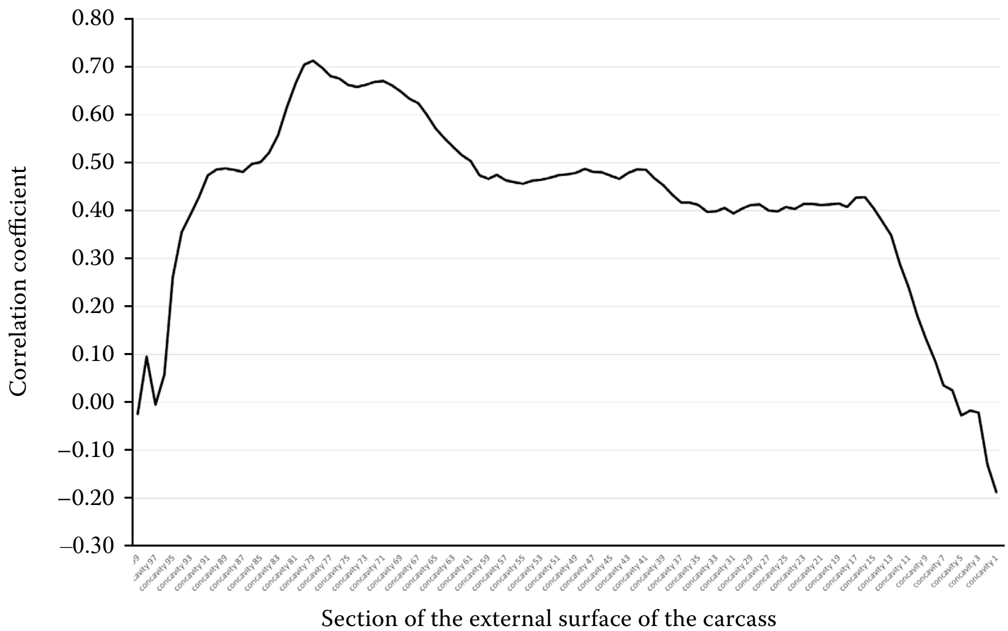

Figure 3. Correlation coefficients between the concavities of the outer surface of the ham and the lean meat content in the carcass

length seemed to be the most uniform to determine carcass lean meat. The correlation coefficients on the whole ham were at a similar level. In the case of concavity on the ham the maximum values were obtained in the middle area of this cut (Figure 3).

The tendency of correlation coefficient variance is presented in the graphs. For each trait there is a maximum coefficient value that might be used for further extensive analysis or for regression equation creation. What is more, based on the correlation coefficient analysis it was established that the carcass lean meat determination is influenced by the back carcass part whereas the middle and front carcass parts, e.g. shoulder, were highly correlated with carcass weight (Figures 4–6). Based on the significance analysis, in the case of carcass geometry and weight correlation coefficients the most important was the anatomical carcass centre

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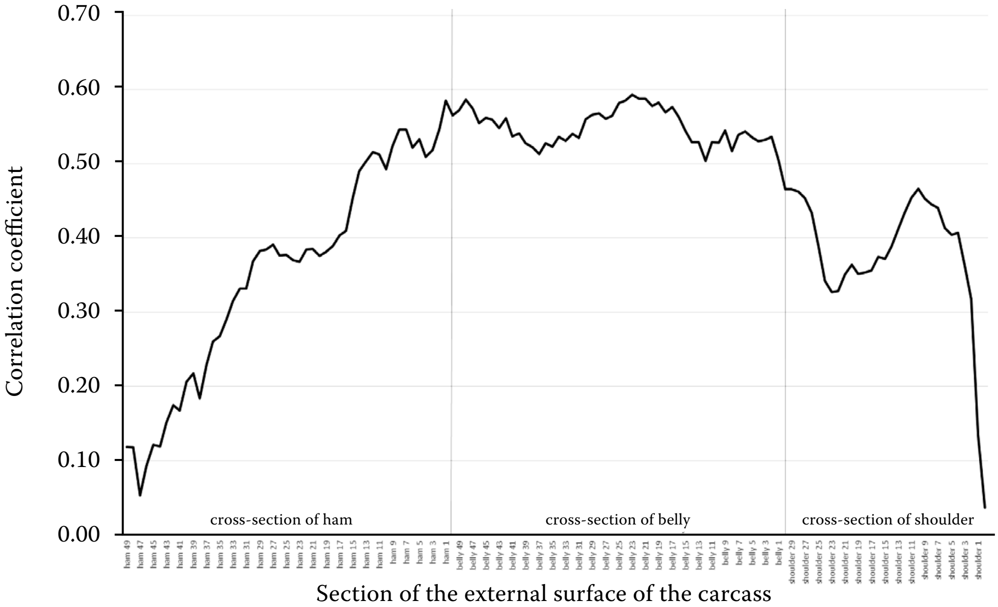

Figure 4. Correlation coefficients between the width of the outer surface of the carcass and the weight of the carcass

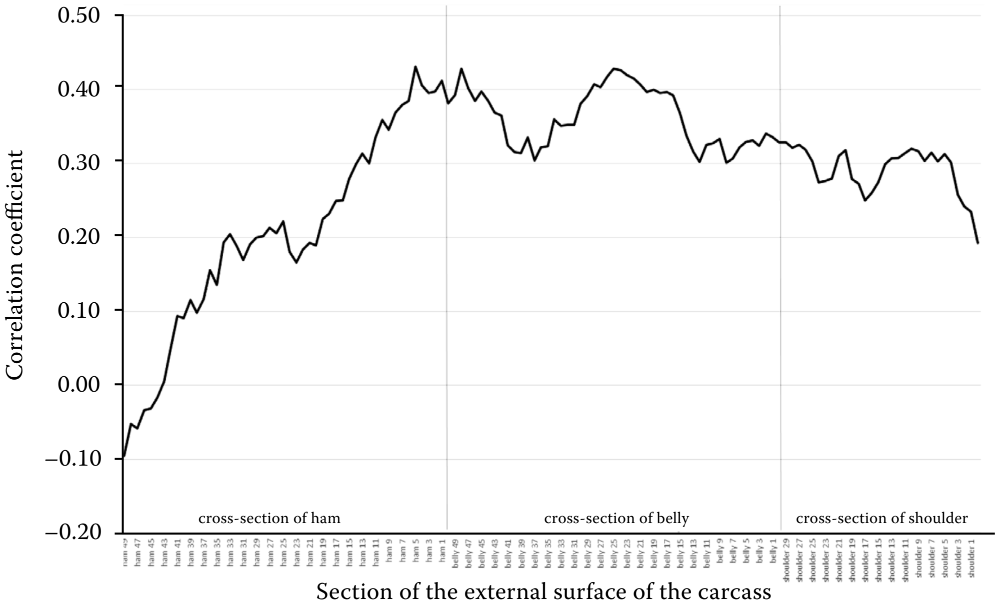

Figure 5. Correlation coefficients between the circumference of the outer surface of the carcass and the weight of the carcass

(the belly). The highest correlation coefficient values were observed there.

The measurements performed on the central carcass part i.e. in the belly area, highly influenced the estimation of the cut percentage share in the carcass. Significant correlation coefficients between the share of some carcass cuts and the circumscribed circle, width, circumference and concavity of this anatomical carcass part were found. What is more, the average correlation coefficients for circumscribed circle, width and radius of curvature measured on the whole carcass length were important for estimating the belly share in the carcass. The low and mostly statistically non-significant correlation coefficients for determining the ham share in the carcass were rather surprising. A very interesting observation was also made for measurements taken in the central carcass part, i.e. on the belly, namely the variability of the average correlation coefficient sign that varied from a positive

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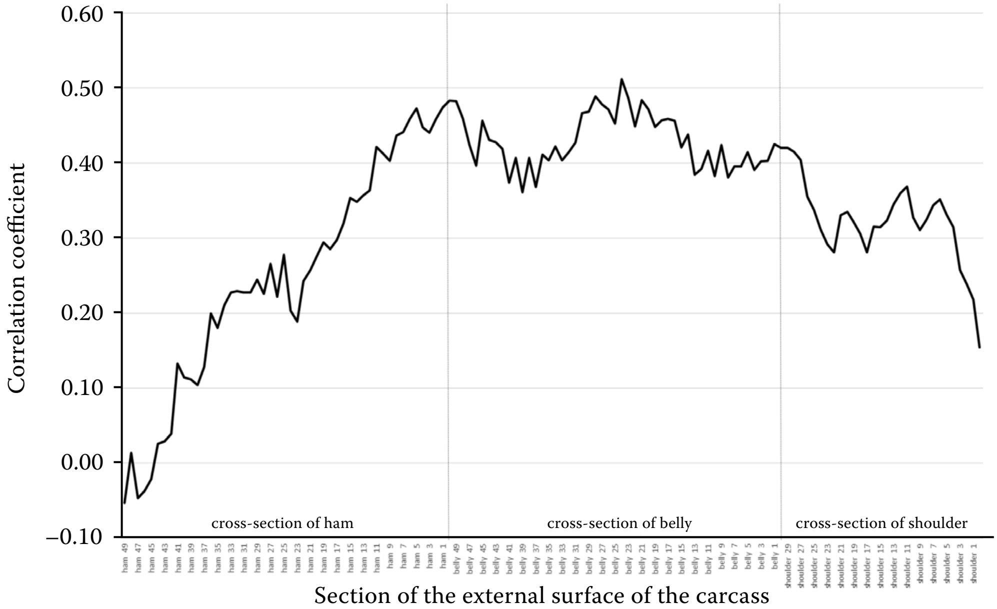

Figure 6. Correlation coefficients between the described circle of the outer surface of the carcass and the weight of the carcass

to a negative correlation depending on the cut the correlation was measured for. The average correlation coefficient was 0.43 for the belly share and 0.37 for the loin share whereas it was –0.33 for the shoulder share and –0.23 for the ham share. The measurements taken on the outer carcass surface were more useful for carcass weight determination than for the lean meat content, which was confirmed by the significant correlation coefficients (14 and 7 significant correlation coefficients, respectively).

DISCUSSION

Based on the literature sources the SEUROP pork carcass grading system should be modified. One of the directions gaining importance is to include in the carcass grading a slaughter value understood in a broad sense and not only one parameter like so far, i.e. lean meat content, which is not grading carcasses in a sufficient way (Vester-Christiansen et al. 2009; Lisiak et al. 2014a,b; 2015; Ho et al. 2019; Janiszewski et al. 2019). As was mentioned in the introduction, the carcass lean meat content in the top pig producing countries has reached a stable level that has remained unchanged for a few years until now. The tools currently used for pig carcass grading are very accurate and the error rate is very low e.g. for Poland Estimeat – RMSEP is 1.68, Autofom III – 1.43. For the Autofom tool it has been a huge progress because as indicated by other authors, the former version reached a 1.9 estimation error (Font I Furnols and Gispert 2009). Many authors underlined also the growing importance of automation in the meat sector and the need for more objective high-tech criteria. Thus, advanced technologies may improve the production and quality of the final product (Banhazi et al. 2012; Kristiansen 2014). It seems that special attention should be paid to non-invasive technologies supporting the carcass slaughter value estimation by a simplified measuring procedure. The economic value of such a system as well as the infrastructural requirements that must be fulfilled by a slaughter line in order to implement a given technique or solution have been very important.

Condotta et al. (2020) reported that depth cameras are more and more often used in the visual/video carcass estimation instead of costly laser scanners. Such cameras are used to create the 3D image and the mapping of processes also in the estimation of live animals. That fact was also confirmed by Shuai et al. (2020). There have been many studies using the simple depth camera technique and especially the Microsoft Kinect sensor for the estimation of live animals and animal movements (Khoshelbam et al. 2012; Stavrakakis et al. 2015; Pezzulo et al. 2018; Condotta et al. 2020). In their analysis Shuai et al. (2020) also used visual

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techniques, and also IT tools like in this research. Estimeat met the majority of requirements the new meat sector equipment is facing. These requirements are simplicity, functionality, automation and accuracy (Zelenak et al. 2004; Lisiak et al. 2015). The research presented in this paper has filled the gap caused by many studies on using this solution for the live estimation of animals without using it for estimation after slaughter.

Due to the 3D model of the pork carcass and due to the performed statistical analysis of the results some correlations between outer surfaces, carcass curvature and carcass slaughter value were determined. The slaughter value estimation based on the parameters of the outer surface seems very promising. Olsen et al. (2017) mentioned that there are a significant number of factors influencing the reliability of the results of carcass lean meat content estimation.

The correlations between the lean meat content, carcass weight and carcass primal cuts are well known and described in the literature. Along with the lean meat content increase the share of lean cuts i.e. loin and ham, increased. In fatter carcasses the belly share is by 1 p.p. higher than in leaner carcass classes (Lisiak et al. 2015; Samardakiewicz et al. 2015; Lisiak et al. 2015). Lisiak et al. (2011) proved that along with the lean meat content increase the 4D ham share in the carcass increased by 9.79% to 14.23%, loin with the bone increased by 9.15% to 11.75%, 4D shoulder increased by 7.56% to 9.65%, neck without the bone increased by 5.45% to 6.09% and category I meat boneless (trim meat) increased by 1.52% to 2.10% whereas the share of the belly, backfat and other fatter cuts decreased. Branscheid et al. (2000) developed regression equations for estimating the share of carcass primal cuts and the measurements taken by the vision tool VCS 2000. The accuracy of these equations was high with the low value of RMESP error. The research of Almeida et al. (2019) showed a strong negative correlation of the lean meat content in ham with the fat in ham, fat in the belly and IMF content. What is more, there is a correlation (approx. 0.81) between the lean meat content in the ham and *m. l. thoracis*. However, there are not too many papers on the estimation of external pork carcass surface and its correlation with the basic slaughter value traits determined from the outer surface of the carcass.

Janiszewski et al. (2019) reported that the value of the five main carcass cuts could range from 43.80 EUR to 69.17 EUR. The sum of the values increased with the growth of the yield of the cuts which, as reported by Lisiak (2014), may however be different within the same class (E). This divergence between carcasses highlights the imperfection of the current carcass classification system. This indicates the need for a change in this matter (Marcoux et al. 2007; Lisiak and Borzuta 2014).

Many years of the selection of pigs towards lean meat content improvement estimated by the SEUROP system like the *longissimus dorsi* thickness and backfat thickness as reported by Lisiak and Borzuta (2014), differences in the primal cuts within the same class (E and S), led to some changes in carcass conformation. This divergence between carcasses highlights the imperfection of the current carcass classification system. It is the effect of using such a carcass grading system and the results of these tests may be a valuable guideline in terms of the further planning of breeding programs. That is why complex research, including the changes in the fattener shape caused by the market requirements, is so important.

CONCLUSION

The possibility of using the external dimensions and geometry of pork carcass for the accurate estimation of meatiness and the share of primal cuts using the technique of acquiring carcass images in a 3D configuration was confirmed. This can be useful in improving the classification methods of the SEUROP system.

On the basis of this study it is to state that the traits correlated with carcass convexity and concavity were more useful for lean meat content determination whereas the trait values obtained as a result of the contour analysis (circumscribed circle and radius of curvature, width) were more useful for carcass and primal cut weight determination. The best lean meat content indicator was the indicator based on ham convexity and belly concavity.

The best lean meat content indicators were concentrated in the ham area whereas the best carcass and main cut weight indicators were concentrated in the central carcass part. The radius of curvature was higher at the points where the curvature was smaller and that was why it was negatively correlated with ham. Contrary to expectations, the thickness does not correlate in most cases with

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the weight or the share of the main primal cuts, except the thickness of ham, which correlates with the lean mean content in cuts.

In the fattener breeding process the ham size increased whereas the carcass front decreased. That was probably why the carcass width or surface size (that are highly correlated with the whole carcass size) correlation with the meat content was positive on the carcass back and negative on the shoulder.

Conflict of interests

The authors declare no conflict of interest.

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