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VERIFICATION OF REGRESSION EQUATIONS FOR ESTIMATING PORK CARCASS MEATINESS USING CGM, IM-03, FAT-O-MEAT'ER II AND ULTRAFOM 300 DEVICES

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Abstract

Four manual classification devices for estimating pork carcass meat content, i.e. CGM, Fat-O-Meat'er II, IM-03 and UltraFom 300 were tested. The experiment was carried out with properly selected raw material (n=141 pigs) from current deliveries for pig slaughter at the Meat Plant SKIBA S.A. in Chojnice. Pork raw material was derived from three different Polish regions and represented different types of fatness, different carcass weights (from 60 to 120 kg) and different sexes (half were gilts and half were barrows). The applied testing procedure was consistent with European Union regulations. The research resulted in the development of regression equations for estimating pork carcass meat content in Poland. These equations are of rectilinear type and use four (in the case of UltraFom 300) or two (in the case of other devices) measurements of backfat and *longissimus dorsi* muscle thickness located at a distance of 6 cm (CGM, IM-03) or 7 cm (Fat-O-Meat'er II, UltraFom 300) from the backfat edge at the section between 3rd and 4th rib, counting ribs from the end (CGM, IM-03, Fat-O-Meat'er II) and also at the height of the last rib section (UltraFom 300). The prediction error does not exceed the termination value of 2.50% established by EU regulations and amounts to 2.16% for CGM, 2.18% for Fat-O-Meat'er II, 1.89% for IM-03 and 2.07% for UltraFom 300. New regression equations have been applied in the meat industry since 12 December 2011.

Key words: pork carcasses, meatiness, regression equations, classification device

The slaughter value of porkers over the last decades in Poland was characterized by certain periodicity of changes. Meatiness of pigs from the general population was 41 to 44% in the 1960s, increased slightly in the 1980s and decreased again to about 43% in the early 1990s (Borzuta et al., 2011). During the same periods, the meatiness of breeding material was much higher compared to the general population, by about 5.6 and 10%, respectively. It was not until the turn of the 20th and 21st centuries that meatiness increased rapidly to reach 54.8% in 2010 within the general population

(Lisiak et al., 2011) and about 59% in nucleus breeding (Blicharski et al., 2010). Since Poland's accession to the European Union, the regression equations for the estimation of meatiness using four classification devices, i.e. CGM, IM-03, UltraFom 300 and AutoFom, have not been modified (Borzuta et al., 2004). Meanwhile, the slaughter value of pigs changed significantly and their carcasses are presently an average of 6 kg heavier (82.7 kg in 2004 and 88.7 kg in 2007) and their meatiness about 3% higher (an increase from 52% to 54.8%). It is recognized that meatiness estimation methods should be adapted to the slaughter value of pigs from the general population (Borzuta, 1998; Zelenak et al., 2005; Nissen et al., 2006; Engel et al., 2012). Therefore, every single EU member state develops regression equations for its own population and periodically verifies them as slaughter performance improves. Changes in testing procedure of the equipment used is another important reason for verification of the regression equations. Initially the equations were developed based on full dissection results, known as the DLG (*Deutsche Landwirtschaftliche Gesellschaft*) method (Borzuta, 2002). After the introduction of a simplified dissection method, the so-called Walstra and Merkus method (Walstra and Merkus, 1996; EEC Regulation no. 3220/1984; EEC Regulation no. 2967/85) all EU countries performed the first verification of the equations. The introduction of a new formula for calculating the proportion of dissected meat in the Walstra and Merkus method in 2006, forced all member states to verify once again regression equations for the classification devices used (EC Regulation no. 1249/2008, EC Regulation no. 1197/2006). Analysis made by Wajda et al. (2008) demonstrated that the difference in meatiness between dissection results obtained with the old and new calculation formula averaged 1.96% in favour of the new formula; the differences were greater for light pig carcasses (2.5%) and smaller for heavy ones (1.54%). Similar results were obtained by Lisiak (2011), who showed that the differences in meatiness calculated with the old and new formula are also dependent on the level of meat content and the type of equipment used. The purpose of the study was to develop new regression equations for estimating pork carcass meatiness in Poland using four manual classification devices: CGM, IM-03, UltraFom 300 and Fat-O-Meat'er II.

Material and methods

In 2009, the slaughter value of pigs slaughtered in the Polish abattoirs was analysed based on measurements of backfat thickness over the last rib using a ruler and post-slaughter carcass weight. Measurements were made on a population of 19656 pigs, which represented raw material from five slaughterhouses: Animex S.A. Group Szczecin Branch; Meat Plant Skiba in Chojnice; Polish Meat Concern Duda S.A. in Grabkowo; Meat Plant ŁMET in Łuków; Meat Plant Dobrowolscy in Wadowice Górne. The results obtained are summarized in Table 1. The average backfat thickness and the standard deviation formed a basis for dividing the population into five pig groups with the following backfat thickness ranges: under 15 mm, 15 to 20 mm, 21 to 25 mm, 26 to 30 mm, and over 30 mm. Afterwards, based on the above ranges,

141 carcasses were selected from the slaughter line in order to test the classification devices according to the experimental design shown in Table 2.

Table 1. The distribution of carcass weight and backfat thickness of pigs slaughtered in five national abattoirs (n = 19656)

Item	Post-slaughter weight, kg	Backfat thickness, mm
Average	88.8	21.2
Standard deviation	10.3	5.6
Minimum value	60.0	5.0
Maximum value	120.0	60.0

Table 2. Number of pigs from particular regions of Poland with different backfat thickness groups, selected for the test

Region	<15 mm	15–20 mm	21–25 mm	26–30 mm	>30 mm	Total
Western	5	17	13	10	3	48
Central	5	14	17	8	5	49
Eastern	4	11	20	6	3	44
Total	14	42	50	24	11	141

Pigs designated for the study came from western, central and eastern Poland. Animals were transported in special vehicles to the Meat Plant Skiba in Chojnice and slaughtered after a few hours of lairage. Carcasses with warm weight of 60–120 kg were selected for testing; in every group there were similar numbers of gilts and barrows. The entire population was represented by 72 barrows and 69 gilts. Carcasses split along the spinal column, with no rejects, were also taken into consideration. Selected carcasses were marked and thickness of backfat and *longissimus dorsi* (LD) muscle was measured using the devices placed at the end of slaughter line in the following order: UltraFom 300, Fat-O-Meat'er II, IM-03 and CGM. According to the procedure provided by the manufacturers, backfat and LD muscle thickness was measured in various anatomical points of the left half-carcass; the principles are presented in Table 3. Another selection was made after an ultrafast chilling of the carcasses in order to reject all asymmetrically cut carcasses. Selected left half-carcasses, at a temperature not exceeding 7°C in the centre of the leg, were then sent for dissection. Dissections were performed according to the EU reference methodology (EC Regulation no. 1249/2008; Walstra and Merkus, 1996) accounting for primal cuts, i.e. leg without shank, shoulder without shank, loin, belly and tenderloin. The level of meat content was calculated following the EC Regulation formula, using dissection data. An approved electronic scale with 15 kg capacity and 1 g accuracy was used for weighing carcass cuts and single dissection elements.

Table 3. Characteristics of backfat thickness and LD muscle measurements used in the regression equations

Device	Type and site of measurement	Distance from carcass midline	Direction of probe operation	Measurement indicator's mark
Ultra-Fom 300	Backfat thickness at the height of the last rib	7 cm	Perpendicular to the width of m. LD	F1
	LD muscle thickness at the height of the last rib	7 cm	Perpendicular to the width of m. LD	M1
	Backfat thickness between 3rd and 4th last rib	7 cm	Perpendicular to the width of m. LD	F2
	LD muscle thickness between 3rd and 4th last rib	7 cm	Perpendicular to the width of m. LD	M2
Fat-O-Meat'er II	LD muscle thickness between 3rd and 4th last rib	7 cm	Perpendicular to the width of m. LD	F2
	LD muscle thickness between 3rd and 4th last rib	7 cm	Perpendicular to the width of m. LD	M2
CGM and IM-03	LD muscle thickness between 3rd and 4th last rib	6 cm	Parallel to the cutting line of the split carcass	F2
	LD muscle thickness between 3rd and 4th last rib	6 cm	Parallel to the cutting line of the split carcass	M2

The regression equations for the tested devices were developed using the PLS-PCR (Partial Least Squares Principal Components Regression) procedure, which is permitted for use by EU regulations (Causeur et al., 2003). The assumption of this method is that prediction error is minimized by using functions and predictors, which explain the variability in the sample and linear model of regression in the most comprehensive way. Estimation accuracy was rated using the RMSEP (root mean square error of prediction) indicator calculated with PRESS statistic, which complies with cross-validation (SAS v. 9.2)

During the calculation it was necessary to separate all outlying values, the number of which was different for particular devices. Outliers were identified in the data set and then eliminated based on the analysis of the following plots: histogram of residuals plot, scatter plot of studentized residuals by predicted values, scatter plot of observed vs. predicted values, needle plot of Cook's D statistic by observation number, standard Q-Q plot of residuals.

Results

a) Optical-needle device Fat-O-Meat'er II

Based on regression analysis it was found that the lean meat content (LMC) equation for carcass meat content estimation using Fat-O-Meat'er II device is:

$LMC_{FOM\ II} = 59.75 + 0.1533\ M_2 - 0.6342\ F_2$ RMSEP = 2.18

A population of 136 carcasses was allowed for analysis and 5 were recognized as outlying observations. Dissection results and meatiness estimation results using the Fat-O-Meat'er II apparatus (Table 4) showed similarities between the 2 examined methods. Figure 1A shows a high correlation between dissection results and data determined by the device. Correct scatter plot of the residuals, which are differences between dissected and estimated meatiness of carcasses, testifies to an adequate adjustment of the equation. These differences are arranged in half above and below the zero line and are evenly distributed (Figure 1B).

Table 4. Average linear measurements and meat content evaluated by dissection and estimated using the Fat-O-Meat'er II device

Traits	N	$\bar{x}$	s	Minimum	Maximum
Weight of carcass (kg)	136	88.56	10.34	67.20	119.17
LMC dis. (%)	136	55.01	4.13	44.29	65.07
LMC_{FOM} (%)	136	55.01	3.53	44.00	61.52
F_2 (mm)	136	20.31	4.97	9.80	35.90
M_2 (mm)	136	53.07	8.19	36.00	73.40

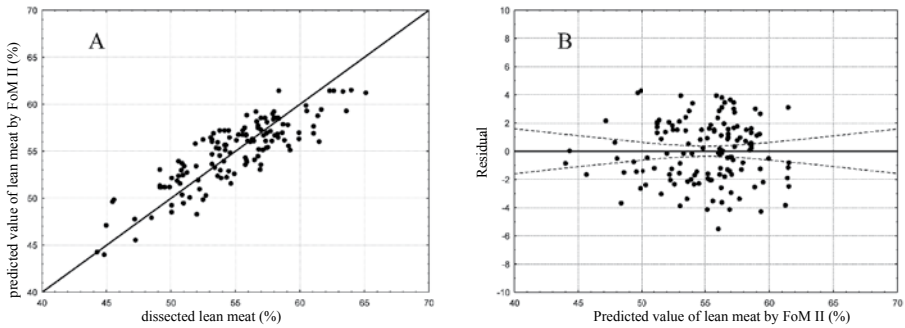

Figure 1. Correlation (A) and scatter plot of the residuals (B) representing differences between lean meat content of carcass evaluated by dissection and that estimated with Fat-O-Meat'er II device

b) Ultrasonic device UltraFom 300

Based on regression analysis it was found that the equation for UltraFom 300 device has the following form:

$LMC_{UF300} = 54.48+0.1272\ M_1 - 0.3090\ F_1 + 0.0828\ M_2 - 0.2802\ F_2$ RMSEP = 2.07

All examined carcasses were taken into consideration as none of them was observed as outlier. The results of pork carcass meatiness evaluation obtained by dissection and by regression equations determined for UltraFom 300 device are present-

ed in Table 5. Average values differ by 0.01% only and the minimum and maximum values by 1.3% and 3.48%, respectively.

Table 5. Average linear measurements and meat content evaluated by dissection and estimated using the Ultra-Fom 300 device

Traits	N	$\bar{x}$	s	Minimum	Maximum
Weight of carcass (kg)	141	88.44	10.34	67.20	123.40
LMC diss. (%)	141	54.97	4.18	44.29	65.07
$LMC_{UF\ 300}$ (%)	141	54.96	3.63	42.99	61.59
M_1 (mm)	141	54.88	6.74	38.70	70.60
F_1 (mm)	141	17.38	5.05	8.90	36.90
F_2 (mm)	141	18.69	5.51	8.90	41.20
M_2 (mm)	141	49.75	6.91	36.20	66.70

Like Fat-O-Meat'er II device, UltraFom 300 shows that the correlation between meat content evaluated by dissection and that estimated using the apparatus is high (Figure 2A).

Scatter plot of residuals presented in Figure 2B shows their even distribution and adequate adjustment of the equation to the examined population.

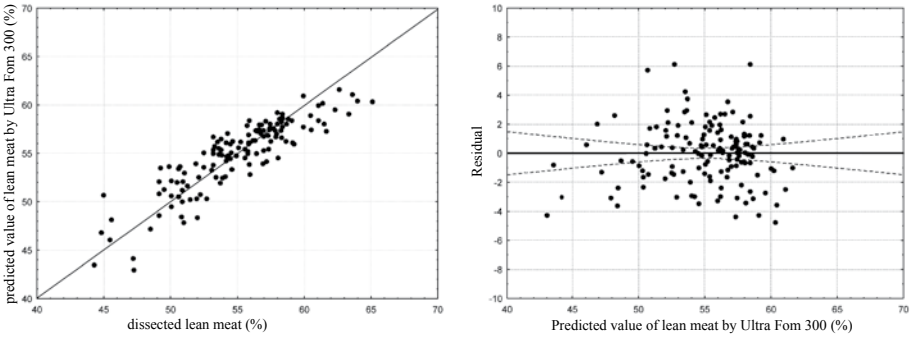

Figure 2. Correlation (A) and scatter plot of the residuals (B) representing differences between lean meat content of carcass evaluated by dissection and that estimated with Ultra-Fom 300 apparatus

c) Optical-needle device CGM

Based on regression analysis it was found that the equation for CGM device has the following form:

$LMC_{CGM} = 59.42 + 0.1322\ M_2 - 0.6275\ F_2$ RMSEP = 2.16

A population of 138 carcasses was allowed for analysis and 3 were recognized as outlying observations. Dissection results and meatiness estimation results using the CGM apparatus are presented in Table 6. Using the regression equation developed for CGM apparatus, we obtained exactly the same average meat content in pork carcasses as by using the dissection. The significant correlation between meatiness determined by dissection and that estimated using CGM device is presented in Figure 3A (plot) and Figure 3B (residuals scatter plot).

Table 6. Average linear measurements and meat content evaluated by dissection and estimated using the CGM device

Traits	N	$\bar{x}$	s	Minimum	Maximum
Weight of carcass (kg)	138	88.49	10.38	67.20	119.17
LMC diss. (%)	138	54.97	4.19	44.29	65.07
LMC_{CGM} (%)	138	54.97	3.63	43.51	61.28
F_2 (mm)	138	18.56	5.12	8.00	34.00
M_2 (mm)	138	54.41	7.95	25.00	72.00

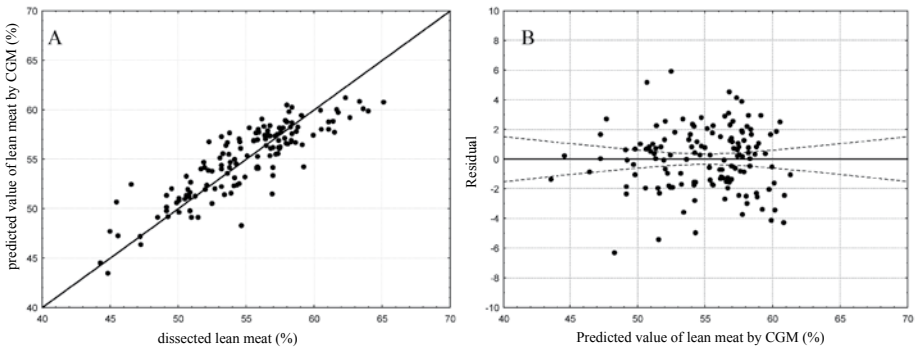

Figure 3. Correlation (A) and scatter plot of the residuals (B) representing differences between lean meat content of carcass evaluated by dissection and that estimated with CGM device

d) Optical-needle device IM-03

Based on regression analysis it was found that the equation for IM-03 device has the following form:

$$LMC_{IM\text{-}03} = 60.55 + 0.1142\ M_2 - 0.6292\ T_2 \qquad RMSEP = 1.89$$

A population of 140 carcasses was allowed for analysis and 1 was recognized as an outlying observation.

Like the other described devices, IM-03 reveals strong accordance of average meatiness determined by dissection and that estimated using apparatus (Table 7).

The results obtained show that the correlation between meat content evaluated by dissection and that estimated using the apparatus is high (Figure 4).

Table 7. Average linear measurements and meat content evaluated by dissection and estimated using the IM-03 device

Traits	N	$\bar{x}$	s	Minimum	Maximum
Weight of carcass (kg)	140	88.19	9.95	67.20	119.20
LMC diss. (%)	140	54.95	4.19	44.29	65.07
LMC_{IM-03} (%)	140	54.96	3.76	43.44	62.24
F_2 (mm)	140	19.35	5.39	6.60	35.90
M_2 (mm)	140	57.62	8.40	32.70	77.60

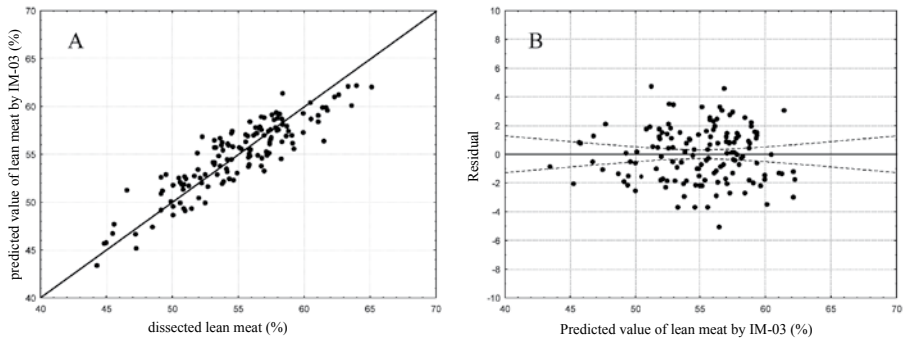

Figure 4. Correlation (A) and scatter plot of the residuals (B) representing differences between lean meat content of carcass evaluated by dissection and that estimated with IM-03 device

Discussion

Pork carcasses selected for the research on manual classification devices were characterized by an average hot carcass weight of 88.4 kg (s=10.34) and an average meatiness of 55% (s = 4.18, min. 44.3%, max. 65.1%) and they represented the population with normal distribution (Figure 5). During a recent test study made in 2002–2003 the average meatiness of carcasses selected for the examination was 52.8% and the average hot carcass weight was about 80 kg (Borzuta et al., 2004). These differences are considerable and they justify the need to adapt regression equations to the changeable pig population, which has increased in weight and LMC. The level of meat content in the tested pigs was similar to the national average, which was about 54.8% in 2010 (Lisiak et al., 2011). All the equations developed

for the tested devices are of rectilinear regression type and are based on two (CGM, Fat-O-Meat'er II) or four LD muscle and backfat thickness measurements (UltraFom 300). The processing capacity of the tested devices is comparable and it is a minimum of 300 carcasses per hour, allowing their use in practically all national abattoirs. Prediction error RMSEP of all tested devices is smaller than the terminal value of 2.5%, which was established by EC Regulation no. 1249/2008. The least prediction error was found for IM-03 apparatus (RMSEP=1.89%), and for the other devices it was slightly larger (2.07 to 2.18%). Compared to the study conducted in 2002–2003 (Borzuta et al., 2004) the prediction error was smaller for CGM (RMSEP 2.38% and 2.16%, respectively), UltraFom 300 (RMSEP 2.28% and 2.07%, respectively) and IM-03 (RMSEP 2.33% and 1.89%, respectively). Prediction error for Fat-O-Meat'er II was 2.18% and was comparable with the optical-needle apparatus CGM. Fat-O-Meat'er II is one of the oldest devices, constructed in the 1970s in Denmark (Borzuta, 1998) and the last technical modification of this device was made in 2010; as a result of this modification Fat-O-Meat'er II was built up and submitted for calibration in Poland in 2011. A device of this type has not yet been used for classification in the national meat industry. Research carried out recently in Spain showed that prediction error RMSEP for the four devices was similar to the results obtained in the study described here. It was 2.30% for UltraFom 300 and 1.80% for Fat-O-Meat'er (Font i Furnols and Gispert, 2009). A relatively high prediction error was stated for automatic devices Auto-Fom (2.30%) and VCS2000 (2.30%), whereas a very low prediction error was obtained for the computed tomography system (1.00%). A similar prediction error (2.10%) to that described here was obtained during the calibration performed earlier in Spain (Commission Regulation EC 11/2009) and a slightly higher one in Poland (2.20%) in a study performed in 2000 (Blicharski et al., 2002) for UltraFom 300. Other studies with Fat-O-Meat'er revealed the following RMSEP prediction errors: Gispert and Diestre (1994) 1.60%, Allen and McGeehin (2001) 2.20%, Brøndum et al. (1998) 2.00%. Except for Gispert and Diestre's (1994) research, the prediction error for Fat-O-Meat'er in the above-mentioned studies is close to that obtained in our work. In studies on the estimation accuracy of classification devices, authors point out factors affecting the size of the error. Nissen et al. (2006) found that the error is dependent on volatility of raw material, sex, structure of the body physique and especially on the proportions of meat parts subjected to dissection, team of butchers carrying out the dissection, etc. It was revealed that the most significant difference in meatiness between the butchers was 1.96%. Left half-carcass is characterized by 0.62% lower meatiness compared to the right half-carcass (average meatiness is 58.34% and 58.96%, respectively). Research by Zelenak et al. (2005) and Engel et al. (2012) indicated that there is no need to adapt two separate regression equations for gilts and for males as the differences caused by sex are not so significant. It would be reasonable to adapt separate regression equations for different genetic types of pigs, but this task is not achievable in industrial practice because it is impossible to identify breeds and crossbreds in the population. Therefore, study results obtained with the devices calibrated separately for each country are taken into account. In summary, the present research provides new regression equations for estimating pork carcass meat content in Poland using four manual classification

devices, i.e. CGM , Fat-O-Meat'er II, IM-03 and UltraFom 300. Equations are of a rectilinear type and use four (UltraFom 300) or two (other devices) measurements of backfat and *longissimus dorsi* muscle thickness. The prediction error RMSEP does not exceed the terminal value of 2.50%, which was established by EU (Commission Regulation no. 1249/2008) and amounts to 2.16% for CGM, 2.18% for Fat-O-Meat'er II, 1.89% for IM-03 and 2.07% for UltraFom 300. By Commission decision 2011/506/EU, all the devices tested were approved for pork carcass classification in Poland since 12 December 2011.

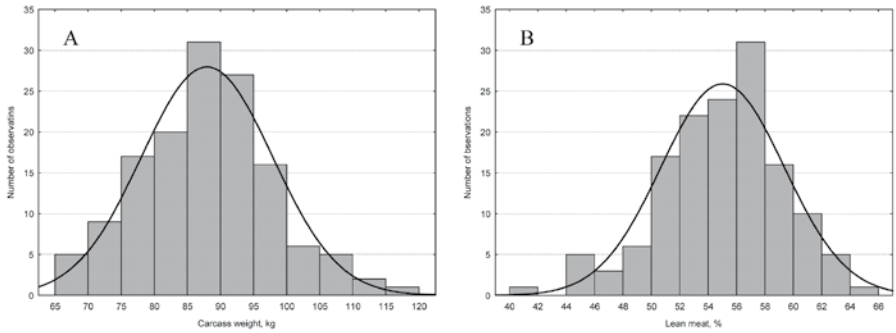

Figure 5. Distribution of weight (A) and lean meat content in dissected carcasses

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Weryfikacja równań regresji do szacowania mięsności tusz wieprzowych za pomocą urządzeń CGM, IM-03, Fat-O-Meat'er II i UltraFom 300

STRESZCZENIE

Wykonano badania testujące czterech ręcznych urządzeń klasyfikacyjnych służących do szacowania zawartości mięsa w tuszach wieprzowych, tj. CGM, Fat-O-Meat'er II, IM-03 oraz UltraFom 300. Doświadczenie przeprowadzono na odpowiednio dobranym surowcu (n = 141 szt.) z bieżących dostaw do uboju trzody chlewnej w Zakładach Mięsnych SKIBA S.A. w Chojnicach. Tuczniki reprezentowały surowiec z trzech regionów kraju o różnych typach otłuszczenia, różnej masie tusz (60 do 120 kg)

oraz różnej płci (w połowie loszki i wieprzki). Zastosowano procedurę testowania zgodną z przepisami Unii Europejskiej. Wynikiem badań jest opracowanie równań regresji do szacowania zawartości mięsa w tuszach wieprzowych w Polsce. Równania te mają charakter prostoliniowy i wykorzystuje się w nich cztery (UltraFom 300) lub dwa (pozostałe urządzenia) pomiary grubości słoniny i mięśnia *longissimus dorsi* w punktach leżących w odległości 6 cm (CGM, IM-03) lub 7 cm (Fat-O-Meat'er i UltraFom 300) od krawędzi słoniny na przekroju między 3 i 4 żebrem, licząc żebra od końca (CGM i IM-03, Fat-O-Meat'er II) lub także na wysokości przekroju ostatniego żebra (UltraFom 300). Błąd szacowania RMSEP nie przekracza określonej przepisami UE granicy 2,50% i wynosi dla poszczególnych urządzeń: CGM – 2,16%, Fat-O-Meat'er II – 2,18%, IM-03 – 1,89% oraz UltraFom 300 – 2,07%. W dotychczas używanych trzech urządzeniach klasyfikacyjnych, tj. oprócz aparatu Fat-O-Meat'er II, jest to błąd niższy od równań opracowanych podczas testowania w 2002 r. o 0,2 do 0,3 punktu procentowego mięsności. Nowe równania regresji obowiązują w przemyśle mięsnym od 12 grudnia 2011 r.