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A comparative assessment of two different methods, using devices Optiscan-TP and Optigrade-MCP, for predicting the lean meat percentage of pig carcasses in Greece in relation to the European reference method

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ABSTRACT: Lean Meat Percentage (LMP) is a key index for assessing pork carcass quality as well as determining carcass classification and price. This framework offers farmers the incentive to achieve the desired organoleptic features; therefore, LMP must be measured objectively online, by means of various measuring instruments. The aim of this work was to assess two different methods for predicting the lean meat percentage of pig carcasses in Greece in comparison to the European reference method. For this reason, 130 pig carcasses (65 males and 65 females) were measured using two prediction devices (Optiscan-TP and Optigrade-MCP) and subsequently were assessed according to European reference method. A formula corresponding to each device was constructed using the ordinary least squares (OLS) method and excluding the same outliers. Calculated RMSEP (Root Mean Square Error of Prediction) for all 130 carcasses was 2.46518 for Optiscan-TP and 2.48489 for Optigrade-MCP. It can be concluded that both methods perform entirely according to EU legislation (Commission Regulation (EC) 1249/2008, European Union, 2008), and results obtained are similar regardless of different measurement points and technologies.

Keywords: pig carcass grading; lean percentage prediction; multiple linear regression

Abbreviations: LMP, lean meat percentage; OLS, ordinary least squares; PLS, partial least squares

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INTRODUCTION

As a biological material, meat is innately variable, so the twin objectives of efficiency and consistent quality are challenging. The development of practical and reliable solutions has occupied the meat industry and meat scientists for many years and, while there have been advances in the area (Delgado-Pando et al., 2021), there is still much room for improvement. Carcass Lean Meat Percentage (LMP) is an important quality index, which is determined online at slaughterhouses by means of various measuring instruments. Carcass classification according to SEUROP scheme sets the price of the carcasses in the majority of EU slaughterhouses; therefore, LMP is the basis for farmers' revenue and pork meat market organization. The classification of pigs in the EU is based on an objective assessment of the carcass content of lean meat after slaughter. As this is a costly process, due to the carcass destruction, prediction is much sought.

Worldwide, several techniques exist for analyzing pig carcasses using non-destructive methods including the two-points (Zwei Punkte, ZP) method, light reflectance, ultrasound imaging (US), dual-energy x-ray absorptiometry (DXA), magnetic resonance imaging (MRI), and computer tomography (CT). The two-points (Zwei Punkte, ZP) method was proposed by Pfeiffer and Falkenberg (1972) and is based on measurement of fat depth over the *m. gluteus medius* (point 1) and on measurement of muscle thickness from the anterior edge of the *m. gluteus medius* to the dorsal side of the spinal column (point 2). All measurements are made at the left carcass side. The light reflectance measures fat and muscle depth corresponding to the penetration point in the left carcass side. Measurements occur by exploiting the different reflectance recorded when a beam of infrared light is introduced into the various tissues. The amount of reflected light is superior when the probe passes adipose tissue to when it crosses muscular tissue (Hulsegge and Mercus, 2010). The ultrasound method is based on the different interaction of ultrasound with the different tissues of a carcass and with the separation surfaces, as well as the reflection of the sound towards the source of sound waves (Halliwell, 2010). The dual-energy x-ray absorptiometry and the computer tomography are based on the measurement of the attenuation of the X-rays that penetrate the carcass. Attenuation is defined as the measure of the ability of a tissue to absorb the photons of the rays (Picouet et al., 2010). The MRI is based on the properties of hydrogen atoms (protons) to orient the axis of rotation of their magnetic moment when a strong magnetic field is applied and return to their original state by emitting energy in the form of radio waves (Baulain, 2013). Devices used in slaughterhouses can be manual, semi-automatic or automatic, and measurements based on different technology as described above. All devices are calibrated for predicting the LMP in different countries (Font i Fournols and Gispert, 2009). The estimation of calibration parameters is based on a trial conforming to EU legislation (Commission Regulation (EC) 1249/2008, European Union, 2008). The dissection trial in the EU stipulates the dissection of at least 120 carcasses, which are representative of the country, following the reference method (Walstra and Merkus, 1995).

In order to develop a reference method in the EU, a major test was carried out in 1990-1991, as reported by Cook and Yates (1992). In this test, only four basic pieces of the carcass are cut (leg, shoulder, loin and belly), representing 75% of the striated muscle tissue. After much discussion on the calculation of lean meat content from the elements of the new EU cutting method, a compromise was reached on the definition of this new criterion. The new lean meat content and cutting method are briefly described by Council Regulation (EEC) No 3127/94 (European Union, 1994) and then in details by Walstra and Merkus (1995).

For the approval of the calibration equation, it is necessary to achieve a Root Mean Square Error of Prediction (RMSEP) lower than 2.5% (Commission Regulation (EC) 1249/2008, European Union, 2008). So, RMSEP is a very important parameter for the assessment of the accuracy of different devices. RMSEP varies depending on the device and country, and is calculated from 1.6% to 2.5% (Brøndum et al., 1998; Busk et al., 1999; Font i Furnols et al., 2004; Engel et al., 2006).

The aim of the current study was the comparative assessment of two different methods, using the devices Optiscan-TP and Optigrade-MCP, for predicting the lean meat percentage of pig carcasses in Greece in relation to the European reference method and to determine whether the results obtained are similar regardless of different measurement points and technologies.

MATERIALS AND METHODS

Lean meat measurement devices

The measurements were made using the two devices Optiscan-TP and Optigrade-MCP. The Optiscan-TP (Classpro Gmbh, Sielenbach, Germany) is a device equipped with a digital image scanner, which takes an illuminated photo of the area of the two measurement points on the carcass. The first point refers on measurement of fat depth over the *m. gluteus medius*, and the second point on measurement of muscle thickness from the anterior edge of the *m. gluteus medius* to the dorsal side of the spinal column. The images are the basis for calculating fat and muscle thickness according to the two-point method (Zwei-Punkte Messverfahren, (ZP), Pfeiffer and Falkenberg, 1972). The Optigrade-MCP (Classpro Gmbh, Sielenbach, Germany) is a device which encompasses an optoelectronic probe using light reflection to measure fat and muscle depth corresponding to the penetration point. Measurements occur by exploiting the different reflectance recorded when a beam of infrared light is introduced into the various tissues. The amount of reflected light is superior when the probe passes adipose tissue to when it crosses muscular tissue (Hulsegge and Mercus, 2010). The device has a 6 mm diameter optical probe, a Siemens infrared photo-diode as well as a Siemens photo-triode (Siemens A.G., Germany), and can measure values ranging from 0 to 110 mm (Hulsegge and Mercus, 2010).

In addition, the Henessy Grade Probe4 (HGP4) device (Henessy Technology, New Zealand) was used for the measurement of the subcutaneous fat of the carcasses and their classification, which was approved for Greece by the Commission Regulation 642//2010 (European Union, 2010). The device is equipped with a 5.95 mm optical probe (and 6.3 mm at the blade at the end of the probe), which includes a light diode Siemens LED type LYU 260-EO (Siemens A.G., Germany) and a Silonex SLCD-61N1 type photodetector, with an operating range between 0 and 120 mm.

Experimental design and pig carcasses

A total of 130 pig carcasses (n = 130, 65 males and 65 females) from 15 different farms were selected to ensure variability. Farms were located in Central Macedonia, Thessaly and Epirus (Greece), with these regions altogether holding 51.80% of national pig production (Hellenic Ministry of Agricultural Development and Food, 201; New Federation of Pig Associations of Greece, 2017), and were selected so that the sample represents the national population in the best possible way according to Commission Regulation (EC) 1249/2008 (European Union, 2008). In particular, given that in the regions of Central Macedonia, Thessaly and Epirus there are 48, 57 and 55 pig farms, respectively, a total representative sample of 15 farms was distributed equally in the 3 regions (5 farms per region or about 10% per region). From each farm 10-12 fattening pigs were taken for slaughter and from the resulting carcasses 8-10 were selected according to the criteria that follow below.

Effort was made to obtain three classes of carcasses, regarding both weight and fat thickness, but it was difficult to have extreme values, due to the small number of available carcasses. The sampling procedure was determined by the gender, weight and thickness of the subcutaneous fat of carcasses. Regarding gender, the distribution was made equally in both genders. Regarding the weight, the carcasses were divided into 3 categories in those with weight <80.9 kg, those between 80.9-89 kg and finally those with weight >89 kg. Carcasses based on subcutaneous fat thickness were also divided into 3 categories with subcutaneous fat thickness <11 mm, between 11-17 mm and ≥17 mm.

All pigs were slaughtered at a slaughterhouse located at Foustani Pella in the region of Central Macedonia, Greece. Usually, about 10-12 pigs from a single farm were transferred to the slaughterhouse, and finally 8-10 of them were selected and dissected each week according to the European reference method.

According to Regulation 1234/2007 (European Union, 2007), carcass is the whole body of a slaughtered animal as presented after bleeding, evisceration and skinning. It is noted, however, that in the 130 carcasses used in the present study the skin had not been removed. Carcasses and half-carcasses are presented without the tongue, the hairs, without the organs contained in the thoracic and abdominal cavities with or without the kidneys, the kidney fat and the pelvic fat and without the sexual organs and the attached muscles and without the udder or the mammary fat. Carcasses improper bisected or showing abscesses, bone fractures, haematomas and extensive bruising were discarded. After selection, carcasses were weighed and transferred in a separated room providing adequate measurement conditions.

All trial carcasses corresponded to the standard presentation according to EU legislation. Sampling procedure was stratified, comprising a wide range of carcass weights and lean contents (Fortin et al., 2003) in accordance with the following criteria:

i. Sex: 50% female (65 carcasses) and 50% male (65 carcasses) were used for the trial.

ii. Weight: The fattening pigs used for the trial had a live weight (LW) between 70-120 kg, in order to represent the Greek market conditions. None of the pigs in the sample weighed less than 70 kg (LW) and only 4 pigs weighed more than 120 kg (LW). Correspondingly, trial carcasses had a (warm) carcass weight (CW) between 49.4-103.8 kg.

iii. Back-fat thickness: Back-fat thickness (including skin) has been measured with HGP_4 device, at 6 cm laterally from the carcass split line and between the 3rd and the 4th ribs, counting from the last rib (6 cm ¾ LR). Three (3) back-fat thickness classes were created; <11 mm, 11-17 mm and >17 mm. The actual distribution of carcasses based on the back-fat thickness in the 3 classes is shown in Table 1 and Figure 1.

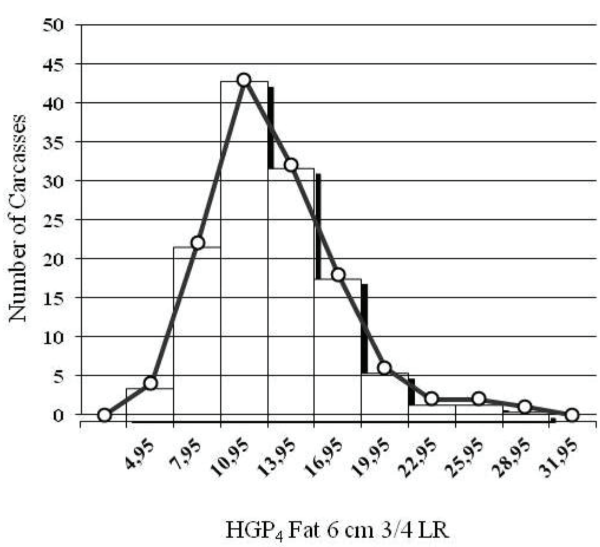


Figure 1. Distribution of trial carcasses (n=130) according to fat depth at 6 cm ¾ LR

Lean meat measurements with the method of imaging and reflection

Fat and muscle thickness of selected carcasses were first measured using Optiscan-TP (Classpro Gmbh, Sielenbach, Germany) which is an electronic, non-invasive classification device based on ZP method. Fat thickness - including rind - was measured (in mm) at the point of minimum thickness of visible fat covering the *m. glutaeus medius*, and muscle thickness at the shortest connection between the front (cranial) end of *m. glutaeus medius* and the upper (dorsal) edge of the vertebral canal as shown in Picture 1 (left).

The second set of measurements was taken using the Optigrade-MCP (Classpro Gmbh, Sielenbach, Germany) device that uses light reflection. Back-fat thickness (including skin) and *m. longissimus dorsi* depth was measured with the device, at 7 cm laterally from the carcass split line and between the 2nd and the 3rd ribs, counting from the last rib (7 cm ⅔ LR), as shown in Picture 1 (right). All measurements were performed on the left half of the carcasses, while it was still warm.

Lean meat measurements according to the European reference method

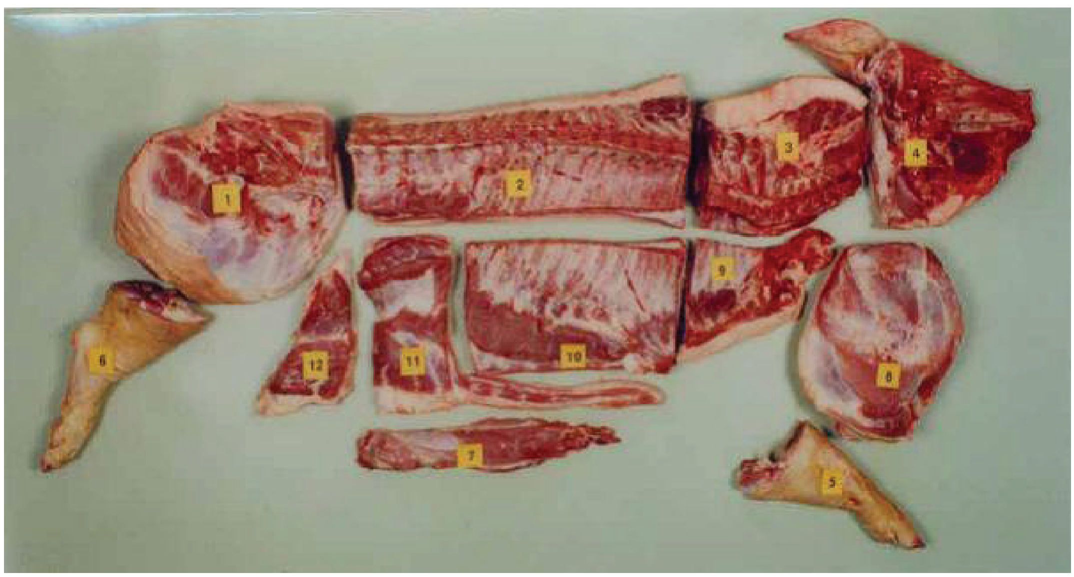
Immediately after measurement completion, pig carcasses were refrigerated. Cold carcasses were weighed and subsequently cut and dissected within 48 h post-mortem, according to the EU reference method (Walstra and Merkus, 1995). The dissection team consisted of four well trained butchers supervised by a member of the research team. Twelve (12) primal cuts were made in the left carcass side and 12 pieces were obtained (leg, loin, neck, head & cheek, front shank & front foot, hind sank and hind foot, tenderloin, shoulder, jawl, belly, ventral part of belly and "to ventral part of belly"). All pieces were weighted using a calibrated scale with an accuracy of 5 g and dissection data were recorded in the special form (Picture 2).

At the beginning of the cutting process, the fillet was detached with a cross section just before the head of the pubic symphysis, removed from the carcass and weighed. Only the four main sections were completely dissected. That means that further dissection was performed for the total separation of different tissues (muscle, inter-muscular fat, subcutaneous fat including skin, and bones) from leg, loin, shoulder, and belly. Fat is found in the subcutaneous tissue, which

Table 1. Distribution of trial carcasses (n=130) according to fat depth at 6 cm ¾ LR.

Back-fat 6 cm ¾ LR	Target %	Actual %	Actual Number	Actual Percentiles - 130 carcasses	
<11 mm	25 %	20,00 %	26	Percentile 25:	11,65 mm
11-17 mm	50 %	60,00 %	78	Percentile 50:	13,70 mm
≥17 mm	25 %	20,00 %	26	Percentile 75:	16,20 mm

Picture 1. Measurement points using Optiscan-TP and Optigrade-MCP



Picture 2. European reference method of dissection (Walstra and Merkus, 1995)

includes the skin and the one between the muscles. However, during the dissection, the remaining pieces arose. The neck and the head weighed together, the forearm, the tibia, the sternum, the umbilicus and the groin. For the leg preparation, the carcass was placed on the anatomical bench with the skin side down and stretched. The leg was separated from the loin and the abdomen with a straight incision at a right angle to the longitudinal axis between the last and penultimate lumbar vertebra, usually between the 5th and 6th lumbar vertebrae. The triangular part of the groin was removed and the leg remained. For the shoulder preparation, the head was first separated from the body by a straight section almost at right angles to the longitudinal axis between the os occipitale and the atlas. The scapula bone was removed with a round incision, following the natural boundaries. For the loin preparation, the neck was separated from the loin between the 4th and 5th thoracic vertebrae at a right angle to the spine. The incision line between the neck and the loin meets the urethral incision of the scapula. For the belly preparation, the sternal region was separated from the belly by an incision between the 4th and 5th ribs, following the line of the ribs. The umbilical cord was separated from the belly by an incision starting 4 cm essentially on the last rib, first in a straight line abdominally and then continuing head-wise along a line drawn parallel and just back to the line formed by the nipples. After dissection, LMP (Y) for each carcass was calculated according to Commission Regulation (EEC) 1249/2008 (European Union, 2008), by using the approved formula:

$$Y = 0{,}89 \times 100 \frac{\text{weight of tender loin} + \text{weight of lean meat in the shoulder, loin, ham and belly}}{\text{weight of tender loin} + \text{weight of dissected cuts}}$$

Statistical analysis

Guidance and recommendations for the statistical calculations involved were provided by Causeur et al. (2006) as well as by EU legislation [Commission Regulation (EC) 1249/2008, European Union, 2008]. Ordinary Least Squares (OLS) regression and Partial Least Squares (PLS) regression were used for the construction of formulas corresponding to Optiscan-TP. Among the equations constructed by the OLS method, the one with the best predictive performance was selected, based on the coefficient R^2, the Root Mean Square Error (RMSE) and the Root Mean Square Error of Prediction (RMSEP). Equations with the OLS method for the Optigrade-MCP device were constructed in a similar way. The one with the highest predictive performance was selected from them. For both equations, the same 10 carcasses with extreme values (outliers) were excluded. Finally, using 120 carcasses, two linear equations were chosen for the calculation of Lean Meat Percentage from fat and muscle thickness; one for Optiscan-TP (y,x_1,x_2) and one for Optigrade-MCP (y_g,x_{1g},x_{2g}). It should be noted that 120 carcasses were used for the calculation of the RMSE and 130 carcasses for the calculation of the RMSEP, since according to the European reference method all the values are included in the calculation of the RMSEP.

According to the PLS method, it was not possible to create equations with high predictive performance and with statistically significant coefficients R^2 and RMSEP. For this reason, no equation with this method was proposed.

RESULTS

The descriptive statistics of carcasses used for the construction of models (n=120, 60 females and 60 males) are shown at Table 2. The weight of the carcasses ranged between 49.4 and 103.1 kg with an average of 74.239 kg. This parameter highlights the large variation in the weights of the Greek pig carcasses. The average of the values concerning the depth of subcutaneous fat at the measuring position was 14.08 mm with limits from 7.00 to 30.80 mm. The depth of the *m. glutaeus medius* measured with the Optiscan-TP device rose in average at 66.13 mm with limits from 55.00 to 86.60 mm. The depth of the m. longissimus dorsi measured with the Optigrade-MCP device was on average of 54.51 mm and ranged from 34.00 to 73.20 mm. The percentage of lean meat resulting from the dissection of the carcasses ranged from 49.85% minimum to 68.21% maximum, with an average of 60%. The predicted percentage of lean meat with the Optiscan-TP device ranged from 50.34% minimum to 67.26% maximum, with an average of 60%. The predicted percentage of lean muscle tissue with the Optigrade-MCP device ranged from 45.73% minimum to 65.53% maximum, with average 60%.

Descriptive statistics regarding the three carcass groups according to back-fat depth at 6 cm ¾ LR are shown at Table 3. The carcasses with subcutaneous fat

Table 2. Descriptive statistics of carcasses used for model construction (n=120)

Trial Carcasses (n=120)	Mean	Standard Deviation	Maximum	Percentile 75	Median	Mode	Percentile 25	Minimum
Warm carcass weight - kg	74.239	11.166	103.800	82.150	74.250	82.600	65.125	49.400
Back-fat 6 cm 3/4 LR	14.08	3.92	30.80	15.85	13.50	12.40	11.60	7,00
Optiscan-TP Fat - mm (x_1)	14.73	4.41	26.10	17.50	14.10	12.20	11.18	5.90
Optiscan-TP Meat - mm (x_2)	66.13	5.97	86.60	69.73	67.00	55.10	62.25	55.00
Optigrade-MCP Fat - mm (x_{1g})	13.40	4.61	33.00	15.70	12.80	12.80	9.90	5.90
Optigrade-MCP Meat - mm (x_{2g})	54.51	7.51	73.20	59.55	54.60	58.80	48.98	34.00
Reference LMP %	60.00	4,03	68.21	63.33	60.47	62.49	57.20	49.85
Predicted LMP % Optiscan-TP (y)	60.00	3.50	67.26	62.52	60.55	50.34	57.58	50.34
Predicted LMP % Optigrade-MCP (y_g)	60.00	3.34	65.53	62.45	60.52	59.18	58.32	45.73

Table 3. Descriptive statistics of carcasses used according to back-fat depth at 6 cm ¾ LR

Carcasses used (n=120)					Count		Column N %	
Back-fat Depth		< 11mm			24		20,00%	
		11-17 mm			75		62,50%	
		>17 mm			21		17,50%	
		Mean	Standard Deviation	Maximum	Percentile 75	Median	Percentile 25	Minimum
Back-fat < 11 mm	Warm Carcass weight - kg	65.542	8.159	90.000	70.550	64.000	60.375	49.400
	Back-fat 6 cm 3/4 LR	9.52	1.10	10.80	10.30	9.80	8.90	7.00
	Optiscan-TP Fat - mm (x_1)	10.00	1.86	13.90	11.03	9.95	8.68	5.90
	Optiscan-TP Meat - mm (x_2)	65.67	6.67	86.60	68.95	67.30	61.58	55.10
	Optigrade-MCP Fat - mm (x_{1g})	8.88	1.70	12.80	9.90	9.05	7.85	5.90
	Optigrade-MCP Meat - mm (x_{2g})	52.13	7.13	66.40	57.45	51.40	46.10	36.20
	Reference LMP %	64.22	1.94	68.21	65.30	63.98	62.78	61.56
	Predicted LMP % Optiscan-TP (y)	63.69	1.79	67.26	65.04	63.76	62.33	60.55
	Predicted LMP % Optigrade-MCP (y_g)	63.14	1.35	65.53	64.14	63.15	62.46	59.38
Back-fat 11-17 mm	Warm Carcass weight - kg	74.673	10.315	103.800	81.750	75.300	67.050	52.600
	Back-fat 6 cm 3/4 LR	13.76	1.,66	17.00	15.30	13.60	12.40	11.00
	Optiscan-TP Fat - mm (x_1)	14.63	3.16	22.10	17.20	14.30	12.15	8.30
	Optiscan-TP Meat - mm (x_2)	66.42	5.89	76.60	70.20	67.40	62.80	55.00
	Optigrade-MCP Fat - mm (x_{1g})	12.88	2.56	19.50	14.60	12.80	11.15	7.90
	Optigrade-MCP Meat - mm (x_{2g})	55.63	7.66	73.20	50.80	55.40	50.25	41.10
	Reference LMP %	60.10	3.05	66.22	62.54	59.72	57.67	53.39
	Predicted LMP % Optiscan-TP (y)	60.12	2.38	64.16	62.07	60.53	58.14	54.68
	Predicted LMP % Optigrade-MCP (y_g)	60.44	1.87	64.82	61.79	60.46	59.35	55.36
Back-fat >17 mm	Warm Carcass weight - kg	82.629	10.308	100.100	88.700	82.600	76.600	54.100
	Back-fat 6 cm 3/4 LR	20.41	3.50	30.80	22.20	19.00	18.00	17.40
	Optiscan-TP Fat - mm (x_1)	20.48	3.66	26.10	24.20	20.40	17.60	14.10
	Optiscan-TP Meat - mm (x_2)	65.58	5.61	77.00	68.30	66.40	62.50	55.20
	Optigrade-MCP Fat - mm (x_{1g})	20.42	4.62	33.00	22.60	18.80	17.70	15.70
	Optigrade-MCP Meat - mm (x_{2g})	53.27	6.83	63.00	58.30	54.70	50.60	34.00
	Reference LMP %	54.85	2.99	60.39	56.94	55.40	52.77	49.85
	Predicted LMP % Optiscan-TP (y)	55.37	3.04	60.79	58.20	54,91	52.91	50.34
	Predicted LMP % Optigrade-MCP (y_g)	54.85	3.33	58.35	57.09	56.28	52.59	45.73

thickness <11 mm had an average weight of 65.542 kg. The measurements of the percentage of lean meat with the European reference method had an average of 64.22%, while with the Optiscan-TP device it was 63.69%, and with the Optigrade-MCP device 63.14%. The carcasses with subcutaneous fat thickness 11-17 mm had an average weight of 74.673 kg. The measurements of the percentage of lean meat with the reference method had an average of 60.10%, with the device Optiscan-TP 60.12% and with the device Optigrade-MCP 60.44%. The carcasses with subcutaneous fat thickness >17 mm had an average weight of 82.629 kg. The measurements of the percentage of lean meat with the reference method had an average of 54.85%, with the Optiscan-TP device 55.37% and with the Optigrade-MCP device 54.85%. We observe that heavy carcasses have a higher deposition of subcutaneous fat and a lower percentage of lean muscle tissue.

Descriptive statistics regarding the two carcass groups according to sex are shown at Table 4. In females, the weight of the carcasses ranged between 52.60 and 93.50 kg with an average of 73.677 kg. The measurements of the percentage of lean meat with the reference method had an average of 61.73%, with the Optiscan-TP device 61.46% and with the Optigrade-MCP device 61.42%. In males, the weight of the carcasses ranged between 49.40 and 103.80 kg with an average of 74.80 kg. The measurements of the percentage of lean meat with the reference method had an average of 58.27%, with the Optiscan-TP device 58.55% and with the Optigrade-MCP device 58.59%. We observe that the female pigs yield carcasses with a higher percentage of lean muscle tissue.

Eventually two models (formulas), one per each Optiscan-TP and Optigrade-MCP devices, were obtained for the calculation of Lean Meat Percentage from fat and muscle thickness as shown at Table 5. Figures 2 and 4 show the measurements related to the LMP, calculated either by the reference method or by using each of the two devices, Optiscan-TP and Optigrade-MCP, respectively, while Figures 3 and 5 show the relationships between the LMP and residues. In addition, Figure 6 shows the best fitted lines for Optiscan-TP and Optigrade-MCP and prediction bias.

Table 4. Descriptive statistics of carcasses used according to sex.

Carcasses used (n=120)					Count		Column N %	
Sex		Female			60		50,00%	
		Male			60		50,00%	
		Mean	Standard Deviation	Maximum	Percentile 75	Median	Percentile 25	Minimum
Female	Warm Carcass weight - kg	73.677	10.207	93.500	81.475	73.150	65.350	52.600
	Back-fat 6 cm 3/4 LR	12.50	2.71	18.40	14.40	12.40	10.50	7.00
	Optiscan-TP Fat - mm (x_1)	13.12	3.38	19.40	15.80	12.55	10.65	5.90
	Optiscan-TP Meat - mm (x_2)	67.46	5.48	86.60	70.15	68.15	64.38	55.00
	Optigrade-MCP Fat - mm (x_{1g})	11.53	3.26	19.50	14.00	11.00	9.08	5.90
	Optigrade-MCP Meat - mm (x_{2g})	55.61	7.60	73.20	60.80	54.9	50.00	41.10
	Reference LMP %	61.73	3.39	68.21	64.08	62.38	58.14	53.39
	Predicted LMP % Optiscan-TP (y)	61.46	2.69	67.26	63.48	61.56	59.40	56.48
	Predicted LMP % Optigrade-MCP (y_g)	61.42	2.34	65.53	62.98	61.87	59.86	55.36
Male	Warm Carcass weight - kg	74.802	12.110	103.800	82.600	75.250	65.125	49.400
	Back-fat 6 cm 3/4 LR	15,65	4,30	30,80	17,85	14,80	12,60	8,60
	Optiscan-TP Fat - mm (x_1)	16.34	4.75	26.10	20.18	16.05	12.58	8.70
	Optiscan-TP Meat - mm (x_2)	64.79	6.17	77.00	68.58	65.65	60.13	55.10
	Optigrade-MCP Fat - mm (x_{1g})	15.27	5.00	33.00	17.78	14.45	11.70	7.00
	Optigrade-MCP Meat - mm (x_{2g})	53.42	7.31	70.50	58.80	54.25	48.90	34.00
	Reference LMP %	58.27	3.91	65.40	61.,63	58.40	55.80	49.85
	Predicted LMP % Optiscan-TP (y)	58.55	3.63	65.30	60.98	59.36	56.01	50.34
	Predicted LMP % Optigrade-MCP (y_g)	58.59	3.60	64.14	61.12	59.38	57.01	45.73

Table 5. Models selected for Optiscan-TP and Optigrade-MCP

Model	Equation	R^2	RMSE	RMSEP n=130
Optiscan-TP	$\hat{Y} = 62,94974 - 0,79348 * x_1 + 0,13218 * x_2$	0,7524	1,99907	2,46519
Optigrade-MCP	$\hat{Y}_g = 66,55617 - 0,72337 * x_{1g} + 0,05761 * x_{2g}$	0,6866	2,24934	2,48489

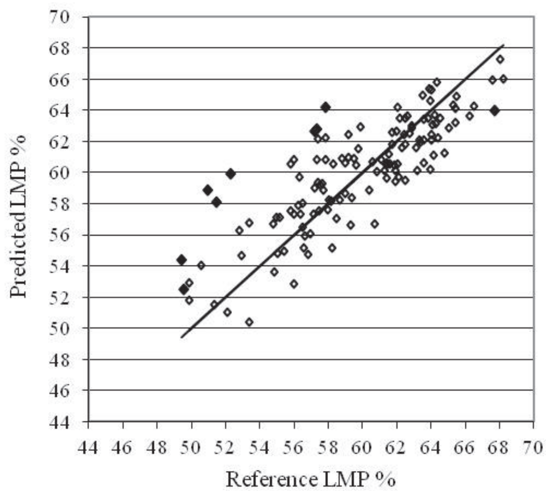


Figure 2. Relation between LMP estimated with Optiscan-TP and Reference LMP. (Black: Outliers)

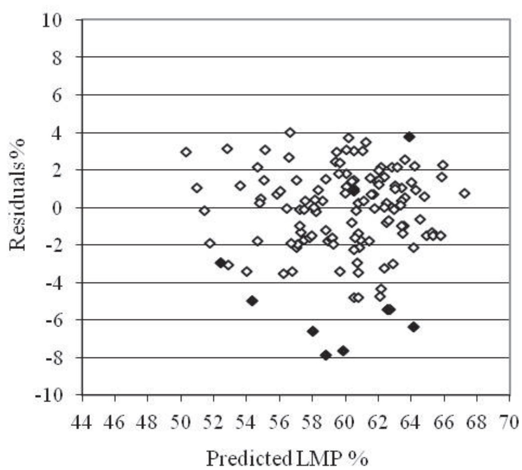


Figure 3. Relation between LMP estimated with Optiscan-TP and residuals. (Black: Outliers)

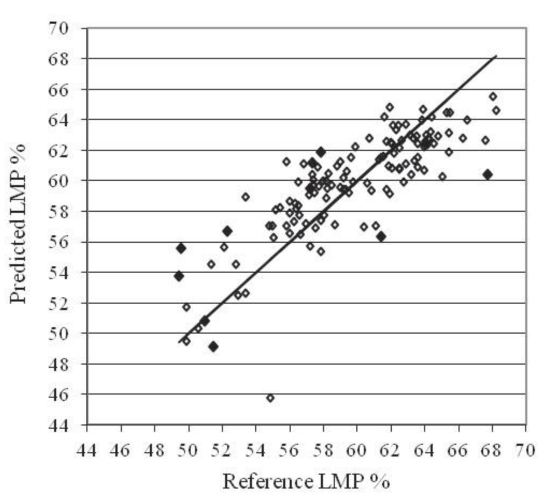


Figure 4. Relation between LMP estimated with Optigrade-MCP and Reference LMP. (Black: Outliers)

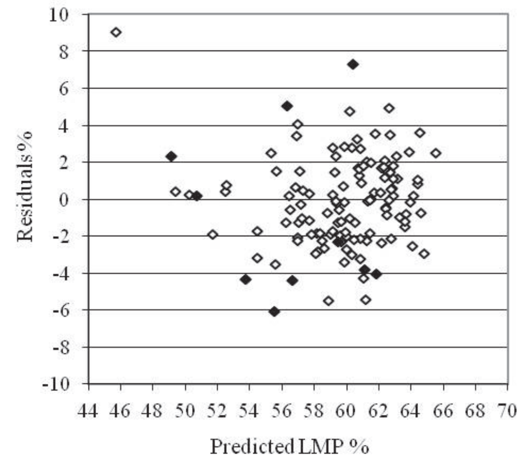


Figure 5. Relation between LMP estimated with Optigrade-MCP and residuals. (Black: Outliers)

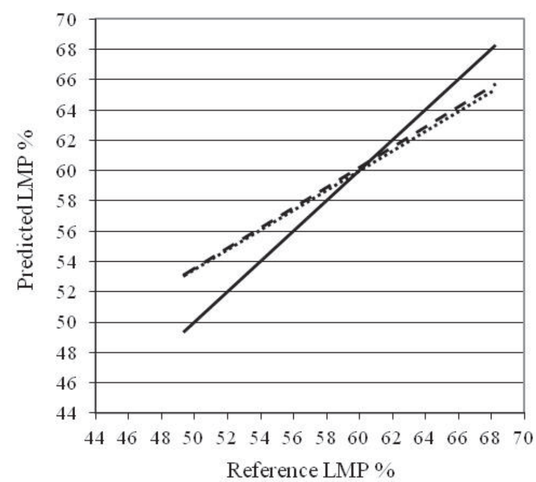


Figure 6. Best fitted lines for Optiscan-TP and Optigrade-MCP and prediction bias
(Straight line: Identity line 1:1 with X=Y / Broken Line: Optiscan-TP / Dotted Line: Optigrade-MCP).

DISCUSSION

The results of the research show that the percentage of lean meat calculated by the two methods and the use of the respective devices for the whole sample is similar to that obtained with the reference method. The coefficient of determination R^2 was statistically significant ($P<0.05$) for both methods, with the Optiscan-TP device showing a higher value. In order to compare the effectiveness of the two models, a common practice is to compare the prediction error - RMSEP - calculated for the whole set of data (n=130), including outliers (Engel et al., 2003; Font i Furnols and Gispert, 2009). For the approval of the calibration equation, it is necessary to achieve a Root Mean Square Error (RMSE) lower than 2.5% (Commission Regulation (EC) 1249/2008, European Union, 2008). The RMSEP was 2.46519 for Optiscan-TP and 2.48489 for Optigrade-MCP. Both values are below the 2.5 limit set by EU legislation. Nevertheless, both RMSEP values can be considered rather high, compared to the results of other studies (Brøndum et al., 1998; Busk et al., 1999; Font i Furnols et al., 2004; Engel et al., 2006). Font i Furmols et al. (2004), who used 262 pig carcasses in which the lean meat percentage was estimated using a Fat-O-Meter device, showed that the calculation accuracy (RMSEP) was 2.30. Lower, compared to the present study, RMSEP values (2.24 and 2.19) were observed when using HGP and Vision devices (respectively), in 180 pig carcasses weighing 71-110 kg (Engel et al., 2006). Higher accuracy (RMSEP = 1.84) appears in the research of Busk et al. (1999) for the estimation of lean meat in 344 pig carcasses weighing 71-110 kg, using Autofom device. In addition, in an earlier study (Brøndum et al., 1998) using the same ultrasound device in 450 pig carcasses, the coefficient of determination R^2 was very high (0.88). Also, higher RMSEP accuracy (1.842) was achieved in the study of Jansons et al. (2016) using an Optigrade device to estimate the lean meat percentage in 145 pig carcasses. Finally, similar accuracy to the results of the present study (RMSEP = 2.42) was determined in the research of Gaureanu et al. (2014) using an Optigrade device in 145 pig carcasses. In all the above studies the lean meat percentage and the accuracy of prediction were evaluated using different devices compared to the present study, except for the last two studies where Optigrade was used. Unfortunately, there are no reports of using the Optiscan-TP device. The higher accuracy achieved in these studies may be due to the higher number of pigs used, the lower variation of pigs' weight or even the lower percentage of extreme values included in the RMSEP calculation. In Figure 6, it is shown that best fitted lines (linear equations) are almost identical for both devices. Similar are the findings of the research of Goenaga et al. (2008) who estimated the lean meat percentage with the use of Henessy and F-O-M devices in 115 pig carcasses and found comparable accuracy of determination with the two devices. This fact suggests that factors depending on measurements (measurement fluctuations for different devices or carcass splitting) do not seem to contribute much to error of prediction. Therefore, the relatively high RMSEP values may have derived from various factors related to sample configuration or carcass dissection.

Carcass selection by means of a variable not included in the models - in our case, back-fat depth at 6 cm ¾ LR measured with HGP_4 - may result in poor predictions (Engel et al., 2003). In most cases, selection on extreme values of the prediction variables improves the accuracy of estimation of constants and coefficients in regression (Engel et al., 2006) and the difficulties in finding carcasses at the extreme values may have also contributed to low accuracy of estimation.

As with other studies (Fortin et al., 2004; Johnson et al., 2004; Goenaga et al., 2008), a bias is detected between the reference and predicted values of LMP that leads to an underestimation of predicted LMP in leaner carcasses and to an overestimation in fatter carcasses. The magnitude of the bias was 3.2% - 3.8% in LMP of carcasses at the extreme grades (69% and 49%, respectively), while within the current values of lean content the difference is much smaller. This bias is common to methods using linear measurements like back-fat and muscle thickness (Johnson et al., 2004; Goenaga, et al., 2008).

This study showed that both Optiscan-TP and Optigrade-MCP devices have similar accuracy of prediction regarding the determination of pig carcass LMP in Greece, regardless of the different measurement points and technologies used. In Greece, pig farmers are paid according to the weight of the carcass or even worse based on the live weight of the animal. Thus, pig farmers who produce pigs with a low live weight, but with a carcass of a higher quality category are not paid properly. The application of the classification of pig carcasses in quality classes using reliable methods and devices by the slaughterhouse facilities of the country, as provided by the relevant European legislation, is the necessary condition, both for the compensation of the effort of the pig farmers and for meeting the nutritional requirements of the consumers.

CONCLUSIONS

Both methods, using Optiscan-TP and Optigrade-MCP devices, to estimate the percentage of lean meat in pig carcasses exhibited similar behavior and showed reliability compared to the European reference method, as they meet both the comparison criteria and the limits set by European legislation. Further research is needed with the use of a larger number of pig carcasses, especially in the extreme values, which may contribute to the further reduction of the RMSEP and to the increase of the intended forecasting accuracy.

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CONFLICT OF INTEREST

None declared by the authors.

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