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# Estimation of lean meat percentage in pig carcass with the use of objective methods with regard to sex

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**Abstract:** In the Czech Republic, the pig carcass classification is mandatory in slaughterhouses processing over 200 pigs weekly. As breeding practices evolve to enhance lean meat yield, it is essential to update regression equations used in classification systems. This study presents new regression models for the Fat-O-Meater II (FOM II) device, using computed tomography (CT) as the reference method. Separate equations were developed for barrows, gilts, and boars to improve the accuracy of lean meat percentage (LMC) estimation. To calibrate the CT method, 24 carcasses were selected across a range of backfat thicknesses and sexes. CT scans were performed on chilled left carcass halves, followed by manual dissection to determine the true LMC. A correction model was applied to align the CT-derived LMC with dissection results. Subsequently, 128 carcasses were measured using FOM II and CT to develop sex-specific regression equations using ordinary least squares. The models revealed sex-specific differences in prediction accuracy. Gilts achieved an $R^2$ of 0.66 and RMSEP of 1.35; barrows had higher $R^2$ (0.759) and greater RMSEP (1.46); boars showed the most consistent composition ($R^2$ = 0.734, RMSEP = 1.14). Compared to the standard method, gilts and boars had slightly higher LMC (+0.03% and +0.82%), while barrows had lower LMC (–0.14%). These differences translated into economic impacts, with gains of CZK 1.23 and CZK 4.33 per gilt and boar carcass, respectively, and a loss of CZK 5.55 per barrow carcass. These results support the formulated hypotheses, and the fact that sex-specific calibration enhances classification accuracy and economic efficiency.

**Keywords:** computed tomography; Fat-O-Meater II; lean meat percentage; pig carcass; sex

Lean meat percentage is one of the goals of pig breeding. In the Czech Republic, this goal is set between 52% for the very good reproductive pig line and 64% for the Pietrain breed (Kvapilik et al. 2009). In the European Union (EU), grading of pig carcasses became mandatory in the 1980s. In the member countries, pig carcass classification at the slaughter line estimates lean meat percentage (%) using fat and muscle measurements, applying standardised prediction equations (Candek-Potokar et al. 2024). Such a classification identifies trade-relevant traits like lean meat percentage, while grading assigns the value based on market needs (Polkinghorne and Thompson 2010). Lean meat percentage and carcass weight are key pricing factors in commodity pork markets (Candek-Potokar et al. 2024). Despite

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the importance of LMC, current prediction models typically rely on general equations that do not take into consideration the sex-related differences in carcass composition (Gondekova et al. 2020).

In the Czech Republic, pig carcass classification is mandatory in slaughterhouses processing over 200 pigs weekly. Of the six approved methods, the Fat-O-Meater (FOM) from Frontmatec Denmark is the most widely used, accounting for 51% of the classified carcasses (Belkova et al. 2024). FOM is a probe-based device, while the EU standard, AutoFOM, uses non-invasive ultrasonic imaging without considering sex differences (Kvapilik et al. 2009). The accuracy of FOM devices in Czech slaughterhouses has been documented in detail (Sprysl et al. 2007).

It is well established that the nutritional and technological value of pork is closely linked to carcass composition, particularly fat percentage and fatty acid (FA) profile, which affects both human health and meat processing characteristics. Lipid composition in pigs is influenced by several factors, including diet, genetics, sex, slaughter weight or age, and overall carcass fatness (Fiego et al. 2005). However, the impact of sex on meat quality remains debated (Xia et al. 2023). Different sexes exhibit distinct growth patterns and body compositions (Lundstrom et al. 2009), which are reflected in variations in FA profiles (Candek-Potokar and Skrlep 2012). Gilts generally show higher lean meat percentage and carcass yield, while castrated males tend to grow faster and accumulate more intramuscular fat (Latorre et al. 2008; Sundrum et al. 2011). Although Xia et al. (2023) found no difference in lean meat percentage between castrates and females, Maiorano et al. (2013) reported higher LMC in gilts compared to barrows, despite similar carcass weights.

In research done by Sheikh et al. (2017), the carcass backfat of barrows was significantly thicker than that of boars and gilts. However, the loin eye area was significantly larger in gilts than in boars and barrows. Because testosterone is known to promote the muscle growth, when it is lacking like in barrows, energy is transferred to the fat tissue at a higher rate. Kozera et al. (2023) observed that while the sex had little effect on overall meat quality, it significantly influenced IMF percentage, an important trait for consumers. These findings underscore the urgent need for classification systems to adapt or to risk falling behind the realities of modern pig production. In the Czech Republic, the last calibration of carcass classification methods occurred in 2012. With ongoing genetic improvements in lean meat percentage, it became necessary to recalibrate existing systems and evaluate new technologies such as the Fat-O-Meater II.

Therefore, this study aimed to develop updated, sex-specific regression equations for the Fat-O-Meater II (FOM II) device, using computed tomography (CT) as a reference method. By addressing the limitations of existing models that overlook sex-related differences in the carcass composition, this research seeks to improve the accuracy of lean meat percentage prediction and support more equitable carcass classification. The findings are expected to contribute to more precise pricing, better alignment with breeding goals, and enhanced transparency in the pork production chain. Based on these findings, hypotheses were formulated that when you use sex as a predictor, then you will obtain more accurate regression equations for lean meat percentage in the carcasses of fattened pigs.

## MATERIAL AND METHODS

### Animals

The pig population in the Czech Republic is relatively small and homogeneous. Foreign hybridization programmes represent 70–75% of all the pigs slaughtered in the country. The most frequently used is the genetics from Denmark (DanBred and Danish Genetics – 36%), other foreign genetics are TOPIGS (17%) and PIC (16%). The remaining 25% of slaughtered pigs are the product of the National Breeding Programme (CzePig). The pigs included in the experiment were selected from the above-described populations kept in the Czech Republic.

For the creation of new regression equations, a total of 128 pigs of different sexes were included in the experiment, specifically boars ($n$ = 12), barrows ($n$ = 52), and gilts ($n$ = 64). The SEUROP system classification criteria were met by all animals. The age of slaughtering was chosen based on reaching the standard slaughter weight of pigs and based on the average age of slaughtered pigs in the EU (150–180 days). They were slaughtered at a commercial slaughterhouse following standard operational procedures. All pigs were measured using the Fat-O-Meater II™ (FOM II) (Frontmatec Group,

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Denmark) device within 45 min after slaughter. After carcass splitting at the slaughterhouse, the carcasses were chilled at 4 °C and stored until further processing. On the subsequent day, the left halves of the carcasses were transported to the CT laboratory of the Czech University of Life Sciences (CULS), Prague, and scanned. Before CT scanning, the head without the cheeks, front, and hind feet was cut off.

## Calibrations

The development of a new regression formula for the FOM II device involved a two-step process to ensure precision.

First, a Computed Tomography (CT) device was calibrated, using the Somatom Scope Power (Siemens Healthineers AG, Germany), which served as a reliable reference and replaced traditional manual dissections. This calibration established a baseline for estimating lean meat percentage. In the second step, the calibrated CT method validated FOM II measurements across a broader sample of pig carcasses from various slaughterhouses, combining CT accuracy with the practical use of FOM II in commercial settings.

The first step of the creation of a new regression formula for FOM II was calibrating the Computed Tomography (CT) device, which was subsequently used in place of laborious, manual, detailed dissections and served as a reference method (Belkova et al. 2024).

The scanning acquisition parameters were as follows: voltage, 130 kV; current intensity, 110–150 mAs; slice thickness, 3 mm; pitch, 1.15; field of view (FoV), 500 mm × 500 mm; collimation, 16 × 1.2 mm. The reconstruction algorithm B31s (i.e. low frequency) was used. CT images were segmented to obtain the number of voxels in the muscle tissue: [0,120] Hounsfield units.

The lean meat percentage obtained by CT was deduced from the volume of lean meat and the volume of the left carcass as follows:

$$LMC_{CT} = 100 \times \frac{volume\ of\ lean\ meat\ by\ CT}{left\ carcass\ volume\ by\ CT} \quad (1)$$

where:
LMC – lean meat percentage;
CT – computed tomography.

In the second step of creating a new formula for the FOM II device, the measurements of pig carcasses were performed at three slaughterhouses in order to fulfil the requirement for a representative sample.

Table 1 provides a summary of the dataset for all 128 pigs, including the descriptive statistics for each classification method.

## General formulae for FOM II

In the Czech Republic, a single regression equation is universally applied to classify pig carcasses, regardless of the animal's sex. Based on the data collected and analysed in this study, a general prediction formula for the FOM II device served as a control in our experiment. The FOM II device is a new version of the Fat-O-Meater I measurement system. FOM II consists of an optical probe with a knife, a depth measurement device having an operating distance between 0 and 125 millimetres, and a data acquisition and analysis board.

Ordinary least squares (OLS) regression was used to estimate the regression formulae for the prediction of lean meat percentage for FOM II as described by Causeur and Dhorne (2003).

Table 1. Descriptive statistics of the dataset for classification methods for all 128 pigs

| Traits | Average | SD | Minimum | Maximum |
|---|---|---|---|---|
| Hot carcass weight | 97.5 | 11.3 | 59.9 | 120 |
| Lean meat percentage by CT | 62.8 | 3.2 | 53.7 | 70.2 |
| Lean meat percentage by CT adjusted | 60.3 | 2.6 | 52.9 | 66.3 |
| Backfat thickness FOM II | 13.8 | 3.0 | 8.2 | 23.7 |
| Muscle depth FOM II | 62.4 | 7.0 | 47.5 | 79.5 |
| Lean meat percentage by FOM II | 60.3 | 2.3 | 52.5 | 65.4 |

CT = computed tomography; FOM II = Fat-O-Meater II

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The root mean square error of prediction (RMSEP) was calculated by the leave-one-out full cross-validation method.

$$LMC_{FOM2} = 65.731\,83 - 0.752\,25 \times BF_{FOM2} + + 0.079\,57 \times MD_{FOM2} \quad (2)$$

$R^2$ = 0.736; RMSEP = 1.376

where:

$LMC_{FOM2}$ – lean meat percentage (%);

$BF_{FOM2}$ – backfat thickness (including the skin) between the second and the third rib from the last rib, 65 mm from the dorsal midline perpendicularly to the skin (mm);

$MD_{FOM2}$ – muscle depth between the second and the third rib from the last rib, 65 mm from the dorsal midline perpendicularly to the carcass (mm).

## RESULTS

### Prediction of specific formulae for FOM II

For more accurate measurements, we created regression equations for each group of pigs based on their sex:

*(i)* Gilts

Compared to the general regression model, the female-specific equation yielded a slightly lower coefficient of determination ($R^2$), with a reduction of 0.076. This indicates that the model for gilts accounts for a slightly lower variation in lean meat percentage than the general model. However, the root mean square error of prediction (RMSEP) was also lower by 0.027, indicating a slight improvement in predictive accuracy. These findings suggest that while the model fit was slightly reduced, the precision of prediction for female carcasses improved.

(*ii*) Barrows

The barrows equation shows a slight yet measurable increase in the coefficient of determination ($R^2$), at 0.023 8, compared to gilts. This incremental rise suggests an improvement in the explanatory power of the model, enabling a more precise quantification of variance within the dataset. The higher $R^2$ value indicates a better fit, suggesting that the regression model captures a greater proportion of systematic variation in the observed data while reducing the residual error. Consequently, the improved model provides a more robust framework for predictive analysis, reinforcing its statistical reliability and applicability in quantitative assessments.

(*iii*) Boars

In our experiment, we analysed twelve boars and developed a new parameter, and a revised equation to predict lean meat percentage was created.

Upon analysis, we observed that the coefficient of determination ($R^2$) for boars was slightly lower compared to the general equation. Specifically, the $R^2$ value for the total dataset was 0.736, while for boars it was marginally lower at 0.734. This indicates a very slight decrease in the predictive accuracy for boars. Additionally, we found that the RMSEP for the revised equation was lower than that of the original equation. The RMSEP for the original equation was 1.375 8, whereas the revised equation showed an improved RMSEP of 1.136 1 for boars. This reduction in RMSEP suggests that the revised equation provides a more accurate prediction of lean meat percentage, particularly for boars. Overall, the revised equation demonstrates a slight improvement in prediction accuracy, as evidenced by the lower RMSEP values, despite the minimal decrease in $R^2$ for boars.

### Comparison of new price calculations

As shown in Table 2, the new equations have led to variations in lean meat percentage across all three groups. We found a lower lean meat percentage in barrows, while gilts and boars exhibited a higher lean meat percentage. The differences in %LM from the standard calculation are presented in Table 2. The difference in %LM is 0.033 for gilts, the difference for boars is 0.819, and the %LM for barrows was calculated to be lower than the standard, with a difference of –0.136, highlighted in red in the table.

Currently, in the Czech Republic, the price for a carcass (class E, 56 %LM) is around CZK 45, which is the average price. Using a simple calculation:

$$\text{CZK per 1 \%LM} = 45/56 = 0.804 \text{ CZK} \quad (3)$$

we get that the cost of 1% of the lean meat content in the Czech Republic is CZK 0.804. Based on this,

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Table 2. Comparison of new price calculations using the new equations

| Gender | $N$ = 128 | Kg in car- -cass | Differences %LM between standard – new equation[1] | CZK/ 1% LM[2] | Differences in CZK/1 %LM[3] | Cost of pig per kg per day | Differences CZK per pig using the stan- dard – new equation[4] |
|---|---|---|---|---|---|---|---|
| Barrows | 52 | 5 276 | –0.169 | 0.804 | –0.136 | 51.7 | –5.55 |
| Gilts | 64 | 6 029 | 0.033 | 0.804 | 0.026 | 51.5 | 1.23 |
| Boars | 12 | 848 | 0.819 | 0.804 | 0.659 | 50.9 | 4.33 |
| | – | **94.2 kg/pcs** | – | – | **old cost** | **51.5** | – |

[1]Differences in lean meat percentage using the standard vs new equation; [2]Cost of one lean meat percentage in Czech crowns; [3]Differences in the price of one lean meat percentage using the new equation; [4]Differences in the price per carcass comparing the new equation against the standard equation
LM = lean meat

we calculated the cost implications of our differences. The cost difference is CZK 0.026 for gilts, while it is CZK 0.659 for boars, and the cost difference for castrated males was measured to be a loss of CZK –0.136. Finally, we calculated the difference using the monetisation equation per carcass in CZK. By applying our classification equation, we would gain an additional CZK 1.23 per gilt carcass and CZK 4.33 per boar carcass. However, for castrated males, we would incur a loss of CZK 5.55 per carcass.

## DISCUSSION

This study aimed to improve the accuracy of lean meat percentage (LMC) prediction in pig carcasses by developing updated regression equations for the Fat-O-Meater II (FOM II) device, using computed tomography (CT) as a reference. While the general model remains suitable for routine use, the sex-specific equations, particularly for gilts and boars, showed improved precision. These findings align with Rombouts et al. (2025), who enhanced FOM II accuracy through parameter transformation and the inclusion of carcass traits such as sex and weight. Together, these approaches highlight the value of refining prediction models to reflect biological variation and evolving carcass profiles.

The results are consistent with previous research highlighting the biological differences between sexes in terms of carcass traits. Studies by Latorre et al. (2003a,b) and Gaureanu et al. (2014) consistently reported higher backfat thickness and carcass weights in barrows compared to gilts, which typically exhibit leaner profiles. These physiological differences are influenced by hormonal factors (Sheikh et al. 2017) and are reflected in growth patterns and fat deposition (Lundstrom et al. 2009; Maiorano et al. 2013). Despite some conflicting findings in a study by Xia et al. (2023), the overall trend supports the need for more tailored classification approaches.

The economic analysis further supports the relevance of sex-specific models. When applying the new equations, gilts and boars showed slight increases in predicted lean meat percentage (LMC), resulting in financial gains of CZK 1.23 and CZK 4.33 per carcass, respectively. In contrast, barrows showed a decrease in predicted LMC, leading to a loss of CZK 5.55 per carcass. Although these differences are modest, they highlight the potential economic impact of more accurate classification systems. These findings align with broader market observations by Utnik-Banas et al. (2022), who emphasised the importance of understanding price variability and its drivers such as production cycles and seasonal fluctuations in shaping the pork market dynamics across the European Union.

While the general model remains suitable for routine classification, sex-specific equations may offer an added value, particularly in systems where pricing is closely tied to the carcass composition. These findings align with broader trends in pig production, where genetic progress and improved management practices continue to influence carcass traits.

## CONCLUSION

Our study demonstrates that incorporating the sex of the animal as a key variable improves the pre-

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diction of lean meat percentage by considering gender differences. We observed that castrated males achieved a higher coefficient of determination ($R^2$) compared to gilts and boars, indicating better predictive accuracy. Specifically, gilts showed an RMSEP of about 1.35, barrows around 1.46, and boars the lowest RMSEP, making the model the most accurate for boars, then gilts, and finally barrows. The updated regression equations also led to measurable differences in lean meat percentage, detailed in Table 2. Economically, the new monetization equations would yield an additional CZK 1.23 per gilt carcass and CZK 4.33 per boar carcass but it would result in a loss of CZK 5.55 per castrated male carcass. These findings underscore the importance of using sex-specific models for enhanced accuracy and improved cost efficiency in predicting the lean meat percentage. The formulated hypotheses can be confirmed by these findings. Future research should validate these models on larger datasets and explore the integration of additional predictors, such as carcass weight or fat distribution, to further enhance the classification accuracy.

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## Conflict of interest

The authors declare no conflict of interest.

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