Intramuscular fat content in different muscles, locations, weights and genotype-sexes and its prediction in live pigs with computed tomography

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Short title Intramuscular fat by muscle, weight & genotype-sex

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Abstract

Intramuscular (IMF) fat content depends on sex, genotype and diet, and varies with pig growth. The aim of the present work was to determine the evolution of IMF by genotype-sex, muscle, and muscle location, to determine relationships between IMF content of different muscles and to predict IMF in live pigs with computed tomography (CT). For this purpose, 155 pigs of seven combinations of genotype-sex were CT scanned and slaughtered at 70, 100 and 120 kg. From the carcasses fat thickness was measured at several locations along the midline. Loin samples from 3 anatomical positions (between the 8th and 9th last ribs, between the the 3rd and 4th last ribs, and between the 3rd and 4th *lumbar vertebrae*) and three ham muscles (*biceps femoris, semimembranous* and *gluteus medius*) were extracted, weighed and IMF was determined with near-infrared equipment. From CT images the distribution of volume by Hounsfield value (unit related with the density) was obtained for each muscle and anatomical location. Marbling was evaluated in the three loin locations. The effects of genotype-sex and live weight and their interaction were included in the statistical model. For prediction of IMF with CT images, partial least square regression was used. The results show differences in IMF content by genotype-sex and muscle. In general, the most cranial part of the loin presented higher IMF content, as well as the *biceps femoris* muscle of the ham. Depending on the genotype-sex, IMF content increased during all growth or increased until 100 kg and then became constant. Correlation coefficients between IMF content by muscle/location were between 0.74 and 0.83 within loin locations and between 0.53 and 0.70 for ham muscles. Correlation coefficients between marbling and IMF content evaluated at the same location varied between 0.51

and 0.66. Prediction of IMF content from CT images is not accurate enough (residual predictive deviation statistical values lower than 1.3). Muscle weight increase with animal growth and allometric coefficients varied between 0.89 and 0.97 for the muscles evaluated. The conclusions of the present work are that IMF content differs between and within muscle, during growth and by genotype-sex and that prediction of IMF in CT images of live pigs is not accurate.

Keywords

swine; marbling; loin; ham; growth

Implications

Intramuscular fat content is related to the eating quality of the meat and it is an important characteristic to improve meat quality. To know the pattern of muscle growth and deposition of intramuscular fat by genotype, sex and weight is important for breeding companies, producers and the meat industry to choose the best slaughter time to obtain the desired product regarding this characteristic. This work presents the intramuscular fat content and muscle weight by genotype-sex, muscle, muscle location and weight of the pig.

Introduction

Intramuscular fat (IMF) is an adipose tissue deposited within the lean tissue. Some previous works showed that its content depends on the breed or genotype (Plastow *et al.*, 2005, Tyra *et al.*, 2013), sex (Gispert *et al.*, 2010,

Jeong *et al.*, 2012, Škrlep *et al.*, 2012), diet (Huang *et al.*, 2008, Cordero *et al.*, 2010, Lambe *et al.*, 2013) and age/weight (Bosch *et al.*, 2012, Tyra *et al.*, 2013). However, some of these factors have not had a clear effect in other works; for instance, Jeong *et al.* (2012) did not find an effect of the diet and weight and Lambe *et al.* (2013) did not find an effect of weight. Additionally, there are differences in IMF content depending on the exact muscle (Lambe *et al.*, 2013, Tyra *et al.*, 2013) and within the same muscle (Faucitano *et al.*, 2004). Furthermore, some works show a relationship between IMF and meat palatability and eating quality and on consumers' acceptability (Brewer *et al.*, 2001, Font-i-Furnols *et al.*, 2012) although this has not been confirmed in other works (Channon *et al.*, 2004, Moeller *et al.*, 2010). Because of the inconsistency in previous findings, it is important to increase knowledge about the growth of IMF tissue and its content depending on the muscle, genotype, sex and weight of the animals.

The knowledge about IMF content in live pigs is important mainly for breeding and nutritional purposes, and several technologies mainly based on ultrasound have been evaluated in live pigs and in carcasses with variable results (Newcom *et al.*, 2002, Lakshmanan *et al.*, 2012, Kvam and Kongsro, 2017). Computed tomography (CT) is a non-invasive technology based on X-rays used for breeding purposes. X-ray pass through the object and are attenuated in different degree depending on the density of the tissues they cross by and, this attenuation, is measured in Hounsfield units (HU). Lean has positive HU values from 0 to +140 and fat has negative HU values from 0 to -149 approximately (Font-i-Furnols *et al.*, 2015), although the limits can change between works. As far as the authors know, only two works have studied the possibility of using CT to estimate IMF

content in live pigs, those from Kongsro and Gjerlaug-Enger (2013) that concluded that CT is not feasible for this purpose, and those from Lambe *et al.* (2013) that concluded that CT has a great potential to determine IMF in live pigs. Thus, further work is needed to evaluate the feasibility of CT to predict IMF in live pigs. The aim of the present work was to determine the patterns of IMF by genotype-sex, muscle and muscle location, to evaluate relationships between IMF content of different muscles and to predict IMF in live pigs with CT.

Materials and Methods

Animals

A total of 182 pigs were used that came from two experiments. Pigs were from seven combinations of genotype and sex: Pietrain × (Landrace × Large White) gilts (PL-F), Landrace × Large White gilts (LL-F), Duroc × (Landrace × Large White) gilts (DL-F), Pietrain × (Landrace × Duroc) gilts (PD-F), Pietrain × (Landrace x Duroc) entire males (PD-M), Pietrain × (Landrace × Duroc) surgically castrated males (PD-C) and Pietrain × (Landrace × Duroc) immunocastrated males (PD-I) (2 vaccines, one at 12 weeks and the other one at 18 weeks of age) (Carabús *et al.*, 2015). There were no parental relationships within the breeds, except for PD-F, PD-M, PD-C and PD-I. Pigs were managed a standard way, fed a commercial diet *ad libitum* (Supplementary Material S1) and when they reach the desired live target body weight (TBW) they were CT scanned and, the same day after the scan, they were slaughtered. No withdrawal period was necessary because meat from pigs was not used for consumption. A total of 27 pigs (4–5 per genotype-sex, except

PD-I because at 30 kg immunocastration was not performed yet and they were the same as PD-M) were slaughtered at 30 kg (TBW), 31 pigs (4–5 per genotype-sex) were slaughtered at 70 kg TBW, 32 pigs (4–5 per genotype-sex) at 100 kg TBW and 92 pigs (11–16 per genotype-sex) at 120 kg (TBW) (Table 1). Slaughter was performed at the experimental abattoir at IRTA Monells following standard commercial procedures and after stunning with CO_2.

Computed tomography scanning and image analysis

Before slaughter live pigs of 70, 100 and 120 kg TBW were scanned with the General Electric HiSpeed Zx/I CT equipment placed at IRTA-CENTA (Monells). Scanning conditions were 140 kV, 145 mA, axials 1 s, 10 mm thick (Font-i-Furnols *et al.*, 2015). Before scanning pigs were anaesthetized by intramuscular injection of azaperone at 0.1 mg/kg and ketamine at 0.2 mg/kg, or intravenous injection of propofol at 0.2 mg/kg only at 100 and 120 kg TBW.

For the image analysis an in-house program of the software Matlab (Matlab Version 7.5.0.342 (R2007b) © The MathWorks, Inc.) was used. A region of interest (ROI) was selected for each of the studied muscles and/or locations (Figure 1). Three ROI's were studied for the *longissimus* muscle in three images, one between the 3rd and 4th *lumbar vertebrae,* one between the 3rd and 4th last ribs and one between the 8th and 9th last ribs. Furthermore, from two images of the ham that allow to visualize the 3 muscles of interest, 3 different ROI's were performed; one image at the joint between the femur and the pubis bones for the muscle *gluteus medius* (GM), and one image in the middle of the femur for the muscles *semimembranosus* (SM) and *biceps femoris* (BF). For each ROI (n=923), the volume associated with each HU value was obtained by

means of the thickness of the image, the matrix size and the displayed field of view (Font i Furnols *et al.*, 2009) and its distribution was used for further analysis.

Carcass measures, muscle sampling and intramuscular fat analysis

After slaughter fat thickness (plus skin) of the 70, 100 and 120 kg TBW pigs was measured perpendicularly to the skin with a ruler on the midline at three different levels of the loin (between the 3rd and 4th *lumbar vertebrae*—LD34LV, between the 3rd and 4th last ribs—LD34LR and between the 8th and 9th last ribs—LD89LR). Moreover, the minimum backfat and skin thickness over the GM muscle was also measured in the ham region.

Between 24 and 48 h after slaughter, the *longissimus* muscle and SM, GM and BF muscles of the ham were removed by trained butchers and weighed. Three samples of 4 cm thickness were obtained at different levels of the loin (LD34LV, LD34LR and LD89LR), minced, homogenized and a subsample of approximately 200 g was used for IMF analysis. IMF was also determined in the muscles SM, GM and BF from the ham using a subsample of approximately 200 g obtained from mincing and homogenizing all the muscle. In the three loin samples, marbling was measured by two trained technicians according to the National Pork Producers Council (NPPC, 1999) scale (from 1=very low IMF to 10=high IMF). Intramuscular fat of all of the muscles was determined using near infrared FoodScan equipment (Foss Analytical, Denmark). IMF for the 30 kg TBW pigs was not considered because the measures were not reliable.

Statistical analysis

Statistical analyses were performed with SAS software (version 9.3; SAS Institute Inc., Cary, NC, USA). The MEAN procedure was used to obtain mean and standard deviation values and the CORR procedure to determine Pearson's correlation between different variables. The analysis of variance was performed with the General Linear Model (GLM) procedure to determine the effect of the different factors on the IMF content. The model included genotype-sex, muscle and TBW as fixed effects. All of the double interactions and the triple interaction were added to the model. However, the triple interaction and the double interaction between muscle and TBW were removed because they were not significant (Supplementary Material S2). The GLM procedure was also used to determine the effect of the genotype-sex on the muscle weight. In this case, the model included the genotype-sex and the TBW as well as their interaction as fixed effects. To avoid the effect of differences in carcass weight within TBW, the difference between the average left carcass weight (within TBW) and the individual left carcass weight was included as a covariate (Supplementary Material S2). In all of the cases, significant differences between least square means were obtained after applying a Tukey test ($P<0.05$).

A prediction equation was obtained by partial least square regression (PLS) to predict the IMF content from the CT images of live pigs. Prediction was performed considering all of the muscles together and the muscles of the loin and the muscles of the ham separately. For this purpose, the PLS procedure was used and the volumes associated with the HU values of the ROIs were used as predictors. The smallest number of factors was selected to provide an error not significantly different ($P>0.1$) from the minimum error as suggested by

SAS. The root mean square error of prediction was calculated by cross-validation leave-one-out ($RMSEP_{CV}$) following a modified version of the macro developed by Causeur *et al.* (2003) (see Supplementary Material S2). Additionally, to evaluate the predictive ability of the model, the residual predictive deviation statistics (RPD) was calculated as the standard deviation divided by the $RMSEP_{CV}$.

Results

Intramuscular fat content by genotype-sex, live weight and muscle

The averaged IMF content by muscle/location, genotype-sex and TBW is presented in Table 2. In the loin, it is possible to see that the mean IMF content at the LD34LR location varied between 1.02% (PL-F at 70 kg) and 2.22% (DL-F at 100 kg), at the LD34VL location the mean IMF content varied between 0.98% (PD-M at 70 kg) and 2.42% (DL-F at 100 kg), and at the LD89LR location the mean IMF content was higher in general and ranged between 1.34% (PD-F at 100 kg) and 3.76% (DL-F at 100 kg). Regarding the ham muscles, SM presented mean IMF values between 1.11% (PD-M at 70 kg) and 2.60% (DL-F at 100 kg), BF between 1.31% (PD-M at 70 kg), and 2.73% (DL-F at 100 kg), and GM presented in general the lowest mean values of IMF, which varied between 1.10% (PD-M at 70 kg) and 2.27% (DL-F at 100 kg).

When the analysis of variance was performed for IMF content, a significant interaction was found between genotype-sex and muscle ($P<0.0001$) and between genotype-sex and live TBW ($P=0.0144$). The least squared means of

these interactions are shown in Table 3. It is possible to see that the highest IMF content was found in the LD89LR in DL-F, LL-F and PL-F, while in the other genotype-sexes this was not significantly different from those of BF and SM (and also GM in PD-M). Loin at location LD34LR presented the lowest IMF content in all of the genotype-sexes, although in some of them it was not significantly different from other locations. PD-C did not present significant differences in IMF content by TBW. However, for PD-F, PD-I, PD-M and PL-F, IMF content was increasing with the live weight of the animal. For DL-F pigs, IMF content was significantly higher in 100 and 120 kg than in 70 kg live weight and in LL-F, IMF was higher in 120 kg than in 100 kg live weight, being in between at 70 kg live weight. In fact, according to Table 2, were the raw mean and SD are presented, in LL-F, this occurred numerically with all of the muscles except BF and GM.

Relationship between intramuscular fat content and marbling by muscle

Correlations of IMF content by muscle/location are presented in Table 4, with all of the correlations being significant (P<0.0001). The highest correlations were between IMF content at different locations of the loin (0.74 to 0.83). Correlations of IMF content between loin locations and ham muscles (0.53–0.70) were similar to those between ham muscles (0.63–0.67), being the lowest between LD34LR and SM (0.56) and between LD34LR and BF (0.53) and the highest between LD89LR and GM (0.70). The correlations by target body weight are presented in Supplementary Table S1 and Supplementary Table S2. These tables show that the correlations were lower in 70 kg live weight pigs than in

100 and 120 kg live weight pigs, maybe because the amount of IMF is lower at this weight for most of the genotype-sexes studied.

When correlations between marbling and IMF content are considered (Table 5) it is possible to see that the highest correlations were between marbling scores in the loin and IMF of the loin. The correlations between marbling and IMF in the same loin locations were between 0.51 and 0.66. As expected, the correlations were lower between marbling in the loin and IMF in the ham muscles. Correlations between subcutaneous fat thickness at the three loin locations and at the ham with IMF content are also presented in Table 5. Although significant (P<0.0001), the correlations are moderate, since except for those of IMF in GM muscle, all are lower than 0.50. Correlations of IMF in GM and the different subcutaneous fat thicknesses were between 0.52 and 0.54, being the highest between GM and subcutaneous fat thickness of the ham, which makes sense since it was measured over the GM muscle. These correlations for each target body weight are presented in Supplementary Table S3 to Supplementary Table S5. It is possible to see that in general, the highest correlations were found for 100 kg live weight pigs.

Prediction of intramuscular fat content with computed tomography

Prediction of IMF from CT images of live pigs had a RMSEP of 0.56–0.66, which according to a mean of 1.79–1.78% implies a coefficient of variation of 31-37%. The prediction when all of the muscles are considered together (RPD=1.09, R^2=0.17) is worse than those when only loin muscles are considered (RPD=1.28, R^2=0.42). The worst prediction is when only ham

muscles are considered in the calculations (RPD= 1.03, R^2= 0.07). Nevertheless, in all the cases RPD was much lower than 3, which is the recommended value for a suitable prediction model (Williams, 2001) (Table 6). In fact, the coefficient of determination was also very low, except for when only loin muscles were considered. The accuracy of the prediction was almost the same when only the Hounsfield values with variance importance for projection (VIP) higher than 0.8 were considered as predictors (results not shown) and, because of that, only the results of prediction using Hounsfield values between −50 and −120 are presented.

Muscles' weight by genotype-sex and target body weight

Muscle growth with the live weight of the pig by genotype-sex is presented in Figure 2. In general, LL-F and DL-F genotypes-sex presented a lower weight of all the studied muscles than the other genotype-sex studied, especially at higher body weights. This difference can be seen also at early weights and it is maintained throughout growth. This is only a tendency in the muscle GM because no significant differences among genotypes-sexes can be seen in this muscle. The highest weights of the muscles were usually by the PD-F genotype-sex, although in most of the muscles/locations, not significantly different than those from the other genotype lines with Pietrain. The average allometric coefficient of the total muscle weight with respect to the live weight of the pig was 0.97 for the loin, 0.89 for SM, 0.95 for BF and 0.92 for GM, although there were some differences between genotypes-sex, with DL-F, LL-F and PL-F having the lowest allometric coefficients (results not shown).

Discussion

Intramuscular fat content varied between muscles (Table 3). Furthermore, within some muscles, such as *longissimus dorsi*, IMF also varied depending on its anatomical position. In this work, we confirmed what was presented by Faucitano *et al.* (2004) for *longissimus* muscle. The IMF content was higher between the 8th and 9th last ribs, then it decreased at the level of the 3rd–4th last ribs and then it increased again, between the 3rd and 4th *lumbar vertebrae.* Thus, IMF content was much higher at the most cranial part of the loin (8th–9th last ribs). Regarding IMF in three ham muscles, there were also some differences and, in general, BF presented the highest IMF values. Lambe *et al.* (2013) found higher levels of IMF in SM muscle compared with LT muscle at the last rib level (1.79 vs 1.18%, respectively), which is in agreement with the present results, but Tyra *et al.* (2013) found the opposite, high IMF levels in LT (at the last rib level) compared to SM (1.95 *vs.* 1.76%).

Intramuscular fat content for all of the muscles was higher in PD-C compared with PD-F, PD-I and PD-M, indicating a higher IMF content for castrated pigs, in accordance with Faucitano *et al.* (2004), Gispert *et al.* (2010) and Jeong *et al.* (2012), among others. Furthermore, IMF content depended on the genotype, with crosses with Duroc higher (DL-F) than those from Landrace-Large White crosses (LL-F) and crosses with Pietrain (PL-F). This is in accordance with the results found by Plastow *et al.* (2005) and Gil *et al.* (2008) studying pure breeds. Pietrain are animals with high muscularity (Plastow *et al.*, 2005, Gispert *et al.*, 2010) and from very lean breed. This high muscularity is related with a low IMF content (Hocquette *et al.*, 2010).

For most of the genotype-sex groups (PD-F, PD-I, PD-M and PL-F) the IMF increased with the growth of the pig, indicating that the highest IMF content is reached at 120 kg, with a content significantly higher than that found at 70 kg (Table 3). These results are in agreement with those found by Bosch *et al.* (2012) when pigs of 95, 113 and 105 kg were studied. A tendency can also be seen for PD-C but not significant differences between weights and, for DL-F, at 100 kg the IMF stops increasing. Bosch *et al.* (2012) did not find significant differences in the IMF content of (Yorkshire × Landrace) × Duroc gilts and barrows at 110, 125 and 138 kg. Thus, for these genotype-sexes, the early development of IMF would avoid the necessity of increasing the weight of the pig to increase its IMF content in all of the muscles. However, there was an opposite finding for LL-F, and the difference in IMF is very important ($P<0.05$) between 100 and 120 kg. Lambe *et al.* (2013) for Pietrain × (Landrace × Large White) intact male pigs fed different diets found no important differences in IMF content in pigs after 60 kg of weight, since the average IMF content was 1.14, 1.12 and 1.18% for pigs of 60, 85 and 115 kg, respectively. Thus, in general, in the present study, the higher the weight (up to 120 kg) the higher the IMF content with some exceptions. In this sense, it is important to know the genotype-sex of the pigs to optimize the IMF content of the final product and to decide the optimal slaughter moment to obtain the desired product.

Since the IMF content is related to the tenderness and juiciness of the meat (Enfält *et al.*, 1997, Heyer and Lebret, 2007, Font-i-Furnols *et al.*, 2012), it is important to know the differences in this content between genotypes-sex and within muscles, because this can help in understanding the eating characteristics of the meat used for consumption. Even though there are

variations between and within muscles in the IMF content, correlations of IMF content within the same muscle (*longissimus*) are high (0.74–0.83) (Table 4). Correlations between muscles of the same animal were always significant and varied between 0.53 and 0.70 (Table 4). These correlations were higher when only 100 kg live weight pigs were considered and lower when only 70 kg live weight pigs were taken into account (Supplementary Table S1). This result may indicate that the knowledge of the IMF content of one muscle can be related to the other muscles, since when it increases, it increases for all of the muscles; nevertheless, the relationship is not perfect and it would be difficult to estimate the IMF content of one muscle from those of other muscles.

The correlation between marbling evaluated according to the NPPC scale and IMF content is higher for the *longissimus* than for the muscles of the ham. This is probably because the NPPC scale was measured in the *longissimus* muscle and, consequently, the similarities are higher. These correlations were always positive and significant, indicating the higher the IMF, the higher the marbling. Nevertheless, the correlation is not perfect, varying from 0.51 to 0.66 in the loin and between 0.33 and 0.50 in the ham muscles. These correlations are lower than those reported by Font-i-Furnols *et al*. (2012), which was 0.89, even in 100 kg live weight animals that presented the highest correlations (Supplementary Tables S3 to S5).

The weight of the *longissimus* muscle was the highest followed by BF, SM and GM (Figure 2), but logically all of the muscles increase in weight when an animal grows. Except for the GM muscle, differences in weight for the same muscle between genotype-sex can be seen at 30 kg TBW and this became more important at 120 kg, where differences are greater. Crosses that do not

include Pietrain (LL-F and LL-F) presented in general a lower weight of the muscles, especially at higher TBW. This is in agreement with the work of Fisher *et al.* (2003) and Carabús *et al.* (2014) where the ham muscles of several genetic types were studied. This makes sense since Pietrain is a highly conformed breed, whose carcasses have higher ham weight, ham lean content and loin lean content, although not loin weight (Gispert *et al.*, 2007). Thus, the most adequate genotype-sex depends on the desired final product. Fisher *et al.* (2003) predicted ham muscle weights for carcasses of approximately 25 kg and 75 kg. For 25 kg carcasses, which would represent 31 kg live weight, the average weight of the muscles SM (367 g) and GM (239 g) are similar to those found in the present project (367 g and 239 g, respectively). In 75 kg carcasses, which would represent approximately 93 kg live weight, the average weight of the muscles SM (833 g) and GM (617 g) are similar to those of 70 kg of the present work (844 g and 616 g, respectively). Thus, it seems that the growth of these muscles, at higher weights, is higher in the present work, probably due to differences in the genotypes used. Moreover, the allometric coefficients for ham (0.89-0.95) and loin (0.97) muscle weight with respect to the live weight of the pig were close to one in agreement with previous works that reported allometric coefficients between 0.87 and 1.13 for ham muscle and 1.01 and 1.03 for loin muscle (Carabús *et al.*, 2014, Carabús *et al.*, 2017).

The estimation of IMF content in live pigs is very important to optimize the slaughter moment of the pig to yield the final desired product. However, this prediction in live pigs by means of CT, in the conditions of this experiment, was not accurate enough and had an unacceptable error (Table 6). This result is in accordance with those reported by Kongsro and Gjerlaug-Enger (2013) who

386 concluded that CT is not a feasible method for prediction of IMF from live pigs.
387 This is probably due to the respiratory movement of the pig and to the size of
388 the voxel that is probably too big because the displayed field of view has to
389 cover all of the body of the pig and, since the IMF is small, it might have many
390 partial volume effect that makes it difficult to identify the IMF. These two
391 reasons can explain why, although still not good, the prediction of IMF in loins is
392 somewhat better (Font-i-Furnols *et al.*, 2013), since there is no breath
393 movement and the displayed field of view can be adjusted to the loin area.
394 Furthermore, the prediction of IMF is better when only loin muscles images are
395 considered in the analysis compared with those of ham muscles. This is
396 probably because for loin muscles, the sample analysed for IMF is almost the
397 same as those analysed in CT images. However, for ham muscles, the whole
398 muscle was minced and the IMF determined, while only one image of the
399 muscle was analysed to predict IMF content. However, Lambe *et al.* (2013)
400 predicted IMF from CT images using the average muscle density as a predictor.
401 The error of prediction was not provided, but the correlation between this
402 density and the chemical IMF was found to be around −0.44 for 60 kg pigs,
403 −0.63 for 85 kg pigs and −0.70 for 115 kg pigs. Thus, these correlations indicate
404 that CT can predict IMF, but the error is probably quite high, especially in pigs of
405 lower weight. In the present project the correlation between averaged
406 Hounsfield value of the ROI of each muscle and IMF content was 0.12 (0.16 at
407 70 kg, 0.24 at 100 kg and 0.15 at 120 kg) and, because of that, this approach
408 for IMF prediction has not been considered.

409 In the conditions of the present experiment, it can be concluded that the IMF
410 content differs between and within muscle, during growth and by genotype-sex.

To optimize the final product for IMF content and amount of muscle it is important to know the growth of these tissues with the growth of the pig. Nevertheless, this is difficult to obtain from live pigs by means of computed tomography since the prediction of this parameter is not accurate enough.

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Declaration of interest

The authors have no conflicts of interest.

Ethics statement

The IRTA's ethical committee approved the protocol.

Software and data repository resources

The data are not deposited in an official repository.

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Table 1 *Number of pigs scanned, slaughtered and sampled (muscle weight and intramuscular fat-IMF) by genotype-sex and target body weight (TBW), total number of muscles evaluated by genotype-sex and mean live weight and warm carcass weight by TBW.*

	TBW				
Genotype-sex[3]	30 kg[1]	70 kg	100 kg	120 kg	Total[2]
PD-C	4	4	4	12	120
PD-F	4	4	4	12	120
PD-I[4]	-	4	4	12	120
PD-M	4	4	5	11	120
DL-F	5	5	5	16	156
LL-F	5	5	5	15	150
PL-F	5	5	5	14	144
TBW (kg)[5]	30.6±1.83	69.15±8.10	100.8±2.87	120.9±6.5	
Carcass weight (kg)[5]	23.4±1.60	56.5±2.23	81.8±2.52	98.4±2.85	

[1]: At 30 kg only the weight of the muscles was measured.

[2]: Total numbers of samples evaluated for IMF considering that for each genotype-sex and TBW, 6 different muscles/locations were analysed.

[3]: PD-C: Pietrain × (Landrace × Duroc) surgically castrated males; PD-F: Pietrain × (Landrace × Duroc) gilts; PD-I: Pietrain × (Landrace × Duroc) immunocastrated males; PD-M: Pietrain × (Landrace x Duroc) entire males; DL-F: Duroc × (Landrace × Large White) gilts; LL-F: Landrace × Large White gilts; PL-F: Pietrain × (Landrace × Large White) gilts.

[4]: At 30 kg, the immunocastrated pigs were entire male pigs.

[5]: Mean ± SD

551 **Table 2** *Mean and standard deviation (in italics) of the intramuscular fat content*

552 *(%) by pig genotype-sex (G-S), muscle/location[1] and target body weight (TBW).*

G-S[2]	TBW	LD89LR	LD34LR	LD34VL	SM	BF	GM
	70	1.95±*0.74*	1.35±*0.27*	1.44±*0.18*	1.83±*0.54*	1.98±*0.36*	1.51±*0.16*
PD-C	100	1.84±*0.52*	1.53±*0.50*	1.75±*0.52*	2.08±*0.46*	2.30±*0.50*	1.70±*0.52*
	120	2.31±*0.81*	1.40±*0.42*	1.58±*0.43*	1.69±*0.54*	2.14±*0.39*	1.68±*0.35*
	70	1.58±*0.65*	1.03±*0.12*	1.15±*0.06*	1.35±*0.19*	1.39±*0.33*	1.22±*0.09*
PD-F	100	1.34±*0.41*	1.04±*0.34*	1.12±*0.32*	1.78±*0.50*	1.93±*0.51*	1.23±*0.15*
	120	1.79±*0.61*	1.10±*0.26*	1.22±*0.27*	1.75±*0.35*	2.07±*0.51*	1.43±*0.25*
	70	1.43±*0.17*	1.03±*0.20*	1.08±*0.16*	1.20±*0.15*	1.36±*0.25*	1.13±*0.24*
PD-I	100	1.75±*0.48*	1.11±*0.23*	1.28±*0.36*	1.33±*0.24*	1.76±*0.39*	1.28±*0.32*
	120	1.86±*0.76*	1.22±*0.46*	1.42±*0.56*	1.61±*0.28*	1.95±*0.41*	1.53±*0.34*
	70	1.36±*0.67*	1.09±*0.47*	0.98±*0.34*	1.11±*0.32*	1.31±*0.35*	1.10±*0.35*
PD-M	100	1.53±*0.49*	1.04±*0.34*	1.10±*0.28*	1.43±*0.32*	1.47±*0.21*	1.33±*0.32*
	120	1.68±*0.50*	1.08±*0.26*	1.19±*0.22*	1.62±*0.39*	1.91±*0.48*	1.43±*0.41*
	70	3.27±*0.13*	2.20±*0.13*	1.88±*0.36*	1.30±*0.36*	1.72±*0.51*	1.34±*0.18*
DL-F	100	3.76±*1.20*	2.22±*0.97*	2.42±*0.95*	2.60±*0.51*	2.73±*0.57*	2.27±*0.96*
	120	3.41±*1.01*	2.09±*0.74*	2.38±*0.72*	2.37±*0.75*	2.49±*0.73*	2.20±*0.55*
	70	2.49±*0.82*	1.59±*0.56*	1.70±*0.12*	1.91±*0.72*	1.78±*0.39*	1.41±*0.41*
LL-F	100	2.46±*0.51*	1.48±*0.65*	1.27±*0.61*	1.55±*0.47*	2.00±*0.13*	1.57±*0.92*
	120	2.66±*0.64*	1.54±*0.42*	1.77±*0.48*	2.14±*0.40*	2.14±*0.62*	1.95±*0.43*
	70	2.12±*0.54*	1.02±*0.20*	1.47±*0.25*	1.27±*0.35*	1.53±*0.77*	1.17±*0.42*
PL-F	100	2.19±*0.98*	1.35±*0.30*	1.51±*0.47*	1.72±*0.38*	1.92±*0.81*	1.72±*0.29*
	120	2.91±*0.76*	1.34±*0.64*	1.60±*0.42*	1.76±*0.51*	1.87±*0.61*	1.84±*0.49*

553 [1] LD34LR: between the 3rd and 4th last ribs; LD34VL: between the 3rd and 4th lumbar *vertebrae*;

554 LD89LR: between the 8th and 9th last ribs; BF: *Biceps femoris*; GM: *Gluteus medius*; SM:

555 *Semimembranosus*

[2] PD-C: Pietrain × (Landrace × Duroc) surgically castrated males; PD-F: Pietrain × (Landrace × Duroc) gilts; PD-I: Pietrain × (Landrace × Duroc) immunocastrated males; PD-M: Pietrain × (Landrace x Duroc) entire males; DL-F: Duroc × (Landrace × Large White) gilts; LL-F: Landrace × Large White gilts; PL-F: Pietrain × (Landrace × Large White) gilts.

560 **Table 3** *Least square means of intramuscular content (%) for the interaction*

561 *between muscle or target body weight (TBW) with pig genotype-sex (RMSE =*

562 *0.52%)*[+]*.*

	Genotype-sex						
	PD-C	PD-F	PD-I	PD-M	DL-F	LL-F	PL-F
Muscle (genotype-sex x muscle, *P*<0.0001)							
LD89LR	2.14[a]	1.60[ab]	1.68[ab]	1.52[a]	3.40[a]	2.51[a]	2.52[a]
LD34LR	1.41[b]	1.02[c]	1.09[c]	1.02[c]	2.08[b]	1.46[c]	1.20[c]
LD34VL	1.58[b]	1.13[c]	1.25[c]	1.06[bc]	2.24[b]	1.59[bc]	1.48[bc]
SM	1.79[ab]	1.62[ab]	1.39[abc]	1.41[a]	2.16[b]	1.92[b]	1.58[bc]
BF	2.13[a]	1.85[a]	1.72[a]	1.62[a]	2.34[b]	1.96[b]	1.73[b]
GM	1.64[b]	1.29[bc]	1.32[bc]	1.28[abc]	1.99[b]	1.69[bc]	1.60[bc]
TBW (genotype-sex x TBW, *P*=0.0144)							
70 kg	1.68	1.29[b]	1.20[b]	1.16[b]	1.95[b]	1.81[ab]	1.43[b]
100 kg	1.86	1.41[ab]	1.42[ab]	1.32[ab]	2.67[a]	1.72[b]	1.74[ab]
120 kg	1.80	1.56[a]	1.60[a]	1.48[a]	2.49[a]	2.03[a]	1.89[a]

[+]Different superscripts within genotype-sex indicate significant differences (*P*<0.05) between muscle or between TBW

LD34LR: between the 3rd and 4th last ribs; LD34VL: between the 3rd and 4th lumbar *vertebrae*; LD89LR: between the 8th and 9th last ribs; BF: *Biceps femoris*; GM: *Gluteus medius*; SM: *Semimembranosus*

PL-F: Pietrain x (Landrace x Large White) gilts, LL-F: Landrace x Large White gilts, DL-F: Duroc x (Landrace x Large White) gilts, PD-F: Pietrain x (Landrace x Duroc) gilts, PD-M: Pietrain x (Landrace x Duroc) entire males, PD-C: Pietrain x (Landrace x Duroc) surgically castrated males, PD-I: Pietrain x (Landrace x Duroc) immunocastrated males

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566 **Table 4** *Pearson correlation coefficients between intramuscular fat content of*
567 *different muscles or anatomical positions for pigs from 70 to 120 kg live weight*
568 *(n=153–155).*

	LD34LR	LD34VL	SM	BF	GM
LD89LR	0.74	0.78	0.63	0.60	0.70
LD34LR		0.83	0.56	0.53	0.62
LD34VL			0.65	0.62	0.66
SM				0.66	0.67
BF					0.63

All the correlations have a *P*-value <0.0001

LD89LR: between the 8th and 9th last ribs; LD34LR: between the 3rd and 4th last ribs; LD34VL: between the 3rd and 4th lumbar *vertebrae*; SM: *Semimembranosus*; BF: *Biceps femoris*; GM: *Gluteus medius*.

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571 **Table 5** *Pearson correlation coefficients between marbling and subcutaneous fat*
572 *thickness with intramuscular fat (IMF) in several muscles of pigs (n=148–153)*[1]

	Marbling (NPPC[3])			Subcutaneous fat thickness (ruler)			
Muscles[2]	LD89LR	LD34LR	LD34VL	LD89LR	LD34LR	LD34VL	Ham[4]
LD89LR	0.51	0.50	0.57	0.44	0.48	0.39	0.49
LD34LR	0.62	0.58	0.60	0.37	0.35	0.28	0.37
LD34VL	0.59	0.57	0.66	0.44	0.41	0.33	0.46
SM	0.33	0.37	0.41	0.46	0.44	0.42	0.48
BF	0.44	0.38	0.43	0.46	0.47	0.40	0.43
GM	0.45	0.47	0.50	0.54	0.54	0.52	0.56

573 [1] All the correlations have a P value <0.0001

574 [2] LD34LR: between the 3rd and 4th last ribs; LD34VL: between the 3rd and 4th *lumbar*
575 *vertebrae*; LD89LR: between the 8th and 9th last ribs; BF: *Biceps femoris*; GM: *Gluteus medius*;
576 SM: *Semimembranosus*

577 [3] National Pork Producers Council (NPPC, 1999) scale from 1: very low to 10: very high

578 [4] Fat thickness over the GM muscle

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582 **Table 6** *Statistical parameters of the prediction of intramuscular fat content (%)*

583 *in pig's muscles from computed tomography images by means of partial least*

584 *square regression (PLS).*

Predictors	Factors	Mean	SD	$RMSEP_{CV}$	R^2	RPD
All the muscles						
HU −50 to +120	2	1.78	0.72	0.66	0.17	1.09
Loin muscles						
HU −50 to +120	2	1.77	0.83	0.65	0.42	1.28
Ham muscles						
HU −50 to +120	1	1.79	0.58	0.56	0.07	1.03

HU: Hounsfield values; Factors: Number of PLS factors; $RMSEP_{CV}$: Root mean square error of prediction obtained with cross-validation leave-one-out; RPD: Residual predictive deviation (s.d./$RMSEP_{CV}$)

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591 **FIGURE CAPTIONS**

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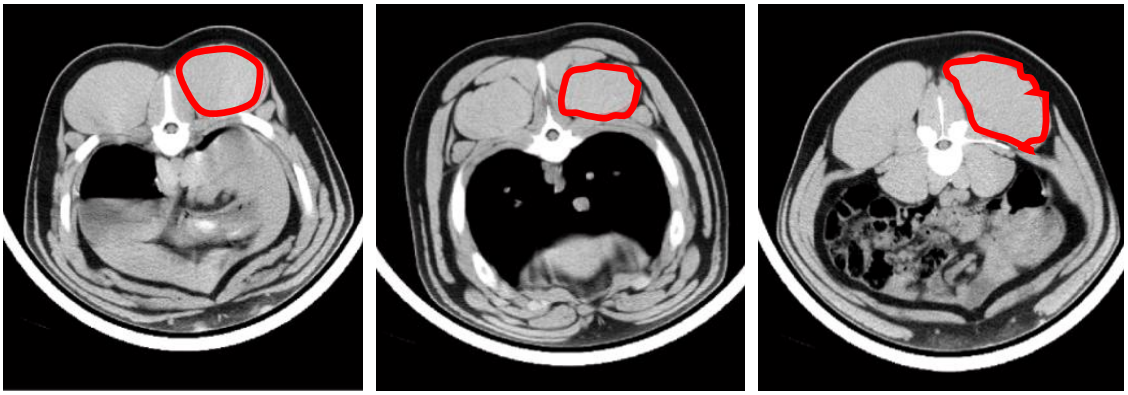
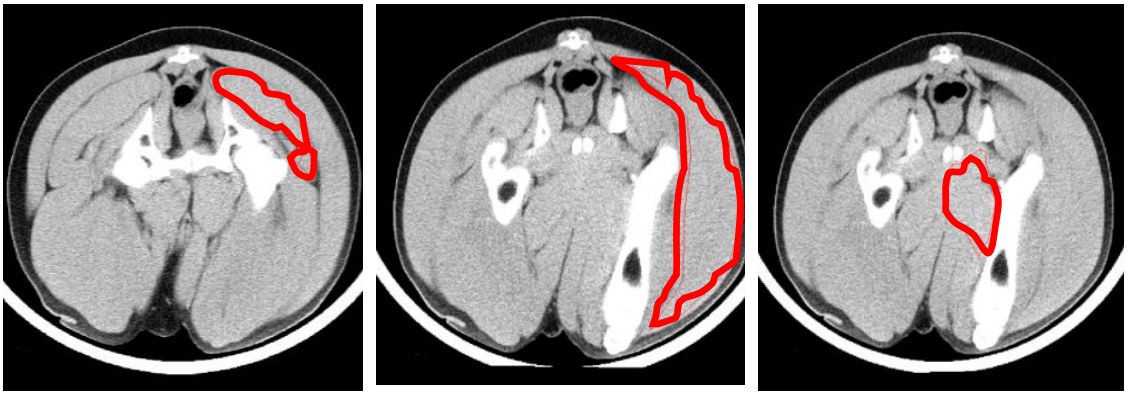


(a) LD34LR (b) LD89LR (c) LD34VL



(d) GM (e) BF (f) SM

593 **Figure 1** Region of interest of the muscles and anatomical locations evaluated
594 from computed tomography images of live pigs: (a) LD34LR, *longissimus*
595 between the 3rd and 4th last ribs, (b) LD89LR, *longissimus* between the 8th and
596 9th last ribs, (c) LD34VL, *longissimus* between the 3rd and 4th lumbar vertebra,
597 (d) GM. *gluteus medius*, (e) BF, *biceps femoris* and (f) SM, *semimembranosus*

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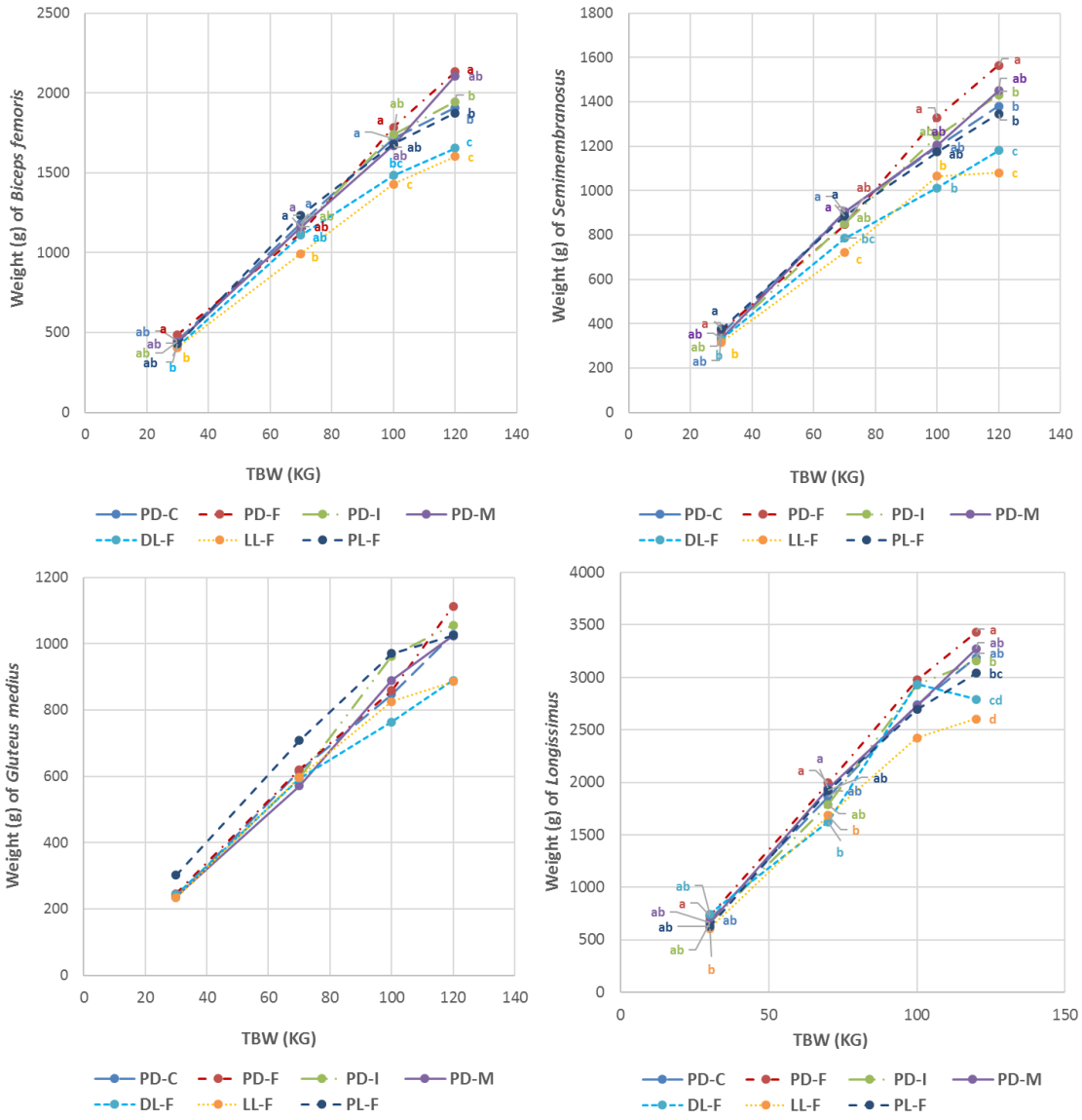

Figure 2 Trends of the weight of the muscles with the growth of the pig by genotype-sex.

Footnote: PL-F : Pietrain x (Landrace x Large White) gilts, LL-F: Landrace x Large White gilts, DL-F: Duroc x (Landrace x Large White) gilts, PD-F: Pietrain x (Landrace x Duroc) gilts, PD-M: Pietrain x (Landrace x Duroc) entire males, PD-C: Pietrain x (Landrace x Duroc) surgically castrated males, PD-I: Pietrain x (Landrace x Duroc) immunocastrated males; TBW: live target body weight