A matter of body weight and sex type: pig carcass chemical composition and pork quality

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13 **ABSTRACT**

14 This study compares minced carcass chemical composition and meat quality of castrated (CM),
15 immunocastrated (IM) and entire male (EM), and female (FE) pigs at 70, 100 and 120 kg target
16 body weights (TBW) (n=80; 20 per sex). Sex affected fat, protein, and moisture content of the
17 minced carcasses. Carcass fatty acid (FA) composition was affected by sex, with higher saturated
18 and monounsaturated FA content in CM than in FE, IM and EM, and higher polyunsaturated FA
19 in CM than in EM, with FE and IM in between. Except for intramuscular fat, which was higher
20 in CM than in FE and EM, no significant differences between sexes were found in meat quality.
21 TBW affected carcass chemical composition and some meat quality traits. An interaction between
22 sex and TBW was found with IM approaching EM or CM depending on TBW.

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24 **Keywords:** minced carcasses, fat content, fatty acids, mineral content, immunocastration

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26 **1. Introduction**

27 It is well known that nutritional and technological value of pork depend on the chemical
28 composition of the carcass, in particular its fat content and fatty acid profile, which are important
29 not only from the perspective of human health but also for meat processing and sensory properties
30 (Čandek-Potokar & Škrlep, 2012; Wood et al., 2004).

31 Focusing on the technological quality, fatty acid (FA) composition may affect the firmness of the
32 fat and the oxidative stability of the meat. The FA profile can be modified with diet (Duran-
33 Montgé et al., 2010; Pérez-Juan et al., 2010), and it is related to the level of carcass fatness as
34 well (Wood et al., 2008). Thus, differences among sex types known to differ in body and carcass
35 composition will lead to differences in the FA profile. A meta-analysis carried out by Pauly et al.
36 (2012) showed that saturated FA are lower and polyunsaturated FA are higher in entire males
37 than in castrated and immunocastrated males. Nevertheless, the changes associated to
38 immunocastration can be different depending on the fat depot (Poklukar et al., 2021). In addition,

differences in carcass chemical composition are expected to be greater at higher body weights (Arthur et al., 2011; Mörlein and Tholen, 2015).

There is a tendency in the EU to abandon surgical castration of male pigs due to animal welfare issues. Thus, if the use of this procedure is diminished or stopped and the production of entire males or immunocastrates increases, final pork quality is likely to be altered. Nevertheless, for both alternatives, published results on differences in meat quality are not always consistent (Škrlep et al., 2020). Therefore, comparative studies with the sex types available in the market, including female pigs, are essential. Since body composition changes with growth (Ruiz-Ascacibar, 2018), studying the sex effect at distinct relevant stages of the pig growth adds to understanding if the differences between sex types vary according to growth stage.

The objective of this study was to evaluate the gross chemical composition of the whole carcass and some meat quality traits (i.e. pH, electrical conductivity, colour and intramuscular fat content) of pigs from four sex types (castrated males, immunocastrated males, entire males, and females) at three target body weights (TBW) i.e. at 70, 100 and 120 kg. Productive performance and the characteristics of the carcass, main cuts and internal organs have been previously published (Zomeño et al., 2022).

2. Material and Methods

The procedures used in this research were approved by the Committee of Ethics and Animal Experimentation (CEEA) of IRTA and Generalitat de Catalunya (DAAM Protocol number 5298).

2.1. Animals and experimental design

This study was carried out with 80 pigs of the same genetic type (Pietrain × (Landrace × Duroc)) from four different sex types (ST, n=20 each): surgically castrated males (CM), immunocastrated males (IM), entire males (EM) and females (FE).

Thirty-two pigs (8 per sex) were reared in two collective pens (13.5 m^2; 5.0 m length × 2.7 m width) and slaughtered at 70 or 100 kg TBW. The remaining 48 pigs (12 per sex) were reared in

individual pens (3.0 m^2; 2.5 m length × 1.2 m width) and slaughtered at 120 kg TBW. All pens were equipped with a slatted floor surface, one drinking bowl and one free-access feeder. All the pigs were fed *ad libitum* with the same commercial diet according to a two-phase feeding programme containing 10.2 and 10.1 MJ net energy/kg, 18.0% and 17.0% CP and 0.91% and 0.90% digestible lysine, respectively. Surgical castration of male piglets was performed within the first 7 days of age. For immunocastration the vaccine Improvac® (Zoetis, Alcobendas, Spain) was administered twice: the first dose (V1) at 12 weeks of age and the second one (V2) at 18 weeks of age, at approximately 70 kg TBW. The vaccine was injected subcutaneously just behind and below the base of the ear by technical staff in accordance with the manufacturer's instructions.

When pigs reached the desired TBW, they were slaughtered: 16 pigs at 70 kg (4 CM, 4 IM, 4 EM and 4 FE), 17 pigs at 100 kg (4 CM, 4 IM, 5 EM and 4 FE), and 47 pigs at 120 kg (12 CM, 12 IM, 11 EM and 12 FE). This last TBW, 120 kg, was considered the most relevant one in this study because it is closer to the commercial slaughter weight.

2.2. Slaughtering and carcass measurements

Slaughtering was carried out following standard procedures at the IRTA-Monells slaughterhouse (located 300 m from the experimental farm) after animals were fasted for a minimum period of 8 hours. Pigs were stunned using 85% CO_2.

After evisceration and splitting of the carcass, backfat thickness (mm) was measured at the split line of the left half carcass perpendicularly to the skin using a ruler at the following sites: between the third and fourth lumbar vertebrae (Fat34LV); between the third and fourth last ribs (Fat34LR); between the eighth and nineth last rib (Fat89LR); between the fifth and sixth thoracic vertebrae (Fat56TV). Carcass lean meat percentage (LMP) was determined with Fat-O-Meat'er (FOM) II (Frontmatec A/S, Smørum, Denmark) using the Spanish official FOM equation (European Commission, 2020).

The carcasses (left and right half parts) were kept in a chilling room for approximately 24 hours at 2-3ºC and after that time they were weighted. Left half carcasses were used for meat quality

determinations (section 2.3). Afterwards, they were cut according to the European reference method (Walstra & Merkus, 1995), and the proportion of the main cuts (ham, loin, shoulder, belly, and tenderloin) with respect to carcass weight was calculated. See Zomeño et al. (2022) for a more detailed description. Right half carcasses were stored at −20°C until the mincing process and the subsequent chemical composition analysis (section 2.4).

2.3. Meat quality analysis

In all left half carcasses (n=80), the pH of the *Longissimus thoracis* (LT) muscle was determined 45 minutes after slaughter (pH 45min) and 24 hours post-mortem (pH 24h) at the level of the last rib using a portable equipment with a Xerolyt electrode (Crison, Barcelona, Spain) with the automatic temperature compensation function. The pH meter was calibrated with pH 7.0 and pH 4.0 buffers prior to measurements. At 24 hours post-mortem, electrical conductivity of the LT muscle was recorded using the Pork Quality Meter (PQM-Kombi, Aichach, Germany) at the last rib level. Colour was measured in the LT muscle, on the cross section at the level of the last rib after 15-20 minutes of blooming. A subjective colour score was obtained using the Japanese scale colour (Colour JSC: score 1–6, with 1: extremely pale to 6: extremely dark) (Nakai et al., 1975). Scores were obtained from two experienced technicians, and the mean of their two scores was recorded. An objective measurement (CIE, 2004) was performed using a Chroma-Meter 200 (Minolta Co., Ltd., Osaka, Japan) with standard illuminant D65, observation angle of 10° and an aperture of 8 mm, and determining luminosity (L*), redness (a*) and yellowness (b*) indexes.

Intramuscular fat of the LT muscle (IMF) was determined. Samples of 4-cm thickness were obtained at the level of the last rib at 24 hours post-mortem, and then they were vacuum-packed and stored at −20 °C until the analysis. Intramuscular fat percentage was determined using Near Infrared Transmittance equipment (Infratec 1265 Meat Analyzed, Tecator AB, Uppsala, Sweden) scanned in the region between 800–1000 nm, in 2 nm increments. This equipment averaged the results of 15 readings from each minced and homogenized sample of 100 g and it was calibrated to predict total muscle fat triglycerides.

2.4. Carcass chemical analysis

First, the frozen entire right half carcasses (n=80) (including bones) were reduced into small pieces using a cutting guillotine (Model D, Spain). The teeth were removed during this step. Then, the different pieces were gradually placed in an industrial mincer (Grinder Cato-pa160, Spain) and ground for three times using sieves with a smaller diameter each time. The minced sample was thoroughly homogenized in a blender. Afterwards, samples (500 g) were collected, vacuum-packed and stored at −20°C until further analysis.

In all carcasses (n=80), fat, protein, moisture, ash, Ca and P contents were determined in duplicate. The fat content was determined by solvent extraction with petroleum ether (Soxtec 2050, Tecator, Höganäs, Sweden) in a sample of around 5 g. The determination of the protein content was based on the Kjeldahl total nitrogen content using a nitrogen/protein analyser (Büchi Distillation Unit B-324 and Digester Unit B-414, Flawil, Switzerland) using a sample of 1.5 g. The moisture content was determined by sample drying in an oven at 100°C to 105°C until constant weight in a sample of approximately 10 g. The determination of the ash content was performed by heating 4 g of sample in a muffle oven at 550°C for 2 to 3 h. Finally, the Ca and P content were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES; spectrophotometer Optima 4300 DV, Perkin Elmer Inc., Wellesley, MA, USA). The sample (approximately 0.5 g) was previously mineralized in a microwave (MARSXpress, CEM, Matthews, NC, USA).

Fatty acid (FA) profile was determined in 68 carcasses: 13 from those animals slaughtered at 70 kg (3-4 per sex type), 13 from those at 100 kg (3-4 per sex type), and 42 from those at 120 kg (9-12 per sex type). Firstly, the fat extraction was performed using chloroform/methanol extraction by Folch et al. (1957) from a sample of 10 g. Then, FA methyl esters were prepared using the American Oil Chemists' Society (AOCS) Official Method Ce 2-66 and analysed in an Agilent 8860 Gas Chromatograph System (Agilent, Santa Clara, CA, United States) equipped with a split/splitless injector. The separation of FA methyl esters was performed in a HP-88 column (Ref. 112-8867, Agilent, Santa Clara, CA, United States) (60 m × 0.25 mm× 0.20 μm) and detected with a flame ionizing detector (FID) and a temperature gradient oven. For individual FA

identification a commercial reference (Supelco 37 Component FAME Mix Ref. CRM 47885, Sigma-Aldrich, Seelze, Germany) was used.

2.5. Statistical analysis

Statistical analysis was performed with SAS v. 9.4 software (SAS Institute Inc., Cary, NC, USA). Data were analysed using a generalized linear mixed model (GLIMMIX procedure) including TBW (70, 100, and 120 kg), ST (CM, IM, EM, and FE), and their interaction as fixed effects. For those variables more dependent on body weight (i.e. cold carcass weight, subcutaneous fat thicknesses, fat, protein, and moisture content of the minced carcass, and IMF content), heteroscedasticity was corrected by using the weighted least square approach (Font-i-Furnols et al., 2015). The SLICEDIFF option was used for the comparison of LSMEANS. Tukey test was used to compare the adjusted LSMEANS values at the 0.05 significance level.

Principal components analysis (PCA) was applied to obtain a multidimensional view of the studied traits' interrelationship. Therefore, the FACTOR procedure of SAS was used applying a mean and centring pre-processing. For a more global view of the characteristics of carcass and meat quality, FA percentages (%) as well as data of estimated carcass lean meat (%) and the proportion (g/kg) of the main cuts (ham, loin, shoulder, belly and tenderloin) evaluated at the same animals (Zomeño et al., 2022) were included in this analysis. A first PCA was conducted including those carcasses with all data (n=68), and a second PCA including those from animals slaughtered at 120 kg and with all data (n=42).

3. Results and discussion

3.1. Carcass composition

Results from carcass characteristics and their proximate composition are presented in Table 1 and Supplementary Figures 1 and 2. Sex had a significant effect on carcass weight and subcutaneous fat thicknesses measured at all sites, and this effect was constant across the 3 TBW since no significant TBW × ST interaction was found. Castrated males and FE presented heavier carcasses

than IM, with EM carcasses being in between (Table 1 and Supplementary Figure 1). Regarding the subcutaneous backfat, carcasses of CM and FE showed greater thicknesses than IM in the ham area (Fat34LV). In the loin area, however, CM showed higher values than IM and EM at the point between the 3rd and 4th last ribs (Fat34LR), and higher than EM between the 8th and 9th last ribs (Fat89LR) and the 5th and 6th thoracic vertebrae (Fat56TV) (Table 1 and Supplementary Figure 1). Female carcasses had intermediate fatness levels at the three anatomical locations of the loin area. The differences obtained are in line with those observed in other anatomical fat positions in the same animals (Zomeño et al., 2022) and confirm a different carcass fat deposition in IM pigs; they were more like EM in the ham area and more like CM in the loin area. These findings agree with previous studies comparing body and carcass composition of these four sexes (Fàbrega et al., 2010; Gispert et al., 2010). For some variables, especially those related to fat content, the interaction was not significant, although we expected it to be because of the inclusion of IM pigs in the trial. The lack of significance for the interaction can be due to the fact that the interaction does not exist or because of the small number of animals at 70 and 100 kg TBW. Despite this low animal number at 70 and 100 kg TBW, the outcome provided is novel and valuable.

Significant differences among sexes were observed for fat, protein and moisture content of the minced carcasses while the ash and mineral content (P and Ca) did not change (Table 1). Carcasses of CM had, overall, a higher fat content than those of FE and these, in turn, had a higher content than EM. Immunocastrated carcasses were leaner than CM and similar to FE and EM (Supplementary Figure 2). For protein content, carcasses of EM and FE had higher values than those of CM, with IM being in between (Table 1 and Supplementary Figure 2). Moisture content of carcasses from different sexes changed with TBW (TBW × ST interaction P = 0.001). In detail, EM and IM showed a higher moisture content than CM at 70 kg and 100 kg, and at 120 kg EM had the highest value, FE and IM had intermediate values, and CM the lowest value. The differences obtained for fat and moisture content across sexes are in line with the allometric growth of these components estimated by Zomeño et al. (2016) in the same four sexes. These authors did not find any difference in the allometric coefficients of protein, but Schinckel et al.

(2008) reported higher values in FE than in CM, in line with our results. Zomeño et al. (2016) obtained a similar growth for ash content between sexes, in agreement with the present results; although they estimated different allometric coefficients for Ca and P that were not corroborated in our study.

Carcass weight, subcutaneous fat thickness and fat content of minced carcasses significantly increased with increasing TBW (Table 1 and Supplementary Figures 3 and 4). On the contrary, protein, moisture, ash and P content decreased. These findings were expected and agree with the evolution of carcass composition with animal age and body weight (Arthur et al., 2011; Schinckel et al., 2008; Ruiz-Ascacibar, 2018).

Table 2 shows FA composition of minced carcasses according to TBW and ST. Significant differences among sexes were observed for all the FA groups and for several individual FA. The total content of saturated (SFA) and monounsaturated (MUFA) FA was higher in CM than in IM, EM and FE and these differences were constant across TBW (Table 2 and Supplementary Figure 5). These results were caused by the differences observed in the palmitic (C16:0) and stearic (C18:0) acid total content, and by those observed in the oleic acid (C18:1 n−9 cis), which are the most abundant individual SFA and MUFA in the pig minced carcass, respectively. Other individual SFA and MUFA were affected by the ST as well (Table 2). For instance, myristic (C14:0), margaric (C17:0), palmitoleic (C16:1), and gadoleic (C20:1) acids. In addition, the total content of polyunsaturated FA (PUFA) was higher in CM compared to EM, with IM and FE in between (Table 2 and Supplementary Figure 5). This was mainly due to the higher total content of linoleic acid (C18:2 n−6) in CM than in EM. The total content of n–6 and n–3 FA was higher in CM than in EM as well. Likewise other individual PUFA such as eicosadienoic (C20:2) and eicosatrienoic (C20:3) were affected by the ST, whereas linolenic (C18:3 n−3) and arachidonic (C20:4 n−6) acids were not altered. Finally, the PUFA/SFA ratio was lower in CM than in the other three ST, whereas the n–6/n–3 ratio was not altered. Overall, these differences are consistent with those observed for carcass fat content (Table 1) and can be explained by the fat saturation (corresponding to a higher de novo synthesis of SFA and MUFA) and a more diluted effect on

PUFA content with increasing fat content (Mauvoisin and Mounier, 2011; Wood et al., 2008). The FA composition of the minced carcass can give an overview of the global nutritional characteristics of the carcass. However, most published studies have focused on FA composition of specific porcine tissues, and there is limited information on the FA of the whole pig carcass. Moreover, to our knowledge, no studies have been published comparing the whole carcass FA content between sexes, which makes this study novel and unique. Previous investigations in the subcutaneous fat (loin area) and LT muscle reported lower SFA and higher PUFA percentages in EM than CM (Mackay et al., 2013; Pauly et al., 2012; Poklukar et al., 2021). Font-i-Furnols et al. (2012) found higher MUFA percentage in the subcutaneous fat (ham area) of FE than IM. These findings agree with our results when expressing FA as percentages, with more monounsaturated fat in CM and FE than in IM and EM (47.1% and 46.7% vs. 45.3% and 44.7%) and less polyunsaturated fat in CM than in EM, IM and FE (16.9% vs. 20.2%, 19.6% and 18.9%, respectively). Nevertheless, in our study, IM showed similar values to EM and FE for PUFA percentage and to EM for MUFA percentage, which is consistent with results of Mackay et al. (2013), but not with the other above-mentioned studies. Therefore, the discrepancies observed between studies could be explained by a different response of FA composition depending on the anatomical location of the sample analysed (e.g. subcutaneous fat vs. intramuscular fat vs. whole carcass fat). Indeed, FA profile varies according to fat tissue location (Daza et al. 2017). Recently, Poklukar et al. (2021) showed that immunocastration changed FA profile more slowly at the withers than at the last rib, and more rapidly in the LT muscle (IM were closer to CM than to EM).

Target body weight affected FA total content (Table 2 and Supplementary Figure 6). The content of SFA and MUFA was higher in pigs slaughtered at 120 kg than at 70 and 100 kg TBW. The content of PUFA, n–6 and n–3 was higher in pigs slaughtered at 100 kg and 120 kg than in pigs slaughtered at 70 kg TBW. These results are coherent with the increase in carcass fat content with increasing animal age and body weight.

When TBW and ST were considered together, SFA total content was 1.4 times higher in CM than in IM and EM at 70 kg, but at 100 kg it was 1.34 times higher than IM and 1.49 times higher than EM, and at 120 kg, 1.20 and 1.55 times higher than IM and EM, respectively (Table 2). Thus, although no significant interaction TBW × ST was found, differences in SFA content between CM and EM were similar to those between CM and IM before the second vaccination, but the difference in SFA content was higher between CM and EM than between CM and IM, indicating an increase in the saturation of fat of IM pigs after the second vaccination, and approaching those of CM in agreement with what has been published in literature (Škrlep et al., 2020). A similar pattern was found for MUFA since at 70 kg CM had 1.35 and 1.47 times higher total content than IM and EM, respectively, while at 120 kg CM had 1.25 and 1.59 times higher content than IM and EM, respectively. As expected, the opposite situation was found for PUFA because CM had 1.05, 1.17 and 1.16 times higher total content than IM at 70, 100 and 120 kg, respectively, while they had 1.17, 1.13 and 1.27 times higher total content than EM at 70, 100 and 120 kg, respectively. These findings can be associated to the differences in carcass fat content between sexes (Škrlep et al., 2020; Gispert et al., 2010).

3.2. Meat quality

Meat quality traits measured in the LT muscle are shown in Table 3. Intramuscular fat percentage was higher in CM than in FE and EM, with IM in between (Table 3 and Supplementary Figure 7). This result agrees with those observed for the subcutaneous fat thickness in the loin area (Fat89LR and Fat56TV) and the fat content of minced carcass in the present work. A significant TBW × ST interaction was found for electrical conductivity, although the differences among LS-means were not relevant in terms of technological quality. In fact, the values obtained for electrical conductivity were lower than 6, which is a common cut-off value used to classify meat as PSE (Guàrdia et al., 2004). Redness index was higher in CM than in FE, but these differences were only found at 70 kg TBW (TBW × ST interaction). Therefore, except for IMF percentage, there were no major differences observed in meat quality between sexes, which agrees with

276 literature (see meta-analyses of Pauly et al. (2012) and Trefan et al. (2013) or the review of Škrlep
277 et al. (2020)) usually reporting inconsistent results on the effect of sex on pork quality.

278 The pH value at 45 minutes and at 24 hours post-mortem was affected by the TBW, with higher
279 values in pigs of 70 kg than in pigs of 100 and 120 kg TBW group. Consistent with pH values,
280 lightness was higher at 120 kg than at 70 kg (Table 3 and Supplementary Figure 8). Higher redness
281 at 100 and 120 kg than at 70 kg can partly be related to higher luminosity and partly to higher age
282 of pigs. However, as already explained for the effect of sex, the differences in meat quality were
283 not consistent.

284 *3.3. Relationship between carcass composition and meat quality*

285 Figure 1 shows the results of the principal component analysis including all samples. The first
286 principal component (PC1) (horizontal axis) explains 30.2% and the second principal component
287 (PC2) (vertical axis) explains 17.1% (left plot) of the total variation. Fatty acids included in the
288 PCA are expressed in percentage in order to differentiate the amount of fat with its quality and
289 explore differences in the proportion of the different FA among sexes and weights. The PC1 is
290 related to carcass lean (LMP) and protein and moisture content (minced carcass) on the right side
291 (positive correlation to PC1). On the left side (negative correlation to PC1), variables related to
292 fat (minced carcass fat content, subcutaneous fat thickness, and IMF) and MUFA percentage are
293 placed. In addition, the proportions of ham, shoulder and tenderloin are placed on the right side
294 whereas those of loin and belly as well as carcass weight are on the left side (data from Zomeño
295 et al., 2022). The PC2 is mainly explained by the SFA percentage on the negative side (bottom)
296 and by the PUFA, n–6 and n–3 on the positive side (top). Considering the experimental groups,
297 EM are placed on the right side of PC1 because they are associated with higher carcass leanness
298 and protein content. However, CM are placed on the left side of PC1 because they are associated
299 with higher carcass fat content. Females and IM are in the middle part, and thus, not related to
300 any of the PCs considered because they have intermediate levels of fatness. The TBW groups are
301 separated by the PC 1 and 2. The most evident is the group slaughtered at 120 kg, which was
302 placed on the negative side of PC1; it is associated with higher carcass fatness, as expressed by

303 several variables such as fat thickness and IMF. The group slaughtered at 100 kg was positioned
304 on the positive side of PC1 and PC2, and closer to PUFA. The group slaughtered at 70 kg is placed
305 on the right side (lower part) and more related to leaner carcasses. The right plot of Figure 1 shows
306 the results when plotting the third PC (vertical axis). Although this PC explains only 8.2% of
307 variation, it clearly separates FE (placed on the negative side) from IM (placed on the positive
308 side). In this case, IM are positively related to SFA content, Ca and P content, and lighter meat
309 colour, and FE with darker meat colour, carcass MUFA content and ham proportion. Overall,
310 these results corroborate well with those obtained when the traits were analysed individually (see
311 Tables 1 and 2 of this paper).

312 Figure 2 shows the results of the PC analysis considering only the group slaughtered at 120 kg
313 TBW. In this case, PC1 is associated with PUFA and n–6 percentages that are placed on the
314 positive right and with leaner carcasses, carcass protein and moisture content, while SFA is placed
315 on the negative side close to fat variables. The PC2 explains mainly the variables related to muscle
316 colour and MUFA percentage. Males are clearly separated by PC1, with EM on the right side,
317 CM on the left one, and IM in an intermediate position although closer to CM. Females are
318 represented by the PC2.

319 Looking at the two PCA analyses, it can be seen that EM are characterised by leaner carcasses at
320 all three TBW and, in addition, by having more n–6 PUFA and greater ham, shoulder and
321 tenderloin yields at 120 kg. Castrates are characterised by fatter carcasses with more SFA and
322 greater belly and loin yields at all three TBW. Immunocastrates and FE are not separated by their
323 fat/lean content when all three TBW are included while, at 120 kg, differences among all sexes
324 are clearer. In the case of IM, this is probably explained by the change in fatness after the second
325 dose of the vaccine, since they are closer to EM until that moment, and thereafter they rapidly
326 become fatter and approach CM (Batorek et al., 2012; Poulsen Nautrup et al., 2018). While in the
327 case of FE, their fatness being intermediate between CM and EM (Gispert et al. 2010) explains
328 their position.

329

4. Conclusions

The sex of the pigs does not seem to affect technological meat quality characteristics. However, sex affects intramuscular fat, which is important for the eating quality of the meat. Moreover, pig sex and their body weight proved to be significant factors affecting the content of the main chemical constituents of the carcass, and these modifications lead to important changes of FA profile, which can affect at the subsequent processing and shelf life of the product, because the higher the SFA, like in CM, the better the processing and the lower the oxidation. While FE, CM and EM presented more consistent characteristics across the finishing body weights, IM traits changed more due to the vaccination pattern mainly in terms of carcass fatness and FA composition. Therefore, the interaction between pig sex and body weight needs to be considered when producing carcasses, cuts, or meat products with certain required characteristics. Further studies with a higher number of animals would be necessary to corroborate these findings.

Author's contribution

Cristina Zomeño: Formal analysis, writing - original draft, writing - review & editing.

Marina Gispert: Conceptualization, data curation, formal analysis, funding acquisition, investigation, writing - original draft, writing - review & editing.

Marjeta Čandek-Potokar: Formal analysis, writing - original draft, writing - review & editing.

Daniel Mörlein: Formal analysis, writing - original draft, writing - review & editing.

Maria Font-i-Furnols: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, writing - original draft, writing - review & editing.

Ethical statement

The procedures used in this research were approved by the Committee of Ethics and Animal Experimentation (CEEA) of IRTA and Generalitat de Catalunya (DAAM Protocol number 5298).

Declaration of competing interest

The authors declare no conflict of interest associated with this research.

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TABLES

Table 1. Carcass traits and chemical composition of minced carcass (LSMEANS) of pigs according to sex type (ST) and slaughtered at three target body weights (TBW)

TBW	70 kg				100 kg				120 kg				P-value			RMSE
ST	CM	IM	EM	FE	CM	IM	EM	FE	CM	IM	EM	FE	TBW	ST	TBW × ST	
Pigs (n)	*4*	*4*	*4*	*4*	*4*	*4*	*5*	*4*	*12*	*12*	*11*	*12*				
Cold carcass weight (kg)$^{\alpha v}$	56.26	53.25	56.44	57.19	80.99	78.80	81.17	81.65	96.50	94.65	94.69	96.71	<0.001	0.004	0.632	0.485
Carcass fatness (mm)																
Fat34LV$^{\beta v}$	20.75	15.00	21.00	20.25	29.75	23.50	30.25	24.40	29.25	28.25	28.83	24.82	<0.001	0.003	0.132	2.057
Fat34LR$^{\alpha w}$	13.50	10.25	12.50	12.75	21.75	16.75	15.80	15.75	23.42	21.00	18.00	19.83	<0.001	0.015	0.521	1.973
Fat89LR$^{\alpha x}$	17.25	12.75	13.00	16.75	23.50	21.25	20.20	19.25	28.33	26.33	23.09	24.67	<0.001	0.024	0.559	1.984
Fat56TV$^{\alpha x}$	22.75	21.75	21.00	23.50	30.25	26.75	26.00	25.50	34.66	31.92	27.62	31.42	<0.001	0.001	0.255	1.812
Chemical composition of minced carcasses																
Fat (g/100 g)$^{\alpha y}$	15.37	11.02	11.71	14.65	20.17	15.22	14.09	16.47	24.94	20.50	16.62	20.50	<0.001	<0.001	0.157	1.658
Protein (g/100 g)$^{\gamma z}$	18.69	18.13	19.19	18.83	17.70	18.99	18.86	18.94	17.29	17.54	18.51	18.30	<0.001	<0.001	0.168	0.869
Moisture (g/100 g)	60.42^{c}	65.53^{a}	64.03^{ab}	61.05^{bc}	57.12^{b}	61.63^{a}	63.09^{a}	60.86^{ab}	53.78^{c}	56.15^{b}	60.95^{a}	57.89^{b}	<0.001	<0.001	0.001	1.433
Ash (g/100 g)$^{\delta}$	3.34	3.21	3.38	3.41	2.90	3.31	3.27	2.92	2.96	3.08	3.18	2.90	0.014	0.258	0.644	0.346
Ca (mg/g)	9.56	8.55	9.02	9.92	9.80	9.75	7.27	8.56	7.98	9.22	7.70	7.35	0.091	0.318	0.391	1.978
P (mg/g)$^{\delta}$	6.14	5.66	5.90	6.35	5.95	6.12	4.90	5.51	5.09	5.75	5.11	4.94	0.018	0.435	0.426	0.959

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; Fat34LV = fat thickness between the 3rd and 4th lumbar vertebrae; Fat34LR = fat thickness between the 3rd and 4th last ribs; Fat89LR = fat thickness between the 8th and 9th last ribs; Fat56TV = fat thickness between the 5th and 6th thoracic vertebrae.

^{a,b,c} different superscripts within row indicate significant differences among LSMEANS of TBW×ST (P-value ≤ 0.05) (Tukey test).

$^{\alpha,\beta,\gamma,\delta}$ indicate significant differences among LSMEANS of TBW (P-value ≤ 0.05, Tukey test): $^{\alpha}$ 70 kg < 100 kg < 120 kg; $^{\beta}$ 70 kg < 100 kg ≈ 120 kg; $^{\gamma}$ 70 kg ≈ 100 kg >120 kg; $^{\delta}$ 70 kg >120 kg.

^{v,w,x,y,z} indicate significant differences among LSMEANS of ST (P-value ≤ 0.05, Tukey test): ^{v} CM ≈ FE > IM; ^{w} CM > IM ≈ EM; ^{x} CM > EM; ^{y} CM > FE > EM; ^{z} CM < EM ≈ FE.

Table 2. Carcass fatty acid composition (mg/100 g of minced carcass) (LSMEANS) of pigs according to sex type (ST) and slaughtered at three target body weights (TBW)

TBW	70 kg				100 kg				120 kg				P-value			RMSE
ST	CM	IM	EM	FE	CM	IM	EM	FE	CM	IM	EM	FE	TBW	ST	TBW × ST	
Pigs (n)	*3*	*3*	*3*	*4*	*3*	*3*	*4*	*3*	*12*	*10*	*9*	*11*				
Σ SFA$^{\alpha v}$	5625	3949	3877	5432	6774	5025	4817	5136	9308	7722	5999	6806	<0.001	<0.001	0.294	1355.2
C10:0	7	7	5	9	8	5	7	9	13	10	10	23	0.750	0.252	0.965	14.3
C12:0	10	9	6	9	11	5	11	13	16	11	11	12	<0.001	0.037	0.170	3.0
C14:0	182	125	126	171	210	161	164	180	290	225	196	222	<0.001	<0.001	0.571	40.1
C15:0	9	13	9	9	4	6	9	8	8	8	7	7	0.002	0.467	0.110	1.8
C16:0	3570	2507	2450	3376	4291	3179	3087	3295	5805	4815	3738	4313	<0.001	<0.001	0.323	794.4
C17:0	60	52	34	43	48	45	45	47	57	47	39	46	0.946	0.002	0.411	9.5
C18:0	1744	1235	1223	1783	2195	1618	1496	1565	3074	2574	1969	2134	<0.001	0.002	0.228	487.8
C20:0	23	8	15	22	17	9	8	26	48	35	28	36	<0.001	0.012	0.398	11.6
Σ MUFA$^{\alpha v}$	7030	5207	4780	6705	9220	6393	6304	7310	12335	9838	7742	9796	<0.001	<0.001	0.438	1513.6
C16:1	412	285	273	362	455	343	349	398	598	488	410	510	<0.001	<0.001	0.804	73.3
C17:1	40	37	23	31	40	33	35	39	49	37	31	41	0.024	<0.001	0.330	7.4
C18:1 n–9 cis	6431	4772	4386	6155	8556	5901	5795	6718	11431	9121	7120	9035	<0.001	<0.001	0.409	1411
C18:1 n–9 trans	39	34	26	50	37	29	27	28	48	39	31	37	0.015	0.002	0.074	8.8
C20:1	108	79	72	105	132	87	98	128	209	153	151	172	<0.001	0.005	0.883	33.9
Σ PUFA$^{\beta w}$	2497	2386	2137	2508	3582	3064	3183	3436	4079	3509	3201	3615	<0.001	0.027	0.755	462.8
C18:2 n–6 cis	2187	2121	1879	2202	3129	2696	2784	2982	3563	3081	2788	3139	<0.001	0.032	0.724	403.5
C18:3 n–3	119	118	102	122	213	177	181	190	221	190	163	187	<0.001	0.064	0.760	32.7
C20:2	107	93	90	104	128	92	106	134	170	136	142	158	<0.001	0.013	0.919	24.6
C20:3 n–9	59	44	52	61	89	77	90	96	93	76	78	98	<0.001	0.041	0.944	17.2
C20:4 n–6	14	15	11	15	24	18	21	26	32	26	27	29	<0.001	0.169	0.824	5.5
Σ n–3$^{\beta w}$	123	117	102	121	212	177	180	190	221	189	162	186	<0.001	0.047	0.811	32.39
Σ n–6$^{\beta w}$	2201	2130	1889	2217	3152	2714	2805	3007	3595	3106	2815	3168	<0.001	0.032	0.728	407.57
Σ PUFA/ Σ SFA $^{\gamma x}$	0.437	0.618	0.551	0.461	0.545	0.610	0.662	0.683	0.447	0.461	0.539	0.538	<0.001	0.006	0.052	0.076
Σ n–6/ Σ n–3$^{\delta}$	19.03	18.02	18.70	18.28	14.83	15.27	15.46	15.85	16.25	16.31	17.57	16.98	<0.001	0.455	0.994	2.108

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

[a,b,c] different superscripts within row indicate significant differences among LSMEANS of TBW×ST (P-value ≤ 0.05) (Tukey t-test); [A,B,C] P-value ≤ 0.10 (Tukey test).
[α,β,γ,δ] indicate significant differences among LSMEANS of TBW for fatty acid groups and ratios (P-value ≤ 0.05, Tukey test): [α] 70 kg ≈ 100 kg < 120 kg; [β] 70 kg < 100 kg ≈ 120 kg; [γ] 70 kg ≈ 120 kg < 100 kg; [δ] 70 kg > 100 kg ≈ 120 kg.
[v,w,x] indicate significant differences among LSMEANS of ST for fatty acid groups and ratios (P-value ≤ 0.05, Tukey test): [v] CM > IM ≈ EM ≈ FE; [w] CM > EM; [x] CM < IM ≈ EM ≈ FE.

Table 3. Meat quality traits of *Longissimus thoracis* (LSMEANS) of pigs according to sex type (ST) and slaughtered at three target body weights (TBW)

TBW	70 kg				100 kg				120 kg				P-value			RMSE
ST	CM	IM	EM	FE	CM	IM	EM	FE	CM	IM	EM	FE	TBW	ST	TBW × ST	
Pigs (n)	*4*	*4*	*4*	*4*	*4*	*4*	*5*	*4*	*12*	*12*	*11*	*12*				
pH 45min[α]	6.60	6.75	6.71	6.82	6.52	6.63	6.51	6.40	6.63	6.67	6.54	6.70	0.024	0.491	0.568	0.208
pH 24h[β]	5.63	5.82	5.66	5.71	5.59	5.58	5.56	5.59	5.60	5.54	5.58	5.54	0.002	0.822	0.352	0.128
EC 24h (mS)	3.28	3.96	3.91	4.48	3.72	3.58	4.16	4.75	4.18	3.79	4.45	3.82	0.719	0.034	0.038	0.666
Colour JSC	2.38	2.63	2.63	2.25	2.89	2.25	2.00	3.13	2.63	2.33	2.50	2.54	0.891	0.431	0.122	0.580
L* (luminosity)[γ]	47.77	47.10	48.25	47.29	47.06	49.64	49.82	47.99	48.69	49.73	49.58	49.05	0.017	0.185	0.719	1.963
a* (redness)[δ]	7.17[a]	5.74[ab]	6.62[ab]	5.31[b]	7.20	6.75	7.52	7.66	6.94	7.20	6.62	7.29	0.002	0.389	0.021	0.899
b* (yellowness)	2.02	1.52	2.13	1.69	1.55	1.92	2.63	1.85	1.77	2.13	1.74	1.63	0.782	0.469	0.495	0.862
IMF (%)[v]	1.35	1.03	1.09	1.03	1.53	1.11	1.04	1.04	1.40	1.22	1.08	1.10	0.688	0.013	0.977	0.580

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; EC = Electrical conductivity; JSC = Japanese scale of colour (1: pale, 6: extremely dark); IMF = intramuscular fat.
[a,b] different superscripts within row indicate significant differences among LSMEANS of TBW×ST (P-value ≤ 0.05) (Tukey test).
[α,β,γ,δ] indicate significant differences among LSMEANS of TBW (P-value ≤ 0.05, Tukey test): [α] 70 kg > 100 kg; [β] 70 kg > 100 kg ≈ 120 kg; [γ] 70 kg < 120 kg; [δ] 70 kg < 100 kg.
[v] indicates significant differences among LSMEANS of ST (P-value ≤ 0.05, Tukey test): CM > EM ≈ FE.

FIGURE CAPTIONS

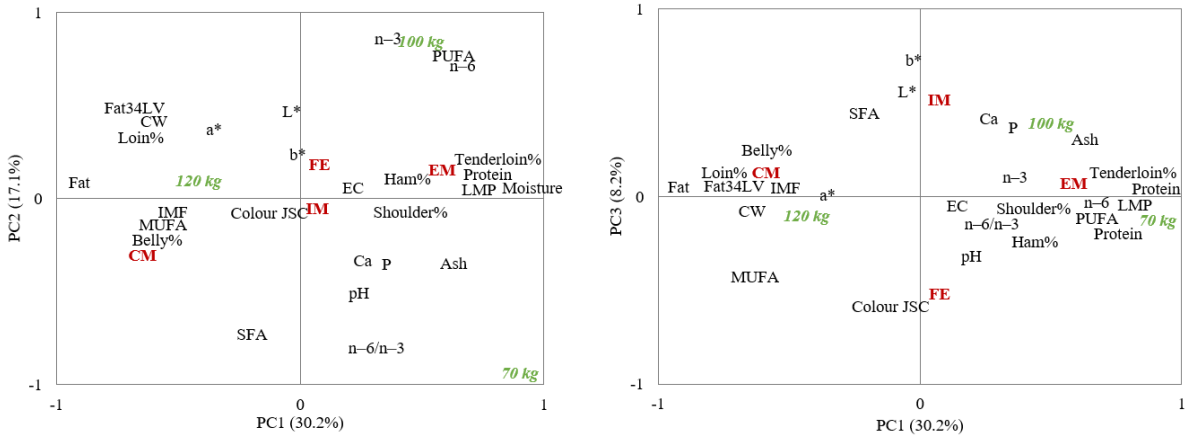
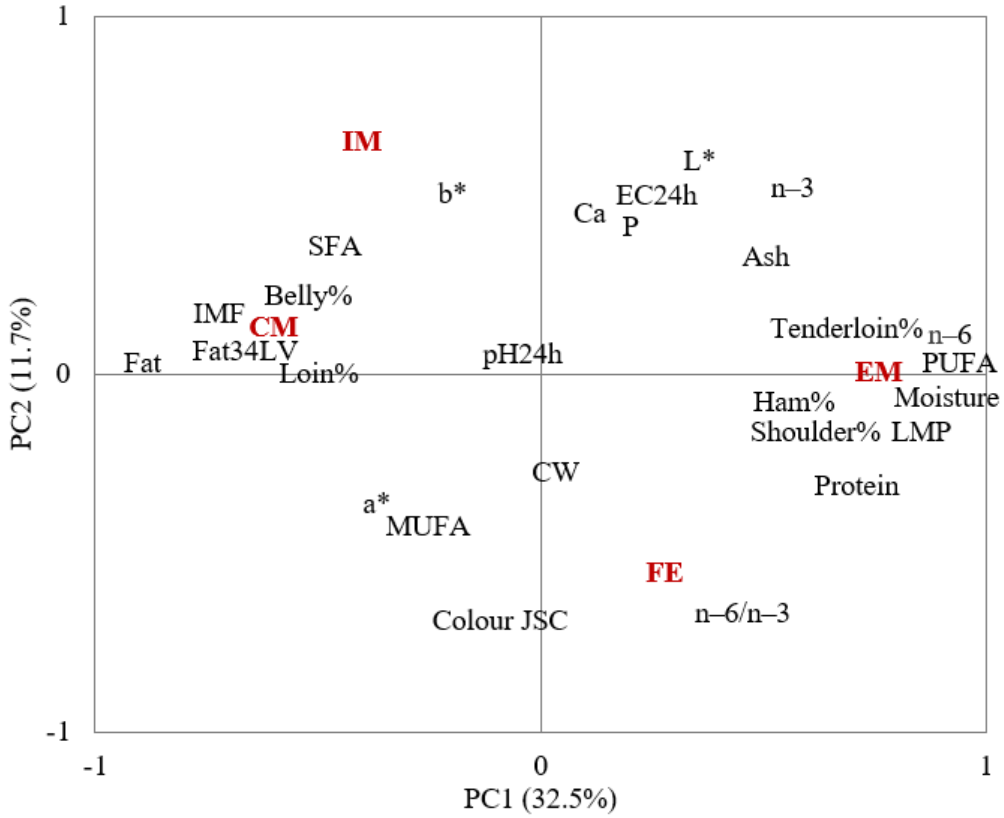


Figure 1. Principal component (PC) analysis with all carcasses (n=68): PC1 and 2 (left plot), PC1 and 3 (right plot). In brackets the variance accounted for each axis. Correlations between variables and factors (black colour) and coordinates of the experimental groups (red colour and bold letters = sex type; green colour, bold and cursive letters = target body weight). Carcass quality: CW (cold carcass weight), Fat34LV (fat thickness between the 3rd and 4th lumbar vertebrae), SFA (saturated fatty acids percentage); MUFA (monounsaturated fatty acids percentage), PUFA (polyunsaturated fatty acids percentage), LMP (estimated carcass lean percentage) and proportion of cuts with respect to CW: Ham%, Loin%, Shoulder%, Belly% and Tenderloin% (Zomeño et al., 2022). Meat quality of *Longissimus thoracis* at 24 hours *post-mortem*: pH, EC (electrical conductivity), Colour JSC (Japanese scale of colour), L*(luminosity), a*(redness), b* (yellowness), and IMF (intramuscular fat percentage). CM: surgically castrated males; IM: immunocastrated males; EM: entire males; FE: females.



503

504 **Figure 2.** Principal component (PC) analysis with carcasses from animals slaughtered at 120 kg
505 target body weight (n=42). In brackets the variance accounted for each axis. Correlations between
506 variables and factors (black colour) and coordinates of the different sex groups (red colour and
507 bold letters). Carcass quality: CW (carcass weight), Fat34LV (fat thickness between the 3rd and
508 4th lumbar vertebrae), SFA (saturated fatty acids percentage); MUFA (monounsaturated fatty
509 acids percentage), PUFA (polyunsaturated fatty acids percentage), LMP (estimated carcass lean
510 percentage) and proportion of cuts with respect to CW: Ham%, Loin%, Shoulder%, Belly% and
511 Tenderloin% (Zomeño et al., 2022). Meat quality of *Longissimus thoracis* at 24 hours post-
512 mortem: pH, EC (electrical conductivity), Colour JSC (Japanese scale of colour), L*(luminosity),
513 a*(redness), b* (yellowness), and IMF (intramuscular fat percentage). CM: surgically castrated
514 males; IM: immunocastrated males; EM: entire males; FE: females.

515

516

SUPPLEMENTARY MATERIAL OF THE ARTICLE:

A matter of body weight and sex type: pig carcass chemical composition and pork quality

BY

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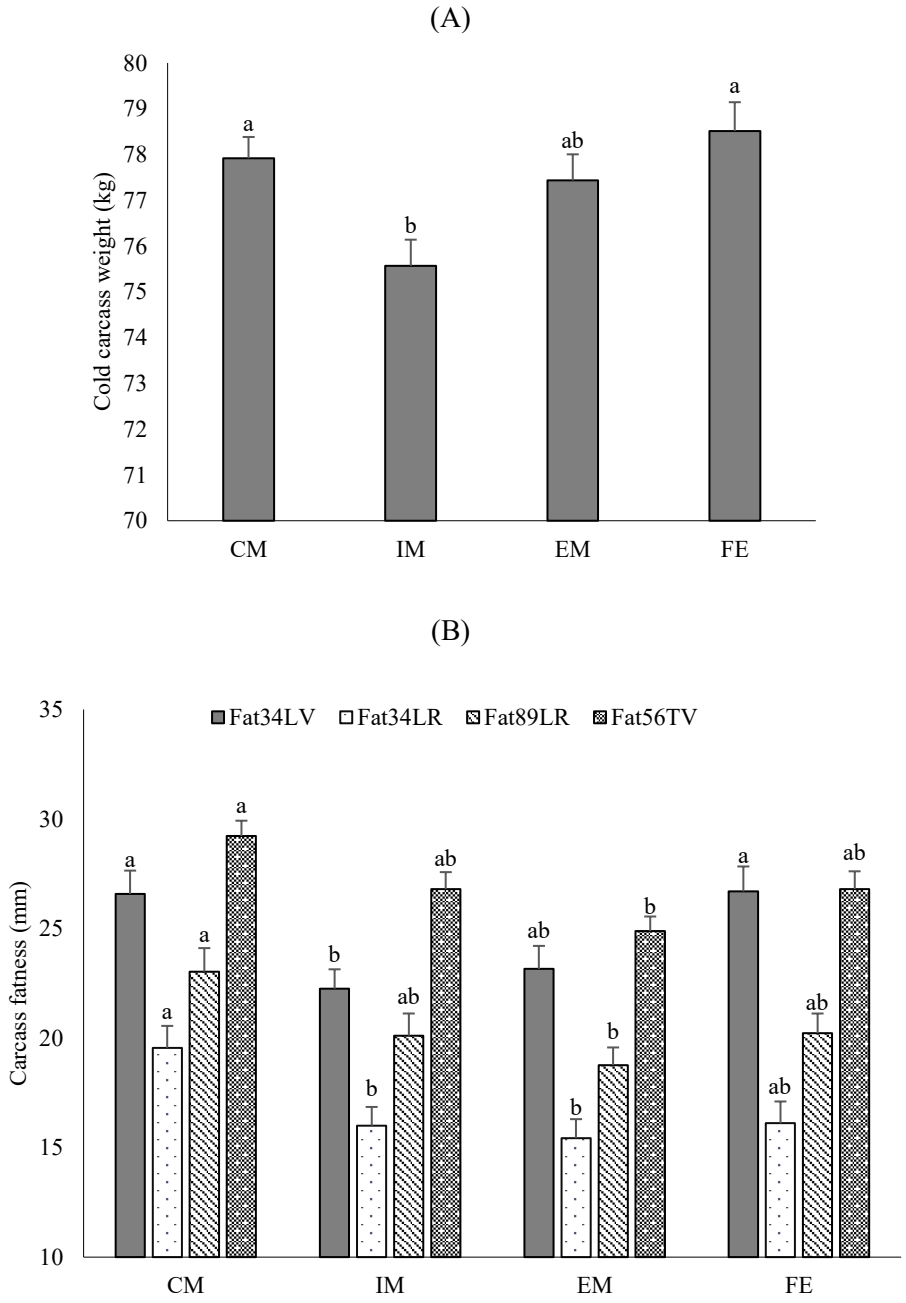
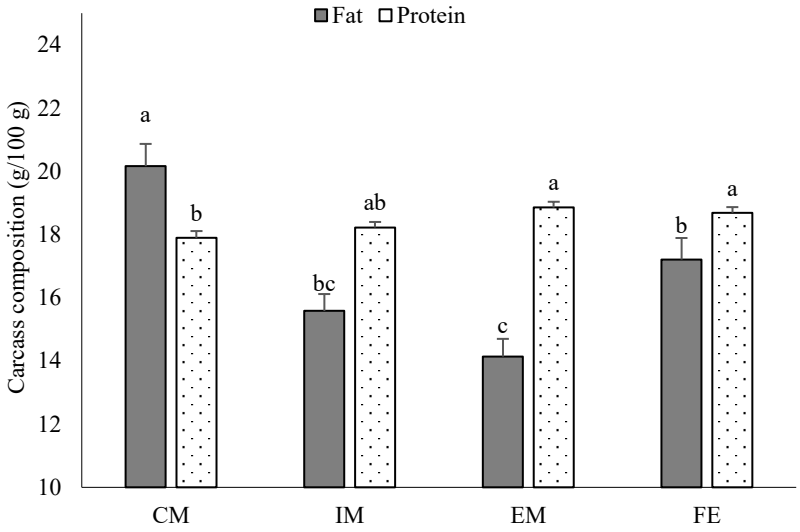
534



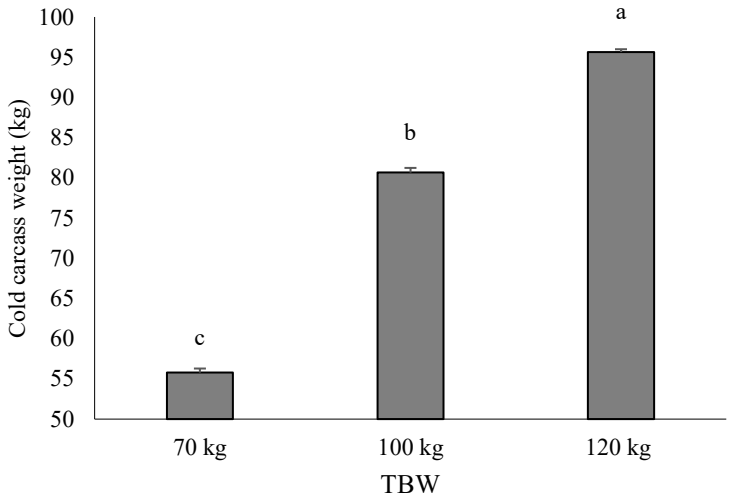
535 **Supplementary Figure 1.** (A) Cold carcass weight (kg) and (B) subcutaneous fat thickness (mm)
536 (LSMEANS and SE) according to sex type averaged for all target body weights (70, 100, and 120
537 kg). Different letters on error bars indicate significant differences between sex types (P-value ≤
538 0.05). CM: surgically castrated males; IM: immunocastrated males; EM: entire males; FE:
539 females. Fat34LV = fat thickness between the 3rd and 4th lumbar vertebrae; Fat34LR = fat
540 thickness between the 3rd and 4th last ribs; Fat89LR = fat thickness between the 8th and 9th last
541 ribs; Fat56TV = fat thickness between the 5th and 6th thoracic vertebrae.



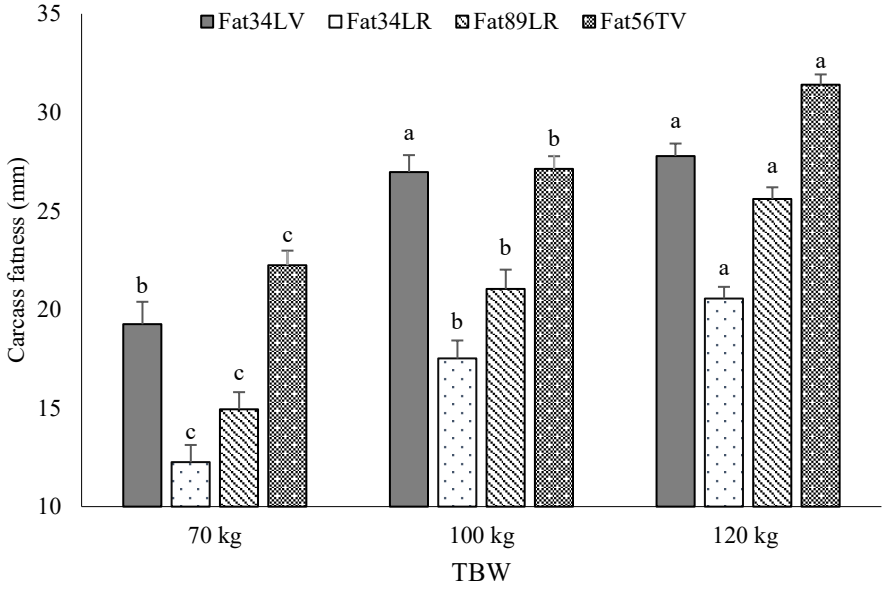
542

543 **Supplementary Figure 2.** Chemical composition of minced carcasses (g/100 g) (LSMEANS and
544 SE) according to sex type averaged for all target body weights (70, 100, and 120 kg). Different
545 letters on error bars indicate significant differences between sex types (P-value ≤ 0.05). CM:
546 surgically castrated males; IM: immunocastrated males; EM: entire males; FE: females.

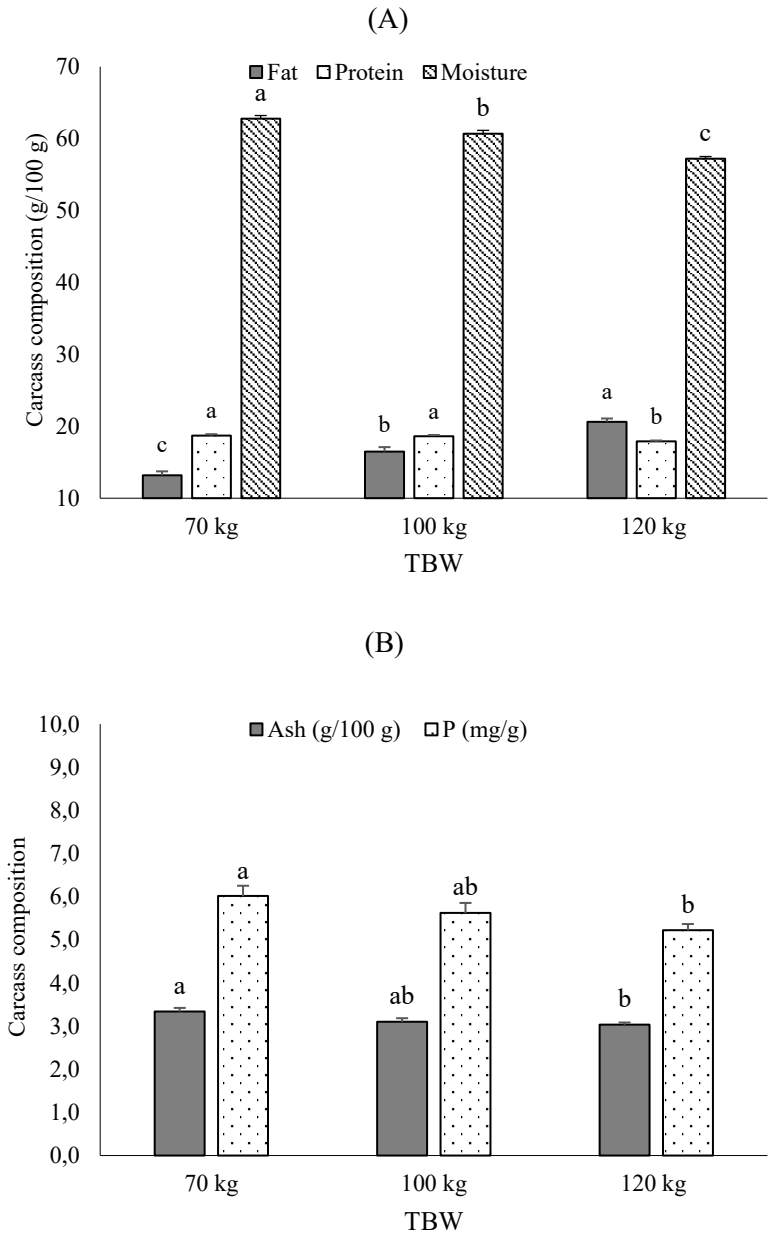
(A)



(B)



Supplementary Figure 3. (A) Cold carcass weight (kg) and (B) subcutaneous fat thickness (mm) (LSMEANS and SE) according to target body weight (TBW) averaged for all sex types (surgically castrated males, immunocastrated males, entire males, and females). Different letters on error bars indicate significant differences between TBW (P-value ≤ 0.05). Fat34LV = fat thickness between the 3rd and 4th lumbar vertebrae; Fat34LR = fat thickness between the 3rd and 4th last ribs; Fat89LR = fat thickness between the 8th and 9th last ribs; Fat56TV = fat thickness between the 5th and 6th thoracic vertebrae.



559 **Supplementary Figure 4.** Chemical composition of minced carcasses (LSMEANS and SE)
560 according to target body weight (TBW) averaged for all sex types (surgically castrated males,
561 immunocastrated males, entire males, and females). Different letters on error bars indicate
562 significant differences between TBW (P-value ≤ 0.05). (A) Fat, protein, and moisture content
563 (g/100 g); (B) ash (g/100 g) and P content (mg/g).

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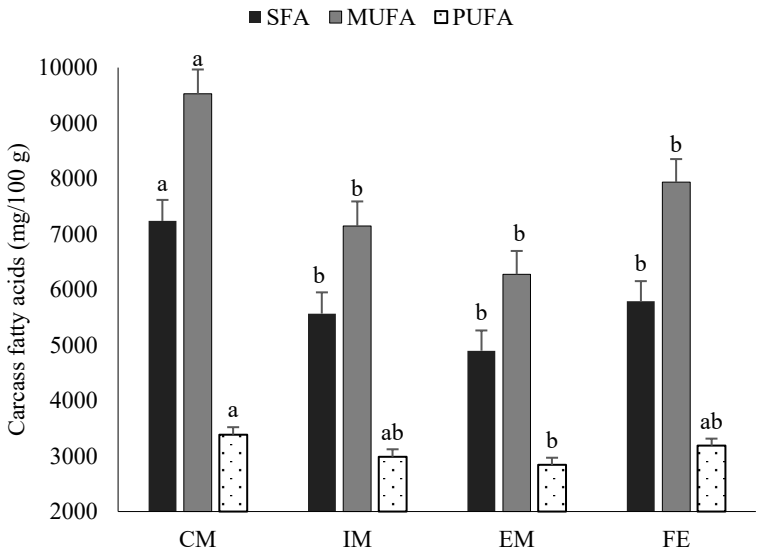
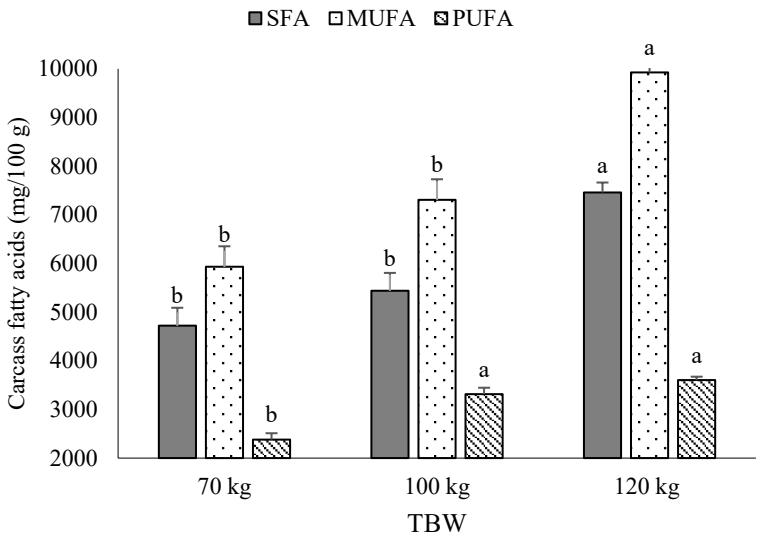


Supplementary Figure 5. Saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) content of minced carcass (mg/100 g of minced carcass) (LSMEANS and SE) according to sex type averaged for all target body weights (70, 100, and 120 kg). Different letters on error bars indicate significant differences between sex types (P-value ≤ 0.05). CM: surgically castrated males; IM: immunocastrated males; EM: entire males; FE: females.



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580 **Supplementary Figure 6.** Saturated (SFA), monounsaturated (MUFA), and polyunsaturated
581 (PUFA) fatty acid content of minced carcass (mg/100 g of minced carcass) (LSMEANS and SE)
582 according to target body weight (TBW) averaged for all sex types (surgically castrated males,
583 immunocastrated males, entire males, and females). Different letters on error bars indicate
584 significant differences between TBW (P-value ≤ 0.05).

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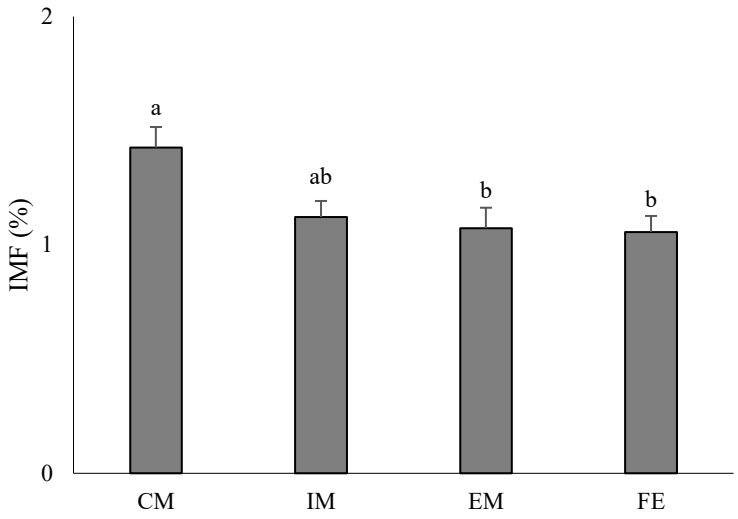
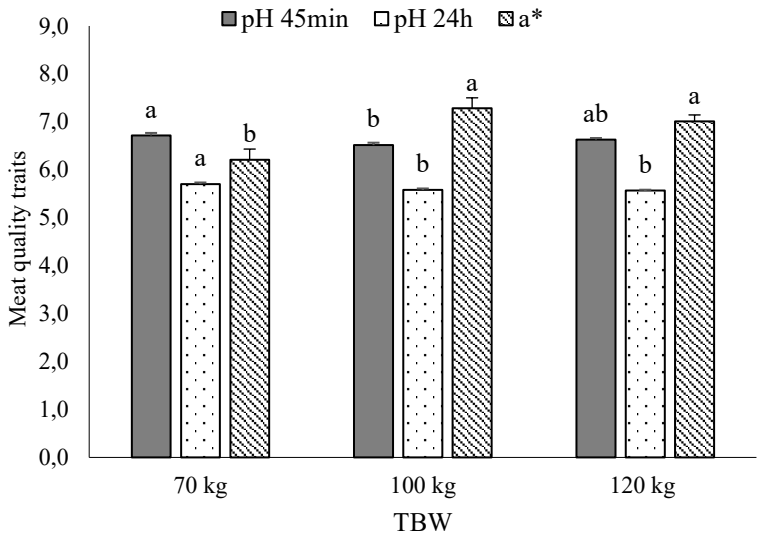


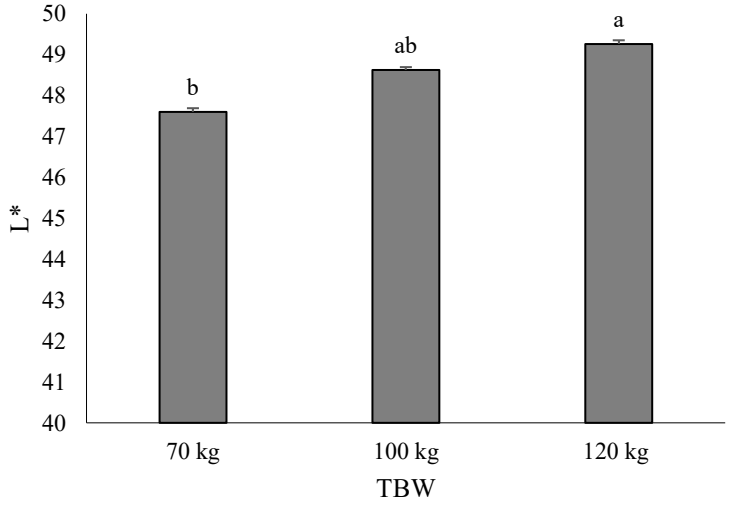
Supplementary Figure 7. Intramuscular fat percentage (IMF) of *Longissimus thoracis* (LSMEANS and SE) according to sex type averaged for all target body weights (70, 100, and 120 kg). Different letters on error bars indicate significant differences between sex types (P-value ≤ 0.05). CM: surgically castrated males; IM: immunocastrated males; EM: entire males; FE: females.

Supplementary Figure 8.

(A)



(B)



Supplementary Figure 8. Meat quality traits of *Longissimus thoracis* according to target body weight (TBW) averaged for all sex types (surgically castrated males, immunocastrated males, entire males, and females). Different letters on error bars indicate significant differences between TBW (P-value ≤ 0.05). (A) pH value at 45 min, pH value at 24 h, and redness (a*); (B) luminosity (L*).