The effect of immunocastration of male and female Duroc pigs on the morphological, mechanical and compositional characteristics of pork belly

Maria Font-i-Furnols[a*], Michela Albano-Gaglio[a], Albert Brun[a], Juan Florencio Tejeda[b], Marina Gispert[a], Begonya Marcos[a], Cristina Zomeño[a]

[a] IRTA-Food Quality and Technology Program, Finca Camps i Armet, 17121 Monells, Spain

[b] UEX- Escuela de Ingenierías Agrarias, Av. Adolfo Suárez s/n, 06007 Badajoz, Spain

*Corresponding author: Maria Font-i-Furnols, e-mail: maria.font@irta.cat

Abstract

Pork belly is an important and heterogeneous cut, characterized by its fat content. Immunocastration is an alternative to surgical castration that can modify the composition of carcasses and cuts and it can affect at its processing. This work compares the morphological, mechanical and compositional characteristics of pork belly of (1) pure Duroc pigs from surgically castrated males (CM), entire females (EF) and immunocastrated females (IF), and (2) Duroc crossbreed pigs from immunocastrated males (IM) and entire males (EM). Two trials were carried out: Trial 1, in which 36 bellies were evaluated, 12 from each sexual type, CM, EF and IF; and Trial 2, where 30 bellies were used, 15 from each sexual type, IM and EM. Results show few differences in bellies from EF and IF, while those from CM were fatter and firmer and with lower polyunsaturated fat. Bellies from IM were longer and firmer than those from EM, and their skin was thinner. IM bellies had higher saturated and lower polyunsaturated fat than those from EM. To conclude, the sex of the pigs affects belly characteristics and this could be a criterion for determining the destination of the bellies in the cutting plant. Immunocastration of pure Duroc females had a lower effect on the belly characteristics when compared to those from entire females, but some differences could be found in the fat distribution. Immunocastration of Duroc crossbred males produces firmer and thicker bellies, with a thinner skin, that could be advantageous for slicing and further processing.

Keywords: computed tomography, firmness, flop, fatness, fatty acids

1. Introduction

Pork belly is an important fatty cut of pig carcasses, which accounts for approximately 10% of its weight (Zomeño et al., 2022) although this percentage can vary depending on how the cuts are made. The quality of the belly is related to the lean and fat content and distribution, thickness, fat characteristics (softness/firmness) and mechanical properties and it varies across anatomical region (Trusell et al., 2011). In general, leaner bellies are thinner (Averette Gatlin et al., 2003), while thicker bellies are fatter. While leaner bellies are in general preferred by most consumers, thinner bellies are not beneficial for producers due to the low processing yield and the possibility of having softer fat (Averette Gatlin et al., 2003). Thus, it is necessary to find an equilibrium that satisfies consumer demand without compromising productivity. The characteristics of the belly are mainly related to the genotype, sex and diet, thus, by modifying these factors, it is possible to modify belly quality (Apple et al., 2011; Duziński et al., 2015; Soladoye et al., 2015).

The Duroc breed and crossbreeds are characterized by their high carcass and intramuscular fat content (Font-i-Furnols et al., 2012), but with a tendency to have high levels of boar taint (Xue et al., 1996) and undesired odour and flavour present in meat from some entire male pigs. Because of this, pure Duroc males (and some crossbreeds) are usually castrated. Immunocastration is an animal-friendly alternative to surgical castration that can be used in males and females, but it can affect the fatness of the carcasses and the quality of the fat. Immunocastrated males behave like entire males until the second vaccine (4-10 weeks before slaughter) at which point they tend towards the behaviour of those

castrated (Dunshea et al., 2001; Gispert et al., 2010), *i.e.* by increasing fat and reducing boar taint. Thus, carcasses from immunocastrated males have a fat content in between those of entire males and surgically castrated males (Carabús et al., 2017; Gispert et al., 2010; Zomeño et al., 2022). The immunocastration of females has been less studied than that of males and is more common in females from fatty breeds to obtain carcasses closer to those of castrated males since it increases the carcass fat content (Daza et al., 2014; Pérez-Ciria et al., 2021). The quality of the fat is also affected by the sex. In general, entire males have higher unsaturated fat, which can result in visual defects and lower oxidative stability, and lower saturated fat than surgically castrated pigs, immunocastrated pigs being in between the two (Škrlep et al., 2020). Regarding fat from females, some research shows they have lower monounsaturated fat than surgically castrated males (Zomeño et al., 2023) while in other research, no differences were reported (Font-i-Furnols et al., 2012).

Regarding bellies characteristics, Kyle et al. (2015) reported that those from immunocastrated males had similar length and were thicker and firmer than those from entire males. Bellies from immunocastrated males had also higher saturated and monounsaturated fatty acids and lower polyunsaturated and iodine value than those from entire males. Bellies from immunocastrated males were also wider and less thick and firm than those from surgically castrated pigs and had lower monounsaturated fatty acids and polyunsaturated fatty acids and iodine value (Boler et al., 2012). Nevertheless, there are few studies in which the effect of immunocastration of gilts on bellies characteristics has been evaluated. In this sense, Palma-Granados et al. (2021) reported higher

proportion of belly in Iberian immunocastrated female pigs than in surgically castrated and immunocastrated male pigs. On the other side, Rodriguez et al. (2019) did not find significant differences in the bellies weight and fat thickness from entire and immunocastrated females of a white crossbreed. Thus, a more in depth study of bellies characteristics from these sexual types of pigs is needed.

The distribution of the fat along the belly slice is an important characteristic because in sliced bellies is what the consumers see and what can make them taken the decision to purchase or not the belly. However, as far as the authors known, there are not studies that look at the fat distribution in the belly slice. The fat distribution can be evaluated without cutting or destructing the belly, by means of a computed tomography device that is based on X-rays and allows to obtain images from the interior part of the belly and to quantify the fat and lean content of the slice or portion of the slice.

According to this, it is important to find out the effect of the immunocastration on bellies morphological, mechanical and compositional characteristics, including the fat distribution along the slice. This would allow to see whether immunocastration of females of fatty breeds increases their fatness and brings them closer to castrated males or whether immunocastration of males, as an alternative to entire males, has an effect on bellies' characteristics since very few information is available in the literature about it. This is a way to enables us to understand the changes in belly characteristics due to the sex type in order to optimize the destination of the bellies and its processing. Thus, the main objective of this work is to compare the morphological, mechanical, and compositional characteristics of bellies from (1) surgically castrated males and

entire and immunocastrated females of a pure Duroc pig line, and (2) immunocastrated and entire males of a Duroc pig crossbreed.

2. Material and Methods

2.1. Animals and bellies

2.1.1. Trial 1

A total of 36 bellies were used, 12 from each sexual type: castrated male (CM), entire female (EF) and immunocastrated female (IF). The bellies came from pure Duroc commercial pigs, all from the same farm and fed *ad libitum* the same diet (2317 kCal/kg net energy, 14.7% crude protein and 5.03% crude fibre between 60 and 90 kg BW; 2395 kCal/kg net energy, 13.7% crude protein and 5.07% crude fibre between 90 and 125 kg BW). Immunocastration of females was carried out with Improvac® (Zoetis, Madrid, Spain) in two doses, the first (V1) at 132 days and the second (V2) after 4 weeks, at 159 days. Surgical castration of male piglets was performed within the first week of life. Pigs were slaughtered in a commercial abattoir after stunning with CO_2 when they reached the target body weight (approximately to obtain carcasses with 95 kg weight). Thus, they were slaughtered at fixed weight. In the case of immunocastrated pigs, they were slaughtered 11 weeks after V2 (at approximately 235 days of life). Carcass weight was recorded and bellies were collected in the cutting plant 24 h *post mortem*.

2.1.2. Trial 2.

A total of 30 bellies were tested, 15 from each sexual type: immunocastrated male (IM) and entire male (EM). The bellies came from commercial Duroc crossbred pigs, all from the same farm and fed *ad libitum* the same diet (2321.5 kCal/kg net energy, 14.9% crude protein and 3.60% crude fibre between 25 and

80 kg BW and 2316.7 kCal/kg net energy, 14.62% crude protein and 3.54% crude fibre between 80 kg BW and slaughter). Immunocastration was carried out with Improvac® (Zoetis, Madrid, Spain) in two doses, V1 at 56 days of age and V2 after 10 weeks, at 126 days of life approximately. All the pigs were slaughtered across 3 different days at 5-6 weeks after V2 at IRTA's abattoir, after stunning with CO_2, and thus, they were slaughtered at fixed age. Carcass weight was recorded, and bellies were collected in the cutting room 24 h *post mortem*.

Bellies from both trials were cut from the left half of the carcass, at the dorsal section, 1 cm from the end of the vertebrae, at the caudal section, 6 cm from the last rib, at the ventral section along the breast line and at the cranial section between the 4^{th} and 5^{th} ribs. Then, ribs were removed from the cut.

2.2. Morphological and mechanical measurements of the bellies

Bellies in both trials were weighed and the proportion of belly with respect to the carcass weight was calculated. For the description of the bellies, 15 areas were identified, similar to those defined by Trusell et al. (2011). From cranial to caudal part, 5 sections were identified as 1, 2, 3, 4 and 5, and from dorsal to ventral, 3 sections named A, B and C. Thus, the combination of all of these allowed 15 different areas, A1, A2,…, C4 and C5 (Fig. 1), to be identified.

The length and width of the bellies were measured at the central section, i.e. length from B1 to B5 and width from A3 to C3 (Fig. 2a). The thickness of each belly was measured skin side-up in the centre of sections B1, B5, A3 and C3. Then the average thickness was calculated. After that, the skin was stretched using tweezers until the base of the belly lifted and the height was measured

(Fig. 2b). The difference between the initial height (thickness) and final height was calculated and used as a measure of firmness in terms of subcutaneous fat and skin separation (*i.e.* cohesiveness). Firmness was also determined by means of the flop distance and angle measured skin-side up and skin-side down (Fig. 2c) by means of the bar-suspension method (Thiel-Cooper et al., 2001) using a horizontal stainless steel bar of 20 mm of diameter. Bellies were suspended from the central part (between A3 and C3) and the distance between the extremes of the dorsal section (from A1 to A5) was determined. The angle was determined using this distance and the length of the belly. Subsequently, the firmness of the subcutaneous fat of the bellies, was also measured, having previously removed the skin, by two trained technicians applying pressure with a finger (Fig. 2d) and using a 5-point scale as defined by Soladoye et al. (2017) from the firmest to the softest: *"1-Firm fat, no finger depression, almost horizontal; 2-Firm fat, no finger depression, partly floppy; 3-Soft spongy fat, finger depression remains, floppy, roll over with resistance; 4-Soft spongy fat, finger depression remains, very floppy, roll over easily; 5-Soft spongy fat, finger depression remains, very floppy, roll over easily, oily".* The average score from both technicians was used.

A square of 4x4 cm^2 of skin from the central part of the belly (B3) was used to measure skin thickness with a "Quick mini 25" (Mituyoto, Kanagawa, JP) micrometer. Then, skin was placed and fixed in a support with the external part of the skin oriented upwards and a puncture test was carried out using a 6 mm cylinder probe fixed in a conical base, and a TA.HD.PLUS Texture Analyser (Stable Micro Systems, Surrey, UK) texturometer equipped with a 250 kg load-cell. A force-time deformation curve was recorded with trigger force of 50 g until

188 the skin broken to measure: the maximum value force (Peak force), leading to
189 the maximum force required to penetrate the sample; the area under the force-
190 time deformation curve (Total force), indicating the total energy required to
191 penetrate the sample; the slope of the force-time deformation curve (Slope)
192 between 75% and 95% of the maximum force, providing the elasticity.

193 **2.3. Physical and chemical compositional measurements of the bellies**

194 Deboned bellies with skin from both trials were subject to computed tomography
195 (CT) scanning using the HiSpeed Zx/I CT device (GE Healthcare, Madrid, ES).
196 Acquisition conditions were helical, pitch 1, 140 kV, 145 mA, 10 mm thickness,
197 displayed field of view 300 mm. The image of the central slice of each belly was
198 analysed as follows: the slice was divided into 5 regions, proportional to the
199 belly width. For each region the proportion of fat was calculated as the volume
200 associated with Hounsfield values from -200 to -20 (Romvári et al., 2005) and
201 using segmentation techniques that consider the neighbouring values to
202 establish the final limit.

203 A sample of 10 g of subcutaneous fat of the central part of the belly (B3) was
204 removed, vacuum packed and frozen at -20ºC for chemical analysis. The
205 remainder of the belly was minced with the cutter. After homogenization of the
206 minced belly, a sample was vacuum packed and frozen at -20ºC for further
207 processing.

208 Moisture (oven air-drying method), protein (Kjeldahl nitrogen), and ash (muffle
209 furnace) of the minced bellies were analyzed following official methods (AOAC,
210 2000). Lipids from the minced bellies were extracted, using
211 chloroform/methanol (1:2, v/v), and quantified according to the method

212 described by Bligh and Dyer (1959). Lipids from subcutaneous fat samples
213 (10g) of the central part of the belly were extracted in a microwave oven
214 following the method described by De Pedro et al. (1997).

215 Fatty-acid composition of subcutaneous fat samples was determined, after lipid
216 extraction, by acidic trans-esterification in the presence of sodium metal (0.1 N)
217 and sulfuric acid (5% sulfuric acid in methanol) according to Sandler and Karo
218 (1992). The fatty acid methyl esters were analysed by gas chromatography,
219 using a Hewlett-Packard HP-4890 Series II gas chromatograph equipped with a
220 split/splitless injector and a flame ionization detector (FID). Separation was
221 carried out on a polyethylene glycol capillary column (HP-INNOWax 30 m long,
222 0.25 mm id, 0.25 µm film thickness; Hewlett-Packard, Palo Alto, CA, USA)
223 maintained at 200 ºC for 25 min. Injector and detector temperatures were held
224 at 250 ºC. The carrier gas was nitrogen at 1.8 mL/min. The individual fatty acids
225 were identified by comparison of their retention times with those of commercial
226 reference standard mixtures (Supelco 37 Component FAME Mix Ref. CRM
227 47885, Sigma Chemical Co., St. Louis, MO, USA). Results were expressed as
228 mg/100g of total fat.

229 Iodine value (IV) was determined according to the modified AOCS equation
230 obtained by Lo Fiego et al. (2016), by including all the unsaturated fatty acids
231 detected by gas chromatography:

232 $$\mathrm{IV} = [\mathrm{C16{:}\,1}] \times 0.950 + [\mathrm{C17{:}\,1}] \times 0.903 + [\mathrm{C18{:}\,1}] \times 0.860 + [\mathrm{C18{:}\,2}] \times 1.732$$
233 $$+ [\mathrm{C18{:}\,3}] \times 2.615 + [\mathrm{C20{:}\,1}] \times 0.785 + [\mathrm{C20{:}\,2}] \times 1.580$$
234 $$+ [\mathrm{C20{:}\,3}] \times 2.386 + [\mathrm{C20{:}\,4}] \times 3.201$$

235 **2.4. Statistical analysis**

The general linear model (GLM) procedure of SAS software (Ver. 9.4, SAS Institute Inc., Cary, NC, USA) was used. Analysis was performed independently for each trial and animal was the experimental unit. The experimental design is factorial with one factor, sex. Thus, the model included the sexual type as a fixed effect. For Trail 2, since animals were slaughtered at a fixed age, the weight was not included as covariate to avoid an underestimation of differences in those characters that grow linearly with the carcass weight. Non other additional covariances were included (the full model can be found in the Supplementary Material). Differences between sexual types have been obtained after and were considered significant if the *P*-value was lower than 0.05. In Trial 1, because comparisons were between more than 2 sexes, Tukey test was applied.

3. Results and Discussion

Results are detailed and discussed conjointly for both trials to avoid repetition. However, it is important to take into account that comparison among sexual types is only possible within the trial, because other factors such as genotype, feeding, immunocastration vaccine protocol and management differ between trials. Thus, the comparisons are between CM, EF and IF of pure Duroc pigs slaughtered at fixed weight (approximately 95 kg carcass weight), which IF received the second dose of the vaccine 11 weeks before slaughter (Trial 1), and between EM and IM Duroc crossbreed pigs slaughtered at fixed age (23-24 weeks), which IM received the second dose 5-6 weeks before slaughter (Trial 2). In the present work, the diet was the same for all the pigs within the same trial, thus, besides the effect of diet on bellies composition and fatty acid profile, differences in belly characteristics (within Trial) were mainly due to sex.

3.1. Morphological characteristics of the bellies

Pork belly is an important cut for the meat industry and its proportion depends on the type of cutting. The tendency in Europe is to increase the carcass weight. Usually, the higher the carcass weight, the higher the belly weight and belly dimensions, although differences at carcass level may not always be significant at the level of the cut.

Logically, because animals were slaughtered at the same weight, no differences in carcass weight between CM, EF and IF pigs from Trial 1 was found (Table 1). Accordingly, no differences in belly weight were detected between sexes. However, the proportion of bellies from CM pigs were 0.73% higher than those from IF pigs ($P < 0.05$), indicating they have a higher yield, and not significantly different from those of EF pigs, which were in between the two. Similar belly proportions between CM and EF were also reported by Gispert et al. (2010) and Zomeño et al. (2022) whereas Duziński et al. (2015) found a higher proportion of belly in CM pigs than in EF pigs. On the other hand, belly weight and proportion in IF and EF pigs were similar, in agreement with Rodrigues et al. (2019) when comparing heavy weighted gilts. In Iberian pigs, Palma-Granados et al. (2021) reported higher belly proportion for IF than CM. Thus, the effect of immunocastration of gilts on belly weight and proportion is not conclusive and it is probably dependent on the animal genotype, the vaccination pattern, the feeding and other management strategies and the weight at slaughter.

Carcasses of IM pigs from Trial 2 were 5.0 kg heavier than those of EM (Table 1). This result is in line with that reported by Gispert et al. (2010), although, in some research, differences in carcass weight between both sexes were not significant (Zomeño et al., 2022), nor were they when different times between

V2 and slaughter were studied (Zoels et al., 2020). Similarly, although the IM carcasses from Trial 2 were heavier than EM carcasses, belly weight and proportion were not significantly different, in agreement with Zomeño et al. (2022), but not in agreement with Gispert et al. (2010) which reported higher belly proportion in IM carcasses than EM. Thus, as well as with females, differences in carcass weight were not translated into differences in belly weight and proportion.

Belly dimensions are important, especially when bellies are sliced. A greater length provides a greater number of slices. Thicker and wider bellies provide bigger slices. Dimensions depend on the characteristics of the belly and the type of cutting. Moreover, production strategies such as genotype, sex and diet, can modify belly characteristics (Soladoye et al., 2015) and it is therefore important to take these into account in order to obtain the desired product.

Regardless of the lack of differences in belly weight and proportion, EF bellies from Trial 1 tended to be wider than CM bellies, IF being in between the two (Table 1). Nevertheless, length was not significantly different between CM, EF and IF bellies. Lowell et al. (2019) reported longer bellies of CM than those of EF, although not being different in width. However, in Trial 2, bellies of IM were on average 2.9 cm longer than those of EM, but no significant differences in width were detected (Table 1).

Belly thickness is difficult to measure because it is very variable and depends on where it is measured (Trusell et al., 2011). Moreover, differences in thickness were not consistent in the various places measured (Fig. 3) and, on average, were not significantly different between sexes (Table 1). For instance, in Trial 1, CM bellies were thicker than EF only at the centre of the dorsal

311 section (A3) (Fig. 3a), while Lowell et al. (2019) and Kyle et al. (2014) reported
312 thicker CM bellies than EF bellies when the average thickness obtained at 8
313 different locations was measured. Moreover, IF bellies tend to be thicker than
314 CM at the ventral section (C3). On the other hand, IM bellies from Trial 2 were
315 0.38 cm thicker than those of EM only in the centre of the caudal section (B5)
316 (Fig. 3b). On average there were no differences in thickness between IM and
317 EM, while in heavier animals (130 kg), Kyle et al. (2014) reported thicker bellies
318 of IM than EM. Thus, considering that thicker is considered better,
319 immunocastration of females or males did not seem to negatively affect the
320 thickness of the bellies when compared to entire females/surgically castrated
321 males or to entire males, respectively.

322 **3.2. Mechanical characteristics of bellies**

323 The firmness of the bellies from Trial 1, measured as the flop distance and
324 angle, is presented in Table 1. Flop distance and angle skin below were higher
325 (higher firmness) in bellies of CM than in those of FE and IF. Flop distance skin
326 above was higher in CM than in IF and flop angle was higher in CM than in EF.
327 Firmness was also measured as the separation of the skin plus fat when
328 stretched with tweezers (Fig. 3), showing higher firmness (less height increase)
329 in bellies of CM than EF and IF in A3. CM also tended ($P < 0.10$) to be firmer
330 than EF in B1, and firmer than IF in B5. Differences in the increased height
331 were not significant in C3 position. Another measurement of firmness was
332 carried out by trained operators scoring the resistance when applying pressure
333 with a finger. The higher the score, the lower the firmness. Results show that
334 firmness was lower in the ventral section (C) and higher in the dorsal section
335 (A), central section (B) being in between the two. In general, firmness was also

336 higher in the cranial than in the caudal section. This in general agrees with the
337 texture measured by Trusell et al. (2011) except in the cranial-central and
338 cranial-dorsal positions. Moreover, when comparing between sexual types, no
339 difference in firmness was found in the ventral region (C), where all the bellies
340 were scored close to 5 (maximum softness). Bellies from IF and EF pigs were
341 not significantly different in firmness in any position, with the exception of B1
342 where IF bellies tended to be firmer than EF ($P < 0.10$). With respect to CM
343 bellies, they were firmer than IF and EF bellies in all the positions of the dorsal
344 region (A) and in B2, B3 and B5, and firmer than IF in B4. In B1 region, bellies
345 of CM and IF were similar and tended to be firmer than EF ($P < 0.10$) (Fig. 4).
346 According to all the measurements of firmness, no significant differences can be
347 found between bellies of IF and EF, indicating that immunocastration may not
348 negatively affect the firmness of the bellies, but also that immunocastration may
349 not improve the firmness of female bellies compared to those surgically
350 castrated. This result was also confirmed by the lack of difference obtained in
351 the texture analysis of the belly (results not shown).

352 When immunocastration is applied to male pigs, differences in belly firmness
353 are more significant and bellies of IM were firmer than those of EM when flop
354 distance and angle were evaluated (Table 1). However, the firmness of the
355 subcutaneous fat evaluated by stretching the skin was only significantly higher
356 (less increase) in IM than EM bellies in B1 position (Fig. 4). Similarly, firmness,
357 scored by the trained operators applying pressure with a finger at the 15
358 different zones (Fig. 4b), was significantly higher in IM than EM bellies in B4, C2
359 and C3 positions and tended to be firmer ($P < 0.10$) at B1, B5 and C1 positions.
360 Thus, especially in the central and ventral section, bellies of IM pigs were firmer

than those of EM pigs, while there was no difference in all the dorsal positions. The increase in firmness in bellies of IM might mean they are more suitable for bacon processing and for export requirements (Uttaro et al., 2020). Moreover, at industrial level, it is difficult to slice soft bellies or bellies with low cohesiveness between skin and subcutaneous fat layer and they must be given a cold shock to facilitate the cutting process. Thus, increasing the firmness could help to slice the fresh bellies.

Skin thickness and firmness was not significantly different between CM, IF and EF (Trial 1; Table 1). However, when males are immunocastrated, significant differences can be found in skin properties, skin from EM being thicker and harder than that from IM (Trial 2; Table 1). A thicker skin might reduce the yield of skinless bellies. Moreover, consumer acceptability of the belly might also be affected by the thickness of the skin.

3.3. Compositional characteristics

Belly fatness is an important parameter that also influences firmness (Soladoye et al., 2017). The tendency is to increase the leanness of the carcasses and the leanness of bellies due to consumer demand for leaner meat (Lebret & Čandek-Potokar, 2022). Leanness is related to genotype and diet, but sex also has an important effect. It is well known that EM carcasses are leaner than EF and that these are leaner that CM (Pauly et al., 2012). Moreover, at the beginning, IM are similar to EM, but after V2 they increase the fat content and become closer to EF (Carabús et al., 2017).

Results show that the protein and ash content of minced bellies was higher in IF than in CM bellies and intermediate in EF ones (Trial 1). Furthermore, dry

matter was higher and moisture lower in CM than in EF and IF bellies. Regarding fat content, bellies from CM pigs were fatter than those from IF pigs, EF bellies being in between (Table 1). When IM and EM were compared, no significant differences in any of the proximate composition parameters were observed (Table 1). Thus, immunocastration, whether of females (Trial 1; Table 1) or males (Trial 2; Table 1) did not have an influence on the fat and lean composition of the bellies. This result is surprising since, in general, immunocastration increases the fat thickness, both in females (Daza et al., 2014; Pérez-Ciria et al., 2021) and probably even more clearly in males (Batorek et al., 2012; Dunshea et al., 2001) especially when the time between V2 and slaughter is long (Allison et al., 2021; Poulsen Nautrup et al., 2018). However, in some research, mainly concerning females, this effect is not so clear (Di Martino et al., 2018; Rodrigues et al., 2019), probably due to genetics, the diet or the time between V2 and slaughter. Besides, it has been reported that the fat allometric growth coefficient of IM is higher than that of EM (Carabús et al., 2017), thus, fat deposition speed of IM is higher than that of EM. On the other hand, the allometric coefficient for belly weight was not significantly different between EM and IM (Carabús et al., 2017). This finding might explain the lack of differences in belly composition between IM and EM. As far as the authors know, no information regarding the allometric growth of fat of IF has been reported.

When looking in more detail at the fat distribution in the central slice of the belly (Fib. 4) it is possible to see that, as is well known, the fat content of bellies is higher in the dorsal section than in the ventral (Trusell et al., 2011). When comparing the distribution of fat depending on the sex type, studied in Trial 1, it

410 is possible to see that CM presented higher fat content in the central and ventral
411 sections of the belly than EF and IF. Moreover, although there were no
412 differences in total fat content between IF and EF (Table 1), in the more dorsal
413 section of the belly, IF presented higher fat content than EF, with IF fat content
414 being similar to those of CM bellies (Fig. 5a). This variation in the distribution of
415 fat in the different anatomical positions of the belly slice could explain the lack of
416 differences in total fat content between bellies of IF and of EF. Also, looking in
417 detail at the fat distribution in the central slice between bellies of IM and EM, it is
418 possible to see that, although there were no differences in the total fat content
419 (Table 1), EM bellies are leaner ($P < 0.05$) than IM bellies in the dorsal and
420 ventral sections, with no significant differences in the central section (Fig. 5b).
421 Thus, although the global fat content is significant, it is also very important to
422 evaluate the distribution of the fat in the different zones of a slice since some
423 differences can be found that might influence processing suitability and
424 consumer preference for the bellies.

425 Fatty acid composition of the subcutaneous fat of the centre of the belly (B3
426 zone) is different depending on the sex type. Although, globally, SFA were not
427 significantly different between sexual types (CM, EF and IF; Trial 1; Table 2),
428 some minor individual SFA like C14:0 (myristic) and C20:0 (arachidic) were
429 higher in the subcutaneous fat of CM than EF bellies, with IF being in between
430 the two. Also, the major individual SFA, C16:0 (palmitic) tended ($P < 0.10$) to be
431 higher in CM than in EF. MUFA globally were also not significantly different
432 between sexes, while C20:1(n-9) was significantly higher in bellies from CM
433 than IF pigs, the subcutaneous fat of EF bellies falling in between. When PUFA
434 are considered globally, they were higher in fat from EF and IF than in those

435 from CM bellies, probably due to the fact that this difference can be observed in
436 the major individual PUFA such as C18:2(n-6) (linoleic). This fatty acid is the
437 major ω6 and probably because of this, the same pattern can be seen, both in
438 ω6 and in the ratio ω6/ω3. Significant differences in IV between sexual types
439 were also found with a higher value in EF than in CM pigs, with IF in between.
440 This differences in PUFA and IV might explain that bellies from EF and IF were
441 less firm than those from CM, when firmness was evaluated as the separation
442 between subcutaneous fat and skin, pressing with a finger the subcutaneous fat
443 and using the flop angle and distance. According to these results, the
444 immunocastration of females does not seem to affect the fatty acid composition
445 of the subcutaneous fat of the belly, when compared to entire females. This is in
446 disagreement with the results reported by Pérez-Ciria et al. (2021) and Daza et
447 al. (2014), in which IF had higher SFA and a lower PUFA, PUFA/SFA ratio, ω6,
448 ω3 and ω6/ω3 ratio, when Duroc crossbreed gilts were studied. Also in a meta-
449 analysis, Poulsen Nautrup et al. (2020) reported that IF had lower IV than EF, in
450 disagreement with the results of the present study. Differences between studies
451 might be due to the diet administered to the pigs, different metabolism due to
452 breed differences, the region from which the subcutaneous fat was obtained
453 (ham or belly) or the methodology used for the FA analysis. According to the
454 present results, immunocastration of Duroc females does not affect the quality
455 of the subcutaneous fat, which is good both from the nutritional and from the
456 technological point of views.

457 When the immunocastration of males is studied (Trial 2; Table 2), subcutaneous
458 fat from IM bellies had higher SFA and lower PUFA, PUFA/SFA ratio, ω6, ω3
459 and IV than that of EM pigs and this might explain the fact that bellies from IM

were firmer than those from EM. Similar results were reported by Kyle et al. (2014), Pauly et al. (2012) and Škrlep et al. (2020). This agrees with the fact that fat from immunocastrated males is firmer than that from EM, improving its technological properties when processed (Škrlep et al., 2020) and being less prone to lipid oxidation (Lebret & Čandek-Potokar, 2022), even though it might be less favourable for human health (Wood et al., 2004). In fact, the results confirm that, in general, the higher the fat content, the higher the saturation.

The belly is a very heterogeneous cut of the carcass, probably due to the different layers of fat and muscle that compose it. It is therefore very important to define and standardise how and where the different quality measurements are taken so that they would be comparable. However, due to the heterogeneity it is difficult for an averaged measure to be representative enough for a whole characterisation, so it makes sense to study the characteristics of the belly slice by regions and non-destructive technologies such as those based on X-ray can be helpful.

4. Conclusions

According to all the results, and under the conditions of the present work, it is possible to conclude that the sex of the pig influences the morphological, mechanical, compositional and chemical characteristics of the belly. This might affect the processing properties and consumer acceptability. Thus, the sex could be a criterion for pre-classifying bellies according to the desired final product to be produced and/or the best processing to be applied. If fatter and firmer bellies are demanded, bellies from CM would probably be more suitable than those from EF and IF and bellies from IM more suitable than those from EM. Furthermore, at similar fatness, the distribution of this fat can be different

depending on the sex type and, consequently, especially when bellies are sliced, it is important that this is considered. For this purpose, non-destructive technologies such as computed tomography have been proved to be useful.

5. Ethical statement

Not applicable.

6. CRediT authorship contribution statement

M. Font-i-Furnols: Conceptualization, Methodology, Formal analysis, Investigation, Writing -Original draft, Writing -Review & Editing, Visualization, Supervision, Project Administration, Funding Acquisition; **M. Albano**: Investigation, Data curation, Writing -Review & Editing; **A. Brun**: Investigation, Data curation, Writing -Review & Editing; **J.F. Tejeda**: Investigation, Data curation, Writing -Review & Editing; **M. Gispert**: Investigation, Formal analysis, Writing -Review & Editing; **B. Marcos**: Investigation, Writing -Review & Editing; **C. Zomeño**: Investigation, Formal analysis, Writing -Review & Editing

7. Declaration of competing interest

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

8. Data and model availability statement

None of the data was deposited in an official repository. Data available under request.

9. Acknowledgements

505 The authors would like to thank the IRTA technicians Agustí Quintana, Albert
506 Rossell, Adrià Pacreu, Cristina Canals and Joel González, for their help in the
507 execution of the project. Thanks also given to José M. Martínez for their
508 contribution in the analysis of fatty acids. Also, the IRTA researcher Israel
509 Muñoz is thanked for his help in the treatment of the computed tomography
510 images. The CERCA programme from the Generalitat de Catalunya is also
511 acknowledged.

512 10. Financial support statement

513 This work has been partly funded by the Spanish Ministry of Science and
514 Innovation, project number RTI2018-096993-B-I00. Michela Albano received
515 funding from the Spanish National Institute of Agricultural Research (INIA)
516 (PRE2019-089669). Cristina Zomeño has received funding from the European
517 Union's Horizon 2020 research and innovation programme under grant
518 agreement No 801370 and the Beatriu de Pinós postdoctoral programme
519 funded by the Secretariat of Universities and Research (Government of
520 Catalonia)"

521 11. References

522 Allison, J. R. D., da Silva, C. A., Callegari, M. A., Dias, C. P., de Souza, K. L. L.,
523 de Oliveira, E. R., . . . Aldaz, A. (2021). Immunization against
524 gonadotropin-releasing factor (GnRF) in market gilts: Effect on growth
525 and carcass parameters, and impact of immunization timing. *Research in*
526 *Veterinary Science*, *136*, 127-137.
527 https://doi.org/10.1016/j.rvsc.2021.02.003
528 AOAC. (2000). Animal Feed, 17th Ed. In (pp. 69-90). Gaithersburg, MD, USA:
529 Association of Official Analytical Chemists (AOAC).

Apple, J. K., Sawyer, J. T., Maxwell, C. V., Yancey, J. W., Frank, J. W., Woodworth, J. C., & Musser, R. E. (2011). Effects of L-carnitine supplementation on quality characteristics of fresh pork bellies from pigs fed 3 levels of corn oil. *Journal of Animal Science*, *89*(9), 2878-2891. https://doi.org/10.2527/jas.2011-3933

Averette Gatlin, L., See, M. T., Hansen, J. A., & Odle, J. (2003). Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes. *Journal of Animal Science*, *81*(8), 1989-1997. https://doi.org/10.2527/2003.8181989x

Batorek, N., Čandek-Potokar, M., Bonneau, M., & Van Milgen, J. (2012). Meta-analysis of the effect of immunocastration on production performance, reproductive organs and boar taint compounds in pigs. *Animal*, *6*(8), 1330-1338. https://doi.org/10.1017/s1751731112000146

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, *37*(8), 911-917. https://doi.org/10.1139/o59-099

Carabús, A., Sainz, R. D., Oltjen, J. W., Gispert, M., & M., F.-i.-F. (2017). Growth of total fat and lean and of primal cuts is affected by the sex type. *Animal*, *11*(8), 1321-1329. https://doi.org/10.1017/s1751731117000039

Daza, A., Latorre, M. A., Olivares, A., & López-Bote, C. J. (2014). The effect of immunocastration and a diet based on granulated barley on growth performance and carcass, meat and fat quality in heavy gilts. *Animal*, *8*(3), 484-493. https://doi.org/10.1017/s1751731113002292

De Pedro, E., Casillas, M., & Miranda, C. M. (1997). Microwave oven application in the extraction of fat from the subcutaneous tissue of Iberian pig ham. *Meat Science*, *45*(1), 45-51. https://doi.org/10.1016/s0309-1740(96)00097-6

Di Martino, G., Scollo, A., Garbo, A., Lega, F., Stefani, A. L., Vascellari, M., . . . Bonfanti, L. (2018). Impact of sexual maturity on the welfare of immunocastrated *v*. entire heavy female pigs. *Animal*, *12*(8), 1631-1637. https://doi.org/10.1017/s1751731117003135

Dunshea, F. R., Colantoni, C., Howard, K., McCauley, I., Jackson, P., Long, K. A., . . . Hennessy, D. P. (2001). Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth

performance. *Journal of Animal Science*, *79*(10), 2524-2535. https://doi.org/10.2527/2001.79102524x

Duziński , K., Lisiak, D., Knecht, D., & Środoń, S. (2015). The estimation of pork carcass primal cuts value based on backfat thickness. *Journal of Central European Agriculture*, *16*(1), 112-121. https://doi.org//10.5513/JCEA01/16.1.1550

Font-i-Furnols, M., Gispert, M., Soler, J., Diaz, M., Garcia-Regueiro, J. A., Diaz, I., & Pearce, M. C. (2012). Effect of vaccination against gonadotrophin-releasing factor on growth performance, carcass, meat and fat quality of male Duroc pigs for dry-cured ham production. *Meat Science*, *91*(2), 148-154. https://doi.org/10.1016/j.meatsci.2012.01.008

Gispert, M., Àngels Oliver, M., Velarde, A., Suarez, P., Pérez, J., & Font i Furnols, M. (2010). Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. *Meat Science*, *85*(4), 664-670. https://doi.org/10.1016/j.meatsci.2010.03.021

Kyle, J. M., Bohrer, B. M., Schroeder, A. L., Matulis, R. J., & Boler, D. D. (2014). Effects of immunological castration (Improvest) on further processed belly characteristics and commercial bacon slicing yields of finishing pigs. *Journal of Animal Science*, *92*(9), 4223-4233. https://doi.org/10.2527/jas.2014-7988

Lebret, B., & Čandek-Potokar, M. (2022). Review: Pork quality attributes from farm to fork. Part I. Carcass and fresh meat. *Animal*, *16*, 100402. https://doi.org/10.1016/j.animal.2021.100402

Lo Fiego, D. P., Minelli, G., Volpelli, L. A., Ulrici, A., & Macchioni, P. (2016). Calculating the iodine value for Italian heavy pig subcutaneous adipose tissue from fatty acid methyl ester profiles. *Meat Science*, *122*, 132-138. https://doi.org/10.1016/j.meatsci.2016.08.002

Lowell, J. E., Schunke, E. D., Harsh, B. N., Bryan, E. E., Stahl, C. A., Dilger, A. C., & Boler, D. D. (2019). Growth performance, carcass characteristics, fresh belly quality, and commercial bacon slicing yields of growing-finishing pigs from sire lines intended for different industry applications. *Meat Science*, *154*, 96-108. https://doi.org/10.1016/j.meatsci.2019.04.010

598 Palma-Granados, P., Lara, L., Seiquer, I., Lachica, M., Fernández-Fígares, I.,
599 Haro, A., & Nieto, R. (2021). Protein retention, growth performance and
600 carcass traits of individually housed immunocastrated male- and female-
601 and surgically castrated male Iberian pigs fed diets of increasing amino
602 acid concentration. *Animal*, *15*(4), 100187.
603 https://doi.org/10.1016/j.animal.2021.100187
604 Pauly, C., Luginbühl, W., Ampuero, S., & Bee, G. (2012). Expected effects on
605 carcass and pork quality when surgical castration is omitted--results of a
606 meta-analysis study. *Meat Science*, *92*(4), 858-862.
607 https://doi.org/10.1016/j.meatsci.2012.06.007
608 Pérez-Ciria, L., Carcò, G., Miana-Mena, F. J., Mitjana, O., Falceto, M. V., &
609 Latorre, M. A. (2021). Immunocastration in Gilts: A Preliminary Study of
610 the Effect of the Second Dose Administration Time on Growth,
611 Reproductive Tract Development, and Carcass and Meat Quality.
612 *Animals (Basel)*, *11*(2). https://doi.org/10.3390/ani11020510
613 Poulsen Nautrup, B., Van Vlaenderen, I., Aldaz, A., & Mah, C. K. (2018). The
614 effect of immunization against gonadotropin-releasing factor on growth
615 performance, carcass characteristics and boar taint relevant to pig
616 producers and the pork packing industry: A meta-analysis. *Research in*
617 *Veterinary Science*, *119*, 182-195.
618 https://doi.org/10.1016/j.rvsc.2018.06.002
619 Poulsen Nautrup, B., Van Vlaenderen, I., & Mah, C. K. (2020). The effect of
620 immunization against gonadotropin-releasing factor in market gilts: Meta-
621 analyses of parameters relevant for pig producers, pork packers and
622 retailers/consumers. *Research in Veterinary Science*, *131*, 159-172.
623 https://doi.org/10.1016/j.rvsc.2020.04.012
624 Rodrigues, L. A., Almeida, F., Peloso, J. V., Ferreira, F. N. A., Allison, J., &
625 Fontes, D. O. (2019). The effects of immunization against gonadotropin-
626 releasing hormone on growth performance, reproductive activity and
627 carcass traits of heavy weight gilts. *Animal*, *13*(6), 1326-1331.
628 https://doi.org/10.1017/s1751731118003099
629 Romvári, R., Szabó, A., Kárpáti, J., Kovách, G., Bázár, G., & Horn, P. (2005).
630 Measurement of belly composition variability in pigs by in vivo computed

631 tomographic scanning. *Acta Veterinaria Hungarica*, *53*(2), 153-162.
632 https://doi.org/10.1556/AVet.53.2005.2.1
633 Sandler, S. R., & Karo, W. (1992). Front Matter. In S. R. Sandler & W. Karo
634 (Eds.), *Sourcebook of Advanced Organic Laboratory Preparations* (pp.
635 iii). Academic Press.
636 Škrlep, M., Tomašević, I., Mörlein, D., Novaković, S., Egea, M., Garrido, M. D., .
637 . . Font-i-Furnols, M. (2020). The Use of Pork from Entire Male and
638 Immunocastrated Pigs for Meat Products—An Overview with
639 Recommendations. *Animals*, *10*(10), 1754. https://www.mdpi.com/2076-
640 2615/10/10/1754
641 Soladoye, O. P., Uttaro, B., Zawadski, S., Dugan, M. E. R., Gariépy, C., Aalhus,
642 J. L., . . . Juárez, M. (2017). Compositional and dimensional factors
643 influencing pork belly firmness. *Meat Science*, *129*, 54-61.
644 https://doi.org/10.1016/j.meatsci.2017.02.006
645 Soladoye, P. O., Shand, P. J., Aalhus, J. L., Gariépy, C., & Juárez, M. (2015).
646 Review: Pork belly quality, bacon properties and recent consumer trends.
647 *Canadian Journal of Animal Science*, *95*(3), 325-340.
648 https://doi.org/10.4141/cjas-2014-121
649 Thiel-Cooper, R. L., Parrish, F. C., Jr., Sparks, J. C., Wiegand, B. R., & Ewan,
650 R. C. (2001). Conjugated linoleic acid changes swine performance and
651 carcass composition. *Journal of Animal Science*, *79*(7), 1821-1828.
652 https://doi.org/10.2527/2001.7971821x
653 Trusell, K. A., Apple, J. K., Yancey, J. W. S., Johnson, T. M., Galloway, D. L., &
654 Stackhouse, R. J. (2011). Compositional and instrumental firmness
655 variations within fresh pork bellies. *Meat Science*, *88*(3), 472-480.
656 https://doi.org/10.1016/j.meatsci.2011.01.029
657 Uttaro, B., Zawadski, S., & Juárez, M. (2020). An approach for objective and
658 automated identification of pork belly firmness. *Meat Science*, *169*,
659 108221. https://doi.org/10.1016/j.meatsci.2020.108221
660 Wood, J. D., Nute, G. R., Richardson, R. I., Whittington, F. M., Southwood, O.,
661 Plastow, G., . . . Chang, K. C. (2004). Effetcs of breed, diet and muscle
662 on fat deposition and esating quality in pigs. *Meat Science*, *67*, 651-667.
663 https://doi.org/10.1016/j.meatsci.2004.01.007

664 Xue, J., Dial, G. D., & Morrison, R. B. (1996). Comparison of the accuracies of
665 chemical and sensory tests for detecting taint in pork. *Livestock*
666 *production science*, *46*(3), 203-211. https://doi.org/10.1016/S0301-
667 6226(96)01385-1
668 Zoels, S., Reiter, S., Ritzmann, M., Weiß, C., Numberger, J., Schütz, A., . . .
669 Weiler, U. (2020). Influences of Immunocastration on Endocrine
670 Parameters, Growth Performance and Carcass Quality, as Well as on
671 Boar Taint and Penile Injuries. *Animals (Basel)*, *10*(2).
672 https://doi.org/10.3390/ani10020346
673 Zomeño, C., Gispert, M., Brun, A., Carabús, A., Soler, J., & Font-i-Furnols, M.
674 (2022). Productive performance and in vivo body composition across the
675 growing and finishing period and carcass traits in pigs of four sex types.
676 *Meat Science*, *192*, 108909.
677 https://doi.org/10.1016/j.meatsci.2022.108909
678 Zomeño, C., Gispert, M., Čandek-Potokar, M., Mörlein, D., & Font-i-Furnols, M.
679 (2023). A matter of body weight and sex type: Pig carcass chemical
680 composition and pork quality. *Meat Science*, *197*, 109077.
681 https://doi.org/10.1016/j.meatsci.2022.109077

Tables

Table 1. Morphological, mechanical and compositional measurements of pork bellies from surgically castrated males (CM), entire females (EF) and immunocastrated females (IF) (Trial 1) and from immunocastrated males (IM) and entire males (EM) (Trial 2).

	Trial 1					Trial 2			
	CM	EF	IF	RMSE	*P*-value	IM	EM	RMSE	*P*-value
Carcass weight (kg)	96.70	98.88	95.33	7.30	0.493	107.68^{a}	102.85^{b}	5.85	0.032
Belly weight (kg)	4.96	4.89	4.55	0.50	0.117	4.66	4.43	0.57	0.278
Belly proportion (%)	10.27^{a}	9.88^{ab}	9.54^{b}	0.54	0.008	8.64	8.60	0.87	0.907
Belly dimensions (cm)									
Length	46.01	46.33	44.50	2.27	0.126	45.20^{a}	42.32^{b}	2.84	0.009
Width	23.98	25.19	24.48	1.24	0.071	23.62	24.00	1.34	0.445
Average thickness	4.15	4.08	4.04	0.35	0.751	3.86	3.69	0.35	0.191
Belly mechanical properties									
Flop distance skin above (cm)	27.55^{a}	21.80^{ab}	21.21^{b}	5.93	0.024	18.58^{a}	13.44^{b}	4.81	0.007
Flop angle skin above (º)	75.43^{a}	56.74^{b}	57.35^{ab}	18.16	0.026	48.50^{a}	37.02^{b}	11.90	0.013
Flop distance skin below (cm)	29.72^{a}	20.92^{b}	22.98^{b}	6.27	0.004	22.11^{a}	15.81^{b}	6.25	0.010
Flop angle skin below (º)	82.62^{a}	54.37^{b}	62.79^{b}	19.41	0.004	59.45^{a}	44.08	17.97	0.027
Minced belly chemical composition									
Dry matter (%)	64.24^{a}	59.99^{b}	58.47^{b}	3.48	0.001	50.81	48.66	4.12	0.163
Moisture (%)	35.76^{b}	40.01^{a}	41.53^{a}	3.48	0.001	49.19	51.34	4.12	0.163
Fat (%)	49.25^{a}	47.24^{ab}	43.52^{b}	5.55	0.050	35.26	31.98	5.36	0.105
Protein (%)	9.67^{b}	10.97^{ab}	11.90^{a}	1.92	0.026	15.308	15.949	1.80	0.337
Ashes (%)	0.44^{b}	0.52^{ab}	0.54^{a}	0.08	0.013	0.679	0.687	0.09	0.823
Skin properties									
Thickness (mm)	3.20	2.89	3.07	0.58	0.417	1.99^{b}	2.57^{a}	0.44	0.001
Peak force (kg)	71.39	73.32	77.31	16.76	0.680	110.55^{b}	122.96^{a}	15.74	0.040
Total force (kg·s)	114.87	124.71	108.67	28.88	0.400	160.45	179.52	37.53	0.175
Slope (kg/s)	27.43	25.55	31.66	7.01	0.107	40.92	42.50	6.53	0.514

^{a,b} Different superscripts within row and trial indicate significant differences between sexes ($P < 0.05$).

687 **Table 2.** Fatty acids composition (mg/100g) of the subcutaneous fat of the
688 central part of pork bellies from surgically castrated males (CM), entire females
689 (EF) and immunocastrated females (IF) (Trial 1) and from immunocastrated
690 males (IM) and entire males (EM) (Trial 2).

	Trial 1					Trial 2			
	CM	EF	IF	RMSE	*P*-value	IM	EM	RMSE	*P*-value
C14:0	1419[a]	1324[b]	1403[ab]	86	0.024	1406	1408	107	0.959
C15:0	53	50	45	8	0.081	53	57	12	0.357
C16:0	23855	23218	23689	687	0.077	25018[a]	24261[b]	920	0.032
C17:0	285	282	240	50	0.061	284	330	70	0.081
C18:0	10038	10090	10051	784	0.986	12167	11529	967	0.082
C20:0	211[a]	187[b]	195[ab]	23	0.039	239	225	41	0.375
SFA	35862	35152	35623	1210	0.355	39164[a]	37811[b]	1761	0.045
C16:1	2944	2770	2970	401	0.423	2808	2860	285	0.621
C17:1	363	356	318	46	0.053	327	377	79	0.095
C18:1(n-9)	46383	46318	45761	1239	0.411	44412	44354	1348	0.907
C20:1(n-9)	1119[a]	1008[ab]	958[b]	118	0.007	921[a]	831[b]	92	0.012
MUFA	50808	50450	50005	1335	0.348	48471	48421	1390	0.922
C18:2(n-6)	11371[b]	12382[a]	12348[a]	901	0.014	10871[b]	12150[a]	1193	0.007
C18:3(n-3)	783	811	846	63	0.067	513[b]	580[a]	61	0.006
C20:2(n-9)	662	673	651	50	0.547	521	533	57	0.572
C20:3(n-6)	113	119	113	18	0.584	119	128	64	0.715
C20:4(n-6)	228	245	246	29	0.239	223	247	43	0.135
C20:3(n-3)	176	168	166	15	0.238	117	129	24	0.177
PUFA	13331[b]	14401[a]	14371[a]	997	0.019	12365[b]	13766[a]	1324	0.007
PUFA/SFA	0.37[b]	0.41[a]	0.40[ab]	0.04	0.028	0.32[b]	0.37[a]	0.05	0.007
ω3	958	980	1013	60	0.101	631[b]	708[a]	70	0.005
ω6	11709[b]	12748[a]	12707[a]	921	0.014	11213[b]	12523[a]	1228	0.007
ω6/ω3	12.21[b]	12.99[a]	12.53[b]	0.37	<0.001	17.79	17.67	0.85	0.704
Iodine Value	67.67[b]	69.28[a]	68.90[ab]	1.60	0.049	63.88[b]	66.35[a]	2.50	0.011

SFA: saturated, MUFA: monounsaturated and PUFA: polyunsaturated fatty acids; ω3: omega 3; ω6: omega 6.

[a,b] Different superscripts within row and Trial indicate significant differences between sexes ($P < 0.05$).

691

Dorsal zone (spine)

	1	2	3	4	5
A	A1	A2	A3	A4	A5
B	B1	B2	B3	B4	B5
C	C1	C2	C3	C4	C5

Cranial (shoulder) — **Caudal (ham)**

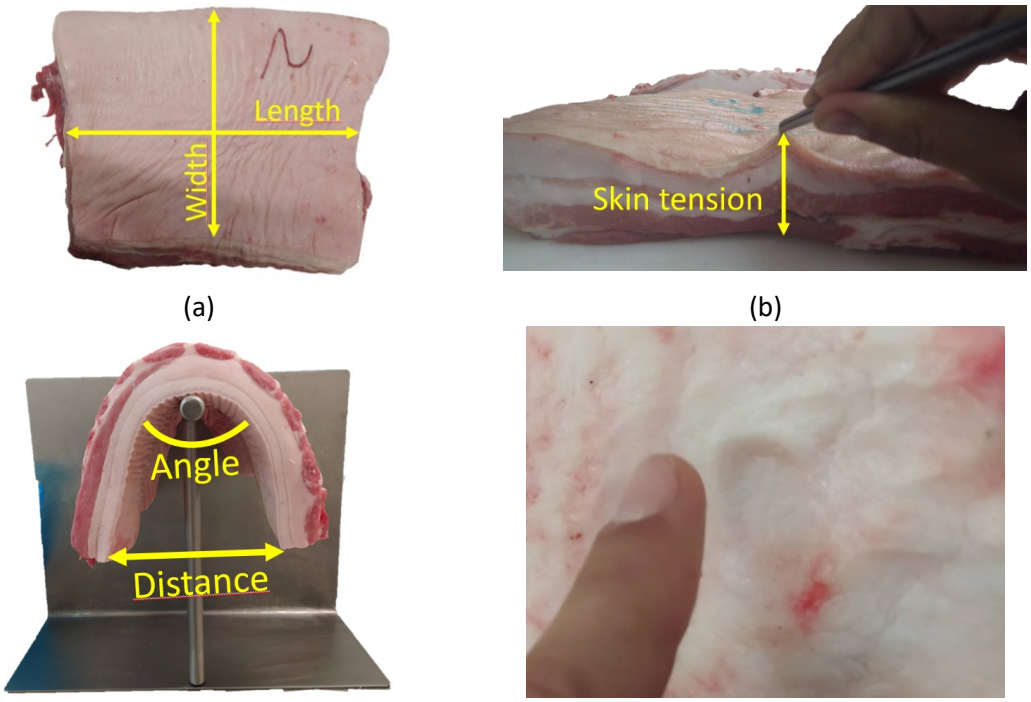
Ventral zone (breasts)

692

693 **Fig. 1.** Areas identified in the bellies.

694

695

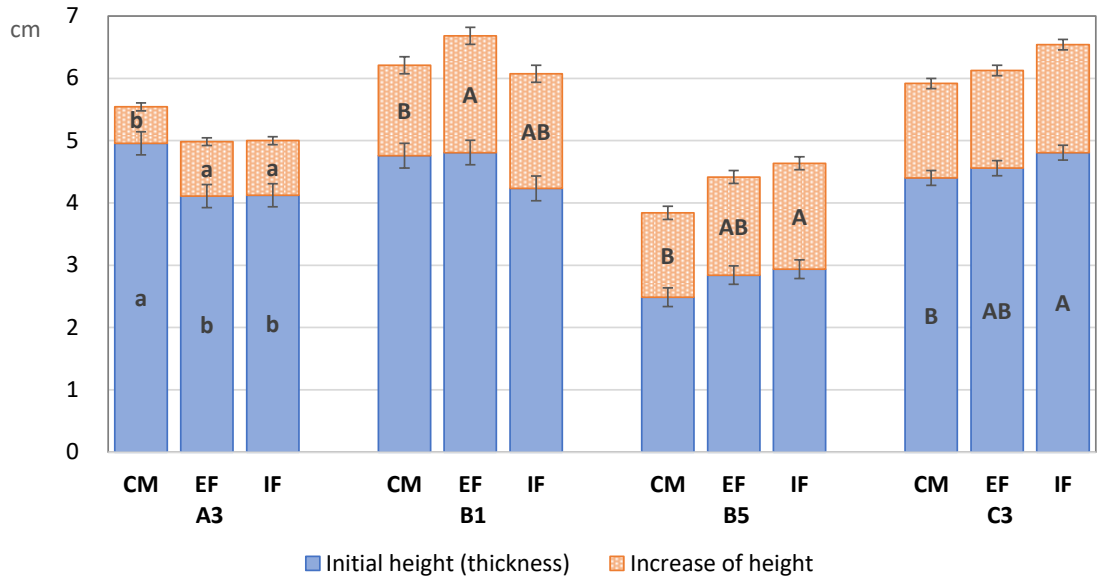


696

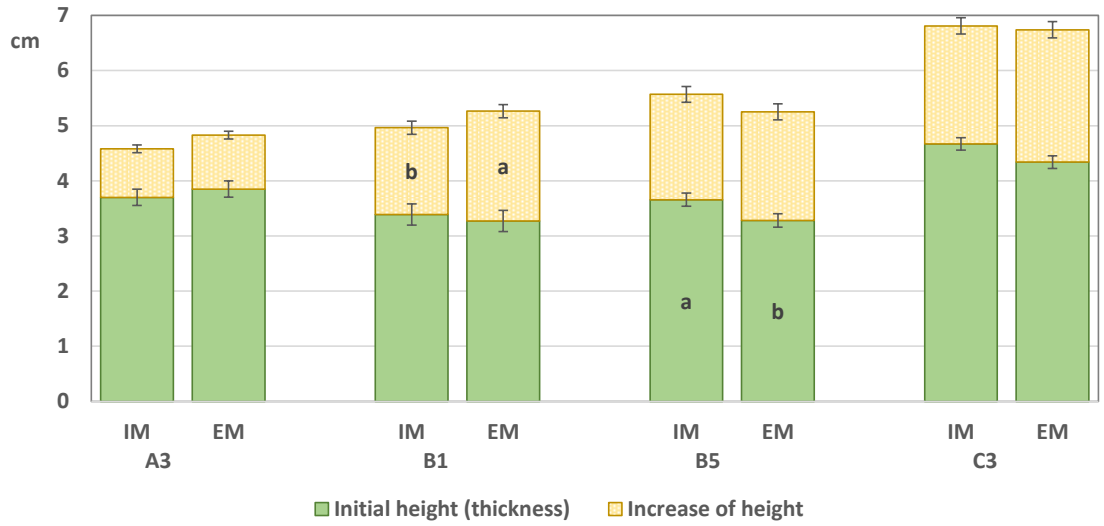
697 **Fig. 2.** Morphological and mechanical measurements in the bellies, a: length

698 and width, b: flop angle and distance skin below, c: skin tension measurement;

699 d: firmness measurement applying finger pressure.

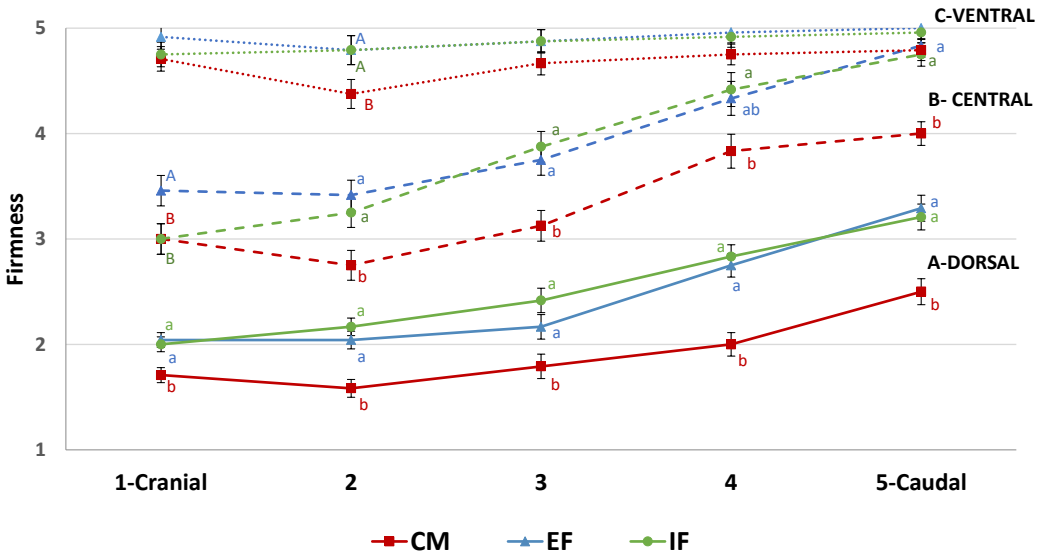


(a)



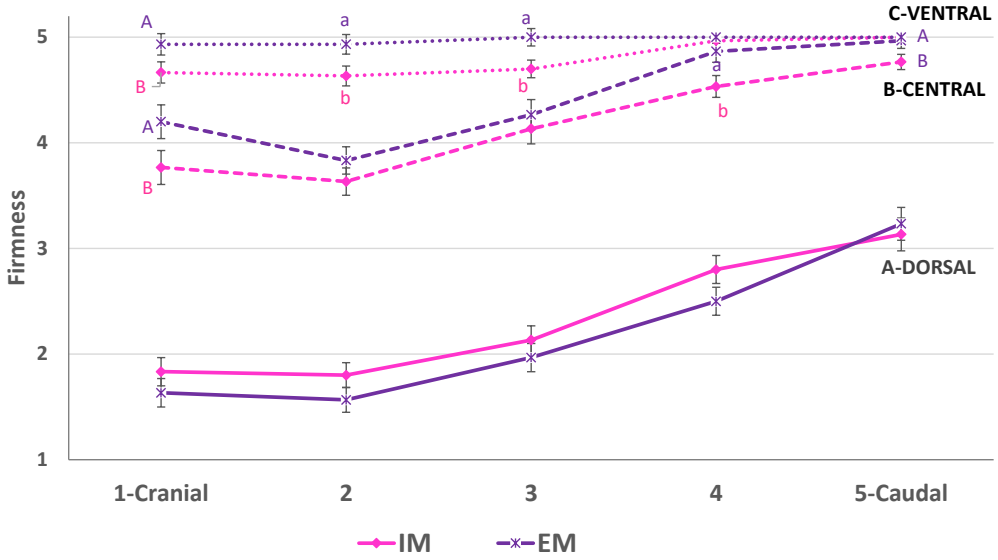
(b)

Fig. 3. Belly thickness, evaluated as the initial height (cm), and belly firmness, evaluated as the difference between the initial and final heights (after stretching the skin with tweezers until the base of the belly lifts up) measured in the centre of each of the four sides (see **¡Error! No se encuentra el origen de la referencia.**) for bellies from (a) Trial 1 [Castrated males (CM); entire females (EF); immunocastrated females (IF)] and (b) Trial 2 [immunocastrated males (IM) and entire males (EM)]. Bars represent standard error of the mean. Different letters between sexual types [within the same location and measurement (initial or increase)] indicate significant differences ($P < 0.05$ lower-case letters; $P < 0.10$ capital letters).



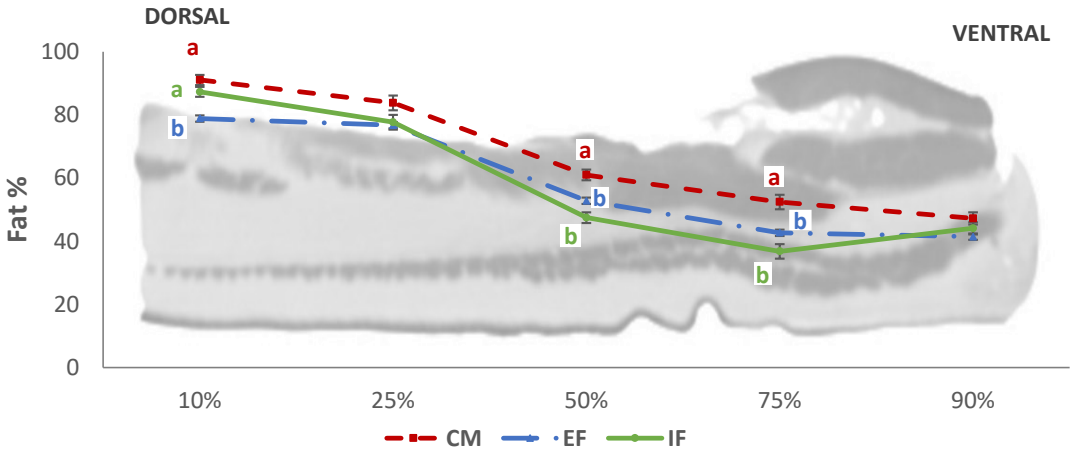
<

(a)

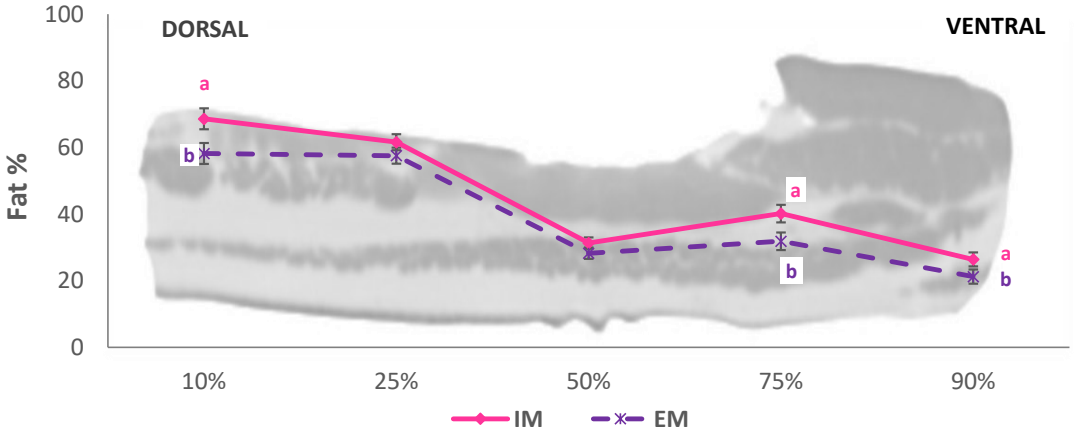


(b)

Fig. 4. Belly firmness, evaluated by two trained technicians applying pressure using a finger (from 1: firm fat to 5: soft spongy fat) in 15 different locations of the belly (see **¡Error! No se encuentra el origen de la referencia.**) for bellies from (a) Trial 1 [Castrated males (CM); entire females (EF); immunocastrated females (IF)] and (b) Trial 2 [immunocastrated males (IM) and entire males (EM)]. Bars represent standard error of the mean. Different letters between sexual types [within the same location and measurement (initial or increase)] indicate significant differences ($P < 0.05$ lower-case letters; $P < 0.10$ capital letters).



(a)



(b)

Fig. 5. Fat percentage of the different regions (5 regions from dorsal to ventral, placed at 10, 25, 50, 75 and 90% of the total area) of the central slice of bellies from (a) Trial 1 [Castrated males (CM); entire females (EF); immunocastrated females (IF)] and (b) Trial 2 [immunocastrated males (IM) and entire males (EM)]. Bars represent standard error of the mean. Different letters between sexual types [within the same location and measurement (initial or increase)] indicate significant differences ($P < 0.05$).