Productive performance and *in vivo* body composition across the growing and finishing period and carcass traits in pigs of four sex types

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Highlights

- Sex differences in performance and body composition change during growth
- Carcass quality variation among sexes is constant during growth
- Fatness of immunocastrates is close to castrate or entire males depending on position
- Females have the largest ham weight and proportion with no variation among males
- Castrates have higher belly proportion than entire males

Abstract

This study compares performance, body and carcass composition among castrated (CM), immunocastrated (IM) and entire males (EM), and females (FE) at 30, 70, 100 and 120 kg of body weight (total of n=92; 20-24/sex type). Overall, IM had similar growth and feed intake to CM and greater than EM and FE. At each slaughter stage, IM had a lower killing-out percentage than CM and FE, in line with their heavier liver and kidneys. Flare fat proportion and backfat thickness on the ham and at the last rib level were similar for IM, EM and FE, and these were lower than CM. In EM and FE, backfat between the 3rd and 4th last ribs was lower and carcass lean content was higher than in CM, whereas IM were intermediate and not different to the other sexes. Females showed the largest ham proportion, this cut being leaner and less fatty than in CM. Belly proportion was higher in CM than in EM.

Keywords: tissular composition, carcass quality, commercial cuts, viscera, immunocastration

1. Introduction

After the EU agreement to abandon the surgical castration of piglets by 2018 (European Declaration on alternatives to surgical castration of pigs in 2010), some countries have begun to raise entire males or to vaccinate pigs against gonadotrophin-releasing hormone (GnRH) (i.e. immunocastration) (Backus et al., 2018; European Union, 2019). Entire males and immunocastrates are considered to have: *i*) improved animal welfare status since there is no pain associated with surgical castration; *ii*) increased economic profitability determined by a better feed conversion and higher lean deposition, especially in entire males; *iii*) less environmental impact associated with a superior growth efficiency and lower nitrogen excretion (Čandek-Potokar et al., 2017; Kress et al., 2019; Škrlep et al., 2020). Despite these advantages, surgical castration is still the standard for pig farming in most EU Member States. This is mainly due to the uncertain economic feasibility of the transition and the challenges posed to the pork supply chain dynamics and relationships as well as the management of the risk of boar taint in entire males (European Union, 2019).

Entire males and immunocastrates present very distinct physiological characteristics compared to castrated males, and these determine marked differences in growth, body composition as well as carcass and meat quality (Čandek-Potokar et al., 2017; Škrlep et al., 2020). Nevertheless, these characteristics are similar for entire males and immunocastrates until the second dose of the vaccine (usually administered 4–6 weeks prior to slaughter), and thereafter immunocastrates present more similar performance and carcass fatness to castrates with intermediate levels of carcass lean content between entire and castrated males (Batorek et al., 2012; Poulsen Nautrup et al., 2018). Published results comparing entire males, immunocastrates and castrates, however, are not always consistent, which can be explained by differences in the dietary levels of protein and amino acids, the immunocastration timing protocol, genetics, animal age, slaughter weight and management system, among others (Moloney & McGee, 2017; Škrlep et al., 2020).

In order to overcome the present challenges and propose viable alternatives, it is necessary to fully characterise the physical tissue composition and product quality of the different sex types available on the market, which also includes female pigs. Knowledge of the specific composition of the carcass and its commercial cuts can also improve pork industry performance by selecting the best type of pig to be produced according to market requirements and optimising the destination of the various cuts whether for sale or further processing. In addition, comprehensive studies covering the entire growing and finishing period can be very informative, especially for immunocastrated males for which the vaccination protocol can be adapted (early or late vaccination) to the specific needs of the pork industry (Čandek-Potokar et al., 2017). However, as far as we know, few studies have compared production traits and body and carcass composition in entire males, immunocastrates, castrates and females simultaneously across the entire fattening period (Fàbrega et al., 2010; Gispert et al., 2010; Morales et al., 2010).

Therefore, the objective of the present study was to assess the evolution of productive performance, body composition including internal organs, and the characteristics of the carcass and its cuts in pigs from four sex types (castrated males, immunocastrated males, entire males, and females) across the period from 30 kg to 120 kg of target body weight (TBW). Animals only differed in their sex condition, whereas other potential influencing factors such as genetics and feeding were the same.

2. Material and methods

2.1. Animals and experimental design

This study was carried out with 92 pigs, all with the same genetic origin (Pietrain × (Landrace × Duroc)), from four different sex types: 24 surgically castrated males (CM), 20 immunocastrated males (IM), 24 entire males (EM) and 24 females (FE). At a mean age of 21 days, the animals were transferred from a commercial farm with a high health status to the experimental farm at IRTA-Monells. The piglets were selected from a total of 24 litters so that one pig of each sex, representative of the average BW within litter, was taken from each litter.

The trial began when the pigs reached an average TBW of 30 kg (31.1 ± 1.0 kg body weight (BW)) and continued until they weighed an average TBW of 120 kg (120.6 ± 2.4 kg BW). All the pigs were fed *ad libitum* with a 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 was performed when the piglets were under 7 days of age. The immunocastration vaccine Improvac® (Zoetis, Alcobendas, Spain) was administered twice: the first dose (V1) at 12 weeks of age and the second dose (V2) at 18 weeks of age, at approximately 70 kg of 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.

Of the total 92 pigs, 48 (12 per sex, randomly chosen but representative of the variation in BW within each sex) were evaluated across the entire trial at four different TBW (30, 70, 100 and 120 kg). They were slaughtered after the last control at 120 kg (approximately 8 weeks after V2). This group of animals was the monitoring group, and they were reared in individual pens (3.0 m^2; 2.5 m length × 1.2 m width). The remaining 44 pigs were reared in collective pens (13.5 m^2; 5.0 m length × 2.7 m width), and each pen housed 12-16 pigs of all sex types. All pens were equipped with a slatted floor surface, one drinking bowl and one free-access feeder. Pigs of the second group under study (n=44) were slaughtered when they reached the desired TBW: 12 pigs at 30 kg (4 EM, 4 CM and 4 FE), and 16 pigs each at 70 kg and 100 kg (4 EM, 4 CM, 4 IM and 4 FE). There were no immunocastrated males in the 30 kg group as, at this age, the vaccination process had just begun and they would have been considered as entire males.

2.2. Production and in vivo body composition measurements

Animals from the monitoring group were individually weighed at four control points across the trial: at 30, 70, 100 and 120 kg TBW. In addition, fat thickness and muscle depth were measured at the last rib, 4–6 cm from the midline, on both the left and right sides, using PIGLOG 105 ultrasound equipment (Frontmatec A/S, Smørum, Denmark), also at 30 (fat thickness only), 70, 100 and 120 kg TBW. Subsequently, the average fat thickness and muscle depth across the sides was calculated.

The average daily gain (ADG, kg/d), the average daily feed intake (ADFI, kg/d) and the feed conversion ratio (FCR) for each pig in the monitoring group were calculated for the entire trial (from 30 to 120 kg) and the finishing period (from 70 to 120 kg) as well as for the following individual periods: from 30 to 70 kg, from 70 to 100 kg, and from 100 to 120 kg.

2.3. Slaughtering, carcass measurements and dissection

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

During evisceration, the weight of white viscera (i.e. pancreas, stomach, spleen, and small and large intestine), red viscera (i.e. tongue, heart, liver, kidneys, lungs, bladder and trachea), brain and tail were recorded. After evisceration and splitting, flare fat was removed and weighed, and carcasses were weighed during the first hour *postmortem* (hot carcass weight).

In addition, on the day of slaughter, the following measurements (mm) were taken on the left half of the carcass:

- Minimum backfat (MFatloin) covering the *Gluteus medius* muscle measured at the midline using a ruler
- Minimum distance (ZPmuscle) from the dorsal edge of the vertebral canal to the cranial end of the *Gluteus medius* muscle measured along the midline using a ruler
- Backfat thickness (Fat34LV) measured 8 cm away from the midline, between the third and fourth lumbar vertebrae, with the Fat-O-Meat'er II (FOM) (Frontmatec A/S, Smørum, Denmark) semi-automatic probe
- Backfat thickness (FatLR) measured 6 cm away from the midline, at the level of the last rib, with FOM
- Backfat thickness (Fat34LR) and muscle depth (Muscle34LR) measured 6 cm away from the midline, at the space between the third and fourth ribs, starting from the last rib, with FOM
- Carcass lean meat percentage was estimated using Spanish official FOM equation (Commission Implementing Decision (EU) 2020/113) using both Fat34LR and Muscle34LR as follows:

  Estimated carcass lean meat (%) = 69.592 - 0.741 × Fat34LR + 0.066 × Muscle34LR

The carcasses were kept in a chilling room for approximately 24 hours at 2-3ºC. After that time, the carcasses were weighed (cold carcass weight), and the following information was taken from the left carcass:

- Carcass length (cm) measured from the cranial border of the pubic symphysis to the recess of the first rib using a tape measure
- Loin length (cm) measured from the first lumbar vertebrae to the first cervical vertebrae
- Visual carcass conformation determined by a trained operator following the photographic model from the former EC Pig Grading Grid for type of muscularity (1 = very good conformation to 4 = very poor conformation)

The killing-out proportion (%) was calculated using the BW registered on arrival at the slaughterhouse and the hot carcass weight. Chilling losses (%) were calculated from the difference between the hot and cold carcass weights.

All left half carcasses were cut into 12 pieces following the European Reference Method (Walstra & Merkus, 1995) and the weight of each piece was determined. The proportions of the cuts of meat with respect to the whole carcass (g/kg) were calculated using the individual weights per carcass weight (considered as the sum of the weights after cutting). The subcutaneous fat of the loin, as well as the subcutaneous and intermuscular fat, the bone and the muscle of the ham, were weighed, and theses weights were used to calculate their proportion (g/kg) of the loin or of the ham.

2.4. Statistical analysis

Statistical analysis was performed using SAS (version 9.4, SAS Institute Inc., Cary, NC, USA). In the monitoring group, production and *in vivo* body composition data for the individual periods were analysed using a mixed model and including repeated measures with the GLIMMIX procedure. The model included period (30-70 kg, 70-100 kg, 100-120 kg), sex type (ST) (CM, IM, EM, and FE), and their interaction as fixed effects. Initial BW was used as a covariate if significant in the model ($P \leq 0.05$). The covariance matrix type used in the model was selected for each variable to present the lowest values of Akaike's information criterion (AIC) and the corrected AIC. The SLICEDIFF option was used for the comparison of least square means (LSMEANS). Production and body composition data of the finishing (70-120 kg) and the entire trial (30-120 kg) were analysed with the MIXED procedure and using a model that included ST as the main effect and initial BW as a covariate.

Slaughter and carcass 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 BW (i.e. killing-out, chilling losses, fat and muscle thicknesses and weight of carcass, cuts and tissues), 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. The pigs slaughtered at 30 kg were not included in the statistical analysis as there were no IM pigs in this group.

Tukey t-test was used to compare the adjusted LSMEANS values at the 0.05 significance level.

3. Results and discussion

3.1. Production traits and in vivo body composition

Results of productive performance and *in vivo* body composition evaluated at different periods of the trial are presented in Table 1. There was no difference for initial BW among the four ST, with an average of 31.8 kg. During the growing period (from 30 to 70 kg), CM had a higher ADFI compared to the other types, but no significant differences were found for ADG or FCR. The superior consumption of castrates agrees with previous research (Pauly et al., 2009; Fàbrega et al., 2010) and is directly linked to surgical castration at a young age that suppresses the production of testicular steroids and consequently modifies activity patterns and feed intake levels (Cronin et al., 2003). Subsequently, during the early finishing (from 70 to 100 kg), IM had a superior ADG than the other types and a higher ADFI than FE, with intermediate values in CM and EM. This finding is explained by the administration of the second immunocastration vaccine with which the sex steroid synthesis block is completed (Dunshea et al., 2001). Throughout the late finishing (from 100 to 120 kg), IM showed a higher ADG than CM and FE, and a higher ADFI than all the other types. Regarding the entire finishing (from 70 to 120 kg), in line with previous studies, IM showed a superior growth than the other sexes and a higher feed consumption than EM and FE (Zamaratskaia et al., 2008; Pauly et al., 2009; Fàbrega et al., 2010).

When the whole trial is considered (from 30 to 120 kg) (Table 1), ADG was higher in IM than in FE and EM, and ADFI was higher in IM and CM than in FE and EM. Nevertheless, no significant differences were found for FCR. Previous studies have also shown similar growth and feed consumption between IM and CM through the whole fattening period (Jaros et al., 2005; Fàbrega et al. 2010; Morales et al., 2010; Škrlep et al., 2010) as well as a similar performance between EM and FE (Fàbrega et al., 2010).

In terms of body composition, there was no difference for fat thickness among ST at 30 kg TBW, but CM showed greater values than IM and EM at 70 kg, and greater values than the other 3 sexes at 100 kg. At 120 kg, CM still had higher fat levels than EM and FE, but similar to IM. Such enhanced fat deposition in castrates and immunocastrates has been described in previous studies (Dunshea et al., 2001; Pauly et al., 2009; Fàbrega et al., 2010; Font-i-Furnols et al., 2012) and is linked to the change in metabolism towards increased fat synthesis after castration, whereas protein deposition remains similar (Batorek et al., 2012; Batorek-Lukač et al., 2016), in line with the similar muscle depth observed among sexes across the trial.

3.2. Slaughter performance and carcass characteristics

Details of slaughter performance and carcass traits evaluated at different moments along growth are shown in Table 2. No significant TBW × ST interaction was found for these traits. This result was unexpected and could be explained by a low sample size, especially at 70 kg and 100 kg TBW, and by a high variability in the experimental groups since, unlike for productive performance and *in vivo* body composition, different individual animals were evaluated at each slaughter point. Nevertheless, significant differences across ST and TBW were found. In detail, CM and FE presented higher carcass weight and killing-out percentages than IM, and EM showed intermediate and not statistically different values compared to the other sexes. Previous studies also reported lower killing-out percentages in immunocastrated pigs (Dunshea et al., 2001; Zamaratskaia et al., 2008; Pauly et al., 2009; Gispert et al., 2010; Morales et al., 2010; Font-i-Furnols et al., 2012; Aluwé et al., 2016). These authors associated this result with a higher weight of the digestive tract resulting from the superior feed intake of these pigs after the second vaccine dose, and of other visceral organs removed during carcass preparation mainly the liver and kidneys (Boler et al., 2014). In the present study, IM also showed heavier livers and kidneys than CM and FE (Table 5), mainly at 100 kg and 120 kg (i.e. after V2 application), which can explain the lower carcass killing-out percentage. However, the weight of white viscera, which comprises the stomach as well as the small and large intestine, were not significantly different among sexes.

In terms of subcutaneous fat thickness, carcasses of CM were fatter than those of EM at all anatomical locations (over the *Gluteus medius*, between the 3rd and 4th lumbar vertebra, at the last rib, and between the 3rd and 4th last ribs). Immunocastrated carcasses presented similar fat levels to EM and FE and lower than CM on the ham (MFatLoin, Fat34LV) and on the loin at the last rib level (FatLR), but intermediate and not statistically different on the loin between the 3rd and 4th last ribs (Fat34LR). These differences among sexes were constant along pig growth. Overall, these results are in accordance with previous studies (Gispert et al., 2010; Morales et al., 2010; Škrelp et al., 2010; Font-i-Furnols et al., 2012; Poklukar et al., 2021) and support the differential deposition rate of adipose tissue in IM pigs compared to the other sexes according to the anatomical location. Regarding muscle depth on the ham (MuscleZP) and carcass lean meat percentage, EM and FE were leaner than CM while IM were intermediate and not statistically different to the other sex types along growth. An intermediate position of vaccinated pigs in meat carcass at slaughter age was also reported by Morales et al. (2010) comparing the same four sexes, Pauly et al. (2009) comparing CM, IM and EM, and Font-i-Furnols et al. (2012) comparing CM, IM and FE. In contrast, Gispert et al. (2010) found a similar lean meat percentage in IM and CM pigs when slaughtered at 180 days of age, although this value was lower compared to that in EM and FE.

As expected, BW at slaughter, carcass weight, killing-out percentage and the length of carcass and loin significantly increased with increasing TBW, whereas visual carcass conformation decreased (Table 2). Likewise, all carcass fat and muscle thicknesses significantly increased with increasing TBW, whereas estimated lean content decreased.

3.3. Carcass cuts, tissues and internal organs

Tables 3 and 4 present carcass data relating to the weight (g) and the proportion (g/kg) of the different joints and tissues. The interaction TBW×ST was not significant for the weight and the proportion of the main primal cuts, although there were some differences across TBW and ST. Ham weight (g) and proportion (g/kg) were higher in FE than in the other sex types along the growth period studied (from 70 to 120 kg). Morales et al. (2011) also reported higher fresh and trimmed ham yield in FE than in CM, with intermediate yields for IM pigs. Moreover, ham composition varied across sexes: EM and FE had leaner hams (higher muscle proportion) than CM; CM had fatter hams (higher subcutaneous fat proportion) than the other 3 sexes; and EM had higher bone proportion than FE, with IM and CM in between. When considering the subcutaneous fat weight of the ham, immunocastrates showed a different pattern across TBW (TBW × ST interaction; Table 3). They showed a similar fat weight to EM and lower than CM at 100 kg, but an intermediate fat weight between CM and EM at 120 kg. All these characteristics of sex types should be considered when deciding the best process the ham should be subjected to, e.g. to be processed as fresh or cooked meat or to be cured or smoked, as well as in determining some crucial aspects of ham processing such as the amount of salt and other ingredients or the curing time (Lebret & Čandek-Potokar, 2022; Škrlep et al. 2016). Loin weight (g) was higher in CM and FE than IM with values for EM in between, but no differences were found for loin proportion (g/kg). In terms of loin composition, a higher subcutaneous fat proportion (g/kg) was found in CM compared to FE and EM, and IM values were in between. These differences were only observed at 120 kg for the subcutaneous fat weight (TBW × ST interaction; Table 3). Overall, these results correlate to those obtained for backfat thickness measured with a ruler and FOM at carcass level and can be explained by the distinct allometric growth of body and carcass fat tissue estimated by Carabús et al. (2017) and Zomeño et al. (2016), respectively, in the same four sex types. Belly weight and proportion were higher in CM compared to EM, with intermediate and similar values in IM and FE. The belly is currently one of the most appreciated cuts of pig carcasses in the Asiatic and North American countries (Choe et al., 2015; Nam et al., 2010; Soladoye et al., 2015), as well as in Europe especially in grilling season (Čitek et al., 2015). This fatty primal cut is the main raw material for bacon production, and, unlike other carcass cuts, its economic value has increased considerably over time (Sullivan, 2018; Sinfoporc, 2021). In the studies of Pauly et al. (2009) and Gispert et al. (2010), belly percentage was also higher in CM compared to EM, while IM had a similar belly percentage to EM in Pauly et al. (2009) and to CM in Gispert et al. (2010). In the case of the tenderloin, weights and proportions were higher in FE than in CM, with IM and EM in between.

When considering other cuts, EM pigs presented a higher proportion of front and hind shanks as well as of hand, foot and head proportions than CM and FE (Table 4). Castrates and FE, in turn, showed a higher proportion of the ventral part of the belly than EM. Castrates also had the highest cheek proportion at 120 kg, without significant differences with the other sexes at 70 kg or 100 kg. Comparisons with other studies are difficult because little information has been found for these cuts in pigs.

Differences across TBW were also found for the weight and the proportion of carcass joints and tissues. As expected, weights of all cuts and tissues increased with increasing TBW. Ham proportion did not significantly change, but bone proportion decreased from 70 to 100 kg, and, from 100 to 120 kg, muscle proportion decreased and subcutaneous fat proportion increased. Loin proportion increased from 70 to 100 kg and subcutaneous fat proportion increased with increasing TBW. These findings are consistent with the evolution of ham and loin and their fat content with animal age and body weight (Čandek-Potokar & Škrlep, 2012; Font-i-Furnols et al., 2015). Lastly, tenderloin proportion decreased from 100 to 120 kg. A reduction in the proportion of this cut was also observed by García-Macías et al. (1996) who compared pigs slaughtered at 90 and 120 kg.

The weight and proportions of other parts that do not belong to the reference carcass are presented in Table 5. During the growth period studied, castrates showed a higher flare fat proportion than in IM and EM, with FE being in between. These differences are in line with those obtained for carcass backfat thickness over the ham region. Lastly, IM pigs showed a higher proportion of red viscera compared to CM and FE. This finding is mainly due to the differences in liver and kidney weights with greater values in IM than in CM and FE. Boler et al. (2014) also reported heavier liver and kidneys in IM than in CM and Pauly et al. (2009) found a higher liver weight in IM compared to CM. The superior size of the liver in IM may be explained by the changes to the hormonal status that occurs in vaccinated pigs after the V2 and their consequent alteration in energy metabolism (Le Floc'h et al., 2019) with an increase in fat synthesis and deposition (Čandek-Potokar et al., 2017; Škrlep et al., 2020; Poklukar et al., 2021). In fact, the liver plays a key role in lipid metabolism (Nguyen et al., 2008), and although the adipose tissue is the main site for *de novo* fatty acid synthesis in pigs (O'Hea & Leveille, 1969), the liver is deeply involved in lipid synthesis and circulation. In this sense, when analysing the proportion of liver in relation to BW, CM and IM present similar values, which may support the relationship among castration (surgical or immune-mediated), lipid metabolism and the liver. The differences for kidney weight and proportion were lower, and, in any case, they may be relevant when comparing the 3 male types with FE.

Differences across TBW were also found for these traits. Flare fat, white and red viscera, and brain and tail weights increased with increasing TBW. However, white and red viscera, and brain and tail proportions decreased with increasing TBW, and only flare fat proportion increased. This last result was expected as body fatness increases along growth (Greenwood & Dunshea, 2009).

4. Conclusions

The sex type impacted production performance and body composition during the pig's growth. These changes also affected slaughter performance, the weight of internal organs, carcass composition in terms of fat and muscle content, and cut yield and composition. Therefore, it is important to select the most appropriate sex type to be reared, together with the target body weight, in order to obtain a carcass and/or a specific cut with the required characteristics for processing in the most efficient way. Complementary knowledge regarding carcass chemical composition and meat quality will be provided in an accompanying paper.

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.

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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 (DAAM Protocol number 5298).

Declaration of competing interest

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

Acknowledgments

This research was funded by the Spanish National Institute of Agricultural Research (INIA) (Project No. RTA2010-00014-00-00). INIA is also thanked for the scholarship for Anna Carabús. CERCA program from the Generalitat de Catalunya is also acknowledged. Cristina Zomeño has received funding from the Secretariat of Universities and Research (Government of Catalonia) and the Horizon 2020 programme of Research and Innovation of the European Union (grant agreement No 801370). The authors thank Albert Rossell, Agustí Quintana, Carles Francàs and Cecilia Pedernera for their valuable technical assistance.

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Tables

Table 1. Productive performance and in vivo body composition (least square means) of pigs according to sex type (ST) and recorded at various individual periods, during finishing and throughout the trial

	ST				*P-value*	RMSE
	CM	IM	EM	FE		
Pigs (n)	*12*	*12*	*11*	*12*		
Growing from 30 to 70 kg						
Initial body weight (kg)	32.1	31.2	32.3	31.4	0.292	0.20
Initial fat thickness[1] (mm)	8.30	7.95	7.86	8.23	<0.001	0.642
Average daily gain (kg/d)	1.21	1.12	1.13	1.09	<0.001	0.117
Average feed intake (kg/d)	2.05[a]	1.79[b]	1.85[b]	1.81[b]	<0.001	0.312
Feed conversion ratio	2.07	1.97	2.02	2.09	0.038	0.313
Finishing from 70 (V2) to 100 kg						
Initial body weight (kg)	71.5	71.8	72.3	70.8	0.292	0.20
Initial fat thickness[1] (mm)	9.25[a]	7.35[b]	7.65[b]	8.13[ab]	<0.001	0.642
Initial muscle depth[1] (mm)	47.66	47.25	49.73	49.08	0.290	0.549
Average daily gain (kg/d)	1.01[b]	1.24[a]	0.93[b]	0.89[b]	<0.001	0.117
Average feed intake (kg/d)	2.87[ab]	3.14[a]	2.86[ab]	2.33[b]	<0.001	0.312
Feed conversion ratio	2.79	2.50	2.96	2.51	0.038	0.313
Finishing from 100 to 120 kg						
Initial body weight (kg)	100.5	102.0	101.9	102.7	0.292	0.20
Initial fat thickness[1] (mm)	9.73[a]	7.66[b]	7.68[b]	7.45[b]	<0.001	0.642
Initial muscle depth[1] (mm)	55.58	56.08	56.45	58.25	0.290	0.549
Average daily gain (kg/d)	0.70[b]	0.91[a]	0.77[ab]	0.64[b]	<0.001	0.117
Average feed intake (kg/d)	2.87[b]	3.46[a]	2.63[b]	2.74[b]	<0.001	0.312
Feed conversion ratio	3.29	3.23	2.85	3.41	0.038	0.313
Finishing (from 70 to 120 kg)						
Average daily gain (kg/d)	0.97[b]	1.09[a]	0.94[b]	0.88[b]	<0.001	0.159
Average feed intake (kg/d)	2.61[ab]	2.80[a]	2.44[b]	2.29[bc]	<0.001	0.468
Feed conversion ratio	2.72	2.56	2.61	2.66	0.565	0.495
All the trial (from 30 to 120 kg)						
Days	92.2[b]	88.9[b]	95.0[ab]	102.2[a]	0.001	7.48
Average daily gain (kg/d)	0.97[ab]	1.02[a]	0.92[b]	0.88[b]	<0.001	0.076
Average feed intake (kg/d)	2.63[a]	2.60[a]	2.38[b]	2.31[b]	<0.001	0.190
Feed conversion ratio	2.73	2.54	2.60	2.61	0.222	0.214
Final body weight	120.6	120.3	120.6	121.4	0.292	0.20
Final fat thickness[1]	10.09[a]	9.06[ab]	7.39[b]	8.16[b]	<0.001	0.642
Final muscle depth[1]	59.92	60.83	58.64	60.92	0.290	0.549

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; V2 = second vaccination dose

[1] measured by ultrasounds at the last rib, 4–6 cm from the midline

[a,b,c] different superscripts within row indicate significant differences among ST ($P \leq 0.05$)

Table 2. Slaughter performance and carcass characteristics (least square means) 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*				
Body weight at slaughter (kg)	72.1	69.6	72.1	72.5	101.7	100.9	102.5	101.3	120.6	120.3	120.2	121.4	<0.001	0.302	0.582	1.54
Hot carcass weight (kg)	57.0	54.5	57.5	58.1	82.6	80.0	82.5	83.0	98.0	96.4	96.6	98.7	<0.001	0.004	0.794	0.66
Killing out (%)	80.2	78.4	80.4	80.9	81.4	80.3	81.2	82.3	81.8	80.6	80.9	81.6	0.001	0.004	0.526	1.10
Chilling loses (%)	2.7	2.5	2.6	2.5	2.2	2.6	2.5	2.1	2.2	2.4	2.6	2.4	0.072	0.100	0.065	0.54
Carcass length (cm)	75.8	73.4	75.9	76.8	82.6	82.6	82.7	83.9	85.6	86.3	85.9	86.7	<0.001	0.165	0.647	1.41
Loin length (cm)	77.1	74.6	77.4	78.3	83.6	84.3	83.6	84.9	87.7	88.5	88.7	89.1	<0.001	0.250	0.686	1.56
Visual conformation	2.50	2.75	2.75	3.00	2.50	2.50	2.80	2.50	2.17	2.33	2.63	2.00	0.004	0.287	0.502	0.251
Ruler measures at midline																
MFatLoin (mm)	8.5	6.3	6.3	8.3	15.0	8.8	7.8	11.5	18.1	15.4	11.4	15.0	<0.001	<0.001	0.191	1.72
MuscleZP (mm)	60.0	61.0	64.0	65.5	69.3	74.0	73.4	73.8	78.9	76.5	81.0	81.9	<0.001	0.008	0.568	2.07
Fat-O-Meat'er (FOM) measures																
Fat34LV (mm)	12.6	9.45	11.0	10.9	19.6	14.4	16.2	16.8	22.4	20.4	16.7	17.7	<0.001	0.002	0.151	1.78
FatLR (mm)	10.1	8.2	7.8	8.4	14.7	10.8	11.6	12.1	16.8	15.2	13.8	13.4	<0.001	0.001	0.623	1.51
Fat34LR (mm)	11.5	10.4	10.4	9.95	16.5	13.0	13.4	13.2	20.6	19.5	16.9	16.9	<0.001	0.005	0.461	1.65
Muscle34LR (mm)	48.6	44.6	46.5	45.9	56.9	59.4	59.4	60.8	61.8	61.5	62.9	65.3	<0.001	0.723	0.695	2.22
Estimated lean meat (%)	64.3	64.9	64.9	65.2	61.1	63.9	63.6	63.9	58.4	59.2	61.1	61.2	<0.001	0.028	0.630	2.70

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; MFatLoin = minimum fat thickness over the *Gluteus medius*; MuscleZP = thickness of *Gluteus medius* muscle; Fat34LV = fat thickness between the 3rd and 4th lumbar vertebrae; FatLR = fat thickness at the last rib level; Fat34LR = fat thickness between the 3rd and 4th last ribs; Muscle34LR= muscle thickness between the 3rd and 4th last ribs

Table 3. Weight (g) of carcass joints and tissues (least square means) 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*				
Left carcass weight	27922	26720	28170	28459	40460	39221	40405	40683	48009	47231	47315	48375	<0.001	0.004	0.794	660.3
Ham	7163	6861	7236	7389	10196	9748	9952	10575	11984	11785	11834	12657	<0.001	<0.001	0.706	21.1
Muscle	5417	5190	5615	5710	7540	7632	7733	8140	8590	8691	9120	9475	<0.001	0.002	0.699	22.6
Subcutaneous fat	871	810	740	843	1550[a]	1063[b]	1116[b]	1277[ab]	2084[a]	1770[b]	1409[c]	1881[ab]	<0.001	<0.001	0.002	14.6
Intermuscular fat	236	221	206	222	321	267	268	292	419	382	344	389	<0.001	0.091	0.952	8.0
Bone	639	641	675	614	786	786	835	866	890	942	961	912	<0.001	0.163	0.550	8.3
Loin	4374	4011	4510	4685	7345	6738	6775	7340	8810	8410	8233	8569	<0.001	0.009	0.237	23.3
Subcutaneous fat	725.0	594.8	663.5	760.2	1667	1158	1157	1291	2362[a]	2098[ab]	1696[c]	1779[bc]	<0.001	0.002	0.029	18.6
Shoulder	4080	3932	3987	4048	5745	5725	5788	5603	6672	6753	6947	6746	<0.001	0.710	0.719	18.3
Belly	2935	2547	2559	2724	4122	3982	3892	3885	5017	4861	4687	4799	<0.001	0.009	0.870	17.4
Tenderloin	398	397	445	451	585	612	587	638	642	642	689	678	<0.001	0.008	0.429	6.9
Neck	2533	2510	2619	2650	3506	3581	3571	3800	4297	4215	4390	4239	<0.001	0.356	0.643	16.0
Front shank	976	970	1018	1001	1370	1322	1490	1355	1592	1538	1620	1627	<0.001	0.003	0.262	8.9
Hind shank	623	652	672	626	833	825	955	869	932	977	1066	970	<0.001	<0.001	0.111	7.7
Ventral part of belly	1006[ab]	856[b]	943[ab]	1074[a]	1429	1278	1276	1270	1647[ab]	1556[bc]	1420[c]	1798[a]	<0.001	<0.001	0.017	12.1
Jawl	552	645	796	563	859	1011	972	843	1102	1077	1168	1114	<0.001	0.012	0.304	12.0
Cheek	714	682	703	778	1008	1013	1113	1007	1357[a]	1213[b]	1095[b]	1176[b]	<0.001	0.320	0.001	10.5
To ventral part of belly	408	341	348	293	560	530	600	661	781	750	693	794	<0.001	0.535	0.247	10.8
Hand	260	291	288	266	355	375	400	372	382	389	415	365	<0.001	<0.001	0.448	5.2
Foot	487	513	504	483	606	620	686	627	673	712	753	676	<0.001	0.001	0.315	6.7
Head	1371	1457	1482	1390	1850	1797	2073	1771	2047	2154	2250	2061	<0.001	0.001	0.442	12.6

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error

[a,b,c] different superscripts within row indicate significant differences among ST within TBW ($P \leq 0.05$). Only presented when *P-value* of TBW × ST ≤ 0.05

Table 4. Proportion (g/kg) of carcass joints and tissues (least square means) 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*				
Ham	256.7	256.7	256.7	259.5	251.9	248.6	250.6	260.1	249.7	249.5	250.1	261.7	0.088	0.004	0.714	0.74
Muscle	756.3	756.2	775.6	772.3	738.9	782.6	777.0	769.5	716.0	737.0	770.7	748.1	0.001	0.001	0.338	2.45
Subcutaneous fat	121.5	117.8	102.3	114.0	152.3	109.3	111.9	120.8	174.6	150.4	119.0	149.0	<0.001	<0.001	0.241	2.10
Intermuscular fat	33.0	32.3	28.6	30.2	31.7	27.5	27.0	27.7	35.2	32.5	29.0	30.8	0.186	0.154	0.997	0.63
Bone	89.2	93.7	93.6	83.5	77.1	80.6	84.1	81.9	74.3	80.1	81.4	72.1	<0.001	0.026	0.747	0.76
Muscle/Bone	8.50	8.14	8.36	9.35	9.59	9.83	9.36	9.49	9.74	9.28	9.53	10.43	<0.001	0.258	0.811	0.588
Loin	156.5	150.1	160.2	164.3	181.4	171.8	167.5	180.4	183.3	178.2	174.0	177.0	<0.001	0.093	0.319	1.05
Subcutaneous fat	164.3	148.2	147.2	160.3	225.7	171.6	170.8	175.6	264.2	249.2	205.3	206.9	<0.001	0.008	0.303	3.68
Shoulder	146.1	147.2	141.4	142.3	142.1	145.9	145.8	137.8	139.0	142.9	146.8	139.4	0.476	0.081	0.316	0.64
Belly	105.1	95.3	91.0	96.0	102.0	101.5	96.5	95.3	104.6	102.9	99.0	99.4	0.087	0.012	0.789	0.75
Tenderloin	14.3	14.9	15.8	15.8	14.5	15.6	14.6	15.7	13.4	13.6	14.6	14.0	<0.001	0.026	0.299	0.11
Neck	90.7	94.0	92.8	93.1	86.7	91.3	88.2	93.4	89.5	89.3	92.9	87.7	0.235	0.566	0.362	0.58
Front shank	34.9	36.3	36.2	35.2	33.9	33.7	36.9	33.3	33.2	32.6	34.2	33.6	<0.001	0.012	0.279	0.18
Hind shank	22.3	24.4	23.9	22.0	20.6	21.0	23.6	21.4	19.4	20.7	22.5	20.1	<0.001	<0.001	0.333	0.14
Ventral part of belly	36.0	32.0	33.5	37.7	35.4	32.6	31.5	31.2	34.3	33.0	30.0	37.2	0.175	0.003	0.065	0.33
Jawl	19.7[b]	24.1[ab]	28.2[a]	19.7[b]	21.3	25.8	24.0	20.8	23.0	22.8	24.7	23.0	0.863	<0.001	0.050	0.33
Cheek	25.6	25.5	25.0	27.3	24.9	25.8	27.8	24.7	28.3[a]	25.7[b]	23.2[b]	24.3[b]	0.708	0.701	0.002	0.24
To ventral part of belly	14.6	12.7	12.3	10.3	13.8	13.5	15.0	16.2	16.3	15.9	14.6	16.4	<0.001	0.765	0.220	0.27
Hand	9.3	10.9	10.2	9.4	8.8	9.6	9.9	9.2	8.0	8.2	8.8	7.5	<0.001	<0.001	0.258	0.07
Foot	17.5	19.2	17.9	17.0	15.0	15.8	17.0	15.4	14.0	15.1	15.9	14.0	<0.001	0.001	0.413	0.12
Head	49.1	54.5	52.6	48.9	45.7	45.	51.3	43.6	42.7	45.6	47.6	42.6	<0.001	<0.001	0.571	0.37

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error

[a,b] different superscripts within row indicate significant differences among ST within TBW ($P \leq 0.05$). Only presented when *P-value* of TBW × ST ≤ 0.05

Table 5. Weight (g) and proportion with respect to body weight (g/kg) of other parts that do not belong to the reference carcass presentation (least square means) 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*				
Weight (g)																
Flare fat	286	169	191	228	589	349	328	416	920	647	541	752	<0.001	<0.001	0.085	11.8
Brain	88	98	88	84	101	99	101	103	91	91	96	96	0.001	0.846	0.292	3.2
Cue	101	114	131	114	131	124	142	148	132	151	172	149	<0.001	0.048	0.821	5.6
White viscera	5185	4779	4829	5050	6162	6437	6035	6127	7151	7832	6772	7547	<0.001	0.265	0.444	27.2
Red viscera	3644	3901	3654	3633	4838	4703	4748	4627	4967	5463	5260	4964	<0.001	0.054	0.257	17.5
Tongue	207	225	232	201	302	314	324	319	343	348	403	385	<0.001	0.166	0.494	6.9
Heart	343	404	381	325	369	383	396	423	462	480	474	441	<0.001	0.253	0.368	31.5
Liver	1412	1379	1327	1302	1554	1737	1594	1493	1723	2017	1738	1667	<0.001	<0.001	0.102	12.1
Kidneys	294	331	291	278	352	387	382	356	376	423	453	367	<0.001	0.001	0.130	6.4
Proportion (g/kg)																
Flare fat	4.0	2.0	2.7	3.2	5.5	3.5	3.2	4.2	7.6	5.4	4.5	6.1	<0.001	<0.001	0.806	1.37
Brain	1.2	1.4	1.2	1.2	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	<0.001	0.604	0.105	0.10
Cue	1.4	1.7	1.8	1.6	1.3	1.2	1.4	1.4	1.1	1.3	1.4	1.2	<0.001	0.153	0.937	0.31
White viscera	71.9	64.3	67.1	67.7	60.5	63.8	58.9	59.2	59.2	65.3	57.2	61.9	0.011	0.619	0.509	7.34
Red viscera	50.5	55.7	50.7	48.8	45.4	46.6	46.3	44.4	41.2	45.5	43.8	41.7	<0.001	0.001	0.560	2.70
Tongue	2.9	3.2	3.2	2.8	2.5	3.1	3.2	3.1	2.8	2.9	3.3	3.1	0.917	0.071	0.660	0.44
Heart	4.8	5.8	5.3	4.5	3.6	3.8	3.9	4.2	3.8	4.0	3.9	3.7	<0.001	0.065	0.093	0.50
Liver	19.6	19.4	18.4	17.3	15.5	17.2	15.6	14.4	14.3	16.7	14.4	13.9	<0.001	<0.001	0.564	1.49
Kidneys	4.1	4.5	4.1	3.6	3.6	3.8	3.7	3.6	3.1	3.5	3.8	3.1	<0.001	0.006	0.275	0.39

CM = surgically castrated males; IM = immunocastrated males; EM = entire males; FE = females; RMSE = root mean square error; White viscera = pancreas + stomach + spleen + small intestine + large intestine; Red viscera = tongue + heart + liver + kidneys + lungs + bladder + trachea