Journal Pre-proof

Carcass quality of immunocastrated boars – A retrospective analysis of slaughterhouse data

Sophie Asanger, Mandes Verhaagh, Yury Zablotski, Sophie Gumbert, Mathias Ritzmann, Susanne Zöls

PII: S0309-1740(25)00087-7

DOI: https://doi.org/10.1016/j.meatsci.2025.109826

Reference: MESC 109826

To appear in: *Meat Science*

Received date: 4 November 2024

Revised date: 3 April 2025

Accepted date: 8 April 2025

Please cite this article as: S. Asanger, M. Verhaagh, Y. Zablotski, et al., Carcass quality of immunocastrated boars – A retrospective analysis of slaughterhouse data, *Meat Science* (2024), https://doi.org/10.1016/j.meatsci.2025.109826

Carcass quality of immunocastrated boars – A retrospective analysis of slaughterhouse data

Sophie Asanger[1], Mandes Verhaagh[2], Yury Zablotski[1], Sophie Gumbert[1], Mathias Ritzmann[1], Susanne Zöls*[1]

[1]Clinic for Swine at the Center for Clinical Veterinary Medicine, Ludwig-Maximilians-Universität München, Sonnenstraße 16, 85764 Oberschleißheim, Germany

[2] Thünen Institute of Farm Economics, Bundesallee 63, 38116 Braunschweig, Germany

*Corresponding Author: Susanne Zöls, Clinic for Swine at the Center for Clinical Veterinary Medicine, Ludwig-Maximilians-Universität München, Sonnenstraße 16, 85764 Oberschleißheim, Germany, s.zoels@lmu.de

Abstract

The aim of the study was to analyze the meat quality of immunocastrated (Improvac®, IC) male in comparison with female (GI), surgically castrated (BA) and entire male (EM) fattening pigs. In contrast to previous experimental studies, this analysis is based on slaughter data from routine slaughtering from one slaughterhouse (Germany), which offered farmers since 2018 the option of voluntarily supplying IC without the usual financial deduction for boars. Carcass parameters were assessed using AutoFOM III™. Until 2022, data from 1,736,684 pigs from 203 farms were available. After checking for completeness, plausibility and gender balance, slaughter data of 1,613,660 pigs with 434,479 IC from 182 farms remained for analysis. Number of IC slaughtered per year increased to 48 % during the study period and largely replaced BA animals (5.4 %) in 2022. Sex had the largest influence on the most important carcass parameters (e.g. lean meat percentage), while carcass weight was mainly influenced by the farm, but also by the change in the price mask. The carcass parameters of IC ranked mainly between GI and BA and within the acceptable range of slaughterhouse requirements, with IC tending to have values closer to GI. The analysis shows that the meat quality of IC animals can meet slaughterhouse requirements comparable to GI and BA. Considering the carcass parameters analyzed in this study immunocastration appears to be a sustainable and future-proof solution to the castration controversy and should be promoted through fair accounting of IC via the standard price masks for BA and GI.

Keywords

Immunocastration, GnRH Vaccine, Improvac®, vaccination, surgical castration, boar, gilts, carcass characteristics, primal pork cuts, AutoFOM III™

1 Introduction

The most mentioned reasons for castrating male pigs are to avoid the risk of boar taint and aggressive behavior but also to influence meat quality (Aluwé et al., 2022; Parois et al., 2017; Squires et al., 2020; Van den Broeke et al., 2022; Wesoly et al., 2015). As awareness of animal welfare issues grows, consumers increasingly reject pork from surgically castrated pigs due to concerns over pain and stress (Aluwé et al., 2020). To counteract this painful procedure, legislation in Germany has been changed and surgical castration without general anesthesia is no longer permitted since 2021 (TierSchG, 2021). However, it is estimated that in Germany approximately 80% of male fattening pigs, which equates to approximately 20 million, were still castrated in 2022 (De Briyne et al., 2016; Harlizius, 2022). Genetic selection and sperm sexing play a rather minor role (Spinaci et al., 2016; Zamaratskaia & Squires, 2009). Proven alternatives to surgical castration are currently boar fattening and immunological castration with an anti GnRH (gonadotropin-releasing factor) vaccine (von Borell et al., 2020).

The fattening of uncastrated male pigs differs significantly from that of early castrated ones, due to the early onset of sexual maturity in domestic pigs (Einarsson et al., 2009; França et al., 2000; Kubale et al., 2013; Parois et al., 2017). The anabolic effect of sex hormones increases feed conversion and influences both behavior and carcass composition towards a higher lean meat content (Bonneau et al., 2018; Li & Patience, 2017; Pauly et al., 2008; Prunier et al., 2013; Zöls et al., 2020). Several studies reported increasing boar-like behavior which can lead to more skin and penile lesions but also to reduced feed intake and daily weight gain during puberty in uncastrated pigs (Heyrman et al., 2019; Parois et al., 2017; Reiter et al., 2017; von Borell et al., 2020; Zöls et al., 2020). In addition, the testosterone-producing Leydig cells in boars also produce the pheromone androstenone from puberty onwards. This is deposited in the fatty tissue together with skatole, both of which are responsible for the development of boar taint (Fazarinc et al., 2023). However, concentrations of both compounds vary with age and hormonal status, as well as for example season and diet (Squires et al., 2020). For boar taint, threshold limits of androstenone and skatole are discussed but not commonly accepted. Measurement is also expensive and time-consuming, so slaughterhouses have relied on human nose-tests to detect tainted boars until now (Font-i-Furnols et al., 2020; Kress & Verhaagh, 2019; Squires et al., 2020). However, boar taint perception also varies between consumers depending on sex but also countries and eating habits (Font-i-Furnols, 2012). In 903 samples from Spanish slaughterhouses, about 10.2% of the entire male pigs showed values over high-level threshold for androstenone and/or for skatole (Borrisser-Pairó et al., 2016). In a study of 16,000 animals, Heyrman et al. (2021) calculated an average prevalence of 1.8 % of tainted boars, which can increase by up to 9.1 % between slaughter rounds within farms.

For immunological castration, the commercially available anti GnRH vaccine Improvac® (Zoetis Belgium SA, Louvain-la-Neuve, Belgium) consists of a synthetically produced GnRH analogue without hormonal function, which is conjugated with an immunogenic carrier protein (diphtheria toxoid) and the adjuvant diethylaminoethyl dextran (EMA, 2009). It triggers the humoral immune response against the body's own GnRH, which reversibly blocks the Hypothalamus-Hypophysis-Gonadal (HHG)-axis by inactivating GnRH. As a result, the Leydig cells are not stimulated and the formation of testicular steroids as well as androstenone in male pigs is reversibly inhibited (Bauer et al., 2008; Claus et al., 2008). First vaccination causes an initial immunological stimulation against body's own GnRH. The second vaccination at least 6 to 4 weeks before slaughter leads to a strong formation of GnRH neutralizing antibodies after one to two weeks (Claus et al., 2008; Zamaratskaia, Rydhmer, et al., 2008; Zöls et al., 2020). Due to low sex hormone concentrations after complete immunization, the behavior and metabolism of immunocastrated male pigs increasingly resemble that of castrated animals with simultaneous avoidance of surgical intervention (Claus et al., 2007; Kubale et al., 2013; Pesenti Rossi et al., 2022). Influenced by vaccination schedule but also other factors like genetic or diet, this can lead to higher intramuscular fat with a lower proportion of polyunsaturated fatty acid (PUFA) and lower lean meat content than in carcasses of entire male pigs (Aluwé et al., 2016; Poklukar et al., 2021; Škrlep, Tomašević, et al., 2020; van den Broeke et al., 2016; Zöls et al., 2020; Zacharias et al., 2019). Moreover, the reduced formation of androstenone leads to an increased skatole degradation capacity and due to both effects, a lower risk for boar taint (Squires et al., 2020).

The wide variety of pork products, the specific quality requirements for pork used in processing and the growing public interest in sustainable production make the demands on pork a complex, multidimensional challenge (Lebret & Čandek-Potokar, 2022). Castration of piglets without anesthesia has long been a common practice in pig farming to avoid boar taint in meat and to produce uniform carcasses. However, due to increasing society awareness of animal welfare, the practice of castration without anesthesia has been heavily criticized in many European countries, leading to agrarian policy measures aimed at establishing alternatives in modern pork production (Aluwé et al., 2020). These methods aim either to ensure effective pain relief during castration or to avoid the surgical procedure altogether. However, the various methods differ significantly in their effects on animal welfare, practicality, and especially economic feasibility, necessitating a thorough analysis to make an informed decision (Bonneau & Weiler, 2019).

In this context, there is still limited knowledge of the economic implications of the various alternatives, in particular immunocastration, boar fattening, and castration under general anesthesia. The challenge is not only to assess carcass quality and the economic profitability of these methods but to analyze gender-specific differences in carcass composition and their impact on market structures. This also results in separate payment systems for entire male pigs, which include price reductions for their carcasses (de Roest et al., 2009; Kress & Verhaagh, 2019; Verhaagh & Deblitz, 2019). A standard payment system is based on the carcass lean meat content or carcass weight. However, in most German slaughterhouses, commercial value is recorded by AutoFOM III™ system and calculated based on carcass composition using an estimated formula, last evaluated in 2011 with carcasses from female pigs and barrows. AutoFOM III™ measures carcass and cuts composition continuously by ultrasound image analysis (Commission Implementing Decision 2011/258/EU, Frontmatec, 2020; Höreth, 2013). Parameters recorded by AutoFOM III™ include the following characteristics: hot carcass weight (kg), lean meat content (%), lean meat content of the belly (%), fat thickness (mm), muscle thickness (mm), as well as the primary pork cuts: belly (kg), ham with bones (kg), lean and boneless ham (kg), loin with bones (kg), lean and boneless loin (kg), shoulder with bones (kg), lean and boneless shoulder (kg) (Frontmatec, 2020). Payment for the carcass is based on defined carcass characteristics (Commission Implementing Decision 2011/258/EU; Kress et al., 2020) that are considered in the slaughterhouse's price mask (see Fig S1 Supplementary). Therefore, the hormonal status and thus the gender of the animals play an important role in determining the commercial value (Kress & Verhaagh, 2019; Zöls et al., 2020).

To address this gap, the present retrospective, cross-sectional observational study analyzed the slaughter data from 1.7 million pigs and over 400,000 immunocastrated (IC) animals. The aim of this retrospective cross-sectional observational study was to compare carcass composition by gender while investigating factors such as hot carcass weight, farm, slaughter date, and the development of individual carcass parameters of the slaughter data from routinely slaughtered immunocastrated (IC) in relation to surgically castrated (BA) male, female (GI) and entire male (EM) pigs during the evaluation period. The study aims to provide a better understanding of the economic and production-related impacts of the various alternatives to piglet castration.

2 Material and Methods

Since 2018, the slaughterhouse Heinz Tummel GmbH & Co. KG (Schöppingen, Germany) (Tummel) has been offering the option of slaughtering immunocastrated (Improvac®) instead of surgically castrated male pigs (BA) without the usual financial deduction for uncastrated boars (EM). The same estimation formulae for AutoFOM III™ and without adapting price mask was used for the immunocastrated animals (IC) (Branscheid et al., 2011; Kress et al., 2020). Farmers were therefore free to decide whether they wanted to deliver surgically or immunocastrated male pigs to the slaughterhouse. In return, they had to confirm that Improvac® had been administered to each immunocastrated animal in this slaughter group in accordance with the manufacturer's recommendations and they had to label them with an additional letter in the stamp identification. The present evaluation considers data of all pigs from farms that delivered at least one IC animal to Tummel between January 2, 2018, and November 24, 2022.

2.1 Data collection and preparation

Slaughter data was available from 203 commercial farms that delivered a total of 1,736,684 fattening pigs to slaughterhouse Tummel. The carcass composition of each pig was assessed using AutoFOM III^{TM} system. Therefore several carcass characteristic and primal pork cut parameters were calculated with the estimated formula which was last evaluated by the Max-Rubner-Institute (Kulmbach, Germany) in 2011 (Branscheid et al., 2011) (Table 1).

Furthermore, a unique identification number, the farm of origin (which was blinded), the animal's original sex (male or female), the corresponding stamp identification, and the date of slaughter were assigned to each animal in the data set. Additionally, the complaints documented during the carcass evaluation were allocated to the animals via numerical codes and employed to exclude those with, for instance, rejected carcasses. Information on housing conditions, feeding regime, detailed genetics, exact age and date of vaccination of the animals was not available for this data analysis.

All these data were collected during daily operations at Tummel and subsequently processed by the data processing company SLA Software Logistik Artland GmbH (Quakenbrück, Germany). Data were then provided in the form of five Microsoft® Excel files for the years 2018, 2019, 2020, 2021 and 2022. The data were prepared using Microsoft® Excel. The original sex designation, either "male" or "female," in conjunction with the additional letter used for stamp identification, was transcoded to one of four new sex groups “immunocastrate (IC)”, “surgical castrate (BA)”, “entire male (EM)” or “gilt (GI)” (Table 2). Furthermore, the new parameters “rating points” and “rating points per kg hot carcass weight (rating points per kg)” were calculated in accordance with the price mask of the slaughterhouse Tummel GmbH & Co. KG (Supplementary material: Figure S1).

The conduct of the study was classified by the Ethics Committee of the Faculty of Veterinary Medicine of the Ludwig-Maximilians-University in Munich as unobjectionable under animal welfare law and approved with the number "AZ 325-02-09-2022".

2.2 Data cleaning

Following data preparation, data were checked for completeness, plausibility and suitability using a predefined nine-step procedure (Table 3). Animals with invalid data (missing, incorrect or no plausible data e.g. 0% lean meat content) or animals that were rejected at the slaughter line were excluded (step 1, 9). Moreover, animals that did not meet the requirements for or were not categorized as fattening pigs, were also excluded (step 2, 3 & 5). As the GI are intended to serve as a control group within the farms for the IC animals, farms with a very unbalanced sex ratio, especially between GI and IC, were excluded. According to this procedure, 123,024 individual animals as well as 21 entire farms of the original data set with 1,736,684 pigs from 203 farms were excluded. Accordingly, 1,613,660 pigs from 182 farms remained in the data set for the following analysis.

2.3 Statistical analyses

The data of 1,613,660 fattening pigs from 182 farms were analyzed with "R" statistical software (version 4.3.1 (2023-06-16)). The average number of animals per farm was described by Mean (Me) ± Standard deviation (SD) and the carcass characteristics and primal pork cuts was described by estimated Mean (eM) ± Standard error (S) and Median (M) ± Inter-Quartile-Range (Iq). Differences in the average number of animals per farm and carcass parameters between sex groups were based on the estimated least-squares marginal means (emmean) of a linear mixed-effect model with the influence factor "sex" and the random effect of "farm". Additionally, in each sex group, differences in hot carcass weight of animals slaughtered before or after the change of slaughterhouse´s price mask (27 February 2020, Fig S1 Supplementary) were calculated based on a linear mixed-effect model with the influence factor "price mask” and the random effect of "farm". Due to the large number of observations, the p-value threshold for significance was adjusted for large sample size to the p-value of 0.0004 according to Good (1988). The parameters lean meat content, fat thickness, rating points per kg, belly lean meat content, lean and boneless ham and hot carcass weight were selected because of their economic importance for further investigations. A classical linear model was used to determine the influence (effect size) of the factor “sex”, “farm”, “slaughter year” and “hot carcass weight” on the selected variables with the sum square from the ANOVA Table being the only effect size. The time course of the carcass parameters and contrasts between the sex groups divided into the five years of the study period were determined using linear mixed-effect models with the interactions between the influencing factors (sex, slaughter year) and the random effect farm.

3 Results

3.1 Number of slaughtered animals

A total of 1,613,660 slaughtered fattening pigs (49,0 % GI) from 182 farms met the inclusion criteria (Table 3). The 822,749 male pigs were subdivided into the following categories: 26.9 % IC, 22.7 % BA and 1.4 % EM (Table 4). All 182 analyzed farms delivered GI and IC from 2018 to 2022. In contrast to IC and GI, BA animals were only brought to Tummel for slaughter by 180 of the 182 farms. During the evaluation period, the average number of IC and BA animals delivered per farm did not differ significantly in contrast to the number of GI animals delivered, which was approximately twice as high. A total of 85 of the 182 farms delivered EM (263 ± 719 animals) during the evaluation period.

3.2 Descriptive and inferential statistics of carcass parameters

Considering the farm as a random factor, the analysis revealed that almost all carcass characteristics and primal pork cuts differed significantly between all sex groups, except for the *belly* (EM vs. GI) and the *shoulder with bones* (EM vs. BA) (Table 5). The estimated mean values for *lean meat content*, *belly lean meat content*, *fat thickness* and *muscle thickness* of ICs were all significantly lower than those of the GI and EM groups and higher than the mean value of the BA group (except for *muscle thickness*). The estimated mean primal pork cut parameters from IC were consistently between the higher values of GI and lower values of BA, with the exception for the *belly*. The carcass weight of IC was the highest, followed by GI, BA and EM, but the differences between BA, IC and GI were within a narrow range of 0.21 to 0.63 kg (Table 5). On 27 February 2020, the slaughterhouse introduced a new price mask with a higher optimal range for slaughter weight (see Fig.1 S 1 Supplementary). When comparing animals slaughtered before (n = 591,196) and after (n = 1,022,464) the 27 February 2020, the hot carcass weight increased significantly in all sex groups (Fig.1).

The categorization of the results of each individual of the 1.6 million analyzed pigs into the ranges of the slaughterhouse´s price mask reveals, that 68.0 % of the IC animals exhibited optimal belly lean meat content (53 - 61.99 %) compared to 69.4 % of BA or 57.9 % of GI animals. The percentage of animals that reached the optimum ranges for lean and boneless ham was similar for IC and BA (81.4 % and 81.9 % respectively), but only 78.4 % met this range in GI group. In contrast, the proportion of animals in the hot carcass weight optimum (90 - 107 kg) was highest in the BA (86.4 %), followed by GI (85.5 %) and IC (83,5 %). The percentages of animals exhibiting values below and above the optimum for further parameters are presented in Table 6. The EM animals are included for the sake of completeness in this table, but it should be noted that these animals were not paid using the specified price mask. Therefore, the proportion of EM animals that met the optimum ranges should not be overrated. To compare the entire carcasses of different sex groups (in terms of weight and carcass composition), Rating points were calculated for each animal based on the ranges defined by the slaughterhouse. The mean of the calculated Rating points of GI was the highest, followed by IC, while BA showed the lowest values also when taking the weight into account (rating points per kg) (Table 5).

3.3 Influence on carcass parameters & Development of the parameters

Comparing the factors “sex”, “farm”, “year” (of slaughter) and “hot carcass weight (factor)” on the selected parameters, it was confirmed, that “sex” had the highest influence on lean meat content, belly lean meat content, fat thickness and rating points per kg followed by “farm”. In contrast, lean and boneless ham was most influenced by “hot carcass weight (factor)”, followed by “farm”. Interestingly, the highest influence on the parameter hot carcass weight was “farm” followed by “year” of slaughter. (Table 7).

The development over the time (year of slaughter) of the selected parameters is shown in Fig. 2 as violin plots divided by sex groups. Fig. 3 shows differences between the sex groups in the corresponding period. From 2018 to 2022, increases in lean meat content, belly lean meat content, lean and boneless ham, rating points per kg and hot carcass weight (except EM in 2022) as well as decreases in fat thickness of varying intensity occurred in all sex groups (Table S2 Supplementary). Until 2020, IC had the highest mean hot carcass weights. However, following a change in price mask procedures in February 2020, GI and BA exhibited higher values in slaughter years 2021 and 2022. In 2022, GI had the highest hot carcass weight. For this parameter, the differences between IC and BA were smallest followed by BA and GI and IC and GI. Lean meat content and belly lean meat content increased in all sex groups during the study period with EM showing highest values followed by GI, IC. Consistently, BA had the highest mean fat thickness followed by IC and GI in descending order. In all years the contrasts IC - GI was lower than the contrasts BA - GI and EM - IC except in 2018.

On average, the heaviest lean and boneless ham over the study period was recorded by GI. BA had the lowest weight, with a non-significant difference from IC in 2018 (p=0.0185) and from EM in 2022 (p=0.4721). The differences BA - GI hardly changed over study period and were more widespread than IC - GI and the lower IC - BA. For GI highest rating points per kg were calculated with followed by EM, IC, and BA. The contrasts of rating points per kg between BA - GI were more widespread than IC - GI except in 2018. Overall, the contrasts between sex groups in the analyzed parameters minimized over the course of the study period, except for EM - GI.

4 Discussion

The aim of this study was to investigate the carcass quality of IC, GI, BA and EM but in contrast to previous studies, using field data rather than experimental data. These originate from slaughterhouse Tummel that, as of 2018, allows its pig-supplying farmers to supply IC on the condition that IC have been classified using the predetermined estimation formulas for the AutoFOM III™ classification system for female and surgically castrated fattening pigs and without financial deductions, as is widely used in entire male fattening pigs (Branscheid et al., 2011; Kress & Verhaagh, 2019). The EM animals are included for the sake of completeness, but it should be noted that these animals were not paid on the basis of the price mask provided. Therefore, the overall assessment for EM should be interpreted with caution.

In the data set provided by the slaughterhouse, each slaughtered animal was assigned the carcass parameters recorded with AutoFOM III™ as well as the slaughter date, number, stamp number, farm and sex (male / female), as well as the results of ante- and post-mortem inspection. As this is a retrospective analysis, it was not possible to include information on the time of vaccination, slaughter age, feeding regime, housing conditions and exact genetics in the analysis, as this information was not requested from the slaughterhouse. In contrast to experimental studies, when IC are mostly immunized according to a defined study design and reared under standardized conditions, this dataset contains data where it was the farmers' voluntary decision to vaccinate or surgically castrate male pigs to deliver them together with the females. Since only farms were included that provided an approximately balanced ratio of male and female animals for slaughter, the female animals can also serve as a comparative variable for the farm and year of slaughter as influencing factors. Accordingly, the dataset contained slaughter data from 1,7 million pigs of 203 farms between 2018 and 2022.

Prior to processing and analysis, the blinded (farm & sex) data set was checked to the predefined exclusion criteria to exclude incomplete and incorrect data from the animals and to avoid bias in the results. For example, animals with incomplete/implausible data (lean meat content of 0 %, missing or ambiguous gender, etc.) were omitted, as measurement or assignment errors could be assumed and to avoid distorting the results. Moreover, nonfattening hybrid were excluded as well as hermaphrodites or cryptorchids, as it was the aim to analyze slaughter data of BA and IC fattening pigs. Even though AutoFOM III™ classification system set weight limits between 50 and 120 kg (Implementing Decision 2011/258/EU) weight limits were adapted, according to the experience of the slaughterhouse for reliable data measurements, and animals between 75 and 130 kg were included.

As a result, a total of 123,024 animals from 21 farms were excluded and 1,613,660 slaughtered fattening pigs (45.5 % GI, 26.9 % IC, 22.7 % BA, 1.4 % EM) from 182 farms met the inclusion criteria for statistical analysis. The balanced gender ratio was also confirmed in the total delivery quantities per farm. Although slaughtered GI per year increased slightly from 2018 to 2022, the number of slaughtered BA decreased from more than 100,000 slaughtered animals per year to less than 20,000 animals in 2022. Meanwhile, the number of ICs slaughtered per year increased especially from 2021 to more than 170,000 animals in 2022. Considering it was a voluntary offer from the slaughterhouse to supply IC instead of BA at any time, the development of the number of slaughtered IC emphasizes that it was an advantageous offer, especially since 2021 when the castration ban without anesthesia took place (TierSchG, 2021). This paper for the first time compares this high amount of data from immunocastrated animals reared under filed conditions and can thus give a hint of how to deal with IC instead of BA.

Comparing the factors sex, farm, year (of slaughter), and hot carcass weight (factor) on the selected carcass parameters, it was confirmed that sex had the greatest influence on lean meat content, belly lean meat content, fat thickness, and rating points per kg. These results are consistent with the meta-analysis by Poulsen Nautrup et al. (2018) and further results, which describe the influence of sex on fattening performance, but also on the proportion of primal pork cuts in fattening pigs due to the presence or absence of steroidal sex hormones (Kress et al., 2020; Van den Broeke et al., 2022; Zöls et al., 2020). Discussing these influencing factors, it must be taken into account that factors like feeding, husbandry and genetics and, in particular, fattening period, slaughter age and time of vaccination weren't considered even if it can be assumed that these also influence the results (Kress et al., 2020; Poulsen Nautrup et al., 2018). To take this limitation into account, care was taken when selecting the farms to ensure that each farm supplied both male and female animals to assume that at least effects such as feeding, genetics and husbandry similarly influence gender groups in a farm. However, as the farmers can directly control fattening duration and slaughter age, this aspect remains a limitation. Thus, no conclusions can be drawn from immunocastration on fattening performance in this evaluation. Accordingly, in this data set, hot carcass weight was the parameter most strongly influenced by farm, followed by year of slaughter and least by sex. However, the results show that the farms cluster the animals mainly by slaughter weight, as possibly this is the simplest (only) parameter that can be constantly checked and influenced by the farmers during the fattening period, and it seems that they orientate themselves towards the optimal weight of the price mask between 90 und 107 kg hot carcass weight, among other things (Niemann, 2017). The fact that hot carcass weight limit was set at values between 75 and 130kg, instead of standard values of 50 to 120kg for which the AutoFOM III™ system was originally verified, may also have influenced the results. The year of slaughter was the second largest influencing factor on carcass warm weight after the farm, which is likely to be caused by the change price mask to higher hot carcass weights. But also the simultaneous start of the COVID pandemic, which led to temporary closures of slaughterhouses may have had an influence (Niemann, 2021). In contrast to the carcass characteristics, the lean and boneless ham was not primarily influenced by sex, but by hot weight (Fischer et al., 2006; Xie et al., 2023). Comparative data to the development of the carcass parameters are lacking, as previous studies have not analyzed the development of carcass parameters in a gender comparison over a period of several years. In summary, the evaluation indicates that gender and thus also immunocastration has a stronger influence on carcass parameters like lean meat content and belly lean meat content and fat thickness, while individual cuts are more likely to be influenced by the hot carcass weight.

Hot carcass weight increased in all gender groups over the analyzed years probably because of better payment for higher carcass weights at the slaughterhouse (Niemann, 2017). Of the IC animals, 83.5% were within the optimum hot carcass range of the slaughterhouse´s price mask and 5.2% were above. The percentage of GI and BA in the optimal range was slightly higher (85.5% and 86.4% respectively) and lower above the optimal range (3.8% and 2.9% respectively). As previously discussed, farmer can influence hot carcass weight with the decision when to slaughter the pigs more directly in contrast to the sex. The lower hot carcass weight of EM as described in other studies is mainly due to the shorter fattening period to minimize the risk of boar taint and also problematic behavior of entire males (Fàbrega et al., 2010; Kress et al., 2020; Poulsen Nautrup et al., 2018; Škrlep, Poklukar, et al., 2020; von

Borell et al., 2020). Fattening period of IC can be prolonged depending on the time of the 2nd vaccination as they have little to no risk of boar taint. Therefore, animals can be slaughtered with higher weights as payment increases with higher weights within the optimum area. As the metabolic pattern after the second vaccination is similar to that of castrates due to the decrease in testosterone levels a higher feed intake and therefore daily weight gain can be expected (Andersson et al., 2012; Kress et al., 2019; Pauly et al., 2009; Zamaratskaia, Andersson, et al., 2008; Zöls et al., 2020). Moreover, hot carcass weight as a factor had the main influence on the primal pork cuts.

The carcass parameters relevant for payment were on average within the optimum range of the price mask for all sex groups. In belly lean meat content there was a tendency for the IC values to be closer to GI group. However, when looking at the proportion of animals in the optimal range, the proportion of IC animals was comparable to that of BA animals, which was the highest. The classification of the IC between BA and GI is due to the fact that the physiology, fattening performance and carcass composition of the immunocastrated male pigs remain the same as those of the intact boars until the second vaccination and that they only adapt to the physiology and carcass of a castrated male pig after immunological castration (Andersson et al., 2012; Claus et al., 2007). This effect on carcass composition can be influenced by the timing of the second vaccination (Andersson et al., 2012; Zöls et al., 2020). These results are in line with further results under farm conditions (Kress et al., 2020) but also experimental studies (Tavarez et al., 2014; Zöls et al., 2020) when e.g. lean meat content was highest in GI and EM followed by IC with lowest in BA. This can be explained by the anabolic metabolism due to elevating testosterone but also estrogen levels with beginning puberty during fattening period which influence protein biosynthesis and degradation and promote protein incorporation (Claus et al., 1994). In surgical castrates, this effect is absent due to the removal of the gonads and the absence of pubertal development, whereas in immunocastrates, production is maintained until the time of the second immunization and thereby influencing the body composition of the animals (Claus et al., 1994; Squires et al., 2020).

Hormone status was also reflected in comparing the differences of the sex groups from 2018 to 2022. GI and EM, with physiological hormone levels throughout the fattening period, showed the smallest differences of lean meat content, while IC was always between EM or GI and BA from 2019 onwards. The reduction in the differences over the study period could also be due to improved management (feeding, vaccination) (Andersson et al., 2012; Niemann, 2021).

Both the optimum range according to the price mask for belly lean meat content (53 % to 61.99 %) and the classification system for carcasses in Germany (SchwHKlV (2022)) indicate that, in addition to a homogeneous carcass with good cut weights, a high lean meat content is desired (Ellies-Oury et al., 2020; Hilgers, 2016; Kress et al., 2020; Westfleisch, 2000). Concerning belly lean meat content, 68.0 % of IC animals and 69.4 % of BA met the optimum area defined by price mask. This emphasizes the results of the mean value comparisons and confirms that IC is comparable to BA in meeting the requirements of the slaughterhouse. Interestingly only 57.9 % of GI met this optimum range. These results under farm condition are similar to others under experimental conditions (Fuchs et al., 2009; Gispert et al., 2010; Pauly et al., 2009; Zamaratskaia, Rydhmer, et al., 2008, Kress et al., 2020) as well as those of the meta-analyses by Batorek et al. (2012) and Poulsen Nautrup et al. (2018). The increase in the payment-relevant parameters lean and boneless ham, lean and boneless loin, lean and boneless shoulder, belly/belly lean meat content and, conversely, the decrease in undesirable fat thickness and moreover, the decrease in sex differences indicate that a learning effect took place between 2018 and 2022, particularly in fattening IC animals. Since the ICs were grouped between the BAs and GIs, it would seem sensible to estimate and pay the ICs using the same formula and price mask. If immunocastrates were billed using the boar mask, they would be rated lower, even though they are superior to entire males (Kress & Verhaagh, 2019).

Except for belly, a similar sequence of primal pork cuts by sex groups was observed. GI, followed by IC, had also the heaviest loin with bones, lean and boneless loin, ham with bones, lean and boneless ham, shoulder and lean and boneless shoulder, while BA had the lightest. According to the literature, anabolic metabolism also leads to a higher proportion of bone, rind and tendons (Bauer & Judas, 2014; Dobrowolski et al., 1995). This is why the differences between IC and EM reduces in parameters lean and boneless ham, lean and boneless loin und lean and boneless shoulder. These results were also corroborated by several authors (Batorek et al., 2012; Fischer et al., 2006; Fuchs et al., 2009; Gispert et al., 2010; Pauly et al., 2009)(Kress et al., 2020; Škrlep, Poklukar, et al., 2020). Overall, around 80 % of the animals of all sex groups met the optimal lean and boneless ham weight. In contrast, the proportion of animals that had the optimal lean and boneless loin weight fluctuated by around 20 % from 57.7 % (GI) to 79.3 % (BA) with proportion of ICs in-between (68.4 %). Nevertheless, EM had the lowest ham with bones in the present study possibly because of a shorter fattening period. As slaughter weight had the main influence on lean and boneless ham, not the anabolic metabolism of EM alone affects this parameter (Fischer et al., 2006; Latorre et al., 2004).

During the included years of slaughter, fat thickness decreased on average in all sex groups, with the greatest reduction in IC and BA. As the market demands a lean carcass and values it more highly, it seems logical that farms try to optimize the carcasses of their animals accordingly with the help of management measures (feeding, vaccination timing, etc., which information is not available in the study) (Hilgers, 2016; Kress et al., 2020; SchwHKlV, 2022). However, the influence of sex was strongest in the present study, and EM with highest anabolic metabolism followed by GI and IC showed the lower fat thickness than BA. Poulsen Nautrup et al. (2018) reports a reduction in the differences in fat measurements between immunocastrates and surgically castrated animals with a longer interval between second vaccination and slaughter, as the period in which the immunized animals exhibit the metabolism of a castrate is extended.

In contrast to the individual parameters recorded by AutoFOM III™, the consideration of Rating points enables the slaughterhouses to analyze the entire carcass (Frontmatec, 2020; Hilgers, 2016; Westfleisch, 2000). Overall, in this study, the Rating points and rating points per kg reflected the tendency of the individual carcass parameters. Thus, IC with the second highest Rating points and rating points per kg ranked on average behind GI, while BA and EM achieved a lower score. Only EM compensated for the lower Rating points by correcting with hot carcass weight. However, it must be noted that the price mask used as the basis for the calculation did not apply to EM. These were assessed using a separate mask. Therefore, this overall assessment for the EM should be interpreted with caution and serves only as a guide. As each slaughterhouse has its own requirements for the animals and therefore has different price masks, the Rating points and rating points per kg calculated based on the slaughterhouses price mask in this study, are only comparable within the animals slaughtered at this slaughterhouse, but not between different ones (C. Niemann, 2017). The calculation did not consider the slaughterhouse-specific, economic deductions and surcharges for too high or too low hot carcass weights.

Studies have already confirmed that, from an animal welfare perspective, immunocastration is a largely painless and animal welfare friendly alternative to surgical castration (Bonneau & Weiler, 2019; Steybe et al., 2021; von Borell et al., 2020). The frequently expressed concerns of consumers have not been confirmed in various studies and often appear to be overestimated (Aluwé et al., 2020; Lin-Schilstra et al., 2022; Lin-Schilstra & Fischer, 2022; Mancini et al., 2017). The effectiveness of the method when used correctly has also been confirmed many times, albeit mostly under standardized test conditions. To the best of our knowledge, our study is the first analysis of more than 1.6 million slaughter data with more than 400,000 IC animals from routine slaughtering in Germany. The decision to vaccinate and administer the vaccine was made by farmers, with economic considerations playing a crucial role in their choices. The ban on piglet castration without anesthesia, which came into force in Germany in 2021 (TierSchG, 2021), may also have forced the decision towards an alternative without surgical castration. The increasing number of IC animals slaughtered compared to the decreasing number of BA and EM animals in the present study also provides an indication of the cost-effectiveness of the method for the farmer. Moreover, the evaluation of the slaughter data showed that in addition to sex or the decision to castrate, the type of housing also has an influence on carcass composition and is even the most important factor for carcass weight. The data revealed that IC animals are classified between GI and BA animals in most carcass parameters. Furthermore, the carcass composition of IC animals was found to fully meet the requirements of the slaughterhouses. The results of this work with regard to carcass parameters are reflected in the results of the '100,000 Improvac® animals' project by Niemann (2021), are in line with the core results of the 'Kiel Declaration' (Krieter et al., 2023) and confirm former results mostly from experimental studies (Kress & Verhaagh, 2019; Poklukar et al., 2021; Poulsen Nautrup et al., 2024; Seiquer et al., 2019; Škrlep, Poklukar, et al., 2020; Škrlep, Tomašević, et al., 2020; Zacharias et al., 2019).

This retrospective cross-sectional observational study on carcass parameters from slaughter data of routinely reared and slaughtered IC animals fills a gap and shows that, considering numerous publications on animal welfare, consumer acceptance and economic efficacy, this method seems to be a suitable solution to the castration controversy. It emphasizes that immunologically castrated (IC) pigs should be promoted through fair accounting via the standard price masks for surgically castrated (BA) and female (GI) pigs.

Financial support statement

This work was supported by Zoetis Deutschland GmbH, Berlin, Germany.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Special thanks to Reinhard Daldrup and Tummel slaughterhouse Heinz Tummel GmbH & Co. KG (Schöppingen, Germany) for providing this data and to the data processing company SLA Software Logistik Artland GmbH (Quakenbrück, Germany).

5 References

Aluwé, M., Degezelle, I., Depuydt, L., Fremaut, D., Van den Broeke, A., & Millet, S. (2016). Immunocastrated male pigs: effect of 4 v. 6 weeks time post second injection on performance, carcass quality and meat quality. *Animal : an international journal of animal bioscience*, *10*(9), 1466-1473. https://doi.org/10.1017/s1751731116000434

Aluwé, M., Heyrman, E., Almeida, J. M., Babol, J., Battacone, G., Citek, J., Font, I. F. M., Getya, A., Karolyi, D., Kostyra, E., Kress, K., Kusec, G., Morlein, D., Semenova, A., Škrlep, M., Stoyanchev, T., Tomašević, I., Tudoreanu, L., Van Son, M., . . . Egea, M. (2020). Exploratory survey on european consumer and stakeholder attitudes towards alternatives for surgical castration of piglets. *Animals : an open access journal from MDPI*, *10*, Article 1758. https://doi.org/10.3390/ani10101758

Aluwé, M., Heyrman, E., Kostyra, E., Żakowska-Biemans, S., Almeida, J., Citek, J., Font-i-Furnols, M., Moreira, O., Zadinová, K., Tudoreanu, L., Lin-Schistra, L., & Van den Broeke, A. (2022). Consumer evaluation of meat quality from barrows, immunocastrates and boars in six countries. *Animal : an international journal of animal bioscience*, *16*(3), Article 100455. https://doi.org/10.1016/j.animal.2022.100455

Andersson, K., Brunius, C., Zamaratskaia, G., & Lundström, K. (2012). Early vaccination with Improvac(R): effects on performance and behaviour of male pigs. *Animal : an international journal of animal bioscience*, *6*(1), 87-95. https://doi.org/10.1017/S1751731111001200

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 : an international journal of animal bioscience*, *6*(8), 1330-1338. https://doi.org/10.1017/S1751731112000146

Bauer, A., & Judas, M. (2014). Schlachtkörperqualität von Mastebern in Vergleich zu Sauen und Börgen. *Züchtungskunde*, *86*(5/6), 374-389. https://www.zuechtungskunde.de/artikel.dll/bauer-et-al_gyydsmbsguya.pdf

Bauer, A., Lacorn, M., Danowski, K., & Claus, R. (2008). Effects of immunization against GnRH on gonadotropins, the GH-IGF-I-axis and metabolic parameters in barrows. *Animal : an international journal of animal bioscience*, *2*(8), 1215-1222. https://doi.org/10.1017/S1751731108002346

Bonneau, M., Čandek-Potokar, M., Škrlep, M., Font-i-Furnols, M., Aluwé, M., & Fontanesi, L. (2018). Potential sensitivity of pork production situations aiming at high-quality products to the use of entire male pigs as an alternative to surgical castrates. *Animal : an international journal of animal bioscience*, *12*(6), 1287-1295. https://doi.org/10.1017/S1751731117003044

Bonneau, M., & Weiler, U. (2019). Pros and Cons of Alternatives to Piglet Castration: Welfare, Boar Taint, and Other Meat Quality Traits. *Animals : an open access journal from MDPI*, *9*(11). https://doi.org/10.3390/ani9110884

Borrisser-Pairó, F., Panella-Riera, N., Zammerini, D., Olivares, A., Garrido, M. D., Martínez, B., Gil, M., García-Regueiro, J. A., & Oliver, M. A. (2016). Prevalence of boar taint in commercial pigs from Spanish farms. *Meat Science*, *111*, 177-182. https://doi.org/10.1016/j.meatsci.2015.10.001

Branscheid, W., Judas, J., & Höreth, R. (2011). Classification of pig carcases: New estimation formulas and new grading apparatuses. *Mitteilungsblatt Fleischforschung Kulmbach*, *50*(191), 9-28. https://www.openagrar.de/receive/import_mods_00002089

Claus, R., Lacorn, M., Danowski, K., Pearce, M. C., & Bauer, A. (2007). Short-term endocrine and metabolic reactions before and after second immunization against GnRH in boars. *Vaccine*, *25*(24), 4689-4696. https://doi.org/10.1016/j.vaccine.2007.04.009

Claus, R., Rottner, S., & Rueckert, C. (2008). Individual return to Leydig cell function after GnRH-immunization of boars. *Vaccine*, *26*(35), 4571-4578. https://doi.org/10.1016/j.vaccine.2008.05.085

Claus, R., Weiler, U., & Herzog, A. (1994). Physiological aspects of androstenone and skatole formation in the boar-A review with experimental data. *Meat Science*, *38*(2), 289-305. https://doi.org/10.1016/0309-1740(94)90118-X

Commission Implementing Decision 2011/258/EU of 27 April 2011 amending Decision 89/471/EEC authorising methods for grading pig carcasses in Germany (notified under document C(2011) 2709) (Only the German text is authentic), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0258

De Briyne, N., Berg, C., Blaha, T., & Temple, D. (2016). Pig castration: will the EU manage to ban pig castration by 2018? *Porcine Health Management*, *2*(1), Article 29. https://doi.org/10.1186/s40813-016-0046-x

de Roest, K., Montanari, C., Fowler, T., & Baltussen, W. (2009). Resource efficiency and economic implications of alternatives to surgical castration without anaesthesia. *Animal : an international journal of animal bioscience*, *3*(11), 1522-1531. https://doi.org/10.1017/S1751731109990516

Dobrowolski, A., Höreth, R., & Branscheid, W. (1995). Der Schlachtkörperwert von Ebern und Börgen und Probleme der Klassifizierung. *Mitteilungsblatt Fleischforschung Kulmbach*, *109*, 6-13. https://www.openagrar.de/receive/openagrar_mods_00001328

Einarsson, S., Andersson, K., Wallgren, M., Lundström, K., & Rodriguez-Martinez, H. (2009). Short- and long-term effects of immunization against gonadotropin-releasing hormone, using Improvac, on sexual maturity, reproductive organs and sperm morphology in male pigs. *Theriogenology*, *71*(2), 302-310. https://doi.org/10.1016/j.theriogenology.2008.07.022

Ellies-Oury, M.-P., Hocquette, J.-F., Chriki, S., Conanec, A., Farmer, L., Chavent, M., & Saracco, J. (2020). Various statistical approaches to assess and predict carcass and meat quality traits. *Foods*, *9*(4), Article 525. https://doi.org/10.3390/foods9040525

EMA. (2009). *Improvac®*. Retrieved from https://www.ema.europa.eu/en/medicines/veterinary/EPAR/improvac. Accessed September 23., 2024

Fàbrega, E., Velarde, A., Cros, J., Gispert, M., Suárez, P., Tibau, J., & Soler, J. (2010). Effect of vaccination against gonadotrophin-releasing hormone, using Improvac®, on growth performance, body composition, behaviour and acute phase proteins. *Livestock Science*, *132*(1), 53-59. https://doi.org/10.1016/j.livsci.2010.04.021

Fazarinc, G., Batorek-Lukač, N., Škrlep, M., Poklukar, K., Van den Broeke, A., Kress, K., Labussière, E., Stefanski, V., Vrecl, M., & Čandek-Potokar, M. (2023). Male Reproductive Organ Weight: Criteria for Detection of Androstenone-Positive Carcasses in Immunocastrated and Entire Male Pigs. *Animals : an open access journal from MDPI*, *13*(12). https://doi.org/10.3390/ani13122042

Fischer, K., Lindner, J. P., Judas, M., & Höreth, R. (2006). Schlachtkörperzusammensetzung und Gewebebeschaffenheit von schweren Schweinen – I. Mitteilung: Material und Methoden, Mastleistung, Schlachtkörperzusammensetzung und Teilstückanteile. *Archiv Tierzucht Dummerstorf*, *49*(3), 269-278. https://aab.copernicus.org/articles/49/269/2006/aab-49-269-2006.pdf

França, L. R., Silva, V. A., Jr., Chiarini-Garcia, H. l., Garcia, S. K., & Debeljuk, L. (2000). Cell Proliferation and Hormonal Changes During Postnatal Development of the Testis in the Pig. *Biology of Reproduction*, *63*(6), 1629-1636. https://doi.org/10.1095/biolreprod63.6.1629

Font-i-Furnols, M. (2012). Consumer studies on sensory acceptability of boar taint: a review. *Meat Science*, *92*(4), 319-329. https://doi.org/10.1016/j.meatsci.2012.05.009

Font-i-Furnols, M., Martín-Bernal, R., Aluwé, M., Bonneau, M., Haugen, J. E., Mörlein, D., Mörlein, J., Panella-Riera, N., & Škrlep, M. (2020). Feasibility of on/at Line Methods to Determine Boar Taint and Boar Taint Compounds: An Overview. *Animals : an open access journal from MDPI*, *10*(10), Article 1886. https://doi.org/10.3390/ani10101886

Frontmatec. (2020). Fully Automatic Ultrasonic Carcass Grading AutoFom III™. Retrieved 06.03.2024, from https://www.frontmatec.com/media/4966/frontmatec-instruments-autofom-_application-note_v1-0-2020_web.pdf

Fuchs, T., Nathues, H., Koehrmann, A., Andrews, S., Brock, F., Sudhaus, N., Klein, G., & grosse Beilage, E. (2009). A comparison of the carcase characteristics of pigs immunized with a ‘gonadotrophin-releasing factor (GnRF)’ vaccine against boar taint with physically castrated pigs. *Meat Science*, *83*(4), 702-705. https://doi.org/10.1016/j.meatsci.2009.08.007

Gispert, M., 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

Good, I. J. (1988). The interface between statistics and philosophy of science. *Statistical science*, *3*(4), 386-397. https://projecteuclid.org/journals/statistical-science/volume-3/issue-4/The-Interface-Between-Statistics-and-Philosophy-of-Science/10.1214/ss/1177012754.full

Harlizius, J. (2022, July). Einsatz von Isofluran zur Narkose von Saugferkeln durch Sachkundige. Das Verfahren ist in der Praxis angekommen! 11. Leipziger Tierärztekongress, Leipzig.

Heyrman, E., Kowalski, E., Millet, S., Tuyttens, F. A. M., Ampe, B., Janssens, S., Buys, N., Wauters, J., Vanhaecke, L., & Aluwe, M. (2019). Monitoring of behavior, sex hormones and boar taint compounds during the vaccination program for immunocastration in three sire lines. *Research in Veterinary Science*, *124,* 293-302. https://doi.org/10.1016/j.rvsc.2019.04.010

Hilgers, J. (2016). *Wie kann der Schlachtkörper optimiert werden?* Retrieved from https://viehvermarktung-online.de/Downloads/LZ_13_2016_S38_S43.pdf. Accessed March 06., 2024

Höreth, R. (2013). AutoFom-I und AutoFom-III im Praxisvergleich. *Mitteilungsblatt Fleischforschung Kulmbach*, *52*(202), 221-231. https://www.openagrar.de/servlets/MCRFileNodeServlet/Document_derivate_00000951/202_B03_Hoereth-1.pdf

Kress, K., Hartung, J., Jasny, J., Stefanski, V., & Weiler, U. (2020). Carcass Characteristics and Primal Pork Cuts of Gilts, Boars, Immunocastrates and Barrows Using AutoFOM III Data of a Commercial Abattoir. *Animals : an open access journal from MDPI*, *10,* Article 1912. https://doi.org/10.3390/ani10101912

Kress, K., Millet, S., Labussière, É., Weiler, U., & Stefanski, V. (2019). Sustainability of Pork Production with Immunocastration in Europe. *Sustainability*, *11*(12), Article 3335. https://doi.org/10.3390/su11123335

Kress, K., & Verhaagh, M. (2019). The Economic Impact of German Pig Carcass Pricing Systems and Risk Scenarios for Boar Taint on the Profitability of Pork Production with Immunocastrates and Boars. *Agriculture, 9*(9), Article 204. https://doi.org/10.3390/agriculture9090204

Krieter, J., Mörlein, D., Pritschau, D., Spieker, C., Erdmann, S., & Tummel, R. (2023). *Kieler Erklärung zur Immunkastration als Alternative zur chirurgischen Ferkelkastration*. Retrieved from https://www.rind-schwein.de/brs-news/kieler-erklaerung-zur-immunkastration-als-alternat.html. Accessed September 05., 2024

Kubale, V., Batorek, N., Škrlep, M., Prunier, A., Bonneau, M., Fazarinc, G., & Čandek-Potokar, M. (2013). Steroid hormones, boar taint compounds, and reproductive organs in pigs according to the delay between immunocastration and slaughter. *Theriogenology, 79*(1), 69-80. https://doi.org/10.1016/j.theriogenology.2012.09.010

Latorre, M. A., Lázaro, R., Valencia, D. G., Medel, P., & Mateos, G. G. (2004). The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. *Journal of Animal Science*, *82*(2), 526-533. https://doi.org/10.2527/2004.822526x

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

Li, Q., & Patience, J. F. (2017). Factors involved in the regulation of feed and energy intake of pigs. *Animal Feed Science and Technology*, *233*, 22-33. https://doi.org/10.1016/j.anifeedsci.2016.01.001

Lin-Schilstra, L., Backus, G., Snoek, H., & Mörlein, D. (2022). Consumers' view on pork: Consumption motives and production preferences in ten European Union and four non-European Union countries. *Meat Science*, *187*, Article 108736. https://doi.org/10.1016/j.meatsci.2022.108736

Lin-Schilstra, L., & Fischer, A. R. H. (2022). Paradoxical consumers in four European countries: Meat-eating justification and willingness to pay for meat from animals treated by alternatives to surgical castration. *Meat Science*, *188*, Article 108777. https://doi.org/10.1016/j.meatsci.2022.108777

Mancini, M. C., Menozzi, D., & Arfini, F. (2017). Immunocastration: Economic implications for the pork supply chain and consumer perception. An assessment of existing research. *Livestock Science*, *203*, 10-20. https://doi.org/10.1016/j.livsci.2017.06.012

Niemann, C. (2017). *Schlachthof Tönnies mit neuer Ebermaske.* Retrieved from https://www.bwagrar.de/Schlachthof-Toennies-mit-neuer-Ebermaske,QUlEPTU0NjM4NDcmTUlEPTE2MjkyNQ.html. Accessed February 27., 2024

Niemann, C. (2021). *Projekt 100.000 Improvac®-Tiere - Auswertung der Schlachtdaten und Hinweise zur Fütterung*. Retrieved from https://www.youtube.com/watch?v=VkY3RW7fo7Q. Accessed July 7., 2024

Parois, S., Larzul, C., & Prunier, A. (2017). Associations between the dominance status and sexual development, skin lesions or feeding behaviour of intact male pigs. *Applied Animal Behaviour Science*, *187*, 15-22. https://doi.org/10.1016/j.applanim.2016.12.001

Pauly, C., Spring, P., O'Doherty, J. V., Ampuero Kragten, S., & Bee, G. (2008). Performances, meat quality and boar taint of castrates and entire male pigs fed a standard and a raw potato starch-enriched diet. *Animal : an international journal of* *animal bioscience*, *2*(11), 1707-1715. https://doi.org/https://doi.org/10.1017/S1751731108002826

Pauly, C., Spring, P., O'Doherty, J. V., Ampuero Kragten, S., & Bee, G. (2009). Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac®) and entire male pigs and individually penned entire male pigs. *Animal : an international journal of animal bioscience*, *3*(7), 1057-1066. https://doi.org/10.1017/S1751731109004418

Pesenti Rossi, G., Dalla Costa, E., Filipe, J. F. S., Mazzola, S. M., Motta, A., Borciani, M., Gastaldo, A., Canali, E., Pilia, F., Argenton, M., Caniatti, M., Pecile, A., Minero, M., & Barbieri, S. (2022). Does Immunocastration Affect Behaviour and Body Lesions in Heavy Pigs? *Veterinary Science*, *9*(8), Article 410. https://doi.org/10.3390/vetsci9080410

Poklukar, K., Čandek-Potokar, M., Vrecl, M., Batorek-Lukač, N., Fazarinc, G., Kress, K., Weiler, U., Stefanski, V., & Škrlep, M. (2021). The effect of immunocastration on adipose tissue deposition and composition in pigs. *Animal : an international journal of animal bioscience*, *15*(2), Article 100118. https://doi.org/10.1016/j.animal.2020.100118

Poulsen Nautrup, B., Van Vlaenderen, I., Aldaz, A., & Mah, C. K. (2018). The effect of immunization against gonadotropin-releasing factor on growth performance, carcass characteristics and boar taint relevant to pig producers and the pork packing industry: A meta-analysis. *Research in Veterinary Science*, *119*, 182-195. https://doi.org/10.1016/j.rvsc.2018.06.002

Poulsen Nautrup, B., Van Vlaenderen, I., Mah, C. K., & Aldaz, A. (2024). Using an economic simulation model to identify key drivers of profitability and estimate the environmental sustainability impact of immunization against gonadotropin-releasing factor (GnRF) in male and female pigs intended for market. *Research in Veterinary Science*, *168*, 105154. https://doi.org/10.1016/j.rvsc.2024.105154

Prunier, A., Brillouët, A., Merlot, E., Meunier-Salaün, M. C., & Tallet, C. (2013). Influence of housing and season on pubertal development, boar taint compounds and skin lesions of male pigs. *Animal : an international journal of animal bioscience*, *7*(12), 2035-2043. https://doi.org/10.1017/S1751731113001596

Reiter, S., Zöls, S., Ritzmann, M., Stefanski, V., & Weiler, U. (2017). Penile Injuries in immunocastrated and entire male pigs of one fattening farm. *Animals : an open access journal from MDPI*, *7*, Article 71. https://doi.org/10.3390/ani7090071

SchwHKlV, Schweineschlachtkörper-Handelsklassenverordnung in der Fassung der Bekanntmachung vom 16. August 1990 (BGBl. I S. 1809), die zuletzt durch Artikel 5 der Verordnung vom 10. März 2022 (BGBl. I S. 428) geändert worden ist, (2022). https://www.gesetze-im-internet.de/hdlklschwv_1986/SchwHKlV.pdf

Seiquer, I., Palma-Granados, P., Haro, A., Lara, L., Lachica, M., Fernández-Fígares, I., & Nieto, R. (2019). Meat quality traits in longissimus lumborum and gluteus medius muscles from immunocastrated and surgically castrated Iberian pigs. *Meat Science*, *150*, 77-84. https://doi.org/10.1016/j.meatsci.2018.12.004

Škrlep, M., Poklukar, K., Kress, K., Vrecl, M., Fazarinc, G., Batorek Lukac, N., Weiler, U., Stefanski, V., & Candek-Potokar, M. (2020). Effect of immunocastration and housing conditions on pig carcass and meat quality traits. *Translational Animal Science*, *4*(2), Article txaa055. https://doi.org/10.1093/tas/txaa055

Škrlep, M., Tomašević, I., Mörlein, D., Novaković, S., Egea, M., Garrido, M. D., Linares, M. B., Peñaranda, I., Aluwé, M., & Font-i-Furnols, M. (2020). The use of pork from entire male and immunocastrated pigs for meat products—An overview with recommendations. *Animals : an open access journal from MDPI*, *10*, Article 1754. https://doi.org/10.3390/ani10101754

Spinaci, M., Perteghella, S., Chlapanidas, T., Galeati, G., Vigo, D., Tamanini, C., & Bucci, D. (2016). Storage of sexed boar spermatozoa: Limits and perspectives. *Theriogenology*, *85*(1), 65-73. https://doi.org/10.1016/j.theriogenology.2015.05.018

Squires, E. J., Bone, C., & Cameron, J. (2020). Pork production with entire males: Directions for control of boar taint. *Animals : an open access journal from MDPI*, *10*, Article 1665. https://doi.org/10.3390/ani10091665

Steybe, L., Kress, K., Schmucker, S., & Stefanski, V. (2021). Impact of Housing Condition on Welfare and Behavior of Immunocastrated Fattening Pigs (Sus scrofa domestica). *Animals : an open access journal from MDPI*, *11*(3), Article 618. https://doi.org/10.3390/ani11030618

Tavarez, M. A., Puls, C. L., Schroeder, A. L., & Dilger, A. C. (2014). Effects of immunocastration and time after second Improvest dose on adipose tissue fatty acid profile of finishing barrows. *Journal of Animal Science*, *92*(8), 3736-3744. https://doi.org/10.2527/jas.2013-7523

TierSchG, Tierschutzgesetz in der Fassung der Bekanntmachung vom 18. Mai 2006 (BGBl. I S. 1206, 1313), das zuletzt durch Artikel 105 des Gesetzes vom 10. August 2021 (BGBl. I S. 3436) geändert worden ist, (2021). https://www.gesetze-im-internet.de/tierschg/BJNR012770972.html

Van den Broeke, A., Aluwé, M., Kress, K., Stefanski, V., Škrlep, M., Batorek, N., Ampe, B., & Millet, S. (2022). Effect of dietary energy level in finishing phase on performance, carcass and meat quality in immunocastrates and barrows in comparison with gilts and entire male pigs. *Animal : an international journal of animal bioscience*, *16*(1), Article 100437. https://doi.org/10.1016/j.animal.2021.100437

van den Broeke, A., Leen, F., Aluwé, M., Ampe, B., Van Meensel, J., & Millet, S. (2016). The effect of GnRH vaccination on performance, carcass, and meat quality and hormonal regulation in boars, barrows, and gilts. *Journal of Animal Science*, *94*(7), 2811-2820. https://doi.org/10.2527/jas.2015-0173

Verhaagh, M. (2024). Betriebswirtschaftliche Auswirkungen von Alternativen zur betäubungslosen Ferkelkastration. *Georg-August-Universität, Göttingen*, http://dx.doi.org/10.53846/goediss-10907.

Verhaagh, M., & Deblitz, C. (2019). *Wirtschaftlichkeit der Alternativen zur betäubungslosen Ferkelkastration – Aktualisierung und Erweiterung der betriebswirtschaftlichen Berechnungen, Thünen Working Paper 110*. https://www.thuenen.de/media/publikationen/thuenen-workingpaper/ThuenenWorkingPaper_110.pdf

von Borell, E., Bonneau, M., Holinger, M., Prunier, A., Stefanski, V., Zöls, S., & Weiler, U. (2020). Welfare aspects of raising entire male pigs and immunocastrates. *Animals : an open access journal from MDPI*, *10*, Article 2140. https://doi.org/10.3390/ani10112140

Wesoly, R., Jungbluth, I., Stefanski, V., & Weiler, U. (2015). Pre-slaughter conditions influence skatole and androstenone in adipose tissue of boars. *Meat Science*, *99*, 60-67. https://doi.org/10.1016/j.meatsci.2014.08.015

Westfleisch. (2000). *Mit AutoFOM in ein neues Zeitalter*. Retrieved from https://www.westfleisch.de/fileadmin/Bilder/03_Landwirtschaft/03.04_Info_Landwirte/2000/Info_Landwirte_2000_November_Dezember_Special_Web_Final.pdf. Accessed March 3., 2024

Xie, L., Qin, J.-t., Rao, L., Cui, D.-s., Tang, X., Xiao, S.-j., Zhang, Z.-y., & Huang, L.-s. (2023). Effects of carcass weight, sex and breed composition on meat cuts and carcass trait in finishing pigs. *Journal of Integrative Agriculture*, *22*(5), 1489-1501. https://doi.org/10.1016/j.jia.2022.08.122

Zacharias, B., Reiter, S., Schrade, H., Zacharias, T., Ritzmann, M., Schütz, A., Andrée, S., Zimmermann, S., & Zöls, S. (2019). GnRH - Vakzination von Mastebern und verschiedene Futterfettquellen. *Tieraerztliche Umschau*, *74*, 2-11. https://www.openagrar.de/receive/openagrar_mods_00054704

Zamaratskaia, G., Andersson, H. K., Chen, G., Andersson, K., Madej, A., & Lundström, K. (2008). Effect of a gonadotropin-releasing hormone vaccine (Improvac) on steroid hormones, boar taint compounds and performance in entire male pigs. *Reproduction in Domestic Animals*, *43*(3), 351-359. https://doi.org/10.1111/j.1439-0531.2007.00914.x

Zamaratskaia, G., Rydhmer, L., Andersson, H. K., Chen, G., Lowagie, S., Andersson, K., & Lundström, K. (2008). Long-term effect of vaccination against gonadotropin -releasing hormone, using Improvac, on hormonal profile and behaviour of male pigs. *Animal Reproduction Science*, *108*(1-2), 37-48. https://doi.org/10.1016/j.anireprosci.2007.07.001

Zamaratskaia, G., & Squires, E. J. (2009). Biochemical, nutritional and genetic effects on boar taint in entire male pigs. *Animal : an international journal of animal bioscience*, *3*(11), 1508-1521. https://doi.org/10.1017/S1751731108003674

Zöls, S., Reiter, S., Ritzmann, M., Weiss, C., Numberger, J., Schutz, A., Lindner, P., Stefanski, V., & Weiler, U. (2020). Influences of immunocastration on endocrine parameters, growth performance and carcass quality, as well as on boar taint and penile injuries. *Animals : an open access journal from MDPI*, *10*, Article 346. https://doi.org/10.3390/ani10020346

Table 1 Carcass composition parameters recorded using AutoFOM III^{TM} system and calculated with the estimated formula evaluated by the Max-Rubner-Institute (Kulmbach, Germany) divided into carcass characteristic and primal pork cut parameters (Branscheid et al., 2011).

Carcass characteristic parameters:		**Primal pork cut parameters:**	
belly lean meat content	(%)	belly	(kg)
fat thickness	(mm)	lean and boneless ham	(kg)
hot carcass weight	(kg)	lean and boneless loin	(kg)
lean meat content	(%)	lean and boneless shoulder	(kg)
muscle thickness	(mm)	loin with bones	(kg)
		ham with bones	(kg)
		shoulder with bones	(kg)

Table 2 Definition and coding of the sex groups (immunocastrate (IC), gilt (GI), barrow (BA) and entire male (EM))

Sex group	**Definition**	**transcoding** (original sex + additional letter in stamp identification)
Immunocastrate (IC)	Male fattening pigs administered GnRH vaccine Improvac® (Zoetis®) according to manufacturer's recommendation	"male" with additional letter R or Y
Gilt (GI)	Intact female fattening pigs	"female" without additional letter Z
Surgical castrate (BA)	Surgically castrated male fattening pigs	"male" without additional letter R, Y or Z
Entire male (EM)	Intact male fattening pigs	"male" with additional letter Z

Table 3 Reason, definition and number of excluded individuals and farms of the predefined nine-step exclusion procedure for completeness, plausibility and study suitability testing of fattening pigs slaughtered from 02.01.2018 to 24.11.2022 at the slaughterhouse Heinz Tummel GmbH & Co. KG (Schöppingen, Northern Germany).

	Reason	Definition	n excluded animals (farms)	n excluded farms (animals*)
Complete dataset with 1,736,684 animals from 203 farms				
1	missing data / data from rejected or non-fattening pigs	*missing data, pigs not meeting the requirements (rejected carcasses, entire males from non-fattening boar farms, cryptorchidism, hermaphrodites; body weight: <75kg or >130kg; private slaughter)*	19,949* (200)	1 (336*)
2	sows & suckling pigs	*pigs marked as breeding sows & suckling pigs*	17 (9)	
3	multiplier farms	*multiplier farms without comparable fattening pig genetics*		3 (22,972)
4	no IC delivery	*no delivery of IC during the study period*		9 (22,216)
5	different genetics	*farms without comparable fattening pig genetics*	19,349 (2)	
6	<5% IC in total supply	*extremely little IC supplied (reliability and comparability questionable)*		5 (33,400)
7	<20% male in total supply	*unbalanced sex ratio ≠ typical fattening farm*		1 (2,874)
8	>80% male in total supply	*unbalanced sex ratio ≠ typical fattening farm*		2 (2,235)
9	no plausibility	*unplausible values*	12 (11)	
Adjusted dataset with 1,613,660 animals from 182 farms				

*324 animals were excluded at both, individual and farm level, and are therefore included in both categories.

Table 4 Number (n) / percentage (%) of animals slaughtered per year and in total and mean ± standard deviation (M±S) & median ± interquartile range (Md±IQ) of animals slaughtered per farm, broken down by sex group (immunological castrates (IC), gilts (GI), barrows (BA) and entire males (EM)).

		Sex group				
		GI **n** [%]	**IC** **n** [%]	**BA** **n** [%]	**EM** **n** [%]	**all** **n**
year	**2018**	135,097 [57.6]	52 [0.2]	116,679 [44.6]	9,636 [3.6]	**261,464**
	2019	148,614 [53,0]	1,966 [0.7]	121,620 [43.3]	8,277 [3.0]	**280,477**
	2020	164,056 [49,8]	79,535 [24.1]	81,994 [24.9]	3,774 [1.2]	**329,359**
	2021	181,055 [46,8]	179,349 [46.3]	26,359 [6.8]	479 [0.1]	**387,242**
	2022	162,089 [45.6]	173,577 [48.9]	19,228 [5.4]	224 [0.1]	**355,118**
total animals		**790,911** [49.0]	**434,479** [26.9]	**365,880** [22.7]	**22,390** [1.4]	**613,660**
from farms		**182** [100]	**182** [100]	**180** [98.9]	**85** [46.7]	**82**
n animals per farm	*M±S*	4,346 ± 3,781	2,387 ± 2,050	2,033 ± 2,197	263 ± 719	
	Md±IQ	3,253 ± 5,010	1,861 ± 2,722	1,320 ± 2,877	34 ± 115	

Table 5 AutoFOM III™ data (Estimated Mean ± Standard Error (eM±S) & Median ± interquartile range (M±Iq)) of carcass characteristics and primal pork cuts of immunocastrates (IC), gilts (GI), barrows (BA) and entire males (EM). Significant differences between sex groups are indicated.

Parameter		Sex group (number of animals)			
		IC (n=434,479)	**GI** (n=790,911)	**BA** (n=365,880)	**EM** (n=22,390)
CARCASS CHARACTERISTICS					
Lean meat content (%)	*eM±S*	61.70 ± 0.06^{c}	62.75 ± 0.06^{b}	59.68 ± 0.06^{d}	62.89 ± 0.06^{a}
	M±Iq	61.90 ± 3.30	62.90 ± 3.30	59.80 ± 3.80	62.50 ± 2.90
Belly lean meat content (%)	*eM±S*	59.15 ± 0.08^{c}	60.37 ±0.08^{b}	56.38 ±0.08^{d}	61.01±0.09^{a}
	M±Iq	59.5 ± 4.80	60.0 ± 4.60	56.0 ± 5.30	60.0 ± 4.10
Fat thickness (mm)	*eM±S*	13.00 ± 0.04^{b}	12.30 ± 0.04^{c}	14.30 ±0.04^{a}	11.90 ± 0.05^{d}
	M±Iq	12.74 ± 2.47	12.09 ± 2.29	14.15 ± 2.89	12.13 ± 2.20
Muscle thickness (mm)	*eM±S*	66.57 ± 0.12^{b}	68.64 ± 0.12^{a}	65.98 ± 0.12^{c}	64.34 ± 0.12^{d}
	M±Iq	66.69 ± 6.41	68.76 ± 6.39	66.16 ± 6.32	64.10 ± 6.00
Hot carcass weight (kg)	*eM±S*	97.15 ± 0.13^{a}	96.81 ± 0.13^{b}	96.60 ± 0.13^{c}	95.52 ± 0.13^{d}
	M±Iq	96.40 ± 7.60	96.20 ± 7.00	96.00 ± 6.60	94.60 ± 7.00
PRIMAL PORK CUTS					
Belly (kg)	*eM±S*	13.68 ± 0.03^{b}	13.38 ± 0.03^{dc}	13.78 ± 0.03^{a}	13.39 ± 0.03^{cd}
	M±Iq	13.55 ± 1.59	13.29 ± 1.50	13.68 ± 1.47	13.39 ± 1.49
Loin with bones (kg)	*eM±S*	12.13 ± 0.02^{b}	12.24 ± 0.02^{a}	11.77 ± 0.02^{d}	12.01± 0.02^{c}
	M±Iq	12.05 ± 1.08	12.18 ± 1.05	11.71 ± 1.02	11.83 ± 1.07
Lean and boneless loin (kg)	*eM±S*	7.54 ± 0.01^{b}	7.71± 0.01^{a}	7.31 ± 0.01^{d}	7.46 ± 0.01^{c}
	M±Iq	7.51 ± 0.80	7.69 ± 0.78	7.29 ± 0.78	7.35 ± 0.76
Ham with bones (kg)	*eM±S*	24.81 ± 0.03^{b}	25.01 ± 0.03^{a}	24.59 ± 0.03^{c}	24.18 ± 0.03^{d}
	M±Iq	24.67 ± 2.00	24.90 ± 1.91	24.48 ± 1.79	23.93 ± 1.92
Lean and boneless ham (kg)	*eM±S*	19.04 ± 0.03^{b}	19.43 ± 0.03^{a}	18.55 ± 0.03^{d}	18.78 ± 0.03^{c}
	M±Iq	18.97 ± 1.73	19.37 ± 1.68	18.51 ± 1.71	18.48 ± 1.66
Shoulder with bones (kg)	*eM±S*	12.08 ± 0.02^{b}	12.10 ±0 02^{a}	11.91 ±0.02^{dc}	11.92 ± 0.02^{cd}
	M±Iq	11.99 ± 0.88	12.03 ± 0.83	11.84 ± 0.80	11.75 ± 0.87
Lean and boneless shoulder (kg)	*eM±S*	9.37 ± 0.01^{b}	9.44 ± 0.01^{a}	9.13 ± 0.0^{d}	9.26 ± 0.01^{c}
	M±Iq	9.31 ± 0.76	9.38 ± 0.73	9.08 ± 0.72	9.10 ± 0.78
CALCULATED RATING POINTS					
Rating points	*eM±SM±Iq*	95.48 ± 0.11^{b}	96.39 ± 0.11^{a}	93.34 ± 0.11^{d}	94.02 ± 0.12^{c}
		96.2 ± 7.6	97.2 ± 6.5	94.3 ± 7.9	94.1 ± 7.9
Rating points per kg	*eM±S*	0.98 ± 0.001^{cb}	1.00 ± 0.001^{a}	0.97 ± 0.001^{d}	0.98 ± 0.001^{bc}
	M±Iq	0.99 ± 0.04	1.00 ± 0.04	0.98 ± 0.05	0.99 ± 0.04

Within a row, estimated means with at least one identical letter do not differ significantly (e.g. "**c**b" to "**b**c; $p \geq 0.0004$) in contrast to those with only different letters (e.g. "**a**" to "**c**b; $p < 0.0004$). The alphabetical order of the first (bold) letter corresponds to the numerical order of the estimated mean.

Table 6 Percentage of immunocastrates (IC), gilts (GI), barrows (BA) and entire males (EM) hitting the optimum and values below or above the optimum of the accounting mask of the slaughterhouse Heinz Tummel GmbH & Co. KG (Schöppingen, Germany).

Parameter	Range	Sex group (% of animals)			
		IC (n=434,479)	**GI** (n=790,911)	**BA** (n=365,880)	**EM** (n=22,390)
Hot carcass weight					
	< 90.0 kg	11.31	10.72	10.69	18.16
Optimum	90.0 – 107.0 kg	83.46	85.47	86.39	78.71
	> 107.0 kg	5.23	3.81	2.92	3.13
Lean and boneless ham					
	< 16.00 kg	1.38	0.64	3.18	2.74
	16.00 - 16.49 kg	1.65	0.84	3.25	3.00
	16.50 - 16.99 kg	3.41	1.85	5.79	5.60
Optimum	17.00 - 20.50 kg	81.36	78.42	81.89	82.32
	20.51 – 21.00 kg	5.75	8.43	3.14	3.16
	> 21.00 kg	6.44	9.83	2.75	3.18
Belly lean meat content - Belly					
	< 12 kg	8.44	11.73	6.02	10.49
	< 48.00 %	0.83	0.50	3.56	0.22
	48.00 - 52.99 %	5.02	3.01	15.82	2.12
Optimum	53.00 - 61.99 %	67.98	57.93	69.37	61.57
	≥ 62.00 %	17.73	26.83	5.23	25.60
Lean and boneless loin					
	< 6.00 kg	0.79	0.39	1.84	1.24
Optimum	6.0 - 7.80 kg	68.37	57.67	79.32	77.58
	> 7.80 kg	30.85	41.94	18.84	21.18

Table 7 Heat Map of influencing factors (sex, farm, year, hot carcass weight (hcw)) on the carcass parameters (lean meat content (%), fat thickness (mm), belly lean meat content (%), Rating Points per kg, lean and boneless ham (kg) and Hot carcass weight (kg)). Color indicates how much of the total variance in the parameter (response variable) is explained by each predictor (green dark=largest influence, green middle=second largest influence, light green light=third largest influence, grey=least influence).

Parameter	**influencing factor**			
	sex	**farm**	**year**	**hcw**
Lean meat content (%)				
Fat thickness (mm)				
Belly lean meat content (%)				
Rating points per kg				
Lean and boneless ham (kg)				
Hot carcass weight (kg)				

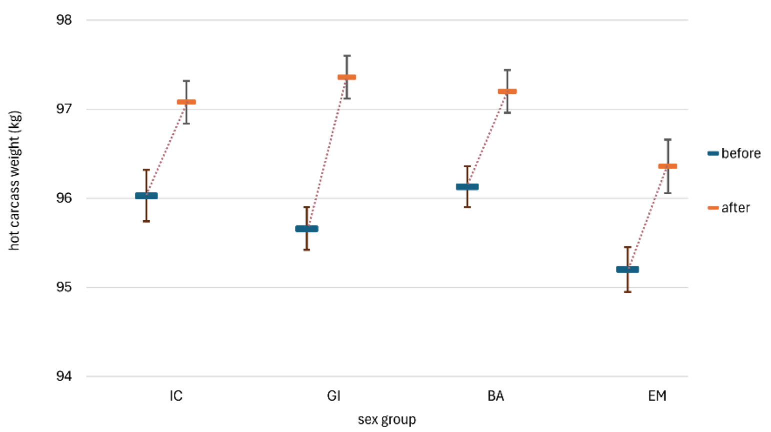

Fig 1 Estimated means (kg) for hot carcass weight with 95% confidence interval before (blue) and after (orange) the change price mask on February 27, 2020, of immunocastrates (IC), gilts (GI), barrows (BA) and entire males (EM). The dotted lines illustrate the significant differences before and after the change of price mask within the sex groups ($p < 0.0004$).

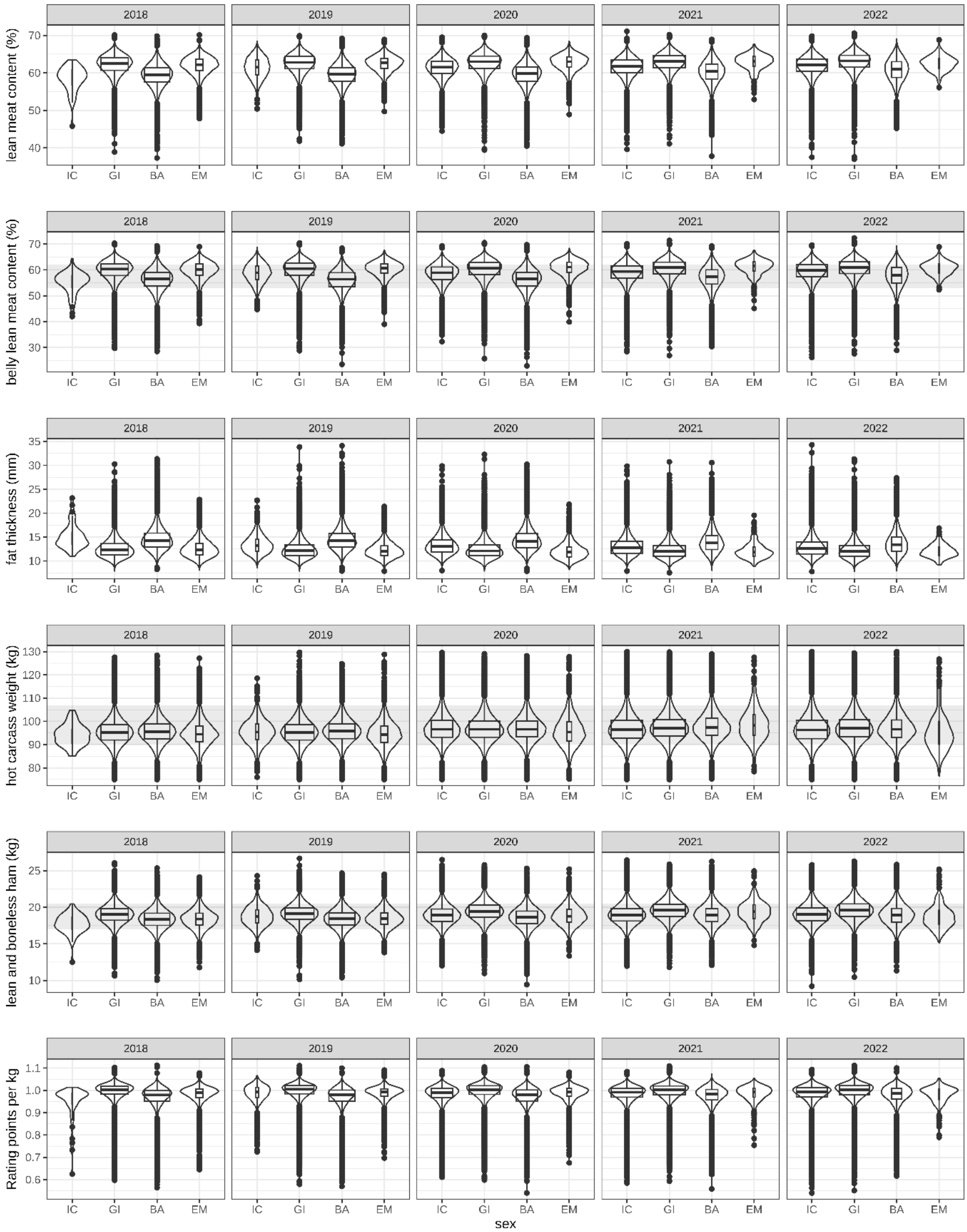

Fig. 2 Violin plots showing lean meat content (%), belly lean meat content (%), fat thickness (mm), hot carcass weight (kg), lean and boneless ham (kg) and Rating Points per kg of immunocastrates (IC), gilts (GI), barrows (BA) and entire males (EM) split by slaughter year and sex group, slaughtered at the slaughterhouse Heinz Tummel GmbH & Co. KG Schöppingen in northern Germany during the study period. Width of the boxes indicate sample size, curved lines are a smoothed histogram of data density along the data points, vertical lines indicate the interquartile range overlaid by outliers (dots), and medians are indicated by a horizontal line.

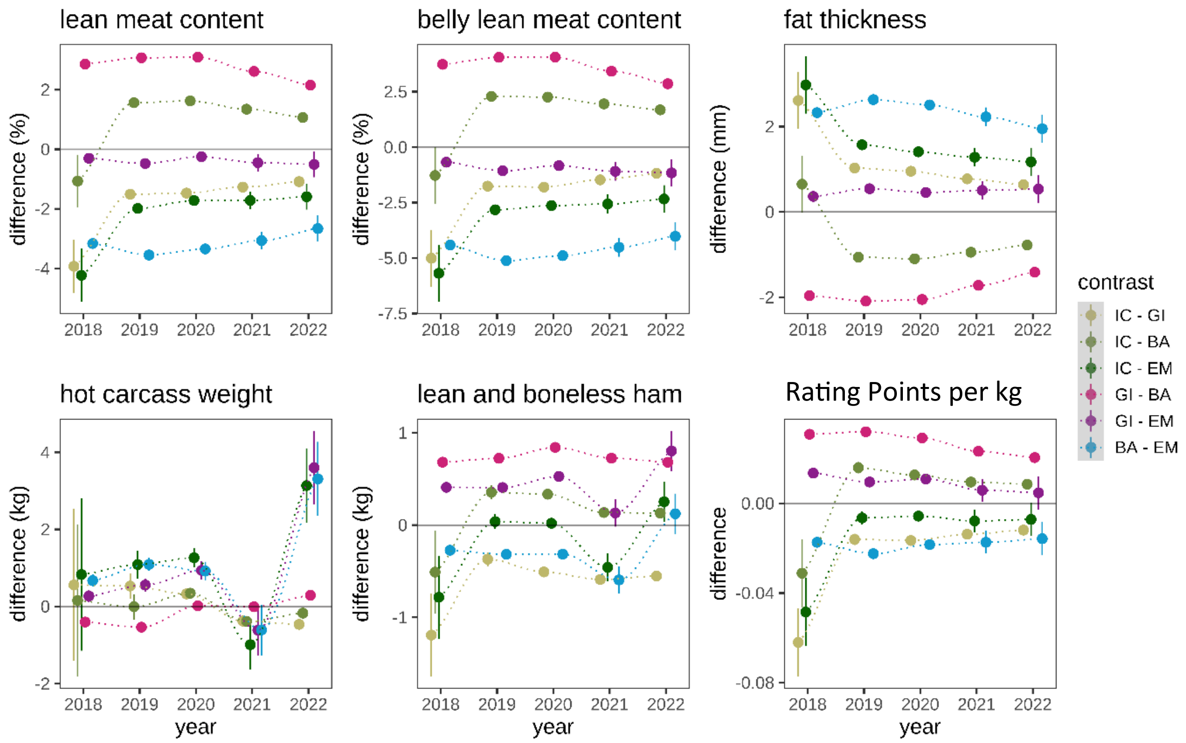

Fig. 3 Differences of lean meat content (%), belly lean meat content (%), fat thickness (mm), hot carcass weight (kg), lean and boneless ham (kg) and Rating Points per kg between immunocastrates (IC), gilts (GI), barrows (BA) and entire males (EM) slaughtered at the slaughterhouse Heinz Tummel GmbH & Co. KG Schöppingen in northern Germany divided by slaughter year.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. We declare, that there were no conflicts of interest.