APPENDIX 8

ALCASDE
Alternatives to Castration and Dehorning

Study on the improved methods for animal-friendly production, in particular on alternatives to the castration of pigs and on alternatives to the dehorning of cattle

D.1.1.4. A report on the meta-analysis of available results regarding meat quality of entire and immunocastrated male pigs

SP1: Alternatives to castration: To develop and promote alternatives to the surgical castration of pigs

WP1.1: Alternatives to surgical castration

Due date of deliverable: October 2009

Actual submission date: November 2009

Final

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The fatty acid composition of the adipose and lean tissues of immunocastrated male pigs can be modulated by specific feeding strategies

Introduction

At a given supply of unsaturated dietary fatty acids (FA) the degree of unsaturation of adipose tissue (AT) lipids increases with decreasing carcass fat deposition. Because carcasses of immunocastrated male pigs (IC) fed standard grower-finisher diets are leaner than those of barrows, one can expect higher levels of unsaturated FA in the AT, which then might negatively affect its oxidative stability and firmness. To insure a good processing quality of the pig's backfat, which is determined in Swiss abattoirs with the fat score (Hadorn et al., 2008; Scheeder et al., 1999), the dietary supply of monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) needs to be limited. Thus, a PUFA-MUFA Index [PMI = 1.3 × MUFA (g/MJ DE) + PUFA (g/MJ DE)] for feed ingredients was introduced in the Swiss feeding recommendations (Stoll et al., 2004). The PMI, which is recommended to be < 1.7 g/MJ DE, takes the dietary concentrations of PUFA and MUFA and their relationship to the fat score into account (Stoll and Bee 2002). The PMI recommendations were defined for barrows and gilts but not for the leaner IC. Therefore, the goal of this study was to determine the effects of castration method and dietary MUFA and PUFA supply (PMI of the diet) on lipid composition of the AT and intramuscular fat (IMF).

Materials and methods

Animals and treatments

In the study a total of 48 Swiss Large White male pigs originating from 12 litters (10 litters with 4 male piglets/litter; 1 litter with 8 male piglets/litter) were used. From weaning until the start of the experimental period (mean ± s.e. body weight [BW] = 28.0 ± 0.5 kg; age = 76.7 ± 1.3 d) pigs were group-penned and had ad libitum access to the same standard starter diet formulated according to Swiss feeding recommendations (Stoll et al., 2004). At an average BW of 13.7 ± 0.5 (age = 49.8 ± 0.01 d), the littermates were allocated according to BW to 4 experimental groups (12 pigs/group): barrows [C17] and 3 groups of IC [IC17, IC15, IC13]. At an average BW of 28.0 ± 0.5 kg, pigs were moved to the grower-finisher barn and fed a grower and a finisher diet from 28-63 and 63-107 kg BW, respectively. The grower-finisher diets differed only in the PMI: pigs in the C17 and IC17, C15 and IC13 group were offered ad libitum the diets with a PMI of 1.7, 1.5 and 1.3, respectively. Pigs were reared in semi-slatted pens (12 animals/pen; 1.5 m2/animal) with the laying area slightly covered with sawdust and straw in environmentally controlled buildings (22°C and 60 to 70% relative humidity). Each pen was equipped with 2 drinkers and 2 single-space computerized feeders (Mastleistungsprüfung MLP-RAP; Schauer Agrotronic AG, Sursee, Switzerland) as described previously (Bee et al., 2008).

Vaccination with Improvac®

The IC pigs were vaccinated twice with 2 ml of Improvac® (Pfizer Ltd., Zurich, Switzerland), which contains a modified form of GnRF (200 µg GnRF-protein conjugate/ml) in an aqueous adjuvant system. Pigs were vaccinated subcutaneously behind and below the base of the ear. The first injection was carried out when the heaviest IC pig reached 25 kg of BW (mean ± s.e. of all IC pigs: BW = 20.7 ± 0.9 kg; age = 64.5 ± 0.1 d); all pigs were injected the same day. The second injection was carried out individually the week the animal reached 68 kg BW (mean ± s.e. of IC pigs: BW = 71.6 ± 0.7 kg; age = 126.2 ± 1.9 d). All IC pigs were slaughtered 4 to 5 wk after the second injection.

Slaughter procedure, carcass measurements and sample analysis

Animals were slaughtered the day after reaching 103 kg BW. Feed was withdrawn from the pigs 12 h before transportation to a nearby commercial abattoir (approx. time of transport 15 min.). During transport and lairage, pigs from different pens were not mixed. At the abattoir, animals were electrically stunned, exsanguinated, scalded, mechanically de-haired and eviscerated. Internal organs were removed and hot carcass weight was determined. The weight of the testes and bulbourethral glands were assessed. Thirty minutes after exsanguination, the carcasses entered the air-chilling system (3°C) for 24 h. Within 30 min. after exsanguination, samples of the longissimus muscle (LM) at the 12th-rib level and backfat (both layers) in the region of the 10th-12th rib level were collected from each carcass, vacuum-packaged and stored at -20°C until determination of the FA composition as described previously (Bee 2001). One day after slaughter, the left side of each carcass was weighed and dissected according to the meat cutting standards applied by the Swiss Performance testing Station (MLP, Sempach, Switzerland), as described previously (Bee, 2001).

Statistical analysis

The data on growth performance, carcass characteristics and FA composition were analyzed with the MIXED procedure of SAS (v. 8.02; SAS Institute, Cary, NC, USA). The effects of castration method (C17 and IC17) and dietary FA composition (IC17, IC15 and IC13) were analyzed separately using the model: $X_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$, ($X_{ijk}$ = observed parameter, μ = overall mean, α_i, = experimental treatments (castration method or dietary FA compsotion as fixed effect), β_j = litter (random effect) and ε_{ijk} = error). In both models, the individual pig served as the experimental unit. Due to extremely low growth a C17 pig was excluded from the trial.

Results and discussion

Comparison of barrows and IC fed the same grower-finisher diet

Compared to barrows (C17), IC17 pigs tended to grow slower (976 vs. 934 g/d; $P < 0.10$), consumed less feed (210 vs. 202 kg; $P < 0.04$), were more feed efficient (2.65 vs. 2.50 kg/kg; $P < 0.01$) and their carcasses were leaner (54.0 vs. 56.2%; $P < 0.01$). These findings are in agreement with previously published results (Pauly et al., 2009). In the AT of IC17, the n-6 and n-3 FA concentration expressed as g/100 g total FA was greater (18:2 = 15.74 vs. 13.98; 20:2 = 0.65 vs. 0.61; 20:4 = 0.34 vs. 0.30; 18:3 = 1.17 vs. 1.04; 20:3 = 0.16 vs. 0.14; $P \leq 0.06$), whereas the saturated FA (39.39 vs. 40.56) and MUFA (42.39 vs. 43.21) level was only numerically lower ($P \geq 0.12$) than in the AT of barrows. In the IMF, the total lipid content, the 16:0 and 20:0 concentrations were lower (total lipid = 9.2 vs. 10.9 g/100 g dry matter; 16:0 = 24.98 vs. 25.46; 20:0 = 0.07 vs. 0.12; $P \leq 0.08$) and the levels of n-6 and n-3 FA were greater in IC17 than C17 (18:2 = 9.21 vs. 7.67; 20:4 = 1.93 vs. 1.60; 22:4 = 0.36 vs. 0.29; 18:3 = 0.41 vs. 0.35; 22:5 = 0.24 vs. 0.19; $P \leq 0.03$). These findings can be partly explained by the well described relationship between intake of unsaturated FA and carcass leanness (Bee and Wenk 1994; Warnants et al., 1999; Wood et al., 2008). However, it is interesting to note that although total feed intake was lower and, hence, a lower amount of dietary PUFA was ingested, the decrease in deposited AT and IMF was still more important resulting in a more unsaturated fat in IC17 than C17 pigs.

Comparison of varying PMI levels of the diet on the tissue FA composition in IC

Except for the linear decrease ($P_l = 0.04$) in total feed intake with decreasing dietary PMI level (202.0 < 195.5 < 191.2 kg), diet had no ($P_l > 0.18$) effect on growth rate, feed efficiency or carcass leanness. With decreasing dietary PMI level, the 16:0 (24.08 > 24.22 > 24.82) and 18:0 (13.32 > 13.89 > 14.17) concentrations in the AT linearly increased (Pl ≤ 0.05) and the n-6 (18:2 = 15.74 < 14.84 < 13.30; 20:2 = 0.65 < 0.61 < 0.58) and n-3 (18:3 = 1.17 < 1.11 < 1.04; 20:3 = 0.16 < 0.14 < 0.14) concentrations, as well as the total FA tissue content (894.4 < 879.3 < 861.3 g/kg AT) linearly decreased (Pl ≤ 0.02). The FA profile of the IMF was not (Pl ≥ 0.15) affected by the dietary FA composition except for a linear decline (Pl = 0.03) in the 20:1 (0.59 > 0.58 > 0.54) and a linear rise (Pl ≤ 0.06) in the 20:4 (1.93 < 2.03 < 2.22) and 22:4 (0.36 > 0.38 > 0.40) levels with decreasing dietary PMI. In agreement with findings of previous studies (Bee 2001; Bee and Wenk 1994; Warnants et al., 1996; Warnants et al., 1999), IMF FA composition was less affected by the dietary FA than the FA of the AT.

Conclusion

In conclusion, average daily gain was similar between IC and barrows. Due to the greater anabolic potential of IC compared to barrows, overall average daily feed intake was lower and feed efficiency was greater in IC. The leaner carcasses of IC resulted in a more unsaturated AT. However, the results of the study showed that by applying a specific feeding strategy the FA composition of the AT could be adjusted: the lowest dietary PMI (1.3) level compensated for the 14% lower deposition of AT as the FA profile was comparable in the AT of IC13 and C17. Thus, in production systems where quality of the AT affects the economic value of the carcasses, the PMI level of diets for IC needs to be reduced to maximize economic return.

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Expected effects on carcass and pork quality when surgical castration is omitted : Results of a meta-analysis study

Introduction

In recent years, pressure from animal welfare organisations, consumers and ultimately legislation increased to extensively study more welfare friendly alternatives to surgical castration of new born piglets. The most promising alternatives to the common practice are surgical castration under anaesthesia or growing entire males (EM) or immunocastrates (IC). Rearing EM instead of castrates (C) has a number of advantages including higher feed efficiency, greater carcass leanness and lower faecal and urinary nitrogen losses (Bonneau, 1998). Similarly, higher feed efficiency and leaner carcasses were observed in IC compared to C (Pauly et al., 2009). However, the incidence of boar taint, a very unpleasant odour and flavour, can occur in pork from some EM as well as IC if vaccination practice is not performed properly. Androstenone (5a-androst-16-en-3-one) and skatole (3-methyl-indole) are thought to be key contributors to boar taint (Bonneau et al., 2000). Many literature reviews are available on boar taint (Bonneau, 1982, Malmfors and Lundström, 1983, Claus et al., 1994, Font i Furnols and Oliver, 1999), but to our knowledge only one focused primarily on meat quality of EM (Babol and Squires, 1995). Due to the production of male's hormones, carcasses of EM as well as of IC, which can be regarded as EM until the second vaccination is performed, are leaner than those of C; however, the general responses of anabolic steroids on pork quality traits have never been reviewed. Many factors have to be taken into account when comparing the impact of the different alternatives to surgical castration. Indeed, boar taint is regarded to be the most important factor, but carcass characteristics, meat and fat quality traits affect also consumer acceptance and are equally important. Thus, the objective of this meta-analysis was to estimate and discuss the possible impact of lack of castration or immunocastration on meat quality traits, which are not related to boar taint but are known to affect consumer acceptance.

This goal was achieved as following:

- Creating a database containing available information regarding carcass and meat quality traits in C, IC and F together with EM. The records included in the database were collected from the literature and from raw data obtained from the pig testing stations.
- Performing a meta-analysis of the information included in the database.

Materials and methods

Twenty-six published (from 1990 until today) and 2 unpublished studies containing results of carcass characteristics and meat quality from EM, surgically castrated pigs (C), IC and female (F) pigs were included in the database (Table 1). The dataset was built on results obtained from a total of 2'683 EM, 3'427 C, 96 IC and 3'736 F. In order to be considered, the publication had to contain at least one meat quality trait and had to have one group of EM, the latter being used as the control group. The following 9 traits were collected and used in the statistical analysis:

- Lean meat (%): lean meat content of the carcass, if available dissected lean yield
- Intramuscular fat (%): intramuscular fat concentration in the longissimus dorsi (LD)
- Initial pH: pH of the LD at 30, 45 or 60 min after slaughter
- Ultimate pH: pH of the LD at 18, 24 or 48 h after slaughter
- L*: lightness of the LD; a greater number indicates a lighter colour

- Drip loss (%): amount of purge formed during the storage of chops at 4°C for 24, 48 or 72 h.
- Shear force (kg): maximum shear force, sheared across the muscle fibre direction of the LD.
- Sensory tenderness: evaluated on a scale from 0 (tough) to 10 (tender)
- Sensory juiciness: evaluated on a scale from 0 (dry) to 10 (juicy).

All original tenderness and juiciness values were transformed when necessary on a scale from 0 (no intensity) to 10 (very intensive) in order to make them comparable among studies.

Statistical meta-analysis

Means and standard deviations of each experimental treatment from the aforementioned publications were inscribed separately. From the raw data of the 2 unpublished studies, means and standard deviations of each experimental treatment were calculated. For published studies containing standard errors of means, standard errors of differences of means, or least significant differences, pooled standard deviations were calculated using the sample sizes and the respective formulae. From the treatment means and the pooled standard deviations, the empirical effect sizes of each study were computed as the difference between treatment means (i.e. group means of IC, C, or F) and the control means (EM), divided by the pooled standard deviation. Therefore the empirical effect sizes as well as estimated parameters of the model are dimensionless quantities. Publications without a group of EM, but only C, IC, or F, were not included in the analysis.

Data for carcass characteristics and meat quality traits were each analysed as multiple-treatment studies, as described by Gleser and Olkin (1994). This linear model accounts for the correlation of the effect sizes as introduced by the common control group (EM). Hence, the comparisons of effect sizes and tests on contrasts of effect sizes are applicable, which would not be the case if each effect size is analysed by a common two-treatment meta-analysis. The estimation of the model parameters β_C, β_{IC}, and β_F (as estimates of population effect sizes for C, IC, and F, respectively) and their standard deviations is based on the generalized least squares procedure including the empirical estimate of the covariance matrix. Furthermore, the contrast of the effect sizes of IC vs. C and F were calculated as $\beta_{IC-C} = \beta_{IC} - \beta_C$ and $\beta_{IC-F} = \beta_{IC} - \beta_F$. Matrix calculations were performed with the statistical program R (R Development Core Team, 2009). Empirical effect sizes, covariance and design matrices were computed with SYSTAT 12 (SYSTAT, 2007). Approximate estimates of mean differences (D_{C-EM}, D_{IC-EM}, D_{F-EM}, D_{IC-C} and D_{IC-F}) were calculated as the arithmetic mean of the differences of the individual studies.

Statistical tests and confidence intervals were computed for the level of significance of 5% ($\alpha = 0.05$). The homogeneity of effect sizes across studies has been tested with the χ^2-goodness-of-fit test as proposed by Gleser and Olkin (1994).

Pearson correlation coefficients between carcass weight and lean meat percentage were calculated separately for each experimental treatment.

Results and discussion

Correlation coefficients between carcass weight and lean meat percentage were not significant ($P > 0.05$) in C and F whereas it was significant in IC ($r = -0.77$; $P = 0.04$). However, the latter was basically a two-point correlation, with only 7 observations. Therefore, carcass weight has not been included as a covariable in the meta-analysis.

The overall tests on homogeneity of effect sizes across experiments is highly significant for any of the evaluated traits (test statistic $Q > \chi^2$; Table 2), indicating that the model parameters β_{IC}, β_C, and β_F may not be interpreted as estimates of pig populations effect sizes. Nevertheless, these models parameters are valid within the present group of studies as a variance-covariance weighted means of the effect sizes. The null hypothesis of the homogeneity test is the assumption that the model with 3 parameters holds across the studies. The statistically evident lack of homogeneity may have various reasons: I) there are no real effects in the populations; II) there are real effects but the numbers of available studies is too small and/or the biological variation of the effect sizes is too large to detect them; III) through genetic selection, the various traits have changed during the last 2 decades; IV) there are real effects but there are (unknown) covariates (e.g.: breed, feeding strategies, environment, slaughter procedure, …) not included in the statistical model, which cause a larger variability among the studies, thus covering real effect sizes. As an example of the large variability of effect sizes present in all the traits, Figure 1 shows the distributions of the empirical effect sizes β_{IC} [b(IC)], β_C [b(C)], and β_F [b(F)] for lean meat percentage. The inhomogeneity among the empirical effect sizes may have different reasons for each of the 9 traits. Additionally, cases II, III and IV can also occur altogether and with the current dataset there is no way to estimate those influences.

Though the parameter estimates of the meta-analysis cannot be extended to the overall pig populations, these results are valid for the group of studies included in the meta-analysis. Table 2 summarizes the estimates of the effect sizes of C vs. EM (β_C), IC vs. EM (β_{IC}) and F vs. EM (β_F), their standard deviations [s(β_C), s(β_{IC}), s(β_F)] as well as lower (LL_C, LL_{IC}, LL_F) and upper (UL_C, UL_{IC}, UL_F) limits of the respective 95% confidence intervals for each trait. Furthermore, the χ^2 and the corresponding Q value are also presented in the table.

As aforementioned, based on the χ^2 test ($Q > \chi^2$) the homogeneity of the effect sizes cannot be assumed. Nevertheless, the numerical values of the effect sizes for carcass lean meat percentage, intramuscular fat content of the LD and shear force values are an indication of a possible trend in the populations because the confidence intervals computed, based on the group of studies, do not include the value zero. It was decided to present as well the estimates of mean differences in Table 3, which are given in the unit of the respective trait, because they are helpful in the interpretation of estimated effect sizes. However, it should be noted that these differences are not computed by any weighting algorithm. Correctly weighting the individual differences one would end up with 36 separate, but correlated meta-analyses.

The most marked effect of the castration method and sex was observed in the carcass composition. As shown by the estimated effect sizes, differences were observed for lean meat and intramuscular fat percentage when comparing C, IC and F vs. EM (lean meat: β_C: -1.404, β_{IC}: -0.808, β_F: -0.277; intramuscular fat: β_C: 1.143, β_{IC}: 0.613, β_F: 0.276, respectively). Indeed, strong effects can be expected for these 2 traits in C and IC compared to EM whereas these are negligible in F compared to EM. This is confirmed by the respective mean differences (Table 3). The lean meat percentage of EM carcasses was 2.69, 1.77 and 0.42% greater than in carcasses of C, IC and F, respectively. In contrast to lean meat, the intramuscular fat content of the LD of EM was lower than in the LD of C, IC and F (0.60, 0.30 and 0.25%, respectively).

The following effect sizes for meat quality traits between C, IC and F vs. EM were significant: initial pH (β_F: -0.111), ultimate pH (β_C: 0.330; β_F: 0.132), L*-value (β_C: 0.193; β_{IC}: 0.454) and shear force (β_C: -0.112; β_{IC}: -0.977; β_F: -0.172). The corresponding mean differences were: for initial pH (D_{F-EM}: -0.01), ultimate pH (D_{C-EM}: 0.02; D_{F-EM}: -0.01), L*-value (D_{C-EM}: 0.53; D_{IC-EM}: 0.88) and shear force (D_{C-EM}: -0.20 kg; D_{IC-EM}: -0.33 kg; D_{F-EM}: -0.30 kg). From these, given the extent of the effect sizes, only the difference in shear force values for IC vs. EM was relevant. Drip loss percentages were similar for all experimental treatments. These effect sizes show that no perceivable meat quality defaults such as DFD (dark, firm, and dry) or PSE (pale, soft, and exudative) are to be expected when producing EM.

Even if initial and ultimate pH, and shear force differ partially between experimental treatments, tenderness and juiciness assessed in the sensory studies did not differ between entire males and the other treatments. However, these results should be considered with caution, because sensory assessments were only performed in very few studies. Furthermore, methods of sensory analysis differed between publications; some studies used a consumer panel whereas others a trained panel.

When replacing production system from C to EM, increased lean meat percentage and decreased intramuscular fat content are the main changes which can be expected as indicated by their large effect sizes. In IC similar, but slightly lower, effects can be expected in carcass composition and intramuscular fat together with lower shear force values. However, the latter must be taken with caution because it is based only on one observation. No relevant changes in the traits studies are foreseen between F and EM. Therefore, the homogeneity of the pork produced would increase if EM are raised.

Table 4 summarizes the contrast of the effect sizes of IC vs. C (β_{IC-C}) and of IC vs. F (β_{IC-F}), and the lower and upper limits of the respective 95% confidence intervals for each trait. The following effect sizes for carcass lean meat percentage and meat quality traits between IC and C and F were significant for lean meat percentage (β_{IC-C}: 0.596; β_{IC-F}: -0.531), ultimate pH (β_{IC-C}: -0.335), L*-value (β_{IC-F}: 0.510), drip loss (β_{IC-F}: 0.306) and shear force (β_{IC-C}: -0.865; β_{IC-F}: -0.805). The corresponding mean differences were: for lean meat percentage D_{IC-C}: 0.83%; D_{IC-F}: -3.22%, for ultimate pH D_{IC-C}: -0.02, for L*-value D_{IC-F}: 0.95, for drip loss D_{IC-F}: 0.62% and for shear force D_{IC-C}: -0.25 kg (Table 3). Although β_{IC-F} for shear force was estimated using the model, no mean difference D_{IC-F} could be calculated because there is actually no experimental study including both treatments (IC and F). For both sets of contrasts, the largest effect sizes were found in shear force. However, up to now only very few studies (D'Souza and Mullan, 2003, Fàbrega et al., 2008, Zamaratskaia et al., 2008, Pauly et al., 2009) including IC together with EM were carried out, which limits the strength of the calculated effects.

In this study, the analysis is limited on the traits listed in Materials and Methods. Meat composition or the lack of cohesiveness between muscles, which are partially cited as a problem in entire male pigs, could not be analysed because not enough results were available.

Conclusion

Within the present group of studies carcasses of EM were leaner and intramuscular fat content of the LD was lower than in C, IC and F pigs. Shear force was higher in EM in comparison to C, IC and F; however, sensory tenderness and sensory juiciness were not affected by castration method and sex. The lack of homogeneity of the effect sizes across the studies indicates that these findings may not yet be extended to the whole pig populations without care.

The present study revealed that in the current situation, the implementation of IC and EM production should not be hindered by meat quality concerns. Furthermore, replacing C by EM or IC will result in a greater homogeneity of carcasses at the slaughterhouse, as shown by the very small effect sizes between EM and F. However, the accentuation towards leaner carcasses and lower intramuscular fat content bears some danger as this could ultimately lead to deviations in meat quality such as tenderness and juiciness especially in pig populations with already low intramuscular fat content.

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<u>Table 1:</u> List of publication and number of observations per publication, sorted by date of publication

	Number of observations				
First author	EM	C	IC	F	References
Warriss et al. (1990)	1	1	0	1	Warriss PD, Brown SN, Adams SJM and Lowe DB 1990. Variation in haem pigment concentration and colour in meat from British pigs. Meat Science 28, 321-329.
Sather et al. (1991)	1	0	0	1	Sather AP, Jones SDM and Joyal S 1991. Feedlot performance, carcass composition and pork quality from entire male and female Landrace and Large White marketweight pigs. Canadian Journal of Animal Science 71, 29-42.
Serra et al. (1992)	4	0	0	4	Serra JJ, Ellis M and Haley CS 1992. Genetic components of carcass and meat quality traits in Meishan and Large White pigs and their reciprocal crosses. Animal Production 54, 117-127.
Edwards et al. (1992)	1	0	0	1	Edwards SA, Wood JD, Moncrieff CB and Porter SJ 1992. Comparison of the Duroc and Large White as terminal sire breeds and their effect on pigmeat quality. Animal Production 54, 289-297.
Dunshea et al. (1993)	1	1	0	1	Dunshea FR, King RH, Campbell RG, Sainz RD and Kim YS 1993. Interrelationships between sex and ractopamine on protein and lipid deposition in rapidly growing pigs. Journal of Animal Science 71, 2919-2930.
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<u>Table 2:</u> Estimated effect sizes for immunocastrates, castrates, and females, their standard deviations, lower and upper limits of the 95% confidence intervals, Chi² test statistic and critical values of the Chi²-distribution [1]

Trait	β_C	β_{IC}	β_F	$s(\beta_C)$	$s(\beta_{IC})$	$s(\beta_F)$	LL_C	UL_C	LL_{IC}	UL_{IC}	LL_F	UL_F	Q	$\chi^2_{crit(0.05)}$
Lean meat (%)	-1.404	-0.808	-0.277	0.029	0.117	0.028	-1.461	-1.347	-1.037	-0.579	-0.332	-0.222	2869.5	42.6
Intramuscular fat in the LD (%)	1.143	0.613	0.276	0.028	0.274	0.028	1.088	1.198	0.076	1.151	0.221	0.332	2103.6	33.9
Initial pH	0.015	-0.047	-0.111	0.026	0.173	0.026	-0.035	0.066	-0.386	0.291	-0.162	-0.060	95.0	51.0
Ultimate pH	0.330	-0.005	0.132	0.025	0.116	0.025	0.281	0.380	-0.232	0.222	0.083	0.181	361.7	69.8
L*	0.193	0.454	-0.056	0.062	0.150	0.061	0.071	0.315	0.159	0.748	-0.176	0.065	85.6	40.1
Drip loss (%)	-0.005	0.252	-0.053	0.053	0.149	0.057	-0.110	0.100	-0.039	0.543	-0.166	0.059	49.3	41.3
Shear force (kg)	-0.112	-0.977	-0.172	0.051	0.356	0.062	-0.212	-0.012	-1.675	-0.278	-0.294	-0.050	62.8	31.4
Sensory tenderness	0.080	0.344	0.029	0.075	0.189	0.082	-0.067	0.228	-0.027	0.716	-0.132	0.189	79.1	26.3
Sensory juiciness	0.034	0.192	-0.118	0.076	0.188	0.082	-0.115	0.184	-0.177	0.561	-0.279	0.042	43.4	25.0

[1] Abbreviations are: IC: immunocastrates, C: castrates, F: females, β_x: effect size of the sex treatment, $s(\beta_x)$: standard deviation of the effect size of the sex treatment, LL: lower limit of the 95% confidence interval for the effect size of the experimental treatment, UL: upper limit of the 95% confidence interval for the effect size of the sex treatment, Q: Chi² test statistic (goodness-of-fit test), $\chi^2_{crit\,(0.05)}$: critical value of the test statistic ($\alpha = 0.05$)

Table 3: ***Arithmetic means of the differences between experimental treatments and significance of the related estimated effect size parameters β_{IC}, β_C, and β_F and effect size contrast for carcass characteristics and meat quality traits. The number of observations is given between brackets[1]***

Trait	D_{C-EM}	D_{IC-EM}	D_{F-EM}	D_{IC-C}	D_{IC-F}	$P\beta_C$	$P\beta_{IC}$	$P\beta_F$	$P\beta_{IC-C}$	$P\beta_{IC-F}$
Lean meat (%)	-2.69 (16)	-1.77 (4)	-0.42 (12)	0.83 (4)	-3.22 (1)	*	*	*	*	*
Intramuscular fat in LD (%)	0.60 (13)	0.30 (1)	0.25 (11)	-0.20 (1)	- (0)	*	*	*	ns	ns
Initial pH	-0.04 (16)	-0.03 (2)	-0.01 (21)	0.00 (2)	0.02 (1)	ns	ns	*	ns	ns
Ultimate pH	0.02 (23)	-0.01 (4)	-0.01 (28)	-0.02 (4)	0.00 (1)	*	ns	*	*	ns
L*	0.53 (13)	0.88 (3)	0.39 (14)	0.20 (3)	0.95 (1)	*	*	ns	ns	*
Drip loss (%)	-0.25 (13)	0.51 (3)	0.02 (15)	0.37 (3)	0.62 (1)	ns	ns	ns	ns	*
Shear force (kg)	-0.20 (11)	-0.33 (1)	-0.30 (11)	-0.25 (1)	- (0)	*	*	*	*	*
Sensory tenderness	0.58 (9)	0.72 (4)	0.05 (6)	-0.02 (4)	0.55 (1)	ns	ns	ns	ns	ns
Sensory juiciness	0.07 (8)	0.36 (4)	-0.11 (6)	0.13 (4)	0.00 (1)	ns	ns	ns	ns	ns

[1] Abbreviations are: EM: entire males, IC: immunocastrates, C: castrates, F: females, D: arithmetic means of the differences; P: level of significance; *: P < 0.05; ns: no significant (P > 0.05)

Table 4: ***Estimated effect size contrasts between immunocastrates, castrates, and females, their lower and upper limits of the 95% confidence intervals***[1]

Trait	β_{IC-C}	β_{IC-F}	LL_{IC-C}	UL_{IC-C}	LL_{IC-F}	UL_{IC-F}
Lean meat (%)	0.596	-0.531	0.366	0.826	-0.762	-0.299
Intramuscular fat in the LD (%)	-0.530	0.337	-1.067	0.008	-0.202	0.876
Initial pH	-0.062	0.064	-0.401	0.277	-0.276	0.403
Ultimate pH	-0.335	-0.137	-0.563	-0.107	-0.366	0.093
L*	0.261	0.510	-0.038	0.560	0.202	0.817
Drip loss (%)	0.257	0.306	-0.038	0.552	0.002	0.609
Shear force (kg)	-0.865	-0.805	-1.563	-0.167	-1.512	-0.097
Sensory tenderness	0.264	0.316	-0.110	0.637	-0.069	0.701
Sensory juiciness	0.157	0.310	-0.216	0.530	-0.072	0.692

[1] Abbreviations are: IC: immunocastrates, C: castrates, F: females, β_{X-Y}: estimated effect size contrast between the experimental treatment X and Y, LL: lower limit of the 95% confidence interval for the effect size contrast, UL: upper limit of the 95% confidence interval for the effect size contrast

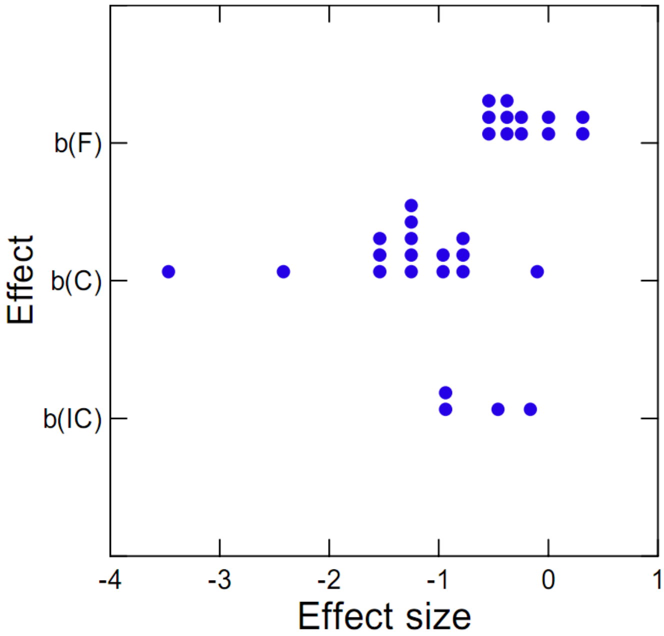

Figure 1: ***Empirical effect sizes for lean meat percentage of immunocastrates [b(IC)], castrates [b(C)] and female pigs [b(F)].***