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Consumer evaluation of meat quality from barrows, immunocastrates and boars in six countries

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ABSTRACT

The practice of surgical castration of piglets and its alternatives is still under debate. Production of boars may impair meat quality due to boar taint and reduced tenderness compared to meat from surgically castrated male pigs, while immunocastration reduces boar taint and may improve meat quality but seems to be less accepted by the pig chain. In this study, we aimed to evaluate the consumer's sensory appreciation of meat from barrows (**BAs**), immunocastrates (**ICs**) and boars (**BOs**) in six European countries, taking into account the selection of tainted carcass and consumers' appreciation of boar taint. Loin chops of 30 BAs, 30 ICs and 30 BOs were evaluated by 752 consumers in six countries: Belgium, Czech Republic, Poland, Portugal, Romania and Spain. Consumers rated odour, flavour, tenderness, juiciness, overall liking and willingness to buy and sensitivity to and liking of androstenone (**AND**) and liking of skatole (**SKA**) was also tested. In each of the six countries, consumers liked the odour of the BO samples less than that of BA, and IC intermediate. For flavour, tenderness, juiciness, overall liking and willingness to buy, liking scores given by the Czech, Polish and Portuguese consumers significantly differed between the BA, BO and IC. Willingness to buy was highest for BA by Czech and Polish consumers and for BA and IC by Portuguese consumers. The frequency of the negative check all terms that apply terms also differed, with a higher frequency of disgusting for BO compared to BA and IC and of off-flavour, irritating, manure, sweat, disappointing compared to BA, and intermediate for IC. 31% of the consumers disliked the odour of AND (**NEG_{AND}**), and 36% of them were not sensitive; in contrast, 77% of the consumers disliked SKA (**NEG_{SKA}**). The decrease in flavour liking score for BO compared to BA and IC was more outspoken by the NEG_{AND} consumer, while NEG_{SKA} consumers gave an overall lower liking score independent of the type of male pig. The results of this study indicate that IC can be a valid alternative for surgical castration.

Implications

Alternatives for piglet castration are the production of boars or immunocastrates, facing issues in terms of sensory quality and acceptability, respectively. To achieve a broad transition, alternatives should be accepted at national level as well as export markets. This consumer study therefore evaluated the sensory quality of barrows, immunocastrates and boars with and without boar taint in six countries. All consumers liked the odour of boars less, while results of the immunocastrates were mainly in line with the barrows, showing the potential of immunocastration and the importance of a good boar taint detection system at slaughter in case of boars.

Introduction

The ban on surgical castration of male piglets (barrows, **BAs**) has long been discussed, but the production of male pigs without

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surgical castration (boars, **BOs**) or with the application of immunocastration (immunocastrates, **ICs**) still faces challenges related to meat quality and market acceptance. In case of production of BO, boar taint can be present in 5–10% of the carcasses. This off-odour occurs due to the accumulation of skatole (**SKA**) and/or androstenone (**AND**) in the fat. Skatole has been described as a manure-like, naphthalene odour (Annor-Frempong et al., 1997; Dijksterhuis et al., 2000) and can be perceived by approximately all consumers. Not everyone is able to smell AND, which has a more sweaty, urine-like odour (Bonneau et al., 1992; Dijksterhuis et al., 2000). Depending on the methodology used, the percentage of anosmia of this compound is estimated between 27 and 82% (Weiler et al., 2000; Bonneau and Chevillon, 2012; Font-i-Furnols, 2012). In general, females and young people are more sensitive to AND, but geographical differences have also been described (Bekaert et al., 2011; Weiler et al., 2000), suggesting that the acceptability of boar meat may also differ geographically. However, not only the ability to smell the compounds but also whether people like or dislike these compounds may impact consumers' liking of boar meat (Font-i-Furnols et al., 2003; Bonneau and Chevillon, 2012; Meier-Dinkel et al., 2013). Overall, the effect of SKA and AND gradually influences consumer liking, and most studies indicate that consumer approval is more affected by SKA compared to AND (Dijksterhuis et al., 2000; Bonneau and Chevillon, 2012; Meier-Dinkel et al., 2015; Heyrman et al., 2018). Carcasses with boar taint should therefore be selected at the slaughter line to avoid negative consumer reactions, but the application of an objective method has not been available for a long time and is so far only applied in a Danish slaughterhouse (Borggaard et al., 2020; Font-i-Furnols et al., 2020). As an alternative, people who are sensitive to AND and trained to detect boar taint are employed in slaughterhouses to select the tainted carcasses, which is known as hot iron or human nose method. Nevertheless, consumers may still notice differences between meat from BO and BA even when boar taint is absent, with BO meat being perceived as less tender or juicy (Aluwé et al., 2013; Heyrman et al., 2018; Škrlep et al., 2020), although this is not univocal in all studies. This difference is associated with the lower intramuscular fat content and in some cases also lower water-holding capacity of BO meat compared to BA meat (Škrlep et al., 2020). Immunocastration of male pigs may provide a good alternative, as it enables the production of male pigs without surgical castration, reduces boar taint and results in a meat quality which is either intermediate between BO and BA or comparable to BA (Aluwé et al., 2013; Škrlep et al., 2020). Immunocastration is however still not yet widely implemented, as stakeholders question the acceptance of immunocastration by the consumers. Nevertheless, most studies indicate that consumers generally have a positive or neutral attitude towards IC, and that IC and castration with anaesthesia and/or pain relief have higher acceptability compared to surgical castration without anaesthesia (Viske et al., 2006; Fredriksen et al., 2011; Aluwé et al., 2020; Sodring et al., 2020). Consumer acceptance of BO is more variable and is mainly affected by the perception that boar taint might be present (Viske et al., 2006; Heid and Hamm, 2013).

Several studies have been performed to evaluate consumer liking of meat and meat products from BO with varying levels of boar taint in different EU countries, e.g. Matthews et al. (2000) and Aluwé et al. (2018). The number of consumer studies including meat from IC and liking and appreciation of boar taint covering different countries is however limited, although being important to get these alternatives introduced beyond a national level. We therefore aimed to evaluate the consumer's sensory appreciation of meat from BA, IC and BO with and without boar taint in six European countries, taking into account the sensitivity towards AND and appreciation of AND and SKA. Samples were characterised by profiling the meat samples and olfactory and chemical boar taint evaluation of the fat samples.

Material and methods

Samples

Meat samples originated from 30 BAs, 30 ICs and 30 BOs (Hybrid sow × Piétrain boar) raised at the experimental farm at Flanders Research Institute for Agriculture, Fisheries and Food (ILVO, Melle, Belgium). Pigs were produced in three rounds, with 3 week difference between rounds. All pigs received the same three-phase diet. Surgical castration was performed before the age of 7 days with pain relief (0.2 mL Metacam® (Meloxicam, 5 mg/mL)). Immunocastrates received the first vaccination (Improvac®, Zoetis Belgium, Louvain-la-Neuve, Belgium) at 13 weeks of age and the second vaccination at 20 weeks of age. Time between second vaccination and slaughter varied between 4 and 6 weeks. Timing of slaughter was defined at pen level, when the average pen weight reached around 118 kg in order to have comparable slaughter weights per group. This resulted in seven slaughter events in total (August–October 2018). Pigs were slaughtered in a commercial slaughterhouse (COVAMEAT, Wijtschate, Belgium) using carbon dioxide anaesthesia followed by exsanguination after a minimum 1 h of lairage.

Samples of subcutaneous neckfat were taken at the slaughterhouse from all 30 ICs and 30 BOs and stored vacuum packed at −20 °C until analysis of boar taint by chemical analysis and by an expert panel.

The loins (40 cm around the 13th rib) were collected 24 hours postmortem, trimmed of visible fat and sliced (2.5 cm thickness). Characterisation of the loins used for the consumer panel was done for all 30 BAs, 30 ICs and 30 BOs based on instrumental meat quality and sensory evaluation of meat quality by a trained panel. For each of the measurements, slices were always taken at the same position (slice) following a standardised protocol taking into account the variation within the loin, resulting in one slice for sensory profiling, six slices for the consumer panel (one per country), one slice for intramuscular fat content, two slices for shear force, two slices for drip loss. For sensory analysis (sensory profiling and consumer panel) and analysis of shear force and intramuscular fat, samples were stored vacuum packed and frozen at −20 °C until analysis.

Instrumental meat quality

Instrumental meat quality was determined as described by Van den Broeke et al. (2022). Briefly, at the slaughter line, pH_i was measured 35 min postmortem in the loin (*musculus longissimus thoracis et lumborum*). The ultimate pH was measured in triplicate and drip loss was determined in duplicate using the EZ method as described by Christensen (2003). Warner-Bratzler shear force was measured according to Boccard et al. (1981). Intramuscular fat content was assessed using near-infrared spectroscopy by the Agricultural Institute of Slovenia (**KIS**) as described by Škrlep et al. (2020).

Sensory and chemical evaluation of the neckfat samples

Chemical analysis of the boar taint compounds (AND, SKA) was performed using High-performance liquid chromatography (HP 1200, Agilent Technologies, Waldbronn, Germany) at KIS (Kress et al., 2020), with the concentrations expressed on liquid fat. All fat samples were also scored by four panellists on two consecutive days after heating them with a hot iron (ERSA RDS80 at a

temperature setting of 350 °C) in the laboratory. The panellist was selected and trained as described by Aluwé et al. (2017) and Heyrman et al. (2020) (Supplementary Fig. S1). Scores were given according to a 5-point scale, with 0 = no taint, 1 = light taint, 2 = fair taint, 3 = strong taint, and 4 = very strong taint. The average score of the eight scorings (four panellists × two scorings) was considered as the final score. Thresholds to define an animal as tainted were 250 ppb of SKA and/or 2 000 ppb for AND for the chemical analysis and an average score higher than one for the odour score.

Sensory profile

Assessment of the loin samples was performed in an accredited sensory laboratory (contract No AB 564) that meets the requirements of ISO 8589:2010 of the Warsaw University of Life Sciences (SGGW-WULS) in Warsaw, Poland. All loin samples (30 BAs, 30 BOs, 30 ICs) were evaluated by a group of ten trained experts that were all sensitive to SKA and AND. They were selected from a group of 13 assessors on the basis of their ability to differentiate SKA and AND on paper strips according to the procedure established and described by Heyrman et al. (2020). Samples were evaluated in 30 sessions (10 days, three sessions per day, three samples (BO, BA, IC) per session). The pork samples were thawed at 4 °C one day before the evaluation. Slices of the loin were grilled (Tefal, model GC3060, Rumilly, France) until a core temperature of 72 °C was reached. No fat, salt, or herbs were added. Individual samples of the loin (∼10 g) were placed on platters coded with three-digit random numbers, covered with a lid and given to the assessors in a random order using the sequential monadic test. The sensory evaluation of the samples was made by the Quantitative Descriptive Analysis. Twenty-four attributes (Supplementary Table S1) were chosen and defined in accordance with ISO 13299:2016. The intensity of the descriptors was measured on a linear unstructured scale: 0–10 cm, anchored "none" to "very strong" for nine odour attributes (meat, fatty, toasted, acidic, sweet, sweat, manure, overall boar taint, sharp), five texture descriptors (hardness, tenderness, gumminess, ease of fragmentation, juiciness), four taste attributes (sour, salty, sweet, bitter), seven flavour cues (meat, fatty, toasted, sweat, manure, overall boar taint, persistent) and overall sensory quality (assessed from low to very high). Natural water was used as the taste neutraliser between the evaluation of the loin samples.

Consumer panels

Consumer tests were performed in six EU countries at one to two locations per country, all following the same standardised protocol: at ILVO (Melle) and at VG-sensory (Deinze) in Belgium; at Czech University of Life Sciences Prague in Czech Republic; at Warsaw University of Life Sciences in Warsaw, Poland; at the Laboratory for quality of animal products of INIAV in Portugal; at the Interdisciplinary laboratory for Research on Heavy Metals Accumulation in the Food Chain and Modeling – Food rheology and texture laboratory, in Romania; and at Eurofins (Barcelona) and IRTA (Monells) in Spain. Consumer characteristics for recruitment were as follows: an equal proportion of females and males, aged between 18 and 65 years and used to eating pork as a hot dish at least twice a month. In each of the 23 sessions, six consumers assessed the meat per session, with the exception of Portugal, which had three consumers per session, and Spain, which performed the last five sessions with three consumers instead of six. All 30 BAs, ICs, and BOs were thus evaluated in each country, by three up to six consumers. In total, 752 consumers participated in the study (Table 1). Overall, female consumers were slightly overrepresented, especially in Romania. The average age was 38 ± 15 years. More than 50% of the participants ate pork at least twice a week with their hot meal and 80% twice or more in their cold meals. The consumer test consisted of three parts. First, consumers evaluated the meat samples. Second, consumers performed a smell test to determine their sensitivity to SKA and AND. Third, consumers filled in a posthoc questionnaire on demographics and cooking and pork liking characteristics (Table 1). The questionnaire was provided in English and each country's sensory test leader translated it into the national language. This translated questionnaire was then made available via LimeSurvey. Each study part was performed in all countries, except for the smell test in Romania.

Sample preparation, serving and evaluation

Meat was thawed for 24–30 hours at 5 °C before preparation. Slices were grilled (model GC3060, Tefal, Rumilly, France or similar) at heat setting 2 for 7–8 minutes until a core temperature of 72 °C was reached. No fat, salt, or herbs were added. Each pork slice was cut into six pieces. Samples were served covered with a lid, one by one, with approximately 4 minutes between each sample. Time between frying and serving was kept as short as possible so that serving (core) temperature was approximately 70 °C. Before the first and after each serving, consumers were advised to eat a small amount of bread or cracker and drink some water to cleanse the palate. Each consumer received four meat samples, which were served in the same balanced design in each country. Each set of four samples consisted of three samples, one of each of the three treatment groups (BA, IC, BO) and the fourth sample was again one sample from one of these three treatment groups. The order of the treatment groups was balanced so that each sequence was equally represented and afterwards, animals were randomly assigned to this sequence. For each sample, consumers were first asked to score odour before tasting the sample on a 9-point scale from 'dislike extremely' (1) to 'like extremely' (9). Subsequently, they were asked to taste the sample and score flavour/taste, tenderness (at first bite), juiciness (after chewing) and overall liking on the same 9-point scale. Then, a set of 14 terms was presented and consumers were asked to check all terms that apply (**CATA**) to describe the sample. CATA terms were presented in the same order for all consumers. The examined terms were off-flavour, sour, traditional, irritating, manure, sweat, delicate, satisfactory, pleasantly surprised, disappointing, negatively surprised, disgusting, delicious and intriguing.

Androstenone and skatole sensitivity

Sensitivity to AND and SKA was tested by using paper smell strips spiked with either 20 µl odour solution or the pure solvent (propylene glycol) (Mörlein et al., 2013). The AND and SKA solutions had a concentration of 5.0 µg/g, which can be considered high. All material was prepared and provided by ILVO. Four triangles were presented and consumers were asked to indicate the odd sample. The first two triangles included AND, and the next two triangles included SKA. Consumers were instructed to sniff each strip and to give their best guess in case they did not smell a difference. For each triangle, consumers were also asked to score their odour appreciation of the odd sample on a 9-point scale from 'dislike extremely' (1) to 'like extremely' (9).

Consumers were then classified as 'sensitive' to AND and SKA if the two odd samples in the respective triangles were discriminated correctly. Based on the average liking scores for AND and SKA, consumers were then classified in sensitive consumers disliking AND (average liking score $\leq$ 3) (**NEG$_{AND}$**), sensitive, neutral or liking AND (average liking score > 3 (**SENS$_{AND}$**), and insensitive for AND (**INSENS$_{AND}$**) as well as sensitive and disliking SKA (**NEG$_{SKA}$**) or sensitive and neutral or liking SKA (**SENS$_{SKA}$**) in line with the classification used by Meier-Dinkel et al. (2013). All consumers included in the results were sensitive to SKA.

Table 1
Demographic and pork consumption characteristics of the consumers participating in the sensory study per country and in total (as % of the number of consumers).

Item	Country						Total
	Belgium	Czech	Poland	Portugal	Romania	Spain	
Number of consumers	139	138	138	83	131	123	752
Gender (%)							
Female	47	57	50	60	68	52	55
Male	53	43	50	40	32	48	45
Age (years)	41 ± 15	34 ± 14	38 ± 13	47 ± 17	29 ± 14	45 ± 13	38 ± 15
Who is preparing the main dish (%)							
Mainly me	50	32	41	48	18	64	42
Mainly others	31	23	21	19	39	7	24
Sometimes me, sometimes others	19	45	38	33	43	29	35
How much do you like the pork you usually buy and eat?	7.1 ± 1.1	7.4 ± 1.2	6.9 ± 1.2	6.8 ± 1.5	7.1 ± 1.5	7.1 ± 1.4	7.1 ± 1.3

Statistical analysis

The sensory profiling results were statistically analysed with XLSTAT version 2017 software by Addinsoft (Paris, France). The sensory data were examined using ANOVA with Fisher's Least Significant Difference posthoc test (5% significance level). Two-way ANOVA with interactions was performed to determine the differences between the meat samples originating from BO, BA and IC in the intensity of the descriptors, taking products, assessors and interactions into account as fixed variables. All data analysis of meat instrumental meat quality and the consumer test were done in R using the lme4 package for the models (Bates et al., 2015; Team, 2017). For the analysis of meat quality, linear mixed models were fitted with treatment group as fixed effects and slaughter date and pen as random effect and animal as experimental unit. Consumer liking scores were analysed in a mixed effect model resulting from stepwise descending model selection starting with: type (BO, BA, IC), country (Belgium, Czech Republic, Poland, Portugal, Romania and Spain), type × country interaction, sequence (samples 1–4), gender, liking of pork, and cook as fixed effects (Blanch et al., 2012; Heyrman et al., 2021; Meier-Dinkel et al., 2013). Consumer and animal were considered to be a random effect. When the p-value for an effect was >0.05, it was left out of the model. For the CATA terms, Cochran's Q-test was used to find significant differences between alternatives ($P < 0.05$) for each of the terms (Meyners et al., 2013). In order to test the effect of sensitivity to and dislike of AND (NEG_{AND}, $SENS_{AND}$ and $INSENS_{AND}$) and SKA ($SENS_{SKA}$, NEG_{SKA}) and the differentiation between BO with and without boar taint (according to both sensory and chemical criteria) on the consumer liking score for flavour, a data subset was made. Androstenone and SKA sensitivity/dislike and their interaction with type (BA, IC, and BO – BO with and without boar taint) were added to the basic model for selection of the final model. The interaction between gender and AND sensitivity was also taken into account.

Results

Characterisation of the meat samples

Differences in instrumental meat quality of the BA, IC and BO samples were limited to differences in intramuscular fat content, with a higher level for BA compared to IC and BO and no differences in water-holding capacity (Table 2). Androstenone ($P < 0.001$) and SKA ($P = 0.052$) levels in fat were lower in IC (AND: <LOD, SKA: 139 ± 61 ppb) compared to BO (AND: 2 141 ± 2 223 ppb, SKA: 318 ± 306). Only one immunocastrate had an elevated level of SKA (265 ppb), while 20 of the 30 BOs had elevated boar taint levels (11 animals > 2 000 ppb AND, 13 animals > 250 ppb SKA) based on chemical analysis. Five of these BOs with elevated SKA and/or AND were also considered as tainted by the expert panel (Fig. 1). Sensory profiling indicated differences in the intensity of all attributes ($P < 0.05$) except for sour taste (Fig. 2), with the greatest distance in sensory characteristics between BA and BO, and IC mostly in line with BA. Samples from BA represented the lowest intensity for hardness, gumminess and the highest intensity for ease of fragmentation, tenderness and juiciness, and of meat and toasted odour and flavour as compared to BO. The intensity of overall boar taint odour and flavour, sweat, and manure odour and flavour, along with sharp odour and persistent impression, was highest for BO.

Consumer appreciation of meat from barrows, immunocastrates and boars

Consumers liked the odour of BO less compared to that of BA and IC mostly intermediate ($P = 0.016$) (Fig. 3). For flavour, tenderness, juiciness and overall liking, results differed between countries ($P < 0.05$), with significant differences in liking scores between the BA, BO and IC given by the Czech, Polish and Portuguese consumers. The flavour of BO scored less compared to that of BA by Czech, Polish and Portuguese consumers. Tenderness was lowest for BO by the Czech (compared to BA), Polish (compared to BA and IC) and Portuguese consumers (compared to IC). Juiciness of BA scored best compared to IC and BO respectively by Czech and Polish consumers. Overall liking as well as WTB was highest for BA by Czech consumers, by Polish consumers (not differing from IC) and best for BA and IC by Portuguese consumers. When these liking scores are represented as the percentage of dislike (score ≤ 3), this is reflected in an increase of dissatisfied consumers for BO compared to BA and IC for tenderness (30.8, compared to 24.2 and 26.6%) and flavour (27.2 compared to 20.1 and 21.0%). The frequency of the negative CATA terms also differed between BA, BO and IC (Fig. 4). Frequency of disgusting was higher for BO compared to BA and IC. Frequency of off-flavour, irritating, manure, sweat, disappointing was also significantly higher for BO compared to BA, and intermediate for IC ($P < 0.05$). The frequency of the positive term delicate was higher for BA compared to BO and IC ($P < 0.05$). Only for WTB, there was an effect of gender, with an overall higher WTB by men (5.12 ± 0.10) compared to women (4.81 ± 0.09) ($P = 0.006$). Consumers who liked to eat pork always gave higher scores to each of the attributes ($P < 0.001$) and scores also increased with increasing serving order ($P > 0.05$).

Effect of consumer sensitivity and (dis)liking of androstenone and skatole and boar taint on flavour liking

Based on the methodology used in this experiment, 31% of the consumers were sensitive and disliked the odour of AND (NEG_{AND}), 33% were sensitive but neutral or positive towards the odour

Table 2
Instrumental meat quality of the barrow (BA), immunocastrate (IC) and boar (BO) samples (n = 30 per treatment group).

	BA		IC		BO		
Item	Mean	SD	Mean	SD	Mean	SD	P-value
pHi	6.36	0.28	6.40	0.24	6.34	0.33	0.388
pHu	5.40	0.09	5.41	0.10	5.47	0.09	0.397
Drip loss (%)	7.37	2.11	7.07	1.48	7.11	2.19	0.903
Intramuscular fat content (%)	2.53[b]	0.82	1.99[a]	0.56	1.63[a]	0.44	<0.001
Shear force (N)	53.32	10.58	56.88	10.40	51.04	10.70	0.246

pH_i: the pH measured at 45 min postmortem.
pH_u: the ultimate pH, measured at 24 h postmortem.
[ab] Different superscripts indicate significant differences between treatment groups (P < 0.05).

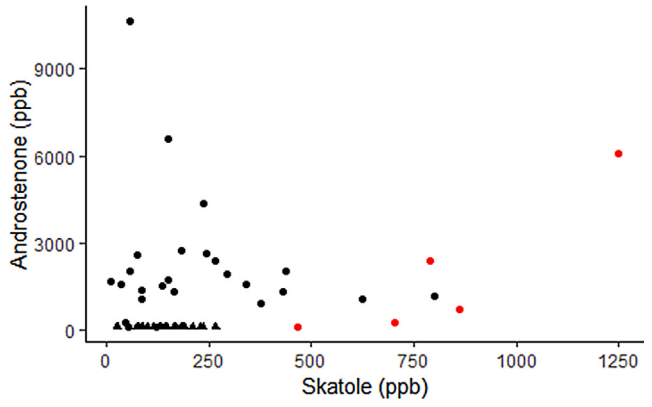

Fig. 1. Back fat skatole and androstenone levels (ppb) of the 30 immunocastrates (triangle) and the boars (circle) which were indicated as non-tainted (black) or tainted (red) according to the olfactory evaluation (mean score > 1).

($SENS_{AND}$) and 36% of them were not sensitive ($INSENS_{AND}$) (Table 3). Portuguese consumers had the highest frequency of NEG_{AND} (P < 0.05), while the percentage of $INSENS_{AND}$ was highest for the Polish consumers (P < 0.05) and male consumers (P < 0.001). Seventy seven percentage of the consumers disliked the odour of SKA (NEG_{SKA}), with the highest percentage for the female consumers.

For flavour, there was an interaction between male pig type and AND appreciation (P = 0.032), with a more outspoken decrease in flavour liking score for BO compared to BA and IC by the NEG_{AND} consumer (Fig. 5a). When differentiation between non-tainted (BO_{NoBT}) and tainted boars (BO_{BT}) was made based on the boar taint odour score of the fat samples, the flavour liking score given by the consumers significantly differed between the male pig types for NEG_{AND} and $SENS_{AND}$ but not for $INSENS_{AND}$ consumers. For $SENS_{AND}$, BO_{BT} had a significantly lower flavour liking score than BA. For NEG_{AND}, BO_{BT} and BO_{NoBT} had a lower score than IC and BA (Fig. 5c). With differentiation based on chemical method, the lowest flavour liking score was given to BO_{TAINT} (5.56 ± 0.12[a]), followed by BO_{NoBT} (5.61 ± 0.17[ab]), IC (5.99 ± 0.10[b]) and BA (6.07 ± 0.10[b]) (Fig. 5e) independent of the sensitivity or appreciation of AND of the consumers. Overall, NEG_{SKA} consumers gave an overall lower liking score compared to $SENS_{SKA}$ consumers, independent of the male pig type or boar taint classification (Fig. 5b, d, f).

Discussion

The sensory profiling discriminated BA from BO, with IC mainly in line with BA based on differences in texture and boar taint. BO represented the highest intensity for hardness, gumminess and the lowest intensity for ease of fragmentation and tenderness. For juiciness, differences were small, with BO intermediate between BA and IC. The lower rating of BO for texture seems to be mainly related to the low intramuscular fat content of BO compared to IC and BA. Water-holding capacity and shear force did not differ significantly. These findings are in agreement with the conclusion made in the review of Škrlep et al. (2020), with water-holding capacity in general either not being different between

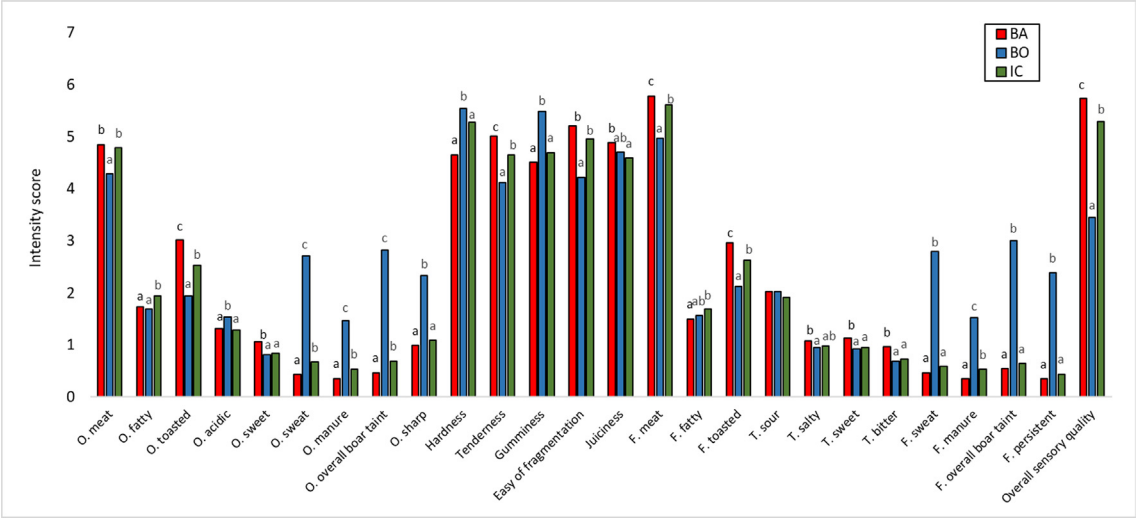

Fig. 2. Sensory profiling of meat from 30 barrows (BAs), immunocastrates (ICs) and boars (BOs) with attributes for odour (O.), texture, taste (T), flavour (F.) and scored on a linear unstructured scale from 0 (low intensity) to 10 cm (high intensity) by 10 assessors per sample. [abc] different superscripts indicate significant differences between treatment groups (P < 0.05).

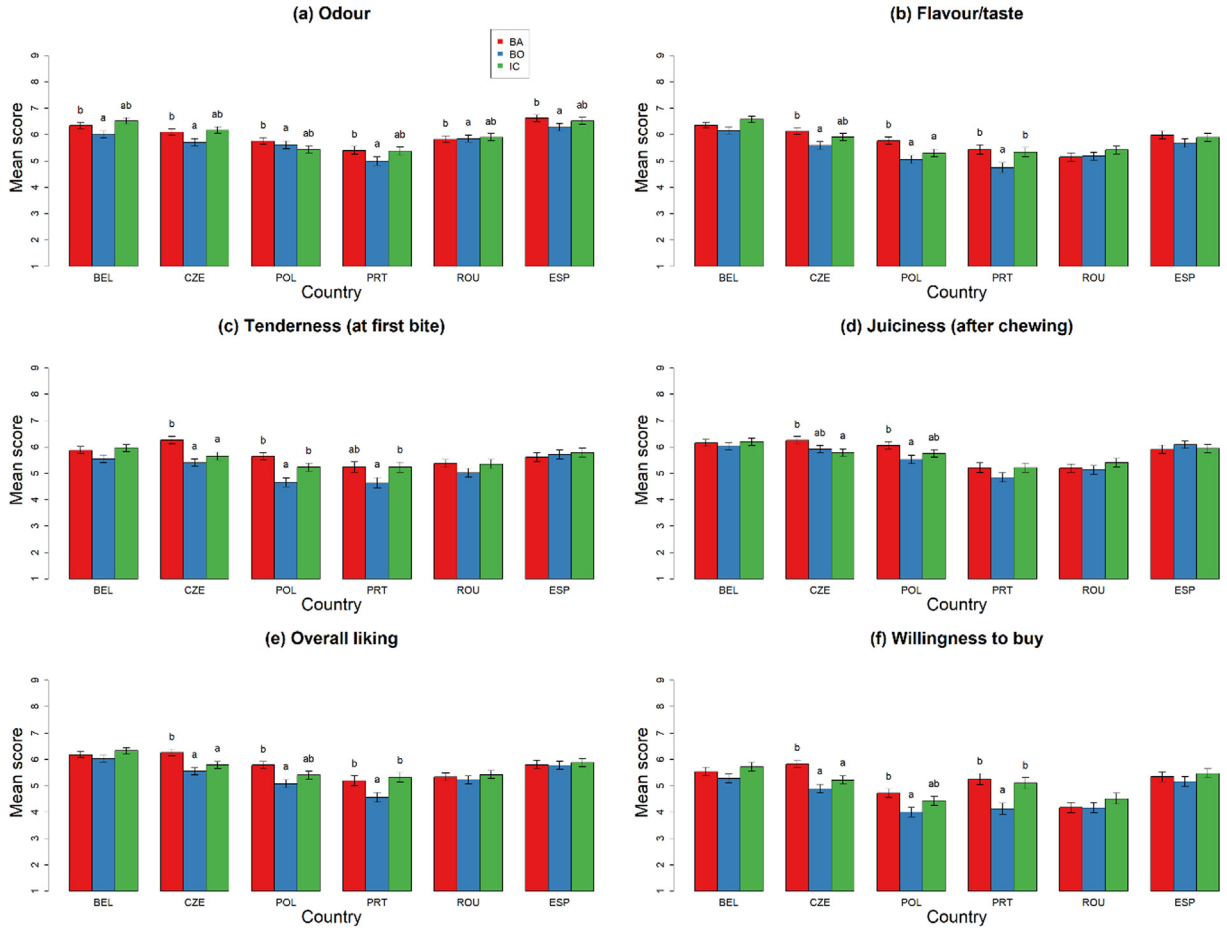

Fig. 3. Consumer ratings of (a) odour, (b) flavour/taste, (c) tenderness, (d) juiciness, (e) overall liking and (f) willingness to buy for the panels performed in Belgium (BEL, n = 139), Czech Republic (CZE, n = 138), Poland (POL, n = 138), Portugal (PRT, n = 83), Romania (ROM, n = 131) and Spain (ESP, n = 123) on a 9-point scale from 'dislike extremely' (1) to 'like extremely' (9) of meat from barrows (BAs), immunocastrates (ICs) and boars (BOs). [abc] different superscripts indicate significant differences between treatment groups (P < 0.05).

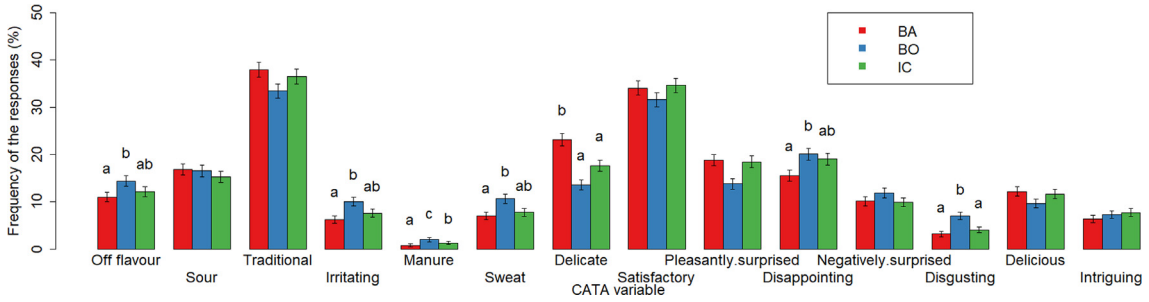

Fig. 4. Frequency of Check-All-That-Apply (CATA) scoring by the consumers (n = 752) of meat from 30 barrows (BAs), immunocastrates (ICs) and boars (BOs). [abc] different superscripts indicate significant differences between treatment groups (P < 0.05).

BO, BA and IC or slightly better for BA in case of differences. The differences between studies may be due to the analysis method used, as well genetics, handling or diet. As indicated in the study performed parallel to this study (Van den Broeke et al., 2022), meat quality differences are for instance more outspoken at a low energy diet compared to a high energy diet. The animals selected for the collection of loins used in this consumer study were all fed the high energy diet (Van den Broeke et al., 2022), resulting in smaller differences between the three types of male pigs for water-holding capacity.

Boar taint was clearly reduced by applying immunocastration based on the chemical as well as the olfactory evaluation of the neckfat samples of the BO and IC. Sensory profiling confirmed that the loin chops from the BO had a higher intensity of overall boar taint odour and flavour, sweat, and manure odour and flavour, along with sharp odour and persistent impression. Also, all consumers indicated that they did not like the odour of BO as much as BA and IC and ticked more negative attributes describing boar taint, such as off-flavour, irritating, manure and sweat. In accordance with the results of the liking scores, the percentage of dissatisfied consumers was higher for BO compared to BA (+6.6% for tenderness and +7.1% for flavour) and IC (+4.2% for tenderness and +6.2% for flavour). Also Matthews et al. (2000) observed an increased percentage of dislike of BO compared to gilts of 3% for

Table 3
Percentage of pork consumers' sensitivity and appreciation of androstenone (AND) and skatole (SKA) based on the classification used by Meier-Dinkel et al. (2013) by country (BEL: Belgium, CZE: Czech Republic, POL: Poland, PRT: Portugal, ESP: Spain), gender and overall.

		Country					Gender	
Item[1]	Total	BEL	CZE	POL	PRT	ESP	Female	Male
SKA								
NEG_{SKA} (%)	77.4	83.5	75.4	82.5	79.5	61.0	80.1	74.2
$SENS_{SKA}$ (%)	22.6	16.5	24.6	17.5	20.5	39.0	19.9	25.8
AND								
NEG_{AND} (%)	31.1	33.1	29.2	27.5	41.1	27.3	34.7	26.7
$SENS_{AND}$ (%)	32.6	35.4	33.1	30.8	26.0	36.4	35.1	29.7
$INSENS_{AND}$ (%)	36.2	31.5	37.7	41.7	32.9	36.4	30.2	43.6

[1] NEG_{AND} (AND sensitive, average liking score $\leq$ 3), $SENS_{AND}$ (AND sensitive, average liking score > 3), and $INSENS_{AND}$ (not AND sensitive), as well as NEG_{SKA} (SKA sensitive, average liking score $\leq$ 3), and $SENS_{SKA}$ (SKA sensitive, average liking score > 3).

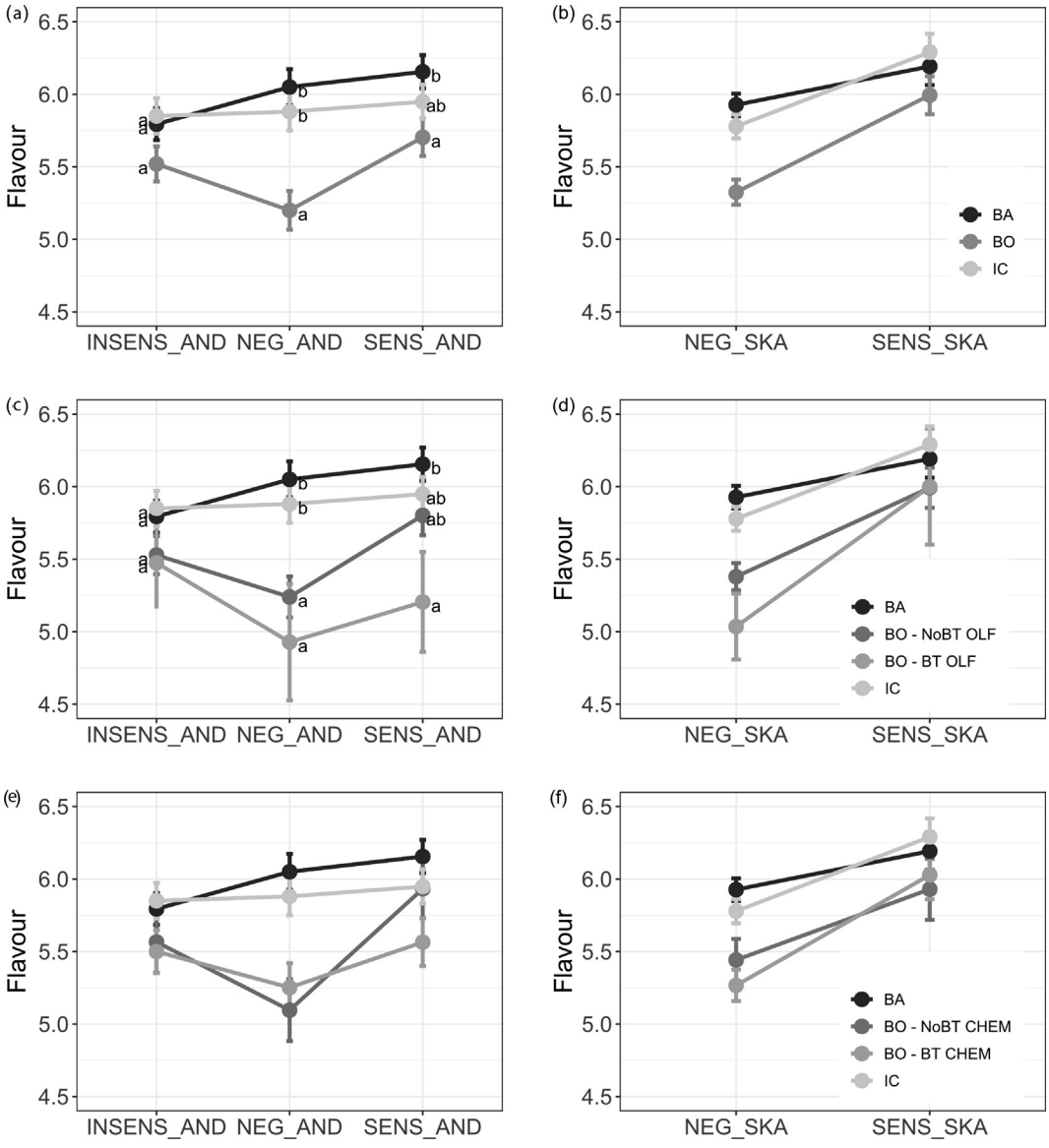

Fig. 5. Flavour liking score of the consumers (n = 621) scored on a 9-point scale (1: dislike, 9: like) based on liking and appreciation of androstenone (AND) (left panel) and skatole (SKA) (right panel) for 30 barrows (BAs), immunocastrates (ICs) and all boars (BOs) (a, b), and for non-tainted (BO-NoBT) and tainted boars (BO-BT) based on olfactory (OLF; c, d) and based on chemical (CHEM; e, f) boar taint evaluation, with NEG_{AND} (AND sensitive, average liking score $\leq$ 3), $SENS_{AND}$ (AND sensitive, average liking score > 3), and $INSENS_{AND}$ (not AND sensitive), as well as NEG_{SKA} (SKA sensitive, average liking score $\leq$ 3), and $SENS_{SKA}$ (SKA sensitive, average liking score > 3) based on the classification used by Meier-Dinkel et al. (2013). ^{ab} different superscripts indicate significant differences between treatment groups (P < 0.05).

flavour and 6% for odour. The results of this study indicate that some of the consumers noticed differences between the alternatives with a lower appreciation of BO compared to BA and in most cases also lower compared to IC, although not for all attributes in each country. Some studies confirm country or cultural differences in the capability to discriminate between the different types or

boars with and without boar taint (de Kock et al., 2001, Font-i-Furnols et al., 2016), but not all (Aluwé et al., 2018). In the study of Matthews et al. (2000), the percentage of dislike was higher for female consumers compared to male consumers, higher for those mainly doing the cooking as well as the less frequent pork eaters. Meier-Dinkel et al. (2013) found that women overall gave lower liking scores than men. In this study, we found a lower WTB by women compared to men, but no significant differences in the liking scores. The effect of pork preference was evident in this study: consumers who liked to eat pork always gave higher scores to each of the attributes. The same findings were also illustrated in the study of De Kock et al. (2001), emphasising the higher impact of pork liking on the overall scores than frequency of pork consumption. Another factor potentially explaining these differences is the sensitivity and appreciation of the boar taint compounds. The percentage of 36% of $INSENS_{AND}$ is in accordance with the wide range reported in previous studies of 27 up to 68% (Weiler et al., 2000; Bekaert et al., 2011; Bonneau and Chevillon, 2012; Mörlein et al., 2013; Aluwé et al., 2016; Heyrman et al., 2018). A number of studies also report the percentage of consumers perceiving AND as clearly unpleasant. This percentage is ranging from around 21% (Meier-Dinkel et al., 2013), 33% (Font-i-Furnols et al., 2003), 31–41% (Blanch et al., 2012) and between 44 and 50% (Bonneau and Chevillon, 2012). The study of Blanch et al. (2012) describes different percentages of NEG_{AND} between countries, being lower in the UK (31%), compared to Spain and France (41%). The appreciation of SKA is less frequently investigated. The overall percentage of dislike of SKA in this study of 77.4% is higher than that found in the study of Meier-Dinkel et al. (2013). They found that 39% of the consumer clearly disliked SKA, but similarly, the dislike of SKA was twice as high as compared to AND. In the study of Font-i-Furnols et al. (2016), the frequency of NEG_{SKA} was 38% in Russia and 30% in China. In our study, Portuguese consumers had the highest frequency of NEG_{AND}. This is somehow against expectations as production of boars is common practice in Portugal, as well as in Spain, which may suggest that consumers could get used to the smell. This may be the case for SKA in Spain as the share of NEG_{SKA} was lowest for the Spanish consumers. The higher number of female consumers participating in the consumer study in Portugal compared to Spain being more sensitive and negative towards SKA and AND probably explains the deviating results for Portugal. Other studies indeed already reported a higher AND sensitivity of females versus males (de Kock et al., 2001; Bekaert et al., 2011; Blanch et al., 2012), but this is less studied for SKA.

A number of studies have evaluated the effect of AND sensitivity on the rating of boar meat, some of which also included the consumers' appreciation of AND. Several studies conclude that AND sensitivity increases the chance that boar meat products are disliked at higher boar taint levels and distinguished from control samples, especially if these consumers dislike AND (Weiler et al., 2000; Font-i-Furnols et al., 2003; Aluwé et al., 2013; Mörlein et al., 2013). Some studies did not find a significant interaction between AND level of the boar meat product and consumer sensitivity, indicating that sensitive consumers overall give lower liking scores compared to non-sensitive consumers (Lunde et al., 2010; Aluwé et al., 2011; Aaslyng et al., 2016). In other studies (Aaslyng et al., 2015), there was no effect of AND sensitivity on the liking score. In the current study, we also observed a non-interactive effect for the appreciation of SKA on the liking score, with overall lower scores given by those consumers that disliked SKA. The consumers' ability to differentiate between the male types did however depend on their sensitivity and appreciation of AND. $INSENS_{AND}$ consumers were not able to differentiate BA and IC from BO. NEG_{AND} consumers liked the flavour of the BO samples less compared to the BA and IC. This was still the case when the BOs were classified as tainted or non-tainted based on olfactory evaluation. $SENS_{AND}$ consumers also liked BO less than BA, but less explicitly and with IC intermediate. BO samples classified as untainted based on olfactory evaluation were not scored significantly different from BA and IC by these $SENS_{AND}$ consumers. The study of Bonneau and Chevillon (2012) found that NEG_{AND} consumers were better able to discriminate boar tainted samples than $INSENS_{AND}$ or $SENS_{AND}$, but only in case of a combination of a high SKA and AND level. This was only applicable for one out of the thirty boars included in this study. This may also partly clarify why the fat samples from the boars with increased AND levels but lower SKA levels were not defined as tainted based on the boar taint odour score of trained panellists, despite being both sensitive and trained. When BOs were classified based on chemical analysis, there was no longer an interactive effect. Results are thus more in line with expectations for the boar taint odour score, indicating that this better resembles the consumer view. However, the differences in liking score between the boars with and without boar taint are not significant, suggesting that not only boar taint but also textural differences between BO, IC and BA may affect the final flavour liking score of this lean type of pork, as also indicated by the sensory profiling.

Conclusion

Sensory profiling differentiated BO from BA based on the presence of boar taint, and differences in texture, and IC mostly in line with BA. All consumers liked the odour of BO less and selected more of the boar taint related CATA terms. Flavour and texture related liking scores also differed between BA, IC and BO for the Czech, Polish and Portuguese consumers, pointing towards geographical differences in the ability to discriminate the male types for these attributes. However, this may also be related to the SKA and AND sensitivity and appreciation of the consumers included in the panel as well as other factors. Overall, 31% of the consumers disliked the odour of androstenone, while 36% of them were not sensitive. Seventy seven percentage of the consumers disliked SKA. Consumers disliking AND liked the flavour of the BO samples, also in case of boar taint absence less compared to the BA and IC, while consumers that were insensitive for AND were not able to differentiate these groups. Consumers that disliked SKA gave overall lower liking scores. The results of the study confirmed that classifying the consumers based on their AND and SKA sensitivity and appreciation is relevant when studying the differences between the castration alternatives and the presence of boar taint. Including CATA also gives the possibility to better understand the differences in consumer liking scores and could be further improved by adding texture related terms. The sensory study confirms the importance of guarantying good pork quality when shifting towards alternatives for the castration of piglets.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2022.100455.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings are available to reviewers.

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Declaration of interest

The authors declare no conflict of interest.

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