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Evaluation of producing and marketing entire male pigs

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ABSTRACT

This paper presents the results of a research program that was aimed at evaluating: (1) sensory evaluation of meat from entire male pigs, (2) preventive measures to reduce boar taint prevalence, (3) accuracy of detection for boar taint, and (4) the relationship between farm management characteristics and levels of mounting and aggressive behaviour of boars. Using observational and experimental studies data were collected in various segments of the pork supply chain. Consumer acceptance of meat from entire male pigs was evaluated. The effectiveness of preventive measures to reduce boar taint prevalence was determined. The relationship of farm (management) characteristics with boar taint prevalence, animal behaviour, skin lesions and lameness respectively was analysed. The similarity of the rank order between consumer perception of odour and human nose scores, skatole and androstenone levels respectively was determined. Consumers evaluate meat that passed the boar taint detection test comparable to meat from gilts. Meat samples that did not pass this test were evaluated less favourable. Ranking AI boars on their genomic breeding values for low boar taint resulted in a reduction in boar taint prevalence of 40%. The skatole level is lower in boars fed via a long trough than in boars fed by a single space feeder. Few eating places, restricted feeding, a low level of amino acids in the diet, insufficient water supply of the drinking system, illness of the pigs, a suboptimal climate and fear for humans were associated with a higher level of sexual and aggressive behaviour and more skin lesions. A partly open pen wall, clean pens and pigs, wider gaps of the slats, feeding by a long trough, and feeding wet by-products were associated with less sexual and aggressive behaviour and less skin lesions. Having more than 30 animals per pen was associated with a higher probability of high boar taint prevalence levels. Hygienic conditions were associated with lower boar taint prevalence levels. Assessing similarity of the rank order comparison between consumer perception and three selected boar taint detection parameters for the consumer perception attribute odour of meat resulted in the highest Kendall's W values for the human nose scores. In conclusion, boar tainted meat was rated as less pleasant by consumers compared to meat of gilts and non-tainted boar meat, indicating the need of detection as a safety net at the slaughter line. Breeding was an effective preventive measure to reduce boar taint. Farms with appropriate management, feeding and housing conditions have reduced levels of mounting and aggressive behaviour. Human nose scores were a better predictor of the rank order of consumer perception, compared to skatole levels and to androstenone levels.

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1. Introduction

One of the main challenges for the pork supply chain is to adapt pig production to societal demands with regard to animal welfare, especially to end the current practice of castrating male piglets. In most countries in the EU, castration of male piglets is common practice [1]. To improve animal welfare, in 2009 the Dutch pig sector agreed with the Declaration of Noordwijk on the ambition to ban castration of male piglets from 2015 onwards. On EU-level the European Declaration on alternatives to surgical castration of male pigs of June 2010 proposes ending surgical castration of male piglets from 2018 onwards [2]. Although it is more profitable and efficient to produce entire males due to their enhanced feed conversion and higher proportion of lean meat on their carcasses, it is recognized that the quality of meat from some entire males is negatively influenced by odour and taste, referred to as boar taint [3]. These off-flavour compounds in meat render the meat less suitable for human consumption [4]. Boar taint has been described as 'animal', 'urine', 'faecal' and/or 'sweat' like odour. People sensitive to androstenone can smell this odour [5]. Consumption of cold products from tainted meat does not induce such strong negative reactions among consumers as consumptionof products immediately after heating [6]. However, the majority (and most valuable) of the parts of the pig are destined for the fresh meat market. Boar taint can be largely (> 60%) attributed to three compounds, namely androstenone, skatole and to a lesser extend indole [7,8]. Although castration has been partially abandoned in a number of countries (e.g. Spain, Ireland and the United Kingdom), in most countries all male pigs except those retained for breeding are castrated. In the Netherlands, a five year research program was carried out aiming at both limiting the occurrence of meat with an off-flavour as well as excessive mounting and aggressive behaviour of boars. This is a pre-condition for realising market acceptance of meat from non-castrated pigs. To support the ambition to produce and market meat from entire male pigs this research is aimed at getting an insight into the (1) consumer evaluation of meat from entire male pigs, (2) effectiveness of preventive measures to reduce boar taint prevalence, (3) accuracy of in-line detection of boar taint using the human nose scoring system, (4) relationship of farm (management) characteristics with farm level boar taint prevalence, and mounting and aggressive behaviour of entire male pigs, and (5) effect of measures to limit mounting behaviour. Selected preventive measures to reduce boar taint prevalence were within line selection of low boar taint producing boars, simultaneous dry feeding by a long through, feeding a boar taint reducing diet and keeping pigs in litters. Farm level measures to limit mounting behaviour of boars were green light, more total pen space and a hiding wall. This paper reports the results of the research. Section 2 describes the material and methods. Research results on consumer acceptance, preventive measures and detection are presented in section 3. Observational studies and experiments on animal behaviour and boar management are presented in section 4. Using cost estimates and technical parameters, the farm level economics of producing entire male pigs, compared to producing barrows were evaluated in section 5. Finally, section 6 presents the concluding comments and general discussion.

2. Material and methods

Data on technical results, animal behaviour and boar taint prevalence are collected using observational and experimental studies. We assess the impact of preventive measures (breeding, feeding, housing conditions) on boar taint levels and on undesirable animal behaviour, using observational and experimental methods. Using cost estimates and technical parameters, we evaluate the economics of producing entire male pigs, compared to producing barrows.

2.1. Experiments and observational studies

Table 1 gives an overview of the experimental and observational studies that were used to provide empirical evidence on the research questions.

2.2. Recording of boar taint

Boar taint is often measured through two malodour compounds, androstenone and skatole. Another approach is to heat the fat samples and record intensity of the boar taint using human nose scores (HNS). Trained assessors can be used to determine the level of boar taint odour after heating a sample of pork. [9] showed that human nose scores have good correlations with boar taint compounds, androstenone and skatole. At the same time different assessors had different sensitivities to androstenone and skatole. The correlations of HNS by individual assessors with androstenone ranged from 0.22 to 0.52 while those with skatole ranged from 0.31 to 0.89. In this way, the assessors covered a wide range of variation commonly observed in sensitivities of pork consumers to these compounds. The reproducibility, calculated as the intra-class correlation model, i.e. for the 5 scores, of HNS ranged from 0.19 to 0.32. This reflects the natural variation in the ability of human beings to detect different odours. [9]. The average correlations of HNS by all assessors with androstenone was 0.42, while that with skatole was 0.69, suggesting that skatole is a better predictor of boar taint. In addition, sensitivity and specificity of the HNS scoring method was evaluated in two ways. First, the commonly used thresholds of 1.0 μg/g for androstenone and 0.250 μg/g for skatole were considered. However, the proportion of boars that should be considered truly positive for boar taint based on these thresholds was much higher (44.0%) compared to the actual proportion (8.7%) based on HNS. Therefore, in a second estimation, average scores of the assessors for each boar were used and the threshold was set at the average HNS of 2.5. The boars having average HNS above 2.5 were considered truly positive for boar taint. The average sensitivity based on this average score of the assessors was then 75% and the specificity 93%. Details on sensitivities and specificities of each tester with each of the two methods are given by Mathur et al. [9].

Samples of fat from 6,574 intact males were collected after slaughter. The samples were then heated by a hot iron and scored by a total of eight assessors from the Topigs Research Center IPG and one assessor from VION Food. Each sample was scored by three assessors. Actual human nose scores of each of the boar by three assessors were used. The scores were then transformed into an underlying normal distribution with threshold dependent upon each assessor using the procedure described by Mathur et al. [9]. The assessors recorded the intensity of boar taint on a scale of 0 to 4. They were asked to record 0 for no detectable boar taint, 1 for no boar taint but some off odour, 2 for more off odour but no boar taint, 3 for some boar taint odour and 4 for strong boar taint odour. In this way, they were asked to record scores 3 and 4 if they expected that those samples will be rejected by most consumers who can smell boar taint.

In addition to HNS, the levels of two main boar taint compounds, androstenone and skatole were also determined for a subset of 5,025 of the animals. Some of them had more than 3 observations each for human nose scores. The levels of these boar taint compounds were determined through chemical analyses. The fat samples were initially analysed at the Norwegian School of Veterinary Science in Oslo, Norway and later at Co-operative Central laboratory in Veghel, the Netherlands for both boar taint compounds. The androstenone level was determined using liquid

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Table 1
Overview of experiments and observational studies.

	(N =)[a]	Material	Description	Characteristics
Consumer evaluation meat from male pigs	196 consumers	Pork chops from gilts and boars	Consumer evaluation in a sensory lab environment, respondents in The Netherlands	89 male, 107 female; mean age = 44.9 yr, s.d. = 16.4
	202 households	Pork loins	Sensory evaluation by 199 households in The Netherlands, both the cook and a taster gave quality ratings.	37 male, 145 female; mean age =44.6, s.d.=13.7 (non-response = 47)[b]
	240 households	Loins, chops with a rib, and belly from 55 boars.	Sensory evaluation by 120 households in Germany and 120 households in the Netherlands; Only the cook gave quality ratings. Meat samples from 55 boars with varying human nose scores.	NL: 15 male, 100 female; mean age = 49 yr, s.d.=12.7(non-response = 5) GER: 33 male, 80 female (non-response = 7)[c]
Preventive measures to reduce boar taint	406 boars	AI boars	Observational study on genetic selection: Within line selection of low boar taint producing boars according to eight sources of information, simultaneously using biopsies, genetic markers and slaughter line data.	406 AI boars
	576 boars	Finishing pigs (Tempo boar x (Dutch Landrace x Dutch Large White) sow)	Experiments on feeding and housing: (1) litters versus single sex groups, (2) simultaneous dry feeding by a long through versus sequential dry feeding by a single space feeder, and (3) feeding a boar taint reducing diet versus a conventional diet	24 pens with litters and 24 pens with single sex mixed boars, 12 pigs per pen
	1.7 million boars	Pig carcasses	Observational study on the relation between carcass weight and boar taint prevalence: Carcasses with boar taint assessed by 34 testers	Boars from 1,585 farms slaughtered from August 2012 till October 2013
	455 boars	Pig carcasses	Observational study on the relation between age at slaughter and boar taint: Boar taint assessed by 4 testers	Boars from 1 farm, delivered in 3 rounds with 2 batches per round
Boar taint and behaviour	70 farms	Four pens per age group of 5, 9 and 13 weeks	Observational study on relation of farm (management) characteristics with boar taint prevalence, animal behaviour, skin lesions and lameness respectively: univariate analysis followed by analysis of the 25% best, 50% middle and 25% best farms	Behavioural measurements in 3 periods of 5 minutes/pen Boar taint data provided by slaughter plant
Measures to detect boar taint	240 households	Pork loins and pork chops from 55 boars.	Observational study on in-line detection for boar taint: similarity of the rank order between consumer perception of odour and human nose scores, skatole and androstenone respectively for meat samples from 55 boars with varying human nose scores.	NL: 15 male, 100 female; mean age = 49 yr, s.d.=12.7(non-response = 5) GER: 33 male, 80 female (non-response = 7)[b]
	19,383 pig carcasses	Subcutaneous fat in the neck of pig carcasses	Observational study on effect of fatigue on human nose scores: regression analysis on percentage of carcasses in 5 human nose score categories for 9 assessors testing with a slaughter line speed of 650 carcasses per hour	Testing from September 2010 to July 2012.
Animal behaviour	12 pens, 18 pigs 8 pens, 15 pigs 48 pens, 12 pigs 24 pens, 12 pigs and 24 pens, 24 pigs	Finishing pigs (Tempo boar x (Dutch Landrace x Dutch Large White) sow)	Four experiments on effect of farm level measures on mounting behaviour of boars: (1) Effect of straw versus rubber mat and three versus six eating places, (2) Effect of additional sugar beet pellets and a dummy sow, (3) Effect of litters versus single sex groups and of sequential versus simultaneous feeding, and (4) Effect of light, group size and hiding side walls	2 × 2 factorial design in the first three trials, and 3 × 2 x 2 factorial design in the last trial

[a] N denotes the total sample size.
[b] These figures represent the characteristics of the cook
[c] The German respondents were asked to report their age in cohorts rather than years, and the frequencies were: 18-29: 37 respondents, 30-50: 49 respondents, above 50: 27 respondents

chromatography-mass spectrometry (LC-MS) in accordance with Verheyden et al. [10]. More details of this procedure are given by Ampuero Kragten et al. [11]. Skatole and Indole were extracted from the fat sample using a mixture of methanol and hexane at 40 °C in an ultrasonic bath. It was separated by high-pressure liquid chromatography (HPLC) on a reversed phase column. Fluorescence was measured at 285 nm and 340 nm. Statistical analysis included specific models due to categorical nature of HNS and necessary adjustments for lab differences were made in the statistical analysis.

3. Research results

3.1. Consumer acceptance

In a first study we analysed the sensory evaluation of pork chops from gilts and from boars by consumers in a sensory laboratory environment. Carcasses of boars were tested for boar taint by a trained expert in a inline human nose test on a 2-point scale (0 = no boar taint, 1 = boar taint). Additionally, androstenone and skatole values were determined. An equal number of gilt samples and boar samples defined as tainted and non-tainted were evaluated in a consumer test. In total 196 consumers (89 males and 107 females; mean age 44.9 years, *SD* = 16.4)) participated in the test that was conducted on three different locations in the Netherlands. Consumers were selected according to the following criteria: regular consumer of pork meat products, having no food allergy, and no prescribed diets. Meat samples were prepared by a professional cook on a plate with 180 degree Celsius temperature. The meat samples weighed between 65 and 86 gram. Salt was added, 1 gram per 200 gram meat. All consumers participated in one session each where they evaluated three samples, first a sample from gilts, followed by either a meat sample of boar carcasses that was

Table 2
Average valuation of sensory aspects of pork chops from gilt carcasses, and carcasses from boars that passed or did not pass a trained expert human nose test for boar taint.

Aspect	Gilts	non-tainted boars	Tainted boars	F-value	P-value
Tasty	5.60	5.69	5.13	5.74	0.0035
Appearance	5.50	5.48	5.11	3.15	0.0438
Odour	5.92	5.97	5.19	15.38	<0.0001
Taste	5.58	5.62	5.20	3.36	0.0359
Mouth feeling	5.44	5.86	5.17	7.48	0.0006

considered boar tainted or one that was not boar tainted based on the trained expert human nose test. Every sample was evaluated one by one on a 9-point Likert scale (1 "totally not" to 9 "very") for: tasty and for the pleasantness of appearance, smell, taste and mouthfeel. The results are presented in Table 2.

The results in Table 2 show that the boar tainted meat was rated as less pleasant on almost all aspects compared to meat of gilts and non-tainted boar meat. The boar tainted meat is less tasty compared to the two other types of meat. Also, the boar tainted meat has a less pleasant appearance, odour and taste. In terms of mouth feeling, the boar tainted meat was evaluated as less pleasant than non-tainted boar meat.

In a second field experiment, involving 202 households in the Netherlands, the pig odour perception of consumers during cooking and actual consumption was studied. In each household the person who was mainly responsible for preparing food (the cook) was the main participant (n = 202, 37 male, 118 female, 47 non-response; mean age = 38.7, s.d. = 20.7). In addition, for each household except the single person households a family member aged 16 or older (usually the partner) participated in the study. Participants consumed and evaluated loins in a home environment. All 202 households were divided in seven groups, one control and six experimental groups (see Table 3). All groups tested gilt meat in the first week. The experimental groups then tested twice boar meat and twice gilt meat in a random order, one day a week during the five-week period according to the randomization scheme in Table 3. The control group ate gilt meat all 5 times. Trained experts were used to identify and select samples of boar tainted meat. Carcasses of boars were tested for boar taint. Based on androstenone and skatole values a first selection was made of boar meat with either high or low values. Second, 5 trained experts rated the boar meat in a human nose test. A fat sample was heated with a soldering iron and smell was rated on a five point score ranging from 0 to 4 (0 for no detectable boar taint, 1 for no boar taint but some off odour, 2 for more off odour but no boar taint, 3 for some boar taint odour and 4 for strong boar taint odour). When three trained experts rate a neck fat sample a 2 or higher on the five point scale it was selected as boar tainted boar meat. This selection took place on 15 different days between September 8th and November 18th 2010. In total 14 trained experts were involved (6 from VION and 8 from IPG). Each sample selected in the VION slaughterhouse after repeated testing (score 3 and 4) was tested again by three trained IPG experts. The household rated the meat products on odour during cooking and dinner and on taste and quality during dinner. The cooks rated odour and appearance of the product during preparation. Cooks and one family member rated odour, flavour, exterior, and overall quality of the product during consumption. Perceived *odour* was measured by the mean of two 9-point item scales ('this odour is [very unpleasant-very pleasant]' and 'this odour is [very untasteful-very tasteful]'). Perceived *flavour* was measured similarly by three 9-point item scales ('taste good', 'taste nice', and 'taste tasty'). *Exterior* was measured by two 9-point item scales ('this meat looks appealing/juicy/taste' [totally disagree to totally agree]). The overall *quality* perception was measured along two 9-point item scales ('this piece of meat has a good quality' and 'this piece of meat is all right' [totally disagree to totally agree]). The respondents in the study are a sample of a consumer population, and the gilts and boars in the study are selected from a pig population. This implies that the offered meat products should be considered as a sample of a population and not as fixed factors in an experiment. Therefore, random coefficient models rather than fixed-effects ANOVA models were used. In addition, random effects models also enable to account for the fact that members of the same household may influence each other's evaluations. That is, in the analyses, the models accounted for the fact that evaluations from the cook and her family member may not be independent from each other. In the cases where households ate boar meat with a high boar taint risk more than once, it was studied whether learning effects occurred in the evaluations of the meat

Table 3
Experimental design for the evaluation of meat samples by consumers in a home environment.

	N=	Week 1	Week 2	Week 3	Week 4	Week 5
Random experimental groups	30	Gilt	Gilt	Gilt	Boar	Boar
	28	Gilt	Gilt	Boar	Gilt	Boar
	28	Gilt	Gilt	Boar	Boar	Gilt
	28	Gilt	Boar	Gilt	Gilt	Boar
	29	Gilt	Boar	Gilt	Boar	Gilt
	32	Gilt	Boar	Boar	Gilt	Gilt
Control group	24	Gilt	Gilt	Gilt	Gilt	Gilt

Boar = boar tainted meat that was selected by trained human experts, and also had high levels of Androstenone and Skatole.

In a distinct lab-setting the same panel of respondents was asked to rate the odour of a mixture of artificial derived androstenone (± 10 mg/kg) and skatole (2.9 mg/kg). The respondents judged the odour by means of two 9-point item questions ('this odour is [very pleasant-very unpleasant]' and 'this odour is [very tasteful-very untasteful]'). The sensitivity score was derived as the simple mean of the two item scores. We denote this metric as sensitivity. A score of 5 (neither tasteful nor untasteful) or higher (tasteful) was given by 21.3% of the cooks and 27.8% of the family members. The lowest possible scores (twice 1) were given by 33.0% of the cooks and 25.8% of the family members. Fig. 1 shows the scores for the cooks on boar tainted meat compared to gilt meat that is indexed on 100. Boar 1 indicates the first judgment of boar-tainted boar meat, and Boar 2 indicates the second judgment of boar-tainted boar meat. Similar results were found for the family members.

The results in Fig. 1 show no differences between the first and second time of the boar tainted meat evaluation. Thus no empirical evidence was observed for enhanced or reduced learning effects among consumers, as the scores of the second-time boar-tainted boar chops were also significant and negative. The rating of gilt meat after a respondent has encountered boar-tainted boar meat was not significant different from the overall mean. So, when respondents have to rate gilt meat in the week after they had to judge boar-tainted boar meat, the associated gilt scores were in line with the baseline (gilt) ratings. Boars with a high risk for boar taint were rated lower on odour during cooking and dinner, and lower (i.e. more negative) on taste and overall quality.

In a third consumer study, an international survey among 120 German and 120 Dutch households, we also considered the overall quality perception of three different types of boar meat: belly, chops (with a rib), and loins. The question of interest was whether homogeneous segments can be formed on the basis of these three boar meat types. The participants were asked to prepare the meat products at home, one type a week, as a part of their regular main dish. A questionnaire was handed out, in which consumers were asked to score on statements about the odour and overall quality of the meat product, identical to the method described for study 2.

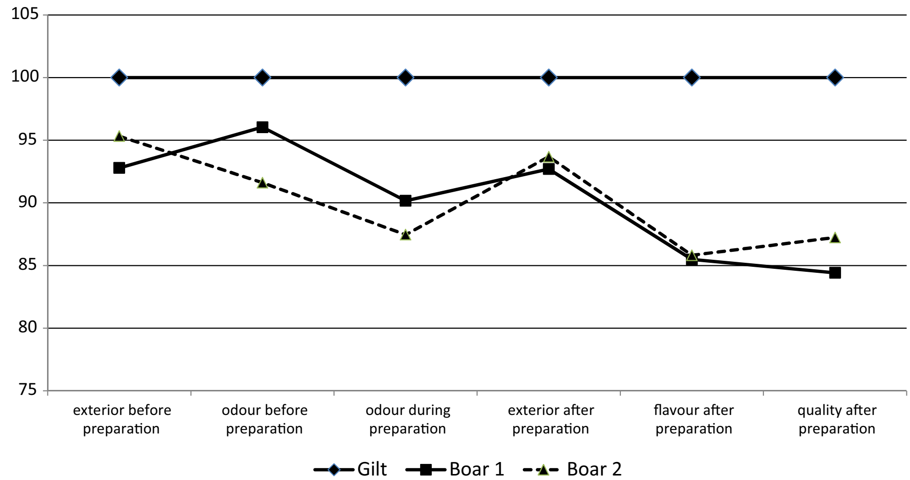

Fig. 1. Scores of cooks on selected quality aspects of boar tainted meat compared to gilt meat.

The selected households ranged in size from 1 person (singles) to 4 household members, their household members ranged in age from 20 to 75, and the selected households were regular pig-meat eaters (at least once a week).

To ensure that the entire range of potential non castrated boars was considered in the study, inline human nose scores were used as selection instrument. For each possible inline human nose score (ranging from 0 to 4) eleven boars were selected, the in-line detection method was similar to the one described for study 2. The total number of boars used in the survey was 55. Each boar was judged by 16 to 30 German and Dutch households. This spread in household number is the result from nonresponse effects and the fact that the total number of meat products was fixed whereas the number of household members varies between 1 to 4 members[1]. The households prepared and consumed the meat at home. The quality statements of each part (belly, chop or loin) from each boar were based upon survey questions about odour during cooking and overall quality of the meat. The households prepared and consumed the meat at home. The 120 households per country were randomly assigned to all possible combinations of human nose scores (i.e. 0&1, 0&2, 0&3, 0&4, 1&2, 1&3, 1&4, 2&3, 2&4, 3&4) and also the order (e.g. 01 or 10) was random for the two loins, two bacons and two shoulder loins. However, all households received first loin, than shoulder loin and finally belly.Using a finite mixture model, we superimposed three partitions (A, B, and C) of the overall quality scores for the 55 boars. Doing so, it was revealed that most quality scores (45%) are in the midrange of the 9-point scale. We refer to this midrange segment with the letter B. Segment B has a mean quality score of 5.9. Above midpoint scores were found in 34% of the cases (Segment A, with a mean score of 7.9). Finally, the below-midpoint segment (C with a mean score of 2.6) represents the remaining 21% of the cases. Using this three-segment classification we studied to what extent the consumer quality scores are related to meat-type or country. In other words, we studied whether the frequencies of the three meat types and of the Dutch and German consumers are distinctive across segments. Table 4 shows the results. As can be derived from Table 4, the meat-type frequencies, are not skewed enough to attribute a particular meat type to one of the three segments. So by only knowing the meat type, one cannot foresee the quality perception among consumers.[2] Different parts of the same carcass were not rated differently on sensory perception. The same result yields the comparison of nationalities, as one can observe in Table 4 that substantial percentages of *both* nationalities can be found in all three segments. It is however interesting to see that the German consumers scores (37%, 39%, and 25%) are more equally divided across the segments than the Dutch scores (30%, 53%, and 17%). The Dutch scores show the highest percentage for segment B (53%). So, our findings suggest that, at the national level, the German consumers have a more outspoken opinion about the quality of boar meat than the Dutch consumers, but there is not enough empirical evidence that Dutch and German consumers belong to a distinct segment in the market in terms of overall quality ratings.

Table 4
Results on overall quality scores for the 55 boars.

Segment	Above midpoint (34%)	Midrange (45%)	Below midpoint (21%)	Total
Mean quality score	7.9	5.9	2.6	
Loins	46%	43%	11%	100%
Chops (with a rib)	27%	48%	25%	100%
Belly	31%	43%	26%	100%
Netherlands	30%	53%	17%	100%
Germany	37%	39%	25%	100%

3.2. Effect of measures to prevent and/or reduce boar taint prevalence

Both preventive and corrective measures to prevent and/or reduce boar taint prevalence were evaluated. We evaluated the following preventive measures: breeding, feeding and mixing of animals. Boar taint can be measured on an individual animal objectively through its components androstenone and skatole or through the subjective human nose score [9]. We also evaluated online

[1] A detailed overview of the number of household judgments for each selected boar can be obtained from the authors.

[2] In our home studies, consumers were also found to be very heterogeneous in their quality ratings of meat with an aberrant odour that would have been rejected for the EU market on the basis of the inline human nose score. We present average odour score of eight households that participated in the consumer studies. Four different households provided odour scores of the same boar that would have been rejected for the EU market on the basis of the inline human nose score. The households scored the meat in terms of the meat odour when consuming the meat. All questions were measured on a nine-point scale, where a higher score represents a higher appreciation by the consumer. The lowest score was 4 and the highest score was 9. Less different odour scores were observed of households associated to a boar that would have been accepted for the EU market based upon the inline human nose score. The lowest score was 6 and the highest score was 7.5.

detection with trained humane experts as a safety net at the slaughter plant. We applied a Human Nose System (HNS) using a categorical scale from 0 to 4 (0 = normal pork odour; 1 = deviant, but no boar taint; 2= more off odour but no boar taint; 3= some boar taint; and 4= strong boar taint). The system is based on sensory assessment of all entire male carcasses by trained assessors at the slaughter line. Subcutaneous fat in the neck of the boar is heated with a metal plate heated by a gas burner. The slaughter line speed is up to 650 pigs per hour. Assessors perform maximum half an hour of continuous assessment of carcasses, after which a minimum of 15 minutes of resting is required. Assessment is located in the slaughter line after splitting, before the cooling area. A selection and training protocol is applied.

3.2.1. Preventive measures: genetic selection to reduce the risk of boar taint

Choosing low boar taint sires to produce commercial finishers might have consequences for other traits. The majority of pigs are raised for meat production, where growth, carcass quality and feed efficiency are the most relevant traits. Genetic correlation of boar taint with these traits is slightly favourable: lower boar taint animals are leaner and more feed efficient [12]. The relations with reproduction traits are more difficult to analyze, but are in general very low and can be mitigated through accounting for these correlations in selection indices and using appropriate economic weights in breeding goals [13].

Genetic evaluations of androstenone, skatole and the human nose score show significant genetic variation, indicating heritable differences between breeds and families within breeds. For androstenone 54% of the observed differences between individual animals are of genetic origin, with, similarly, 48% for skatole. For the human nose score this level is 12-19% mainly due to the categorical scale (0-4) and to differences in human perception of boar taint. Averaging the score of a number of observers and/or scoring large family groups can circumvent this lower heritability. Genetic selection against or sorting on boar taint is therefore a realistic alternative. Selection is the process of consistently using lower boar taint animals as parents for the next generation but not to produce subsequent generations for further genetic improvement, sorting is the separation of a number of very low boar taint animals within a specific generation, a ‘quick fix’ solution. Genetic merit for boar taint can be estimated quite accurately if biopsies, genetic markers [14] and slaughter line data are used simultaneously. The low boar taint producing boars were selected according to: levels of androstenone, skatole and indole estimated using fat biopsies of the sire itself and from the carcass samples of sibs and half-sibs, human nose scores measured on carcass fat samples of sibs and half-sibs, and genomic information using specific DNA markers with significant association with boar taint. The information from these sources was combined to estimate genomic breeding values. If artificial insemination (AI) boars are ranked on this genetic merit and the most extreme low boar taint boars in the AI studs are sorted a reduction of 40% can be realized (Table 5).

If the genetic merit is used for within line selection, boar taint can be gradually reduced over a number of generations. In 5 generations the incidence of boar taint can be reduced to half of the current level, maintaining around the same selection intensity as in the current breeding goals [13]. In fact, inclusion of boar taint in breeding goals for dam lines is especially important, as the dam lines already have higher levels of boar taint. In the study by Mathur et al. [13] 4.2% carcasses with boar taint in Pietrain sire line were identified, compared to 18.9% and 18.7% in Landrace and Yorkshire dam lines, respectively. Therefore, the economic benefits of including boar taint in breeding goal are higher.

Table 5
Expected reduction due to AI boars sorted on genetic merit for boar taint (N = 406).

Human Nose Score	Frequency in the population	Frequency in offspring from low boar taint sires	Difference due to low boar taint sires (%)
4 strong boar taint	.014	.008	-41%
3 boar taint	.032	.019	-40%
2 weak boar taint	.063	.051	-19%
1 deviant, but no boar taint	.123	.114	-8%
0 normal pork odour	.768	.808	+5%

3.2.2. Preventive measures: Feeding and housing

At Swine Innovation Centre Sterksel it was investigated whether keeping boars in litters, feeding them by a long trough and feeding a boar taint reducing diet will reduce mounting behaviour and the percentage of boars with boar taint [15]. In total 576 growing and finishing pigs (Tempo boar x (Dutch Landrace x Dutch Large White) sow) were allocated to a 2 × 2 x 2 factorial experiment. Treatments were: 1) litters versus single sex groups; 2) simultaneous dry feeding by a long trough (12 feeding places for 12 growing and finishing pigs) versus sequential dry feeding by a single space feeder (1 feeding place for 12 growing and finishing pigs); 3) feeding a boar taint reducing diet the last week before delivery to the slaughterhouse versus feeding a conventional diet. Twenty-four pens with litters (288 boars and gilts) and 24 pens with single sex mixed boars (288 boars) were involved in the trial. There were 12 pigs per pen. The growing and finishing pigs that were fed by a single space feeder were fed ad libitum. Those that were fed by a long trough were fed three times a day.

The most important changes in the boar taint reducing diet compared to the conventional diet were: (1) reducing the crude protein content from 15.0 to 13.3%; (2) increasing the level of fermentable non-starch polysaccharides from 9.65 to 13.75% by adding 10% sugar beet pulp and 3% chicory pulp (inulin) to the diet; (3) adding 0.5% sepiolite (a clay mineral that among others binds nitrogen) to the diet; (4) adding synthetic tryptophan to the diet to decrease the level of indigestible tryptophan; and (5) adding 0.25% benzoic acid to the diet. The human nose score, androstenone and skatole were analysed for the fixed effects of housing (litters vs single sex groups), feeding system, and the diet during the last week before delivery. Non-significant interactions were omitted from the model. Androstenone and skatole levels were log transformed before analysis. The results are presented in Table 6.

The results in Table 6 reveal no clear differences in average boar taint prevalence using HNS scores ($p = 0.18$), the percentage boars with score 3 + 4 ($p = 0.12$), the androstenone level ($p = 0.27$) and the skatole level ($p = 0.21$) between single sex housed boars and boars kept in litters. There is no significant effect of the feeding system on average boar taint score, on the percentage boars with score 3 + 4 ($p = 0.70$) and on the androstenone level ($p = 0.96$). The skatole level is lower in boars fed via a long trough ($p = 0.006$) than in boars fed by a single space feeder.

Feeding a boar taint reducing diet did not reduce the level of androstenone ($p = 0.96$). The level of skatole was numerically, but not significant, lower ($p = 0.16$) by feeding a boar taint reducing diet compared to feeding a conventional diet.

3.2.3. Preventive measures: slaughter weight, slaughter age and carcass traits

A statistical study was conducted to estimate the effect of individual carcass weight on the risk of boar taint using an in-line boar taint detection by HNS. Data of slaughter results and human nose sores of 1.7 million boars were collected at a commercial slaughterhouse during the period from August 2012 till October 2013. A

Table 6
Human nose scores and androstenone (mg/kg fat) and skatole (μg/kg fat) levels of boars kept in litters or with only boars together and being fed via a single space feeder or a long through and receiving a special diet.

	Housing of boars		Feeding system		Special diet	
	Mixed, own litters	Single sex	Single space feeder	Long through	Yes	No
Number of tested boars	140	252	193	199	197	195
Average HNS score:	0.24	0.32	0.32	0.26	0.25	0.33
- % score 0 (no boar taint)	85.7	83.7	82.9	85.9	88.4	80.5
- % score 1 (deviant, but no boar taint)	5.7	3.6	5.2	3.5	1.5	7.2
- % score 2 (weak boar taint)	7.9	9.9	9.3	9.1	7.6	10.8
- % score 3 (boar taint)	0.7	2.4	2.1	1.5	2.0	1.5
- % score 4 (strong boar taint)	0.0	0.4	0.5	0.0	0.5	0.0
Average androstenone level:	0.70	0.81	0.77	0.78	0.78	0.76
- % < 0.5	46.8	44.0	43.8	46.2	44.8	45.1
- % between 0.5 and 2.0	49.6	48.8	50.0	48.2	49.0	49.3
- % > 2.0	3.6	7.2	6.2	5.6	6.2	5.6
Average skatole level:	89.2	103.5	113.4[a]	83.7[b]	91.6	105.1
- % < 100	72.7	69.6	66.1	75.1	73.2	68.2
- % between 100 and 150	8.6	10.4	9.4	10.2	9.3	10.3
- % > 150	18.7	20.0	24.5	14.7	17.5	21.5

a,b Averages with a different letter within a main effect in a row are different (P < 0.05)

mixed model approach with GenStat GLMM procedure was used to estimate the variance components farm, slaughter date, tester, farm-by-slaughter date and tester-by-slaughter date of Boar Taint measured by a Human Nose Scoring method at the slaughter line [9]. It is a mixed model because random and fixed effects are included in the model. For instance, the random farm effects take into account that different delivery batches of the same farm are correlated. During the mentioned period the boar taint detection was conducted by 34 trained testers on individual boar carcasses delivered from batches of 1,585 farms. Each boar was scored once in the slaughter line. The average percentage boar taint during August 2012 and October 2013 was 3.31%.[3] For backfat thickness 90% of the boars were in the range between 9-18 mm. of backfat. The average slaughter weight is 91.9 kg and almost 95% of the carcass weights are in the range 80-105 kg. The estimated relation between carcass weight and boar taint was highly significant ($p < 0.001$) and strongly positive. Correcting for backfat thickness made the relationship between carcass weight and boar taint much weaker. The estimated regression coefficient on the logit scale decreased from +0.017 (se = 0.002) to 0.007 (se = 0.002), but was still significant ($p < 0.01$). The estimated regression coefficient for backfat on the logit scale was +0.083 (se = 0.004). This indicated for example that boars with 18 mm of backfat have a much higher probability of having boar taint when compared to boars with 9 mm of backfat (4.4% versus 2.1%). Fig. 2 shows this relationship between boar taint and backfat thickness.

Additionally data of slaughter results and human nose scores of 455 boars, delivered in 6 delivery batches of one farm were collected at a commercial slaughterhouse from September 2011 till February 2012. These boars were raised in 3 groups in time, were each group was delivered in two delivery batches. GenStat GLMM with a random effect of slaughter date was used to examine the effect of age at slaughter on the incidence of boar taint measured by HNS. During the mentioned period the boar taint detection was parallel conducted by 4 trained testers on individual boar carcasses delivered from batches from a farm, were individual information of age of the boars was available. As boars were delivered as they reached their target weight, the variation of age in the data was mainly caused by difference in growth rate. At this farm each group of pigs that started together (round) was delivered in 2 delivery batches, were the second delivery batch was two weeks after the first delivery batch. Carcasses of boars with a higher age at slaughter appeared to have a higher probability ($p < 0.10$) of having boar taint. In this experiment the percentage of boars slaughtered at 185 days and having boar taint is almost 1.7% higher compared with boars slaughtered at 165 days (4.7% versus 3.0%).

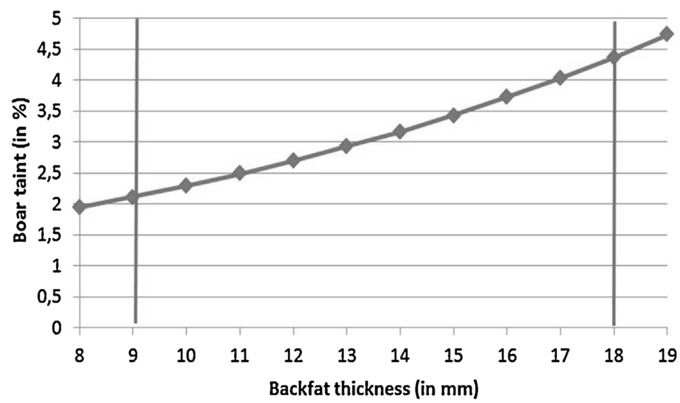

Fig. 2. Relation boar taint and backfat thickness.

The main conclusions of the variance analyses of boar taint measured by the detection of boar taint in the slaughter line are: (1) carcass weight is a risk factor with, corrected for backfat thickness, a slightly positive correlation with boar taint; (2) as incentive parameter for boar taint, backfat thickness seems to be of more importance then carcass weight; and (3) age at slaughter is a predictive parameter for the risk of boar taint.

3.3. In-line detection for boar taint

For pig-meat suppliers it is of interest to foresee the quality perception *before* the product enters the market. A composite of quality measures for boar taint is available, including chemical lab tests, inline human nose scores, and representative consumer panels. Concentrating on odour as the main quality measure, it was investigated which composite of measures has the most predictive power. To ensure that the entire range of potential non castrated boars was considered in the survey, inline human nose scores were used as selection instruments. For each possible inline human nose score (ranging from 0 to 4) eleven boars were selected. The consumer quality score of each of the 55 boars was judged by 4 to 6 households (240 households in total). These were typical households that ate pork at least once a week. They prepared the meat

[3] The range in average farm level boar taint prevalence for 90 percent of the farms is equal to 1.4% - 5.8%.

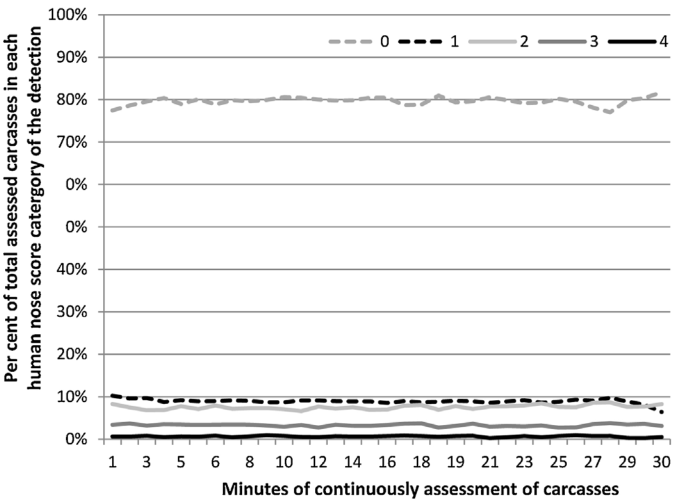

Fig. 3. Effect of fatigue on human nose scores.

products at home. We analysed similarity of the rank order of the 55 boars between consumer perception of odour and three selected boar taint detection systems with Kendall's W [27]. Consumer perception of odour was measured as the average of scores given to loin chops during opening the package, backing and eating. Kendall's W between consumer perception of odour and HNS was equal to 0.63, between consumer perception and androstenone 0.50, and between consumer perception and skatole 0.56, with respective P-values equal to 0.092 for HNS, 0.482 for androstenone, and 0.263 for skatole. This indicates that HNS was the best predictor of the rank order of consumer perception of odour of the three.

When people perform assessment tasks too long, they can become tired and their judgement may become insecure. Therefore, assessors need to be replaced prior to the moment that such changes occur. We analysed if assessors in a commercial slaughter house in the Netherlands showed a change in their scoring performance for boar taint within the half hour they continuously assess carcasses for boar taint. Assessors heated subcutaneous fat in the neck with a metal plate heated by gas burner and smelled the odour. They were only allowed to assess carcasses for a maximum of half an hour nonstop. After this a period of at least 15 minutes of recovering was required. On a daily basis assessors judged a maximum of 1000 carcasses. The slaughter line speed was 650 pigs per hour. Data were used of nine assessors, who assessed 19,383 carcasses from September 2010 to July 2012. The results are presented in Fig. 3. The percentage of carcasses in each of the HNS categories remained stable for 30 minutes of continuous assessment of boar carcasses. This indicates that in the half hour of nonstop assessment no fatigue of the assessors occurred.

These results were confirmed by an additional analysis. Fatigue can be observed if the percentage of carcasses assessed at the slaughter line in the 5 HNS categories shows a decreasing or increasing trend during the half hour assessment period. To identify if such a trend exists, we used the model percentage HNS category$_i$ = constant + $\beta_{1,i}$. score moment + $\beta_{2,i}$. assessor + $\beta_{3,i}$. assessor . score_moment + error$_i$. In this model, score moment was the trend variable, where its value equalled 1 for the first assessed carcass in each assessment period, 2 for the second carcass, etc. The variable percentage HNS category$_i$ was the percentage of carcasses assessed in HNS category i (i = 1,2,3,4), assessor indicated the assessor, and error$_i$ was the error term. The score moment indicated overall impact of fatigue and the interaction between assessor and score moment the impact of fatigue of an individual assessor. Data of 2618 assessment periods of between 200 and 300 consecutively assessed carcasses (23 to 35 minutes) conducted by 8 assessors were used. The coefficients of the variable score moment $\beta_{1,i}$ were not significantly different from zero (each at least $p > 0.45$) and only 2 of the 32 coefficients $\beta_{3,i}$ of the interaction between assessor and score moment were significantly different from zero at $p < 0.05$.

4. Animal behaviour and boar management

4.1. Experimental studies

Producing entire male pigs (boars) can result in higher levels of sexual and aggressive behaviour and impair animal welfare compared to castrated male pigs and gilts. Four experiments were conducted to test the effect of several measures on mounting behaviour of boars. Two experiments were conducted in enriched pens with 1.6-1.9 m^2/pig (Experiment 1 and 2) and two in conventional pens with 1.0 m/pig, to reduce aggressive behaviour (Experiment 3 and 4). In the first experiment the effect of straw versus rubber mat in the lying area, and 3 versus 6 eating places (one feeder had 3 eating places) was tested in a 2 × 2 factorial design in 12 pens with 18 males or castrates [16]. In the second experiment the effect of additional sugar beet pellets and a dummy sow to mount on was tested in a 2 × 2 factorial design in 8 pens with 15 males [16]. In the third experiment the effect of litters versus single sex groups and of sequential feeding by a single space feeder versus simultaneous feeding by a long trough was tested in a 2 × 2 factorial design in 48 pens with 12 pigs [15]. In experiment 4 the influence of light schedules and light color, group size and hiding side walls was investigated in a 3 × 2 x 2 factorial design in 24 pens with 12 pigs and 24 pens with 24 pigs [17,18]. In all experiments skin lesions (score 0-5), lameness (score 0-2) and mounting attempts per pen per snap-shot were measured five times during the growing and finishing period. The response variables were analysed for the fixed effect of the treatments, batch and day of measurement using REML in Genstat.

In experiment 1 males showed more skin lesions (0.64 versus 0.48; p = 0.059) (Fig. 4a) and mounting behaviour (0.29 versus 0.12; p < 0.007) than castrates, but no difference in lameness (0.41 versus 0.30; p = 0.27) was observed. Straw and an additional feeder did not reduce mounting behaviour. An additional feeder did not reduce lameness (0.40-0.31; p = 0.47) but tended to reduce skin lesions (1.88-1.48; p = 0.098) (Fig. 4a).

In experiment 2 additional sugar beet pellets did not reduce skin lesions, lameness and mounting behaviour. The dummy resulted in less lameness (0.23 versus 0.32; p = 0.018) but did not reduce skin lesions (0.73 versus 0.81; p = 0.597). Moreover, it didn't reduce mounting behaviour. In experiment 3 the percentage of boars with mounting behaviour was similar in pens with litters and in pens with only boars (Fig. 4b). No effect of feeding system on mounting behaviour was observed (p = 0.42). Males had more lameness (p = 0.04) and skin lesions on the fore-hand than females (p = 0.004). No effect of mixing strategy (litters versus single sex males) and feeding system on skin lesions was found. In the afternoon, the percentage of pigs with mounting behaviour was higher than in the morning (Fig. 4b). It can be concluded that mounting behaviour was not reduced by the tested measures.

In experiment 4, the influence of light schedules and light color, group size and hiding side walls was investigated [17,18]. In total 864 growing-finishing pigs (Tempo boar x (Dutch Landrace x Dutch Large White) sow) from 23 to 120 kg were allotted to a 3 × 2 x 2 factorial experiment. Treatments were:

1) Artificial light regime and light color: normal light (artificial light: 8.00-16.00 h) versus a gradually increasing light schedule (artificial light: 8.00-16.00 h at the start and 5.00-21.00 h at

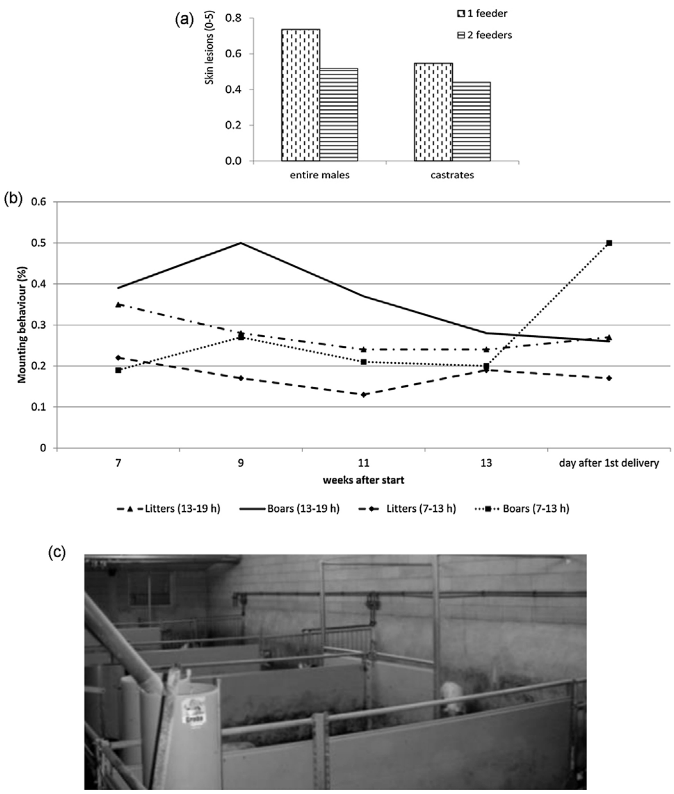

Fig. 4. Skin lesions in Experiment 1 (a); mounting behaviour in Experiment 3 (b); Pen with a hiding wall 4 (c).

the end) versus green light (artificial green light: 8.00-16.00 h). In all treatments light intensity was 40 lux.

2) Group size: 12 versus 24 pigs per pen. Space per pig was 1m^2 in both treatments.
3) Hiding wall: a hiding wall versus no hiding wall in a pen (see Fig. 4c).

Boars and gilts were mixed within a pen (6 boars and 6 gilts per pen or 12 boars and 12 gilts per pen) and were fed al libitum by one (12 pigs per pen) or two (24 pigs per pen) single space feeders. Behavioural measurements were carried out in week 5, 7, 9, 11, 13 and on the day after first delivery to the slaughterhouse. In observation periods of 5 minutes every hour sexual (mounting) and aggressive behaviour of the boars and gilts was recorded.

Green light did not reduce mounting and aggressive behaviour of the boars compared to normal light (Fig. 5b). The increasing light schedule did not reduce mounting behaviour but it did reduce aggressive behaviour of the boars around delivery of the pigs. Boars that were exposed to the increasing light schedule started earlier in the morning with mounting behaviour and stopped at a later hour than boars that were exposed to normal or green light but the number of mountings between 8.00 and 13.00 h was lower (Fig. 5b). More total pen space (24 pigs versus 12 pigs; 1 m^2 per pig) did not reduce mounting behaviour of the boars but it resulted in a higher score for skin lesions. A hiding wall did not reduce mounting behaviour and the score for skin lesions. The percentage of active boars and gilts was similar. Mounting behaviour, however, was clearly much higher in boars than in gilts (Fig. 5a). The number of mountings per boar was higher during the day than during the night and higher in the afternoon than in the morning Fig. 5b). The number of mountings per boar did not increase from week 5 until delivery to the slaughterhouse. Moreover, it did not increase after delivery of the first pigs in a pen. The score for skin lesions was similar in boars and gilts. The score for skin lesions was lower in week 9 and 13 than in week 5 and around delivery of the pigs to the slaughterhouse. Around delivery, aggressive behaviour of the boars was increasing resulting in a higher score for skin lesions. The score for lameness was very low and was not affected by any of the treatments.

4.2. Observational studies on commercial pig farms

Experiences with keeping boars differ between pig farmers. Some pig farmers observe high levels of sexual and aggressive behaviour of the boars on their farms while other farmers do not observe this behaviour. It is not clear how these differences in the level of sexual and aggressive behaviour between farms relate to farm management measures. Moreover, it is not clear why the percentage of boars with boar taint differs between farms.

In a large scale observational study 70 pig farms were visited [17,18]. Each pig farm was once visited by one of three trained employees of Wageningen UR Livestock Research. Data were collected by means of an (oral) questionnaire with questions about farm and management characteristics and by means of observations on the farms. The percentage of boars with boar taint on the 70 farms was provided by the slaughter company. Behavioural measurements, skin lesions, lameness score, pig fouling and human-directed behaviour (approach test according to [19]) were carried out in growing and finishing boars that were kept in the fattening barns for about 5, 9 and 13 weeks. Four pens per age group were monitored. Behavioural measurements (number of mountings, number of head against another pig and number of screams) were recorded in three observation periods of 5 minutes per pen (14.00 h, 15.00 h and 16.00 h). Skin lesions on the forehand and hind quarters (score 0 = no skin lesions; score 5 = severe lesions), lameness score (0 = no lameness; score 2 = severe lameness) and pig fouling were recorded per boar. Human-directed behaviour was recorded per pen.

It was examined whether the farm and management characteristics had a relationship with the number of mounting attempts per boar, head against another pig per boar, screams per boar, with the percentage of active boars and of boars with boar taint, with skin lesions on the forehand (% boars with scores 2 -5), skin lesions on the hind quarters (% boars with score 2-5), and with lameness (% boars with scores 1 + 2).

First, we performed univariate analyses. Then we classified the farms into 25% best, 25% worst and 50% in between. When a parameter in both the univariate analysis and in the analysis of the 25% best, 50% middle and 25% best farms had a significant relation ($p < 0.10$) with the behavioural parameters, the relation was considered to be relevant. Then we did multivariate analyses for 2 parameters. This did not result in more added value, and is not performed for the other parameters. The parameters that had no maximum value, such as number of mounting attempts, were analyzed with a log-linear model (Poisson). The parameters with a value between 0 and 100 such as % boars with boar taint were analyzed with logistic regression. The factor age group (5, 9 or 13 weeks) was in all analyses, except for the parameter boar taint (this feature was available only at farm level), included in the model. Farm was added as a random effect to the model. All analyses were performed in Genstat (2009) with the procedure IRREML. Estimates for the model parameters and F tests for the terms in the model are obtained with the quasi-likelihood method [20]. In Table 7 average limit values of farm level behavioural parameters and boar taint prevalence for the 25% worst farms and 25% best farms are presented. With the exception of boar taint prevalence, the lower and upper limit values of all parameters are quite different.

Farm management characteristics having a significant relationship with more than one behavioural parameter are presented in Table 8.

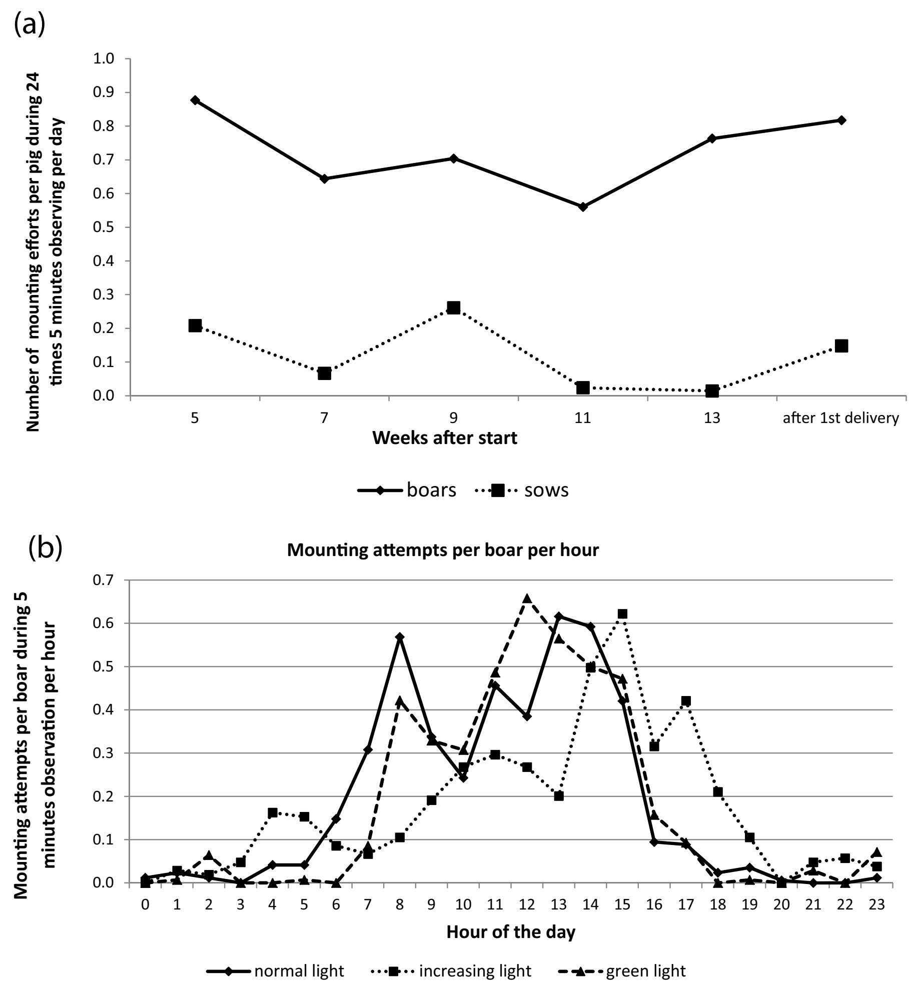

Fig. 5. a Average number mounting attempts per pig for 24 times 5 minutes observation per day.
5b. Average number of mounting attempts per boar during 5 minutes obervation per hour (average over all observation days).

Table 7
Farm level behavioural parameters and boar taint prevalence for 25% worst (highest number of mountings, head against other pigs and screams and highest % pigs with skin lesions, lameness and boar taint) farms and 25% best farms (lowest number of mountings, head against other pigs and screams and lowest % pigs with skin lesions, lameness and boar taint).

	Lower limit value 25% worst	Upper limit value 25% best
Mountings per boar (average number per 3 times 5 minutes)	> 0.65	< 0.25
Head against other pigs per boar (average number per 3 times 5 minutes)	> 0.97	< 0.17
Screams per boar (average number per 3 times 5 minutes)	> 0.20	< 0.04
Skin lesions forehand (% boars with score 2-5)	> 30.4%	< 6.2%
Skin lesions hind quarters (% boars with score 2-5)	> 6.7%	< 0.8%
Lameness (% boars with score 1 + 2)	> 2.5%	< 0.6%
boars with boar taint (% boars)	> 4.6%	< 3.6%

The following measures are associated with mounting and aggressive behaviour of boars:

- *Animal directed approach:* An animal directed approach (attention for the needs of the pigs) is associated with less sexual and aggressive behaviour and less skin lesions.
- *Rest and routine:* Factors that cause stress or give a negative stimulus are associated with a higher level of sexual and aggressive behaviour and more skin lesions. This means that too few eating places, restricted feeding, a low level of amino acids in the diet, insufficient water supply of the drinking system, illness of the pigs, a suboptimal climate and fear for humans are associated with a higher level of sexual and aggressive behaviour and more skin lesions.
- *Housing:* A partly open pen wall, clean pens and pigs and wider gaps of the slats are associated with less sexual and aggressive behaviour and less skin lesions.
- *Feeding and drinking water:* Feeding by a long trough, ad libitum feeding, feeding wet by-products, feeding diets with a high level of amino acids, a good hygiene of the feeding and drinking place and sufficient water supply of the drinking system are associated with less sexual and aggressive behaviour and less skin lesions.

It can be concluded that it is possible to keep boars successfully. On some farms no mounting and aggressive behaviour and no skin lesions were observed. The risk on sexual and aggressive behaviour is low when everything is optimal (see Table 8) for the boars. When the farm conditions regarding feeding and drinking water, housing

Table 8
Management characteristics with significant relationships with behavioural parameters (*).

	Parameter					
	Mounting	Head against other pig	Screaming	Active	Skin lesions	
					fore	back
Age category (old, 13 weeks)		–	–	+	+	–
Sire line (Large White)		+			+	+
More than one animal caretaker		+			+	+
Clean boars		+			+	
Boars not fleeing for caretaker	+	+	+	+		
Noise level > 80 decibel	–			–		–
Partly open pen walls		+		+	+	
Gap width slats>18 mm			+		+	+
<30% slatted floor area dirty		+		+	+	
Ventilation via door- or working corridor		–				–
No floor heating	+	+	+			
High temperature in the barn	+	+		+		
Light intensity (>32 lux)					–	–
Feeding by a long through	+	+	+			
Number of pigs per eating place		–				
Good water supply of the drinking system	+	+	+			
Wheat starch in the diet	+	+	+			
Wheat yeast concentrate in the diet		+			+	
Potato peelings in the diet		+			+	
Corn cob mix in the diet	–	–				
High level of ileal digestible lysine in the diet	+	+				
High energy value in 'grower diet '	+	+				
Ad lib feeding		+				
At a later age starting with feeding according to scheme		+			+	
Abrupt change from one diet to another diet	+	+	+			
Good hygiene of feeding and drinking system		+				+
Sorting strategy at weaning	–		–			
No lame pigs		+				
Separating sick animals	+					
Piglets vaccinated during suckling and rearing period	+	+	+			+

(*) ++ = strong positive relationship;
+ = positive relationship;
- = negative relationship;
– = strong negative relationship.

Table 9
Farm characteristics having a relationship (p < 0,10) with the average boar taint prevalence.

	25% with >4.6% boar taint	25% with <3.6% boar taint
% of clean boars	47	81
Nr. of pigs per pen (% of farms)		
≤ 12	44	67
13–30	19	28
≥ 31	38	6
Gap width of the slats: ≤ 18 mm (vs. wider)	88	50
Quality of the floor good (vs rough)	62	89
> 30% dirty slatted floor	56	17

Table 10
Economic benefits and costs associated with raising boars compared to barrows[a].

	Barrows	Boars
Growth performance		
Daily growth, g/day	792	813
Feed conversion ratio, kg/kg	2.73	2.47
Basic cost parameters		
Labor costs, Euro/fattening pig/year	**2.82**	**2.90**
Piglet costs, Euro/fattening pig/year	**145.58**	**149.19**
Number of fattening pigs	2000	2000
Cycles	3.11	3.19
Piglet price, Euro/piglet	46.28	46.20
Feed costs, Euro/fattening pig/year	**168.16**	**156.18**
Delivery costs, Euro/fattening pig/year	**6.51**	**6.68**
Return, Euro/fattening pig/year	**405.29**	**421.76**
Slaughter pig price, Euro/kg slaughter pig	1.506	1.518
Basic market price, Euro/kg slaughter pig	1.433	1.433
Bonus meat, %		0.011
Bonus meat type		0.009
Extra net return, Euro/fattening pig/year		**24.59**
Extra net return, Euro/fattening pig		**7.71**

[a] Barrows = raising barrows with mixed-sex groups rearing (50% barrows and 50% gilts);
Boars = single sex groups rearing with only boars on the farm (100% boars).

and climate, health of the pigs and/or management are not optimal, there is a risk that sexual and aggressive behaviour and skin lesions will occur. Farm management characteristics having a significant relationship with boar taint prevalence on the 70 farms are presented in Table 9.

More than 30 animals per pen is associated with a higher probability of high boar taint prevalence levels. Clean animals and clean floors, wider gaps between the slats and good quality floors are associated with lower boar taint prevalence levels.

5. Benefits and costs associated with raising entire males across pork chain segments

This section explores techno-economic performance of boars, compared to barrows. Table 10 reports the economic cost and benefits of raising boars, compared to barrows. The comparison is performed for a typical Dutch pig-fattening farm with mixed-sex groups rearing (i.e. 50% male pigs and 50% female pigs = gilts). The comparison is based on the assumption that this farm switches to raising boars only (100% male pigs), and has none of the control measures to prevent boar taint implemented on the farm. The technical parameters used in Table 10 are based on several experiments described in the literature [21,22] representing an average situation.

As shown in Table 10, at the farm level, an improvement in growth performance (due to the better feed conversion ratio) of boars compared to barrows, and an improvement in boar carcass quality (resulting in a better slaughter pig price), according to preferences in the Dutch market, generate a calculated extra net return of 7.71 Euro per fattening pig.

At the slaughter plant level, the current situation is different. Slaughter plants are confronted with extra costs of testing for tainted carcasses and a price reduction for identified tainted carcasses. In the Netherlands, the cost of on-line boar taint test based on human nose scoring system is ca. €1-2 per carcass. The valuable parts of boar tainted carcasses cannot be sold in the higher-end fresh meat market. Tainted carcasses are used for production of processed meat products which are consumed cold. Given that an average price difference between meat used for sale in the fresh meat market and for production of processed meat products is €0.28 per kilogram, this means that the return on tainted carcasses is ca.€25 lower than on not tainted ones [23]

Benefits and costs associated with raising boars are not equally distributed across pork chain segments. Without adoption of any appropriate control measures to prevent the development of boar taint at the farm level, implying a remaining chance of having tainted carcasses at the slaughter plant level, pig farmers continue to benefit from raising entire male pigs; whereas slaughter plants continue to face additional costs and lower market value of tainted carcasses. Depending on specific supply chain circumstances, the loss of benefit due to lower market value of tainted carcasses is borne by the pig farmer or the slaughter plant.

In a non-integrated chain many preventive measures that reduce boar taint will only be implemented when incentives are imposed to stimulate farmers to prevent developing boar taint on the farm. An optimal incentive system should find balance between the economic interests of different chain segments. Basically, the system should help induce appropriate farm-level measures while minimizing costs of boar taint control in primary production and slaughter plant investments in boar taint testing and reduced value of tainted carcasses. Also, the trade-offs between prevalence reduction and related costs for different chain segments should be quantified. The optimal incentive system parameters and economic performance of chain segments can vary greatly with the threshold level. This indicates the importance of accuracy and precision of the applied on line boar taint testing method at the slaughter plant level.

6. Concluding comments

This paper presents research results on the sensory evaluation of meat from entire male pigs, preventive measures to reduce boar taint prevalence, and on detection for boar taint. The conclusion of the consumer studies was that boar tainted meat was rated as less pleasant by consumers compared to meat of gilts and non-tainted boar meat. This clearly demonstrates the need of detection as a safety net at the slaughter line. The results yield useful insights into the effectiveness of breeding to reducing boar taint. Our results also show that farms with appropriate management, feeding and housing conditions have reduced levels of mounting and aggressive behaviour. Human nose scores were a better predictor of the rank order of consumer perception, compared to skatole levels and to androstenone levels.

It must be emphasised that specific findings presented here are dependent on underlying technical assumptions and on the particular research circumstances. This has resulted in at least three important limitations. First, the accuracy and precision of the HNS system strongly depends on the identification and selection of the individual assessors. The HNS method has the advantage of faster speed, low cost compared to chemical analysis for androstenone and skatole, and it does not require a large investment in equipment. This approach is promising and accordingly used for both sorting carcasses at the slaughter plant and for genetic selection. The results showed that HNS predicts boar taint quite accurately, to a level at which major Dutch market parties in a business to business relationship accepted it as a sufficient quality control measure [24]. Even for instrumental detection systems, a 100% guarantee on an individual animal in relation to risk for consumers cannot be given. But these systems are easier to standardise. In theory they can result in more accurate and precise systems and may be more cost-effective in high wage countries. However, they are not available yet, so sensory assessment is currently the only available option for pork supply chains that have the ambition to market entire male pigs.

Second, consumer evaluation of meat was performed using sensory evaluations in laboratory settings and at home tests. Information on the home environment was not collected. Besides the product's physiological characteristics, consumers also make use of extrinsic cues (e.g. price, origin, labelling, and outlet) in quality perception [25]. Including the effect of extrinsic cues on sensory evaluation may contribute to more insight in the consumer acceptance of boar taint.

Finally, in our research genetic selection and farm management demonstrate a rather favourable effect on boar taint reduction. But no significant effect of the feeding system on the percentage boars with high HNS scores was measured, whereas the skatole level is lower in boars fed via a long trough than in boars fed by a single space feeder. Feeding a diet with reduced crude protein content and 10% sugar beet pulp and 3% chicory pulp (inulin) did reduce the level of skatole numerically, but not significant. [26] discuss the mechanisms by which effective feeding strategies and feed additives influence high skatole concentrations in pig tissue. The most efficient feeding interventions are actually the addition of inulin or raw potato starch. But they report on higher percentages of inulin in the diet.

Preventive farm level measures to reduce boar cost money and will only be introduced in a non-integrated chain when incentives are imposed on the farmers to reduce boar taint. These incentives should ideally be higher than the cost of the intervention measure at the farm level and be high enough to cover the costs associated with detection and selling the tainted carcass at the slaughter plant level. This principle determines the price intervention measure to be chosen.

The question is how in the new market equilibrium benefits and costs are allocated - via the price mechanism - to the various supply chain segments. Because most pork supply chains are not integrated the uneven distribution across chain segments of costs and benefits associated with raising boars makes it difficult to introduce chain wide solutions. Boars grow more efficient than barrows contributing to better efficiency at the farm level. Slaughterhouses have higher cost due to testing of the boar carcasses and the lower return on tainted carcasses. The return on tainted carcasses is lower because the valuable part cannot be sold in the higher end fresh meat market. How much lower depends on the total number of boar tainted carcasses that enter the market and how these products are valorized, using masking strategies. The number of tainted carcasses is the product of the number of entire male pigs and the average boar taint prevalence. This latter percentage will be influenced by the extent to which farmers use preventive measures. And this is again depending on the payment scheme that slaughterhouses will apply.

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