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Absence of an effect of dietary fibre or clinoptilolite on boar taint in entire male pigs fed practical diets

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ABSTRACT

This study aimed to evaluate the possibility of reducing boar taint in boars (Piétrain × Hybrid) by addition of different feed ingredients (raw potato starch (RPS) 10%, raw potato starch 10% + wheat bran 5% (RPS + WB), lupins 10%, inulin 5%, clinoptilolite 1%) to a standard diet over a period of 4–6 weeks before slaughter. Control boars (CBOAR) as well as barrows were fed the standard diet. Efficacy of the different feed ingredients was evaluated by different boar taint detection methods: hot iron method, consumer panel, expert panel and laboratory analysis. According to all detection methods, clear differences were noticeable between boars and barrows. No differences in boar taint incidence were found between the boars on the different dietary treatments as assessed by consumers, experts, hot iron method or the concentration of skatole in fat. A significant effect on indole level was found, but no further differentiation could be made. The concentration of backfat androstenone was significantly higher for the inulin and control boar group compared to the lupin group.

In conclusion, none of the feeding strategies tested in this study reduced boar taint in boars at the given percentages.

1. Introduction

Boar taint is an off-odour, released by the heating of meat of some entire male pigs. The main contributors to this unpleasant odour are 5α-androst-16-ene-3-one (androstenone, urine-like odour) and 3-methylindole (skatole, faecal-like odour) (Claus, Weiler, & Herzog, 1994; Rius & Garcia-Regueiro, 2001). Androstenone is produced in the Leydig cells of the testis, in parallel with anabolic testicular hormones. It is metabolised in the liver and partly accumulates in the adipose tissues and salivary glands. Variation of androstenone content in fat tissue depends on the age and/or body weight of the animal, as well as on genetic factors that affect both sexual maturity and the potential for androstenone production (Baltic, Raicevic, Tadic, & Drljacic, 1997; Lundström et al., 1994). Other factors (e.g. feeding level and proximity of females) are important as well, probably by their effect on sexual maturity (Lundström et al., 1994).

Skatole is produced by microbes in the hindgut from tryptophan originating from cell debris of the gut mucosa (Claus et al., 1994; Lanthier, Lou, & Squires, 2007; Wiseman et al., 1999). Skatole thus produced is partly absorbed into the blood and transported to the liver where the majority is degraded and excreted in the urine. The undegraded skatole is deposited in the tissues, particularly tissues with a high fat content. Skatole concentration may be influenced by genetics, feed components and environmental factors like temperature, ventilation, water supply and accumulation of faeces in the pens (Jensen, Cox, & Jensen, 1995).

Several studies have focussed on the effect of feed ingredients on the backfat skatole content of entire male pigs. The inclusion of fibre-rich feedstuffs in the diet influence the backfat skatole content (Jensen et al., 1995; Van Oeckel, Warnants, De Paepe, Casteels, & Boucqué, 1998), but not all types of dietary fibre seem able to increase hindgut fermentation. For example lignin, a component in wheat bran (WB), appeared unable to increase the fermentation whereas pectin, present in sugar beet pulp, readily increases the fermentation (Jensen, Jensen, Laue, Agergaard, & Bibby, 1997). However, the reducing effects of sugar beet pulp on skatole levels, reported in literature are variable (Jensen, 2006).

In contrast, raw potato starch (RPS) was found to be effective in skatole reduction at different concentrations (from 10% to 40%) and over a period of 2 or 3 weeks before slaughter (Claus, Lösel, Lacorn, Mentschel, & Schenkel, 2003; Jensen et al., 1997; Zamaratskaia, Babol, Andersson, Andersson, & Lundström, 2005).

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Wheat bran, a source of insoluble NSP was not shown to possess an effect on its own (Van Oeckel et al., 1998), but can shift the fermentation of RPS further distally. Therefore, the concomitant consumption of insoluble fibre and RPS containing products could combine and strengthen the beneficial effects on colonic physiology of both substrates, thus increasing transit, butyrate and faecal bulk (Govers, Gannon, Dunshea, Gibson, & Muir, 1999; Muir et al., 2004).

Chicory, as well as its component inulin was shown to be able to reduce skatole concentration. Significant reduction of skatole was found for 10% dried chicory (Nielsen, Hansen, & Byrne, 2007) and 5% inulin (reduction in faeces, cross-over experiment) (Rideout, Fan, Cant, Wagner-Riddle, & Stonehouse, 2004). Xu, Hu, and Wang (2002) found a significant reduced conversion of L-tryptophan to skatole at different percentages of fructooligosaccharides (0.5%, 1.0% and 1.5%) *in vitro*. Nielsen et al. (2007) also found a significant reduction of skatole in backfat by the addition of 25% blue lupine during 1 and 2 weeks. Jensen et al. (1997) studied the effect of the inclusion of 10% sugar beet pulp, coconut cake, palm cake, lupines, barley hull meal, fructooligosaccharides and potato starch for 14 days on the reduction of skatole in blood in a cross-over design. Lupines, fructooligosaccharides and potato starch had a significant reducing effect.

Yeast slurry from breweries was shown to be a feed component which elevates the concentration of skatole in the hindgut and in the backfat (Jensen et al., 1995). Yellow peas may also lead to increased skatole deposition (Lundström et al., 1994).

Zeolite is a natural mineral with 90% of the active compound consisting of clinoptilolite. In a study by Baltic et al.(1997), the addition of 0.5% zeolite to the feed significantly decreased the skatole content in fat tissue and the percentage of fat tissue samples with skatole levels above 0.25 mg/kg. The addition of animal fat, B vitamins, ethanol, copper, iron or tryptophan to the diet did not result in significant changes (Jensen et al., 1995).

When performing research on boar taint, a major problem to evaluate the effectiveness of management measures, is the lack of a golden standard to measure boar taint (EFSA, 2004; Haugen et al., 2008). Hence, some studies have reported conflicting results of the effect of feeding treatments depending on the detection method. For example, Nielsen et al. (2007) found differences in effectiveness of feeding days according to the type of evaluation (skatole level vs. sensory evaluation). For this reason, the effect of a variety of feed ingredients on the boar taint level was, in this study, evaluated using several detection methods: the hot iron method, consumer panel, expert panel and laboratory analysis of the main boar taint compounds.

The aim of this experiment was, therefore, to study the effect of five ingredients (*RPS*, RPS supplemented with WB, lupins, inulin and clinoptilolite) added to a basal diet on boar taint incidence in entire male pigs and compared with castrated male pigs on the same diet by using four detection methods. Dietary additives and concentrations were chosen because of their potential effectiveness according to former research and their acceptable applicability on the field in those concentrations, namely price, formulation and animal performances. It was chosen to give the diets for minimal 4 weeks prior to slaughter as an extra phase feeding.

2. Material and methods

2.1. Animals and feeding

The experiment was performed in three replicates, with in total 168 pigs. At an age of 9 weeks, for each replicate, a group of 56 pigs (48 boars and 8 barrows, Piétrain × Rattlerow Seghers crossbred sow) were allocated to 7 pens or 7 treatment groups. In order to minimise the effect of genetic background littermates were allocated to different treatment groups. At an age of 19 weeks the 2 pigs with the most deviating body weights in each pen were eliminated from the group, leading to homogenous groups of 6 pigs per pen at week 21 (Table 1). The 8 boars on control feed were kept together because of ongoing behavioural studies. Pigs followed the same diet until the start of the feeding experiment, at an age of 21 weeks. The different treatments were: control barrows (CBAR), control boars (CBOAR), 10% RPS, 10% raw potato starch + 5% wheat bran (RPS + WB), 10% lupins (LUP), 5% Beneo IPE (ORAFTI, Tienen, Belgium; containing $\geqslant$66% inulin, IN) and 1% VIVOLITH 85 (ORFFA, Londerzeel, Belgium; containing $\geqslant$85% clinoptilolite, CLIN), with the ingredients added to the control feed at the given percentages and prepared by a cold pelleting process. The diets were formulated to fulfil protein needs (Table 2). The pigs had free access to water at all time. To reach a mean commercial live weight of 107 ± 6 kg at slaughter, the three heaviest pigs per pen were slaughtered at 25 weeks of age, the other pigs at an age of 27 weeks. After one hour of transport and about three hours of lairage at the slaughterhouse, the pigs were slaughtered by exsanguination after electric stunning. Pigs were fasted for 24 h before slaughtering. *Longissimus thoracis et lumborum* samples (Kauffman, Smulders, Hartman, Habel, & Bergstrom, 1990) with backfat layer (30 cm around the 13th rib) were taken at the slaughterhouse 24 h after slaughter. *Longissimus thoracis et lumborum* samples were trimmed of visible fat and cut into slices of 2.5 cm and backfat was cut into pieces. Each individual piece was vacuum-packed and stored at −20 °C until tests with consumer and expert panels were performed. Thawing of these samples was achieved by keeping the samples at 4 °C overnight. For laboratory analyses of boar taint compounds, the fat samples were vacuum-packed and stored at −80 °C until analysis.

2.2. Performance parameters

Feed intake and body weight were monitored weekly from week 21 until slaughter in order to calculate average daily feed intake (DFI), average daily gain (DG), and feed conversion ratio (FCR) per pen. At the slaughterhouse, pH was measured 45 min after slaughter at the *longissimus thoracis* between the 12th and 13th rib and in the ham (*m. semimembranosus*). The average of the pH measurements, performed at the left and right side of the carcass, was used for further analysis. Results of carcass classification by means of SKGII (% lean meat, conformation: type index) from the slaughterhouse were registered per animal. Dressing percentage was calculated as the ratio between cold carcass weight and live weight.

2.3. Boar taint detection

Boar taint detection of all pigs was performed by different methodologies: a fast method that can be used on the slaughter line (hot iron), consumer panels evaluating the sensory quality of meat samples, a trained expert panel evaluating the sensory quality of meat and fat samples, and the laboratory analyses of the concentration of the main boar taint compounds in fat samples. Except the animals of the first slaughtering, this could not be evaluated with the hot iron method.

2.4. Hot iron method

In the slaughterhouse, boar taint was scored with the hot iron method (Jarmoluk, Martin, & Fredeen, 1970) on a scale from 1 (neutral) to 4 (very bad) by heating the neckfat with a soldering iron (30 W).

Table 1
Animal performance parameters (mean ± st. dev.) from 21 weeks until slaughter.

	CBAR	CBOAR	RPS	RPS + WB	LUP	IN	CLIN	p_{sex}	p_{feed}
n	17	21	18	18	18	18	17		
W21 (kg)	79 ± 7	80 ± 9	77 ± 8	79 ± 7	75 ± 6	77 ± 8	77 ± 8	0.823	0.522
SW (kg)	108 ± 2	111 ± 3	104 ± 3	107 ± 4	103 ± 1	108 ± 4	106 ± 4	0.070	0.070
DFI (kg)	2.6 ± 0.2	2.4 ± 0.1	2.2 ± 0.1	2.3 ± 0.2	2.2 ± 0.1	2.4 ± 0.2	2.3 ± 0.1	0.225	0.206
DG (g)	800 ± 64	897^{c} ± 35	769^{a} ± 21	807^{abc} ± 38	797^{ab} ± 19	870^{bc} ± 47	827^{abc} ± 24	0.212	*0.010*
FCR (kg/kg)	3.3 ± 0.0	2.7 ± 0.0	2.9 ± 0.1	2.9 ± 0.1	2.7 ± 0.2	2.7 ± 0.1	2.8 ± 0.1	*0.005*	*0.035*
Dressing (%)	79.2 ± 1.1	78.2 ± 1.1	77.7 ± 1.3	77.7 ± 0.7	77.8 ± 1.7	77.8 ± 1.2	77.6 ± 1.2	*0.022*	0.862
Lean meat (%)	56.7 ± 2.2	58.8 ± 2.0	60.2 ± 1.9	58.9 ± 2.1	59.7 ± 1.9	60.4 ± 2.3	59.3 ± 1.5	*0.006*	0.110
Type index[A]	2.5 ± 0.3	2.5 ± 0.3	2.4 ± 0.2	2.6 ± 0.4	2.5 ± 0.3	2.3 ± 0.4	2.3 ± 0.2	0.467	*0.039*
pH LT	5.9 ± 0.2	6.1 ± 0.1^{b}	5.8 ± 0.2^{a}	6.0 ± 0.3^{b}	6.0 ± 0.3^{ab}	6.0 ± 0.2^{ab}	6.0 ± 0.2^{ab}	0.487	*0.003*
pH ham	6.1 ± 0.3	6.2 ± 0.2^{ab}	6.0 ± 0.2^{a}	6.2 ± 0.2^{b}	6.2 ± 0.2^{ab}	6.1 ± 0.2^{ab}	6.2 ± 0.2^{ab}	0.409	*0.002*

Experimental groups. CBAR: control barrows, CBOAR: control boars, RPS: raw potato starch boars, RPS + WB: raw potato starch + wheat bran boars, LUP: lupin boars, IN: inulin boars, CLIN: clinoptilolite boars.
p_{sex}: p for boars vs. barrows, p_{feed}: p for boars on different dietary treatments.
W21: weight at 21 weeks of age, SW: live weight at slaughter, DFI: daily feed intake, DG: daily gain, FCR: feed conversion ratio.
pH LT: pH of *Longissimus thoracis*, between the 12th and 13th rib.
[abc]Results of boars with different superscripts are significantly different.
[A] A lower type index corresponds with a better carcass conformation.

Table 2
Feed composition and calculated (analysed) nutrients of the different diets.

	Control	RPS	RPS + WB	LUP	IN	CL
Ingredients (g/kg)						
Barley	329	296	280	296	313	326
Maize	235	212	200	212	223	233
Soybean meal	173	156	147	156	164	171
Wheat	141	127	120	127	134	140
Raw potato starch	-	100	100	-	-	-
Wheat bran	-	-	50	-	-	-
Lupins	-	-	-	100	-	-
Inulin	-	-	-	-	50	-
Clinoptilolite	-	-	-	-	-	10
Molasses (sugar beet)	35	32	30	32	33	35
Wheat middlings	31	28	26	28	29	30
Rapeseed meal	18	16	15	16	17	17
Lard	12	10	10	10	11	11
Premix	12	11	10	11	11	12
Limestone	8.2	7.4	7.0	7.4	7.8	8.1
Salt	3.5	3.2	3.0	3.2	3.3	3.5
L-Lysine	2.4	2.1	2.0	2.1	2.2	2.3
L-Threonine	0.6	0.5	0.5	0.5	0.5	0.6
DL-Methionine	0.3	0.3	0.2	0.3	0.3	0.3
Natuphos	0.1	0.1	0.1	0.1	0.1	0.1
Nutrients (g/kg)						
Moisture	130 (109)	130 (111)	130 (109)	127 (106)	126 (103)	129 (103)
Crude protein	161 (154)	146 (139)	146 (139)	176 (169)	154 (149)	160 (150)
Crude fat	33 (47)	30 (43)	30 (41)	35 (50)	31 (45)	33 (45)
Starch	392 (413)	432 (457)	421 (455)	361 (379)	372 (405)	388 (426)
Sugars	48 (54)	43 (48)	44 (49)	48 (54)	46 (95)	47 (56)
Crude ash	44 (45)	41 (39)	41 (39)	43 (40)	42 (43)	54 (50)
Crude fibre	42 (42)	39 (39)	41 (39)	53 (53)	40 (38)	42 (40)
Ca	5.3	4.9	4.7	5.0	5.1	5.3
P	5.0	3.8	4.2	3.9	4.8	5.0
P digestible	2.9	2.2	2.3	2.3	2.8	2.9
Ileal digestible lysine	7.7	6.9	6.7	8.2	7.3	7.6
Ileal digestible met	2.4	2.1	2.1	2.3	2.2	2.3
Ileal digestible met + cys	4.6	4.1	4.1	4.7	4.4	4.5
Ileal digestible trypsine	1.4	1.3	1.3	1.5	1.3	1.4
Ileal digestible tryptophan	4.7	4.2	4.1	5.1	4.5	4.6
Net energy (MJ/kg)	9.2	9.1	9.0	9.2	8.8[a]	9.1

Feed. Control: control feed, RPS: control feed + raw potato starch, RPS + WB: control feed + raw potato starch + wheat bran, LUP: control + lupins, IN: control + inulin, CL: control + clinoptilolite.
[a] Energy value of inulin was taken as 0.

2.5. Consumer panel

Consumers scored the meat samples on a scale from 1 (very good) to 6 (very bad) for tastiness, and on a scale from 1 (very good) to 5 (very bad) for odour, flavour and tenderness. Each consumer sat in an individual booth and was given samples from three different treatment groups of boars and 1 from a barrow. Samples were given in random order and the time between each sample evaluation was at least 2–3 min. Meat samples were grilled using a standardised method: 3 min on a grill of 1800 Watt at maximum

power to an internal temperature of 74 °C. Then, after 1 min, samples were put individually on a plate and were covered with a plastic box. Consumers were asked to drink mineral water and eat some white bread in between tasting samples. Each sample was evaluated by six consumers and mean scores were further used.

2.6. Expert panel

Training: seven experts were selected at the ILVO institute, based on their ability to detect the odour of androstenone and skatole. This selection was performed by triangle tests, using different concentrations of skatole (0.5, 0.1, 0.01 and 0.001 ppm) or androstenone (2.0, 0.5, 0.1 and 0.01 ppm) solutions in water. Training started with identifying androstenone and skatole, followed by learning to recognise the concentration of androstenone and skatole by using different dilutions of these compounds in water.

Meat samples: during each session, nine meat samples were evaluated successively using the same protocol as described above for the consumer panel.

Fat samples: were heated in a microwave oven at maximum power (700 Watt) for 50 s (for three samples) in closed jars. Samples were evaluated immediately after removing the lid. Twelve samples were tested successively during each session.

Meat samples were scored for odour and flavour, whereas fat samples were scored for odour only. Scores were given for general odour/flavour, skatole, androstenone, other disturbing components and rancidness, on a scale from 1 (no off-odour/off-taste) to 7 (very strong off-odour/off-taste). Meat taste was also scored on a scale from 1 (very good) to 7 (very bad). Each sample was evaluated by six panel members and mean scores were further used.

2.7. Laboratory analyses

In this study a liquid-chromatographic–multiple-mass-spectrometric ($LC–MS^n$) method was used for the simultaneous determination of indole (2,3-benzopyrrole), skatole (3-methylindole) and androstenone (5α-androst-16-en-3-one) in pig fat samples (Verheyden et al., 2007). In short, sample preparation consisted of extraction of the analytes from the fat matrix using methanol followed by freezing the extract in liquid nitrogen and a filtration step. Subsequently, analyses were carried out on a LTQ linear ion trap mass analyser (Thermo Electron, San José, CA, USA) equipped with an atmospheric pressure chemical ionisation (APCI) interface. Chromatographic separation and mass spectrometric detection of the analytes allowed their identification in samples. Quantification was realised on the basis of calibration curves for each individual analyte in a fat matrix.

2.8. Statistical analysis

Live weight at slaughter (SW), DFI, DG and FCR were analysed with pen as the experimental unit and treatment and replicate as fixed factor. Results from the carcass classification and pH (mean of left and right value) were analysed with the animal as the experimental unit and treatment, replicate and their interaction as independent variables and carcass weight as covariate. Boar taint detection variables were transformed by Box–Cox transformation to ensure a normal distribution (Neter, Kutner, Nachtsheim, & Wasserman, 1996). Differences in evaluation of boar taint by the different detection methods – between boars and barrows, and between the boars on the different dietary treatments – was evaluated on the basis of the scores (mean scores per animal for expert and consumer panel) and concentrations of boar taint compounds (Table 3). Scores for boars and barrows were compared with an independent *t*-test. Scores of the boars on the different treatments were compared for the different detection parameters with ANOVA, with treatment, replicate and their interaction as fixed factors, and the animal as the experimental unit (Statistica 8.0, Statsoft, Tulsa, USA). Tukey's post hoc test was used to compare the different treatment groups. Possible effects of differences in time of slaughter were evaluated by an independent *t*-test.

Cut-off values for the hot iron method, and expert and consumer panel were taken at the corresponding value of a neutral or acceptable evaluation of the sample. Cut-off concentrations for indole (Merks, 2007), skatole and androstenone were set at 0.10 (Moss, Hawe, & Walker, 1993), 0.20 and 0.50 ppm (Babol & Squires, 1995), respectively. Moreover, percentages of off-odour and off-taste are reported.

3. Results

3.1. Animal performance

CBOAR showed a significantly better FCR, a higher percentage of lean meat and a lower dressing percentage compared to CBAR (Table 1). Slaughter weight (SW), DFI, DG, conformation (type index), pH of the *longissimus thoracis et lumborum* and pH of the ham did not differ significantly between CBOAR and CBAR.

Starting weight at 21 weeks was similar for animals on different dietary treatments. No significant effect was seen on DFI. A significant effect of feed treatment was found on DG, with CBOAR growing faster than RPS and LUP and with IN boars growing faster than RPS boars. Overall, dietary treatment had an effect on FCR and type index, but discrimination between individual groups was not possible with Tukey's post hoc test. Dietary treatment also affected ham pH (lower for RPS than RPS + WB) and pH of *longissimus thoracis et lumborum* (lower for RPS than both RPS + WB and CBOAR).

3.2. Reduction and detection of boar taint

All different boars taint detection methods, described in this article, and were performed on all the animals, except for the hot iron method, where the animals from the first slaughtering could not be scored (Table 3). Among the parameters that were evaluated by the expert panel, bad scores for 'other disturbing components' or 'rancidness' were not given (data not shown). Consequently these parameters were omitted from further analyses.

Comparison of CBOAR and CBAR reveal marked differences for almost all boar taint detection parameters of the various detection methods indicating consistently higher levels and an elevated prevalence of boar taint in the entire male pigs. Parameters for which no significant differences were found between boars and barrows were restricted to consumer scoring of meat odour, expert scoring of skatole flavour/taste in fat and meat, and expert scoring of general and androstenone odour in fat.

Not a single parameter of boar taint level was significantly reduced by applying any of the dietary treatments to entire male pigs (Table 3). In fact, the only dietary treatment effect indicated a difference in indole concentration, but no differentiation between treatments could be made using the Tukey's post hoc test. Androstenone concentration was significantly higher for CBOAR and IN compared to LUP. The high frequency of boar taint for RPS was predominantly related to the high skatole and indole concentrations. For IN, boar taint was also high, but in this case it was most related to high androstenone concentrations.

To minimise the variation in slaughter weight, the animals were slaughtered either at 25 or 27 weeks, so that they were subjected to the experimental treatments for 4 or 6 weeks, respectively. No significant differences for experiment duration were found between the detection parameters, but the percentage of animals above cut-off values were higher for the animals slaughtered at week 27 vs. week 25 (Table 4).

Table 3
Scores and concentrations (mean ± st. dev.) for the different experimental groups.

	CBAR	CBOAR	RPS	RPS + WB	LUP	IN	CLIN	p_{sex}	p_{feed}
Hot iron (*n*)	15	18	14	15	15	15	14		
Score	1.1 ± 0.3	1.8 ± 0.7	1.9 ± 0.9	2.0 ± 0.8	1.5 ± 0.5	1.9 ± 0.9	1.6 ± 0.7	***<0.001***	0.939
%>1	7	61	71	67	53	60	57		
%>2	0	17	21	40	0	40	14		
Experts (*n*)	17	21	18	18	18	18	17		
Fat odour									
General	2.0 ± 0.4	2.4 ± 0.9	2.4 ± 0.8	2.3 ± 0.6	2.0 ± 0.5	2.3 ± 0.7	2.0 ± 0.5	0.202	0.583
%⩾3	0	19	22	17	6	28	0		
Androstenone	1.4 ± 0.3	1.9 ± 0.8	1.7 ± 0.5	1.7 ± 0.5	1.6 ± 0.3	1.7 ± 0.5	1.7 ± 0.3	**0.104**	0.970
%⩾3	0	14	6	6	0	0	0		
Skatole	1.4 ± 0.2	1.3 ± 0.4	1.6 ± 0.6	1.4 ± 0.4	1.3 ± 0.2	1.5 ± 0.5	1.2 ± 0.3	0.705	0.789
%⩾3	0	0	6	0	0	0	0		
Meat odour									
General	1.4 ± 0.3	1.6 ± 0.5	2.1 ± 1.0	1.8 ± 0.7	1.6 ± 0.5	1.8 ± 0.9	1.7 ± 0.5	***0.017***	0.641
%⩾3	0	5	22	11	6	6	0		
Androstenone	1.2 ± 0.2	1.4 ± 0.3	1.7 ± 0.8	1.5 ± 0.5	1.3 ± 0.2	1.5 ± 0.6	1.5 ± 0.4	***0.014***	0.610
%⩾3	0	0	11	0	0	6	0		
Skatole	1.1 ± 0.2	1.2 ± 0.3	1.3 ± 0.5	1.2:0.3	1.2 ± 0.4	1.3 ± 0.5	1.2 ± 0.2	0.821	0.886
%⩾3	0	0	0	0	0	0	0		
Meat flavour									
General	1.3 ± 0.2	1.6 ± 0.4	2.0 ± 0.9	1.8 ± 0.6	1.6 ± 0.4	1.7 ± 0.6	1.7 ± 0.5	***0.002***	0.717
%⩾3	0	0	22	0	6	6	0		
Androstenone	1.1 ± 0.2	1.4 ± 0.4	1.7 ± 0.8	1.5 ± 0.4	1.3 ± 0.3	1.4 ± 0.4	1.5 ± 0.5	***0.001***	0.837
%⩾3	0	0	6	0	0	0	0		
Skatole	1.1 ± 0.1	1.1 ± 0.2	1.3 ± 0.4	1.2 ± 0.3	1.2 ± 0.4	1.2 ± 0.4	1.2 ± 0.2	0.727	0.743
%⩾3	0	0	0	0	0	0	0		
Meat taste	2.4 ± 0.3	2.9 ± 0.4	3.4 ± 0.8	3.0 ± 0.6	3.0 ± 0.6	3.1 ± 0.7	2.9 ± 0.5	***0.001***	0.268
%>4	0	0	22	6	6	6	0		
Consumers (*n*)	17	21	18	18	18	18	17		
Tastiness	2.5 ± 0.2	2.9 ± 0.6	3.1 ± 0.6	2.9 ± 0.5	3.0 ± 0.5	3.0 ± 0.5	2.8 ± 0.5	0.056	0.723
%>3	6	43	44	33	39	33	18		
Odour	2.4 ± 0.3	2.6 ± 0.4	2.8 ± 0.7	2.7 ± 0.5	2.7 ± 0.7	2.7 ± 0.5	2.5 ± 0.3	0.237	0.678
%>3	0	19	28	28	28	28	0		
Flavour	2.5 ± 0.4	3.0 ± 0.6	3.2 ± 0.7	2.9 ± 0.6	3.0 ± 0.5	3.0 ± 0.6	2.8 ± 0.4	***0.010***	0.624
%>3	6	43	56	44	39	28	24		
Tender	2.8 ± 0.6	3.4 ± 0.7	3.7 ± 0.8	3.0 ± 0.8	3.4 ± 0.8	3.4 ± 0.6	3.1 ± 0.5	***0.005***	0.050
%>3	35	67	78	44	61	72	59		
Lab analyses (*n*)	17	21	18	18	18	18	17		
Indole	0.02 ± .0.01	0.03 ± 0.01	0.06 ± 0.05	0.04 ± 0.03	0.03 ± 0.02	0.05 ± 0.04	0.04 ± 0.02	***0.022***	***0.009***
%>0.10 ppm	0	0	28	6	0	11	0		
Skatole	0.02 ± 0.01	0.11 ± 0.10	0.13 ± 0.15	0.09 ± 0.08	0.06 ± 0.08	0.09 ± 0.12	0.10 ± 0.13	***<0.001***	0.162
%>0.20 ppm	0	10	33	6	11	11	12		
Androstenone	0.08 ± 0.02	0.29 ± 0.20^{b}	0.25 ± 0.21^{ab}	0.25 ± 0.21^{ab}	0.15 ± 0.06^{a}	0.36 ± 0.23^{b}	0.27 ± 0.15^{ab}	***<0.001***	***0.007***
%>0.50 ppm	0	10	17	11	0	22	6		
% Boar taint[1]	0	14	39	22	11	22	18		

Experimental groups. CBAR: control barrows, CBOAR: control boars, RPS: raw potato starch boars, RPS + WB: raw potato starch + wheat bran boars, LUP: lupin boars, IN: inulin boars, CLIN: clinoptilolite boars.
^{ab}:Results of boars within the same row with different superscript are significantly different.
p_{sex}: *p*-value for boars vs. barrows, p_{feed}: *p*-value for boars on different dietary treatments.
[1] Boar taint defined as indole, skatole or androstenone higher than respectively 0.10, 0.20 or 0.50 ppm.

4. Discussion

Differences in scores and concentrations between CBOAR and CBAR indicate that all the detection methods, described in this article, were performed properly and valid in the sense that they indicated – as expected – an elevated level and percentage of boar taint in entire male pigs.

The main finding of this experiment is that using these different boar taint detection methods, not a single one of the five dietary treatments applied to entire male pigs significantly reduced boar taint to a level below that of boars on the control diet. This result is unexpected since the dietary treatments were selected as promising for reducing boar taint on the basis of available literature. However, the concentrations of the ingredients used in this experiment were chosen at the lower limit of those in literature, so they would be commercially feasible. This might be a reason why other studies with the same or similar feed ingredients did yield more favourable results. RPS appears to be the least interesting feed ingredient in the present experiment, but no explanation for this can be given. Also, Lösel and Claus (2005) found a dose-dependent

Table 4
Effect of time of slaughter on slaughter weight and boar taint compounds.

	Time of slaughter	
	25 weeks	27 weeks
Slaughter weight (kg)	108 ± 6	106 ± 7
n	64	63
%>0.10 ppm indole	2	11
%>0.20 ppm skatole	6	18
%>0.50 ppm androstenone	8	11

decrease of skatole concentration in fat tissue with RPS in the diet: there was a significant difference between the effect of 20% RPS compared to 10% and 0% addition of RPS, while the addition of 30% or 40% of RPS did not further decrease skatole levels. Moreover, Zamaratskaia et al. (2005) found a decrease of skatole concentration in fat when 0.6 kg RPS/d/pig (or about 20%) was added. Hence it is possible that a higher supplementation of RPS (e.g. 20%) than the 10% RPS used in the present experiment would have been more effective against boar taint. In the present experiment, the additional supplementation of 5% WB to a feed with 10% RPS also failed to significantly reduce the incidence of boar taint. Govers et al. (1999) and Muir et al. (2004) also described the effect of the combination of RPS and WB in a ratio of 1:1 and about 2:1 on the fermentation process in the gut, but to our knowledge no studies describing the effect of this diet on boar taint have been published. The addition solely of 30% WB to a standard diet did not have any effect on skatole according to the study of Van Oeckel et al. (1998). For inulin, the applied concentration of 3–4% was lower than in other studies describing positive effects of inulin on boar taint. Hansen et al. (2006) found a reduction of boar taint by addition of at least 11% of inulin. As inulin source, crude chicory roots, dried chicory roots or a combination of one of these with pure inulin was given during 1, 2, 4, 6 or 9 weeks before slaughter. All treatments resulted in a significant decrease of skatole concentration in the blood or the fat tissue, but it is not certain whether the result they obtained was solely due to the inulin in these roots. For clinoptilolite, Baltic et al. (1997) reported positive results with concentrations even lower than the 1% used in the present study: a significant skatole reduction was found with 0.5% zeolite, corresponding with 0.45% clinoptilolite. The reason for the difference in results between our study and the study of Baltic et al. (1997) is not clear, but could be due to the higher basic skatole levels in fat (mean skatole level of respectively 0.23 and 0.35 ppm for control gilts and boars compared to 0.15 and 0.16 ppm with 0.5% zeolite added to the feed), while in our study mean fat skatole level of CBOAR is only 0.11 ppm. This can also be the reason why no significant results were found in our study compared to some other studies with higher mean skatole levels. The reducing effect of 10% lupins on skatole concentration in blood as found by Jensen et al. (1997), could also not be confirmed in our study.

The present study focussed on the effect of feed ingredients on skatole concentrations in the end product (fat and meat) by different detection methods. This is different to some other studies, where concentrations in the blood were measured (Jensen et al., 1997). It would be logical to expect that effects can be seen more readily in pig blood than in fat, although correlations between both have been shown (Claus et al., 1994; Zamaratskaia, Babol, Andersson, & Lundström, 2004). Investigating blood samples, the effect of the performed treatment could also be evaluated per pig, before and after treatment. The accretion of boar taint compounds in the fat tissue depends on the amount of these compounds produced as well as on the amount broken down in the body. If this breakdown is not sufficient, a slight decrease of blood concentrations might still lead to skatole and androstenone concentrations in the fat that are above the cut-off values for boar taint. Overall, the problem with skatole in boars is that some of the boars are not able to eliminate this skatole. The question arises if it is possible to reduce the skatole levels to a level below the cut-off value if a pig tends to have a really high concentration of skatole in fat. Different feed ingredients might be able to reduce skatole production or absorption, but the ability to degrade skatole will not change.

To minimise the variation in slaughter weight, the animals were slaughtered at two time points: the heaviest pigs at 25 weeks and the second group at 27 weeks (Table 4). The longer period that was needed to reach the commercial slaughter weight resulted in an increased proportion of animals with indole and skatole concentrations above cut-off values. As no interaction between age and diet was observed, higher concentrations can be due to the higher age of the second group. This finding indicates that age, independent of body weight, has an influence on boar taint compounds.

Our results suggest that consumers evaluated the meat very critically concerning taste, odour, flavour and tenderness. This might be related to the standardised method of meat preparation, meaning no addition of spices or sauce. The consumers found boar meat less tender than barrow meat. Van Oeckel et al. (1996) reported that meat from barrows was tenderer than meat from gilts, whereas meat from boars did not differ significantly from that of barrows or gilts. In the present study, the lower consumer appreciation concerning tenderness was more obvious than the scoring for odour. These consumers had to evaluate the baked meat only, while in practice consumer perception of odour during cooking is important as well, especially for the problem of boar taint.

The hot iron method resulted in a relatively large portion of animals with boar taint compared to the other methods. If a small amount of off-odour is judged acceptable and the cut-off value for the hot iron scoring is put on 2 (light off-odour) instead of 1 (neutral odour), there would be no barrows with boar taint. The amount of off-odour for the boars would then vary between 0% and 40%. These percentages are more in line with the results found by the other detection methods. As for androstenone, only 10% of the animals had concentrations above cut-off levels. A lot of discussion is still going on about the cut-off values for skatole and androstenone. If cut-off levels are changed to 0.25 ppm for skatole and 1.00 ppm for androstenone instead of respectively 0.20 ppm and 0.50 ppm), a lower frequency of boar taint can be found for RPS (17%), for LUP (0%) and for IN (6%). According to our analyses, androstenone could only be detected in one animal (IN) at a concentration above 1.00 ppm. The more conservative cut-off values are more in line with the results of the hot iron method, expert panel and consumer panel. For the expert panel, the consumer panel and the hot iron method, the concentration of androstenone will also have an influence on the evaluation of feeding strategies primarily aimed at reducing indole/skatole. For example, in our experiment there is a trend for a higher androstenone concentrations in the IN group in comparison with the LUP group. On the one hand the high androstenone can result in a more negative evaluation of the IN group. On the other hand, the low androstenone concentration in the LUP group can make it easier to detect off-odour due to skatole, as can be seen in the scores of the expert panel.

Production performance of CBOAR was superior to that of CBAR, as reported earlier. However, the difference between the dietary treatment groups indicates that this can only be achieved with a well balanced and digestible feed. The pH (one hour after slaughter) was found to differ between the different groups of boars. RPS gave the lowest pH values, RPS + WB the highest pH values. The reason for this difference is not clear. However, in all groups mean pH was between 5.9 and 6.2, indicating a low risk for PSE-meat.

5. Conclusion

Based on our results, it can be concluded that adding 10% RPS, 10% potato starch + 5% WB, 10% lupins, 5% Beneo IPE (containing $\geqslant$66% inulin) or 1% VIVOLITH 85 (containing $\geqslant$85% clinoptilolite) to the diet during 4–6 weeks prior to slaughter failed to reduce boar taint in entire male slaughter pigs.

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