**VALORISATION OF TAINTED BOAR MEAT IN PATTIES,
FRANKFURTER SAUSAGES AND COOKED HAM BY MEANS
OF TARGETED DILUTION, COOKING AND SMOKING**

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ABSTRACT

27 Because of the need to abolish the castration of piglets without anaesthesia/analgesia,
28 the pig industry is searching for a mode of action for the valorization of meat with boar
29 taint, an off-odour in entire male pigs. Carcasses with boar taint were selected by
30 means of sensory and chemical analysis, after which patties with different levels of
31 tainted boar meat were produced, as well as cooked ham and Frankfurter sausages
32 using different smoke condensates and cooking temperatures. For these products, i.a.
33 orthonasal and retronasal boar taint odour were assessed by a trained expert panel.
34 The results offer guidance regarding dilution of tainted meat (with $< 400 \mu\text{g kg}^{-1}$
35 androstenone if skatole is low or $< 200 \mu\text{g kg}^{-1}$ androstenone in concurrence with ≥ 37
36 $\mu\text{g kg}^{-1}$ skatole) and the potential application of smoke condensates (e.g. Rudinsmoke
37 C for sausages and Smokeze LFBN for ham) as promising boar taint masking
38 strategies.

39

40 **Keywords**

41 Androstenone, Boar taint, Consumer acceptance, Indole, Masking strategy, Pork,
42 Skatole

43

1. INTRODUCTION

In light of welfare concerns, there is an industry-wide incentive to ban the surgical castration of male piglets without anaesthesia and/or analgesia (Declaration of Brussels, 2010). The alternatives include castration with anaesthesia and/or pain relief, immunocastration and/or rearing of entire male pigs. The latter demonstrates several distinct advantages for farmers, including a better feed to gain ratio as well as the production of carcasses with a higher percentage of lean meat (Aluwe et al., 2009). Nevertheless, the rearing of entire males for pork production remains problematic because of the potential occurrence of boar taint, an off-odour in meat and adipose tissue. Boar taint is described as a sweaty, urine- and/or fecal-like (orthonasal and retronasal) odour that can give cause to consumer dissatisfaction (Claus, Weiler, & Herzog, 1994; Lundstrom, Matthews, & Haugen, 2009). Indole (IND), skatole (SK) and androstenone (AEON) are considered to be the three main boar taint contributing compounds (Aluwe, Tuytens, & Millet, 2015), although the incidence and perception of boar taint is rather complex and not fully understood to date. About 99% of consumers can perceive IND and SK, but not AEON, of which perception roughly ranges from 30 to 80 % depending on e.g. age, gender, genetic predisposition and country of origin (Bekaert et al., 2011; Wysocki & Beauchamp, 1984).

Considering the pig sector has stipulated that the valorisation of tainted boar meat is part of the terms and conditions for imposing the ban of surgical castration, there is an urgent need for more in-depth experimentation and knowledge on boar taint reducing and/or masking pork production processes. There are several strategies that may facilitate consumer acceptance of tainted boar meat including smoking, fermenting, dry-curing, cooking, seasoning and diluting. The latter, i.e. diluting, is a fairly straightforward strategy that can easily be implemented for certain processed meat products like e.g. patties and a large variety of sausages by blending raw material (Lundstrom et al., 2009; Meier-Dinkel, Gertheiss, Schnackel, & Morlein, 2016). The

potential of dilution in order to increase consumer acceptance is determined by several factors including the severity of the taint and the type of product (Babol & Squires, 1995; Meier-Dinkel et al., 2016). Regarding smoking and cooking, the potential of both of these strategies has been demonstrated in a number of studies - e.g. for the production of Frankfurter sausages - although further optimization of the duration of cooking temperature, smoking cycles, penetration of smoke, and type of smoke is prerequisite (Kallas, Martínez, Panella-Riera, & Gil, 2016; Lundstrom et al., 2009; Martinez et al., 2016; Meier-Dinkel et al., 2016; Stolzenbach, Lindahl, Lundström, Chen, & Byrne, 2009). Therefore, to add to the current knowledge on boar taint masking and reducing strategies in response to the current needs of the pig industry, this paper focusses on (1) the optimisation of blending percentage in pork patties, aiming to define acceptable IND, SK and AEON levels, (2) investigation of the masking potential of specific smoke condensates for the production of restructured cooked ham and sausages, alongside (3) experimentation with cooking temperature in relation to product acceptance by a trained boar taint expert panel. As such and more specifically, the following hypothesis will be addressed; blending of meat and fat with and without boar taint, cooking as well as addition of smoke condensates can significantly mask and/or reduce (the perception of) boar taint and facilitate the consumption of tainted boar meat in patties, Frankfurters and restructured cooked ham.

2. MATERIAL AND METHODS

A schematic overview of the experimental setup of this work is provided as supplementary information figure 1.

2.1. Training of boar taint experts

Trained panelists are better capable and thus more sensitive of detecting deviations or alterations in meat products compared to consumers (Font-i-Furnols, 2012; Verplanken, Wauters, Vercruysse, Aluwé, & Vanhaecke, 2017), and therefore, individuals sensitive to boar taint (as assessed using a triangle test) were trained to sniff and rank different levels (0 - 0.5 - 5 - 50 $\mu\text{g g}^{-1}$) of SK and AEON (the two main (known) boar taint contributing compounds) as well as to perceive boar taint compounds upon singeing of tainted fat, which has been described in detail previously (Wauters, Vercruysse, Aluwé, Verplanken, & Vanhaecke, 2016). Hence, for a more detailed description of the training of boar taint experts as well as sensory evaluation of boar taint meat products (discussed in 2.4.2), the authors refer to Wauters et al. (Wauters, Verplanken, Vercruysse, Ampe, Aluwé, & Vanhaecke, 2017).

2.2. Selection of tainted carcasses (and meat cuts)

2.2.1. Sensory analysis at-line

Boar taint prevalence (yes/no) in freshly slaughtered boars was assessed at a local Belgian abattoir (Debra Meat; Exportslachthuis, Tiel) by 2 alternating trained experts using the soldering iron method (Bekaert et al., 2013). In doing so, a total of 45 moderately to strongly tainted carcasses were selected, of which a neck fat sample was collected and transported to the lab (Laboratory for Chemical Analysis, cooled transport). To permit multiple experiments, the described selection procedure was performed twice (during fall 2017 and early summer 2018). Experiments with meat

from carcasses that were selected during the first selection procedure will be referred to as 'trial 1', and the second as 'trial 2'.

2.2.2. Chemical analysis

2.2.2.1. Reagents and chemicals

Reference standards indole (IND, 2,3-benzopyrrole, CAS: 120-72-9), skatole (SK, 3-methylindole, CAS: 83-34-1) and androstenone (AEON, 5 α -androst-16-ene-3-one, CAS: 18339-16-7), as well as internal standards 2-methylindole (2-MID, CAS: 95-20-5) and androstadienedione (ADD, 1,4-androstadiene-3,17-dione, CAS: 897-06-3) were purchased from Sigma Aldrich (St. Louis, MO, USA). Stock solutions were prepared in methanol, at a concentration of 1 mg ml⁻¹.

Reagents for extraction purposes (VWR International, Merck, Darmstadt, Germany) and UHPLC-MS applications (Fisher Scientific, Leicestershire, VS) were of analytical and of MS-grade. Solid phase extraction (SPE) columns (Oasis HLB, 3 cc 60 mg) were purchased from Waters Corporation (Milford, US).

2.2.2.2. Sample preparation

Sample clean-up and extraction was performed according to the protocol by Bekaert et al. (Bekaert et al., 2012a). In brief, 2 g of neck fat was melted in the microwave (3 min at 300 W), after which methanol was added. Extraction was enhanced by putting the samples in a hot water bath for 60 min. Afterwards, sample preparation continued with a clean-up step through freezing (60 min at -20 °C), centrifugation and solid phase extraction (Oasis HLB, 3 cc 60 mg).

For quantification purposes, calibration curves were prepared by spiking fresh blank neck fat (from a sow) with a standard mixture of IND, SK and AEON (0, 10, 25, 50, 75, 100, 250, 500, 750, 1000, 2000, 3000, 4000 and 5000 μ g kg⁻¹). Prior to extraction of

boar samples and calibration curve samples, internal standards 2-MID and ADD were added at a concentration of 500 µg L⁻¹.

2.2.2.3. UHPLC-HRMS analysis

Chromatographic separation and detection was achieved by means of Ultra High Performance Liquid Chromatography (UHPLC) coupled to High Resolution Mass Spectrometry (HRMS) using an Exactive orbitrap instrument (Thermo Fisher, San José, USA). A detailed description of this method can be consulted in the work by Bekaert et al. (Bekaert et al., 2012b).

2.2.3. Selection, processing and storage of carcasses and meat

Following sensory analysis at-line, the 45 selected moderately to strongly tainted carcasses were re-analyzed sensorially, enabling assessors (n = 3) to assign a sensory score from 0 to 4 (0 = no boar taint, 4 = very strong boar taint). After chemical analysis, and thus based on the results of the chemical and final sensory analysis combined, a final selection of 4 carcasses (as strong as possible and, if possible, different types of 'tainters') was made. After final selection, meat cuts from the 4 selected boar carcasses and gilts (kindly provided by Debra Meat, Exportslachthuis, Tielt, Belgium) were prepared in the slaughterhouse and transported (4°C) to the Research Group for Technology and Quality of Animal Products lab (Ghent, Belgium). This included boneless hams, lean pork meat, belly fat, pork shoulder, back fat and jowl fat.

Pork shoulder, back and jowl fat from the selected boars were chopped using a guillotine cutter (Magurit Gefrierschneider GmbH, Remscheid, Germany) and mixed thoroughly to generate one single batch for each raw material for the production of the sausages (2.3.3). In addition, lean pork meat and belly fat were also chopped using the guillotine cutter and homogenized to generate one batch of each raw material,

which was to be used for the production of patties (2.3.1). Similarly, a homogeneous batch of lean pork meat and belly fat from gilt was generated as well (for the production of the patties). Following this, the boneless hams (selected for restructured ham production (2.3.2)) and homogenized batches of meat and fat were vacuum packed (Webomatic Maschinenfabrik GmbH, Bochum, Germany) and stored at -20°C until the experimental production of pork products took place.

2.3. Production of pork products

2.3.1. Pork patties: effect of dilution

On the day of patty production, the homogenized batches of lean pork cuts and belly fat were defrosted. Patties with 0, 10, 20, 40, 60, 80 and 100 % of tainted meat (and fat, in a 70/30 ratio), complemented with 100, 90, 80, 60, 40, 20 and 0 % of (non-tainted) gilt meat (and fat, in a 70/30 ratio) respectively, were produced simply by adding different ratios of boar taint meat and gilt meat, after which this meat and fat mixture was minced through a 8-mm steel plate using a meat mincer (Minerva Omega Group S.r.l., Bologna, Italy). Following this, the ground meat and fat were mixed with white pepper (2 g/kg, provided by Solina, Eke-Nazareth, Belgium), sodium chloride (13 g/kg, provided by Solina, Eke-Nazareth, Belgium), egg (1 egg/kg, bought in a local store) and bread crumbs (50 g/kg, bought in a local store). The mix was then minced a second time through a 4-mm steel plate, and patties (130 g) were shaped using a household patty mould. The patties were stored at 4 °C, until the sensory test took place later that day.

2.3.2. Restructured ham: effect of smoke condensate

Three preparations of restructured cooked ham were made, with each preparation having its own brine composition (see supplementary table 1) through the addition of none (brine 1) or 1 out of 2 selected smoke condensates Smokeze LFBN (brine 2) and

Smoke BN-9 (brine 3). The dextrose, nitrite curing salt, phosphate, sodium ascorbate and yeast extract were provided by Solina (Eke-Nazareth, Belgium). The smoke products, i.e. Smoke LFBN and Smoke BN-9, were provided by Red Arrow (Apeldoorn, Netherlands).

Boneless hams were defrosted (30 h at 4 °C), trimmed of external fat and connective tissue and ground (Minerva Omega Group S.r.l., Bologna, Italy) through a 4-mm steel plate. The meat of the 4 selected boars (10 kg in total) was tumbled (Rühle GmbH, Grafenhausen, Germany) for 180 min at 7 rpm and 90% vacuum following the addition of the brine (2.5 kg) (see supplementary table 1). Thereafter, the meat was stuffed (Industrial Fuerpla, Valencia, Spain) in polymer casings with a diameter of 90 mm (Solina, Eke-Nazareth, Belgium), clipped (Tipper Tie, Glinde, Germany) and cooked for 3 h 30 min at 75 °C in a climate chamber (Kerres Anlagensysteme GmbH, Backnang, Germany), and finally cooled to and stored at 4 °C.

2.3.3. Frankfurter sausages: effect of smoking method and/or cooking temperature

Starting from the homogenized batch of pork shoulder, back and jowl fat, Frankfurter sausages were made, whereby different smoking methods and/or cooking temperatures were applied (table 1). Cooking programs can be consulted in supplementary information table 2 and 3.

Pork meat (400 g/kg) was vacuum chopped together with ice (250 g/kg), phosphate (3 g/kg) and nitrite curing salt (17 g/kg) in a bowl cutter (Kilia, Neumünster, Germany) until the meat batter reached a temperature of 5 °C. Next, back fat (200 g/kg) and jowl fat (150 g/kg) were added to the meat batter together with dextrose (5 g/kg), white pepper (2 g/kg), mace (0.5 g/kg), cardamom (0.5 g/kg), sodium ascorbate (0.5 g/kg) and glutamate (0.5 g/kg) and vacuum chopped until the temperature reached 14 °C. In case smoke condensate was added to the meat batter (for sausage 7 and 8, see

table 1), this was done together with the spices. After the cutting process, the meat batter was stuffed (Industrial Fuerpla, Valencia, Spain) in collagen casings with a diameter of 22.5 mm (Viscofan, Tajonar-Navara, Spain). In case of sausage 4 to 6 (see table 1), the sausages were drenched in smoke condensate solutions. Sausages were pasteurized in a climate chamber (Kerres Anlagensysteme GmbH, Backnang, Germany) according to the conditions described in supplementary table 2 (sausage 1-3) and 3 (sausage 4-8). After pasteurization, sausages were cooled to 4 °C. Finally, sausages were vacuum packed (Webomatic Maschinenfabrik GmbH, Bochum, Germany) and stored at 4 °C.

Phosphate, nitrite curing salt, dextrose, white pepper, mace, cardamom, sodium ascorbate and glutamate were provided by Solina (Eke-Nazareth, Belgium). The smoke condensates Rudinsmoke B, C or D were provided by Ruitenbergh (Twello, Netherland) and Smokez poly C-10 and Smokez supreme poly C by Red Arrow (Apeldoorn, Netherland).

2.4. Sensory and chemical evaluation of pork products

2.4.1. Meat cooking and serving

Meat samples were served per product, one by one, in randomized order within, but not across panelists. Cooking and preparations for serving of meat products were performed in a room separate from the evaluation room to avoid possible interference and bias due to e.g. the perception of baking odours. Patties and restructured ham (when tasted warm) were baked on contact grills (2000W) greased with sunflower oil. To avoid contamination, each product was prepared on a separate grill. Frankfurters were re-heated in hot water for 4 to 5 minutes, using separate cooking pots for different types of sausages. Core temperature was monitored until 70°C, after which all heated products were cut into smaller pieces and served hot to the experts (with a lid). Frankfurter sausages and restructured ham were also tasted cold. In this case, they

were simply chopped in individual portions and served as such. There was a maximum of 14 samples per session.

2.4.2. Sensory evaluation

The orthonasal odour (further referred to as 'smell' in light of simplicity) and retronasal odour (further referred to as 'taste'), and several other characteristics of the produced pork products were evaluated by a minimum of 7 trained experts (max. 10) in duplicate, i.e. on two separate non-consecutive days ('day 1' and 'day 2').

Sensory evaluation was performed under standardized circumstances, as has already been described in detail by Wauters et al. (Wauters et al., 2017), as well as previously in 2.4.1 Meat cooking and serving. More specifically, evaluation by panelists covered general (overall) smell, boar taint smell, general (overall) taste and boar taint taste of the meat product under investigation on a 150 mm scale; with e.g. 0 representing the total absence and 150 representing the very strong presence of the described attribute. In addition, the overall sensory quality and taste (tastiness), as well as the consumability or acceptance of the product were assessed and scored. The consumability ('overall acceptance') of each sample was scored from 0 to 10, with 0 being non-consumable and 10 perfectly consumable. Products were also ranked according to preference and boar taint perception. Regarding preference, '1' represented the most favored product, with a higher number (lower ranking) correlating with an increasingly less favored product. With regard to boar taint perception; '1' was reserved for the product with least strong boar taint, as perceived by the experts. More details on utilized attributes and scales are provided in supplementary information tables 4 and 5. Besides general smell, boar taint smell, general taste, boar taint taste, general tastiness, consumability and ranking according to preference and boar taint, product texture (i.e. toughness/tenderness (ham and Frankfurters), juiciness (all 3 products), grain/consistency (Frankfurters and hamburgers) and greasiness

(hamburgers)) as well as product specific characteristics (i.e. salty flavor (ham), smoky flavor (Frankfurters), pink color (ham and Frankfurters), marbling (ham) and color homogeneity (ham and Frankfurters)) were assessed as well (but will not be discussed as this did not reveal relevant findings).

2.4.3. Chemical analysis

Analysis of SK, IND and AEON in all products (i.e. in raw patties post production, in pre and post cooking Frankfurters and ham) was performed as described previously in section 2.2.2, and according to Wauters et al. (Wauters et al., 2017).

2.5. Data analysis and interpretation

Initial data processing and interpretation of the chemical analysis of fat and meat was performed using Xcalibur 2.1.0. Statistical interpretation of all data was performed using SPSS 25. Since assumptions for ANOVA regarding independence of observations and normally distributed data could not be met, rating of pork products was assessed using a non-parametric Friedman Test, followed by a Wilcoxon Signed Ranks Test. Correlations were assessed using Spearman's rank. A significance level of 0.05 was taken into account.

3. RESULTS AND DISCUSSION

3.1. Boar taint levels in neck fat from selected boars

For both the first and second trial of experimentation with dilution of tainted boar meat through mixing with gilt meat, four tainted carcasses were selected based on sensory analysis and IND, SK and AEON levels in fresh neck fat, of which detailed results can be consulted in supplementary information table 6. Overall, the boars that could be selected for the second trial demonstrated a more severe taint.

3.2. Patties

3.2.1. Trial 1

In the first trial, 7 different patties with 0, 10, 20, 40, 60, 80 or 100 % of tainted boar meat were produced and evaluated. All trends regarding perceived smell, taste and tastiness can be consulted in figure 1, whilst detailed data (means and standard errors) and correlations between sensory parameters and scores in relation to boar meat percentage can be consulted in supplementary information tables 7 and 8 (the score and ranking interpretation sheet can be consulted in supplementary information table 5).

A significant positive correlation between boar meat % and boar taint taste and smell perception could be retrieved, in contrast to an inverse correlation with general tastiness and assigned product score. However, besides these correlations, the more important question to ask is; up until which level of IND, SK and/or AEON is the product still acceptable for consumption? In this context, it could be observed that tainted boar meat % indeed affected general tastiness ($P < 0.05$), with a significantly lower value for patties containing 60 or 80 % of tainted meat in comparison to patties with 0, 10, 20 and 40 % of tainted meat. There is a distinctively lower appreciation of patties from 60 % mixing onwards, which aligns with the more pronounced perception of boar taint taste in those 60 to 100 % boar meat patties (perception in/for 60% tainted meat patties

is significantly ($P < 0.05$) higher compared to 40%), and is preceded by the increased perception of boar taint smell from 40 % onwards (perception in 40% tainted meat patties is significantly ($P < 0.05$) higher compared to 20%). It can be noted that these observations were not as distinct for the patty with 100% of boar meat; i.e. general tastiness was significantly higher ($P < 0.05$) compared to the 10 and 20 % boar meat patty, borderline significantly ($P = 0.063$) different from the 0 % boar taint patty, but not significantly different compared to the results for the 40% boar meat patty. This can be attributed to an unforeseen scoring bias that can probably be explained by the aversion of the experts towards boar taint; i.e. products that are tasted later on in the series become subject to more stringent scoring by the experts and vice versa. In this particular case, the 100% boar meat patties were tasted early on in the series on both day 1 and 2 (despite randomisation), which should be avoided in future studies.

Overall, IND and SK levels in the trial 1 patties (fresh matter) were relatively low and did not have or had little effect on boar taint perception. There was however a clear rise in AEON concentration with increasing percentage of tainted boar meat (as can be consulted in supplementary information table 9). Hence, combined with the results of the sensory evaluation of the patties (discussed above), it would thus appear that a product with more than approximately $400 \mu\text{g kg}^{-1}$ AEON ($\approx$ levels in the 60% boar meat patty (fresh matter), as reported in supplementary information table 9) is not acceptable and/or “consumable” due to the perception of boar taint.

3.2.2. Trial 2

Since the (meat from) boars that could be selected for trial 1 (supplementary information table 6) did not demonstrate a very strong and/or combined taint (i.e. a combination of IND, SK and/or AEON, as concluded based on chemical analysis), it was decided to repeat the first trial with meat from more heavily tainted boars and/or

boars with a combined taint (e.g. AEON and SK) in a second trial, for which patties with 0, 20, 40 and 60 % of tainted meat (but not 10, 80 and/or 100 %) were produced. Correlations between sensory parameters and scores in relation to boar meat percentage can be consulted in supplementary information table 10, whilst the score and ranking interpretation sheet can be consulted in supplementary information table 5. All trends are shown in figure 2, and detailed data can be consulted in supplementary information table 11. IND, SK and AEON levels in trial 2 patties are reported in supplementary information table 12.

In the second trial, general tastiness of patties was thwarted from 40% of mixing onwards; i.e. there was no significant difference between 0 and 20% ($P > 0.05$), but 40 and 60% were judged less tasty ($P < 0.05$) in comparison to 0 and 20 % of mixing. The same trends could be observed regarding the appreciation of general smell, as well as the perception of boar taint taste and smell; i.e. demonstrating a significant shift and clear cut-off ($P < 0.05$) between 20 and 40%. Depreciation of general taste was more gradual, with a significant difference between 0 and 60% ($P < 0.05$), but only a trend for difference between 0 and 40%, and between 20 and 60% ($P = 0.07$).

Combining the results of the chemical analysis and sensory evaluation of trial 2 patties (as discussed above), it would appear that a patty with more than $37 \mu\text{g kg}^{-1}$ SK in combination with $\pm 200 \mu\text{g kg}^{-1}$ AEON ($\approx$ levels in the 40% boar meat patty) is not acceptable and/or “consumable” compared to respectively $29 \mu\text{g kg}^{-1}$ and $67 \mu\text{g kg}^{-1}$ ($\approx$ levels in the 20% boar meat patty). Acceptable AEON levels in trial 2 were thus clearly lower compared to trial 1, which is most likely attributable to the concurrent presence of SK and possible synergistic effects with AEON. Notably, work by Mörlein et al. has previously hinted at the higher importance of SK compared to AEON (D. Mörlein et al., 2016) in light of consumer acceptance. Moreover, since the vast majority of consumers can detect SK, but not all can perceive AEON (Bekaert et al., 2011), this is of even higher relevance.

376

377 3.2.3. General results and discussion for patties

378 The number of research papers that focus on the investigation of acceptable IND, SK
379 and/or AEON levels in mixed/diluted products is limited. Furthermore, several studies
380 compare and discuss different percentages of mixing of meat with boar taint in different
381 products, but often without including detailed information on IND, SK and AEON
382 concentrations. Yet, acceptable levels of mixing greatly depends on the severity of the
383 taint; i.e. less mixing with meat from gilts and castrates will be required for carcasses
384 with a less severe taint compared to strong 'tainters'. In addition, quite often, another
385 level of complexity is added due to reporting of AEON, IND and SK levels in fat, but
386 not the product itself. Moreover, since product appreciation also depends on several
387 other factors like e.g. the type of meat product (incl. lean/fat ratio), cooking conditions
388 (cooked-in vs. open-cook procedure), context (at home vs. in a controlled
389 environment), serving temperature, consumer profile (age and gender, country of
390 origin, etc.), AEON (and SK and IND) sensitivity, and appreciation of the 'aroma' of
391 AEON, SK and/or IND, it has proven to be extremely difficult to establish clear boar
392 taint threshold levels (Aluwé et al., 2018; Bekaert et al., 2011; Blanch et al., 2012; Font-
393 i-Furnols, 2012; Font i Furnols, Gispert, Diestre, & Oliver, 2003; Meier-Dinkel et al.,
394 2013; D. Mörlein et al., 2016; Trautmann, Gertheiss, Wicke, & Mörlein, 2014; Wauters
395 et al., 2017).

396 In light of the valorisation and marketing of tainted boar meat by mixing/diluting in
397 patties, the results of this study require further confirmation by consumer panels. Since
398 the average consumer will be less sensitive and/or strict compared to the average boar
399 taint expert (Lawless & Claassen, 1993; D. Mörlein et al., 2016), we expect that the
400 acceptable levels of IND, SK and/or AEON will be higher in these conditions than is
401 reported here. Additional experimentation should deliver fine-tuning (e.g. additional
402 seasoning) and also unravel interaction and synergistic effects of AEON, IND and SK.

403

404 3.3. Restructured cooked ham

405 Sensory characteristics of tainted ham prepared with brine without addition of a smoke
406 condensate (= 'control') was compared to tainted ham prepared with brine with added
407 Smokeze LFBN or BN-9 to assess the boar taint reducing and/or masking potential of
408 the smokes. Results of the sensory evaluation of restructured cooked ham samples
409 following experimentation with the addition of smoke condensates to tainted boar meat
410 are discussed below and can furthermore be consulted in figure 3 and supplementary
411 information table 13 (score and ranking interpretation sheets can be viewed in
412 supplementary info. table 5).

413

414 3.3.1. Ham tasted cold

415 When tasted cold, general tastiness was significantly better for ham smoked with
416 Smokeze LFBN compared to Smokeze BN-9 and the control ($P < 0.05$). Smokeze BN-9
417 also delivered a tastier product compared to the control ($P < 0.05$), but the effect of
418 Smokeze LFBN was far more pronounced, which was also reflected in ranking for
419 preference and scoring of overall acceptance, where Smokeze LFBN outranked both
420 Smokeze BN-9 and the control ($P < 0.05$). Both Smokeze LFBN and BN-9 improved
421 general smell ($P < 0.05$), but only Smokeze LFBN significantly improved general taste
422 compared to the control ($P < 0.05$). Perception of boar taint taste was significantly
423 lower in Smokeze LFBN compared to Smokeze BN-9 ($P < 0.05$) as well as the control (P
424 < 0.05), and the same applied for Smokeze BN-9 compared to the control ($P < 0.05$).
425 Regarding the perception of boar taint smell, only Smokeze LFBN delivered significantly
426 better results, with the smell being perceived less strongly in comparison to the control
427 ($P < 0.05$).

428

429 3.3.2. Ham tasted warm

430 In contrast to what was observed for cold serving and tasting, the use of SmokeZ LFBN
431 and BN-9 did not significantly improve the tastiness of ham when tasted warm ($P <$
432 0.05). This was reflected in ranking for preference and scoring of overall acceptance,
433 for which none of the products outranked one or all others ($P < 0.05$). For SmokeZ
434 LFBN however, there was a significantly lower (better) ranking for boar taint compared
435 to the control ($P < 0.05$), whilst the effect on overall acceptance was borderline ($P =$
436 0.09). This can be linked to a significantly lower perception of boar taint taste and smell
437 in SmokeZ LFBN ham compared to the control ($P < 0.05$).

438

439 3.3.3. General results and discussion for ham

440 Addition of smoke condensates to the brine partly concealed the taint in restructured
441 ham (with a preference for SmokeZ LFBN, then SmokeZ BN-9, compared to the
442 control). This demonstrates that the addition of smoke condensates to the brine can
443 reduce the perception of boar taint in restructured ham. Hence, in light of this, further
444 exploration of the use of other types of smoke and/or the use of aromas is
445 recommended, also including experimentation with raw cured-and-smoked ham.

446 As has been documented and reviewed previously, the process of cooking can
447 significantly reduce IND, SK and AEON levels in the cooked vs. the raw ham
448 (Engesser, 2015; Lundstrom et al., 2009). In the current study, the levels (in fresh
449 matter) dropped from an average concentration of $7.6 \mu\text{g kg}^{-1}$ of IND and $70.2 \mu\text{g kg}^{-1}$
450 of AEON to an average of $4.5 \mu\text{g kg}^{-1}$ IND and $40.4 \mu\text{g kg}^{-1}$ AEON (there were no
451 detectable levels of SK ($< \text{LOD}$)); i.e. equaling a decrease of approximately 41 % of
452 IND and 42 % of AEON. This drop might be attributable to the process of cooking itself,
453 although it has been hypothesized that the addition of smoke may also aid in the
454 reduction of boar taint levels through interaction with IND, SK and/or AEON (Engesser,

2015; Lundstrom et al., 2009). However, in the current study, the addition of smoke did not appear to reduce actual IND, SK and/or AEON levels since the concentrations of all 3 major boar taint compounds in different hams, including the control, was highly comparable (with an average of 4,5 $\mu\text{g kg}^{-1}$ IND, 40,4 $\mu\text{g kg}^{-1}$ AEON and no detectable levels of SK (< LOD)).

3.4. Frankfurter sausages

3.4.1. Trial 1

In the first trial, 8 different types of Frankfurter sausages were produced to assess the effect of the addition of different smokes and/or the effect of a different cooking temperature on boar taint perception. The results of the sensory evaluation of can be consulted in figure 4 and supplementary information table 14.

3.4.1.1. *Effect of different smokes*

None of the smoke condensates delivered a significant drop in boar taint perception and/or a significantly tastier product ($P > 0.05$) compared to the traditionally smoked sausage (cooked at 72°C). Nevertheless, boar taint taste in Rudinsmoke C sausages was less pronounced in comparison to the other smokes ($P < 0.05$ when compared to Rudinsmoke B, $P = 0.08$, $P = 0.09$ and $P = 0.08$ compared to Rudinsmoke D, Smokez Poly C-10 and Smokez Supreme Poly C, respectively). To a limited extent, perception of boar taint smell in Rudinsmoke C sausages was less prominent in comparison to Rudinsmoke B ($P = 0.09$), Rudinsmoke D ($P < 0.05$), Smokez Poly C-10 ($P < 0.05$) as well as the traditionally smoked sausage ($P = 0.08$). Results of the chemical analysis of IND, SK and AEON levels in the sausages did not reveal a link with the above mentioned preferences and/or perception of boar taint (data not shown); i.e. the use of a certain smoke condensate did not alter IND, SK and AEON concentrations, but, apparently, only slightly altered their perception.

482

483 3.4.1.2. *Effect of cooking temperature*

484 General tastiness of sausages cooked at 80°C was significantly higher compared to
485 72, but not when cooked at 65 °C, and thus also preferred over 72 (ranked significantly
486 better and scored higher ($P < 0.05$) compared to 72 °C), but not 65°C. Nevertheless,
487 the perception of boar taint taste and smell did not significantly differ for different
488 cooking temperatures ($P > 0.05$), and hence the preference for sausages cooked at
489 80 °C did not appear to relate to boar taint perception, but was most likely due to the
490 formation of Maillard reaction products (Tamanna & Mahmood, 2015).

491

492 3.4.2. Trial 2

493 The boars that could be selected in the first trial did not demonstrate a very strong
494 and/or combined taint (supplementary information table 6), and therefore it was
495 decided to partly repeat the first trial with meat from more heavily tainted boars and/or
496 boars with a combined taint (e.g. AEON and SK) in a second trial. In addition, in the
497 first trial, the sausages were tasted cold. However, since Frankfurters are most often
498 consumed hot, the Frankfurters were indeed tasted hot in the second trial. Since
499 cooking temperature did not affect boar taint perception in the first trial, it was decided
500 not to re-assess the effect of alternative cooking temperatures. Figure 5 depicts the
501 results for trial 2, whilst more details can be consulted in supplementary information
502 table 15.

503

504 3.4.2.1. *Effect of different smokes*

505 General tastiness of the Rudinsmoke C sausage was significantly better compared to
506 the 3 others ($P < 0.05$). This can, at least in part, be linked to a difference in the
507 perception of boar taint, for which there was a (borderline) significant difference with
508 Rudinsmoke D for boar taint taste ($P = 0.06$) and smell ($P < 0.05$), and a borderline

significant difference with Rudinsmoke Supreme Poly C ($P = 0.06$) with regard to boar taint taste. The positive attributes of the Rudinsmoke C smoke condensate was also reflected in a relatively high average overall acceptance of 7 out of 10 and high ranking for preference (ranked 1st). When comparing IND, SK and AEON levels in the different sausages, there was no distinct difference (data not shown). Hence, it can be concluded that the use of different smoke condensates affects boar taint perception, but does not interfere with actual IND, SK and AEON levels.

3.4.2.2. *Effect of cooking*

In this trial, the effect of cooking on IND, SK and AEON levels was assessed by comparing concentrations prior to and after cooking of the sausage. On average, the Frankfurters contained 36.6 $\mu\text{g kg}^{-1}$ IND, 74.4 $\mu\text{g kg}^{-1}$ SK and 425.5 $\mu\text{g kg}^{-1}$ AEON (fresh matter). Prior to cooking, however, the raw material contained 55.2 $\mu\text{g kg}^{-1}$ IND, 103.9 $\mu\text{g kg}^{-1}$ SK and 596.6 $\mu\text{g kg}^{-1}$ AEON, which means cooking decreased IND, SK and AEON concentrations with 34 %, 28 % and 29 %, respectively. In line with what was already discussed for restructured ham, this decrease is likely to be the direct result of the cooking process itself, although it might also be linked to the use of smoke through interaction between IND, SK and/or AEON and certain smoke constituents (Engesser, 2015; Lundstrom et al., 2009). The latter has however, to the best of our knowledge, not been studied in depth.

3.4.3. General results and discussion for Frankfurter sausages

Due to the relatively high fat content of the Frankfurter sausage, IND, SK and AEON levels in the final product were significantly higher in comparison to other pork products like e.g. restructured cooked ham. Nonetheless, this did not result in the immediate rejection of the sausage due to the perception of boar taint because, apparently, the typical smoky aroma of the sausage could, at least in part, mask both orthonasal and

retronasal boar taint odour. There was no clear advantage to the use of an alternative cooking temperature or specific smoke condensates, except for Rudinsmoke C. Regarding the possible effect of cooking temperature on boar taint perception, it must however be noted that any effect of temperature may have been overlooked because of the sausages were tasted cold. Therefore, in follow-up research, the effect of alternative cooking temperatures should be re-assessed following hot consumption. Follow-up studies, including consumer tests, are also recommended to further investigate the potential of traditional smoking, the use of smoke and other aromas for the reduction/masking of boar taint in Frankfurters. Even more so since independent research also points towards the noteworthy potential of smoking for masking of boar taint perception in cooked sausages (Martinez et al., 2016). In contrast, colleagues Aarlyng & Koch, and Mörlein et al. objected to the potential of liquid smoke as a boar taint masking strategy (Aaslyng & Koch, 2018; J. Mörlein, Meier-Dinkel, Gertheiss, Schnäckel, & Mörlein, 2019), but it should however be taken into account that this may be subject to boar taint level and type, as well as the type and concentration of liquid smoke.

The results of the current study demonstrate that the addition of smoke might influence product tastiness, and that the use of smoke condensates may aid in the reduction of boar taint perception, like seems to be the case for e.g. Rudinsmoke C. In addition, the cooking process itself likely contributes to the reduction of IND, SK and AEON levels in comparison to the raw product. It should however be taken into account that these findings and conclusions may be subject to the type of taint, which warrants follow-up research.

Upon comparison of average IND, SK and AEON levels in patties, restructured cooked ham and Frankfurter sausages in relation to general tastiness, it appears that higher levels of IND, SK and AEON may be acceptable in Frankfurter sausages compared to restructured ham and patties. Therefore, moving forward, the valorisation of meat with boar taint in Frankfurters is a valid option, but which of course requires further

confirmation by means of consumer tests. In this context, it would be of specific interest to have a consumer panel compare the acceptability of the traditionally cooked Frankfurter sausage compared to e.g. a Rudinsmoke C sausage and/or e.g. smoking combined with the use of a certain mix of spices with sharp and warm pungent notes (white pepper, mustard, nutmeg mace, coriander, small cardamom and sweet marjoram), of which the boar taint masking potential has been reported previously (Tamanna et al., 2015). The use of white pepper, cardamom and mace is of specific interest for follow-up research since those 3 spices were also used in the current study.

CONCLUSION

Different approaches for the valorisation of tainted pork appeared to be highly promising; i.e. mixing with gilt raw materials in patties, processing into Frankfurter sausages, as well as processing into restructured ham. Hence, it can be concluded that fine tuning of production processes (use of cooking and/or smoke condensates) and mixing with non-boar taint meat (targeted dilution) can significantly reduce (the perception of) boar taint and thus potentially reduce rejection by consumers. Moving forward, additional experimentation and consumer tests are needed to confirm these results in a broader (non-trained) test group as well as to provide more boar taint reducing and/or masking alternatives, like e.g. the use of aromas and marinades.

ACKNOWLEDGEMENTS

The authors would like to thank all members of the boar taint expert panel (from ILVO, KUL & UGent), as well as Dirk Stockx, Beata Pomian, Joke Goedgebuer and Mieke Naessens (UGent) for their most invaluable contribution to this work. In addition, the authors would also like to explicitly thank Liesbeth De Wilde (ILVO), Marijn Dhaenens and Els Beda (Debra Meat) for their assistance in selecting the carcasses and meat cuts.

This project was funded by the Flemish Government through the Agency for Innovation and Entrepreneurship (VLAIO) and Flanders' FOOD (REDBOAR, HBC.2016.0501 and HBC.2017.0103).

Conflict of interest statement

The authors declare that there is no conflict of interest.

TABLES

Table 1: Overview of smoking types and methods for Frankfurter sausage (cooking programs can be consulted in supplementary information table 2 and 3).

Sausage	Type of smoke	Smoking method	Cooking program	Cooking temperature
Effect of t°				
1	Beech wood chips	Traditional	1	72 °C
2	Beech wood chips	Traditional	1	65 °C
3	Beech wood chips	Traditional	1	80 °C
Effect of smoking:				
4	Rudinsmoke B	drenching: 90 s in 20% solution	2	72 °C
5	Rudinsmoke C	drenching: 90 s in 20% solution	2	72 °C
6	Rudinsmoke D	drenching: 90 s in 20% solution	2	72 °C
7	Smokeze poly C-10	1 % added to the meat batter	2	72 °C
8	Smokeze supreme poly C	1 % added to the meat batter	2	72 °C

FIGURE CAPTIONS

Figure 1: Observed trends (mean $\pm$ std. error) for blending of boar taint meat in patties in trial 1, with scale to 150 = 'very unpleasant' for general smell, 150 = 'very strong' for boar taint smell, 150 = 'very unpleasant' for general taste, 150 'very strong' for boar taint taste, 150 = 'very tasty' for general tastiness.

Figure 2: Observed trends (mean $\pm$ std. error) for blending of boar taint meat in patties in trial 2, with scale to 150 = 'very unpleasant' for general smell, 150 = 'very strong' for boar taint smell, 150 = 'very unpleasant' for general taste, 150 'very strong' for boar taint taste, 150 = 'very tasty' for general tastiness.

Figure 3: Observed trends (mean $\pm$ std. error) for restructured ham tasted cold (above) and warm (below), with scale to 150 = 'very unpleasant' for general (G.) smell, 150 = 'very strong' for boar taint (BT) smell, 150 = 'very unpleasant' for general (G.) taste, 150 'very strong' for boar taint (BT) taste, 150 = 'very tasty' for general (G.) tastiness.

Figure 4: Observed trends (mean $\pm$ std. error) for Frankfurter sausages in trial 1, with scale to 150 = 'very pleasant' for general (G.) smell, 150 = 'very strong' for boar taint (BT) smell, 150 = 'very pleasant' for general (G.) taste, 150 'very strong' for boar taint (BT) taste, 150 = 'very tasty' for general (G.) tastiness.

Figure 5: Observed trends (mean $\pm$ std. error) for Frankfurters in trial 2, with scale to 150 = 'very unpleasant' for general (G.) smell, 150 = 'very strong' for boar taint (BT) smell, 150 = 'very unpleasant' for general (G.) taste, 150 'very strong' for boar taint (BT) taste, 150 = 'very tasty' for general (G.) tastiness.

628 **FIGURES**

629 **Figure 1**

630

631 **Figure 2**

632

633 **Figure 3**

634

635 **Figure 4**

Figure 5

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