

# The results of meat quality traits and sensory characteristics according to the concentration of androstenone in uncastrated pigs

Shah Ahmed Belal<sup>1,2</sup> and Jong-Hyun Jung<sup>3\*</sup>

<sup>1</sup>Department of Animal Biotechnology, Jeonbuk National University, Jeonju 54896, Korea

<sup>2</sup>Department of Poultry Science, Sylhet Agricultural University, Sylhet 3100, Bangladesh

<sup>3</sup>Jung P&C Institute Inc., Yongin 16951, Korea



Received: Jan 22, 2024

Revised: Mar 4, 2024

Accepted: Mar 5, 2024

## \*Corresponding author

Jong-Hyun Jung

Jung P&C Institute Inc., Yongin 16951, Korea.

Tel: +82-31-704-8113

E-mail: [jhjh7@snu.ac.kr](mailto:jhjh7@snu.ac.kr)

Copyright © 2024 Korean Society of Animal Sciences and Technology. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

## ORCID

Shah Ahmed Belal

<https://orcid.org/0000-0001-5353-2439>

Jong-Hyun Jung

<https://orcid.org/0000-0003-3667-7710>

## Competing interests

No potential conflict of interest relevant to this article was reported.

## Funding sources

Not applicable.

## Acknowledgements

Not applicable.

## Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

## Abstract

Pork quality is determined by several attributes, among which odor and taste are the utmost significant. Therefore, this study was aimed to assess the effects of boar odor hormone concentration on the quality traits and sensory acceptability of pork. A total twenty-six (26) non-castrated 3-way crossbred (Landrace × Yorkshire × Duroc) pigs were selected with an average body weight (ABW) 115.6 kg before to slaughter. The three treatment groups (low, medium and high) were divided according to the androstenone concentration. In experiment 1, for meat quality traits carcass was selected based on androstenone concentration: low (LC, 0.64–0.69 µg/g, n = 9), medium (MC, 0.70–0.99 µg/g, n = 7) and high (HC, 1.00–1.69 µg/g, n = 10). In experiment 2, for sensory evaluation carcasses were also selected based on the abovementioned conditions. Results revealed that androstenone concentration not effect on proximate components, meat quality traits and fatty acids except palmitoleic acid. Sensory evaluation data showed that boar taint and meat boar taint were significantly increased in a concentration-dependent manner from low to high, whereas, gravy and meat flavor preference were significantly increased in LC group than HC group. In addition, correlation analysis showed that boar taint and meat boar taint were positively, and gravy and meat flavor preference were negatively correlated with boar taint hormones. In essence, our findings indicate that androstenone concentration had no effect on meat qualities, but a high concentration of androstenone had a negative effect on the sensory characteristics in uncastrated pigs.

**Keywords:** Boar taint hormone, Uncastrated pig, Meat quality traits, Sensory characteristics

## INTRODUCTION

Pork is one of the most preferred meat by consumer worldwide [1]. Boar taint, a sensory off-flavor and/or offensive odor [2] connected with mainly two lipophilic compounds: androstenone and skatole (breakdown product of tryptophan) which starts to gather in the fat of sexually matured boars and creates a problem for consumers acceptability. It is a disagreeable odor or taste that is habitually apparent when cooking and/or heating of pork derived from entire male pigs [3]. This undesirable odor

### Authors' contributions

Conceptualization: Jung JH.

Data curation: Belal SA, Jung JH.

Formal analysis: Jung JH.

Methodology: Jung JH.

Software: Jung JH.

Validation: Belal SA, Jung JH.

Investigation: Jung JH.

Writing - original draft: Belal SA.

Writing - review & editing: Belal SA, Jung JH.

### Ethics approval and consent to participate

This study was approved by the Animal Ethics Committee of Jeonbuk National University (approval number: CBNU2018-097). All the experiments were conducted following the guidelines and regulations of Jeonbuk National University.

may be affected negatively by excess accumulation of androstenone and skatole that make obstacle for the entire male pig production [4]. In several countries, pork is only produced from barrows or gilts due to boar taint in boar [5].

To regulate boar taint, castration has conventionally applied in pig husbandry, but animal welfare concerns raised due to pain and stress during surgical castration. In past, to increase fat content pigs were castrated, because of fatter pigs were most desired to consumer as reviewed by Squires et al. [6]. However, nowadays consumer satisfactions have been shifted to lean meat to maintain their good health. Pokorná et al. [5] used a non-invasive method to examine androstenone concentration of saliva by which might improve the animal welfare in pig fattening. In welfare perspective, if castration is removed the aggressive and sexual behaviors are increases in non-castrated male pigs. Aggression may increase stress and as a result decreased immune functions, lost daily weight gain and suffered meat quality in entire males [6–9]. Moreover, in contrast entire pig production, a number of unfavorable consequences of surgical castration are higher feeding cost, reduced carcass value (due to increased fat content), more saturated fat, labor cost and reduced welfare [10].

When consumers decide the quality of pork, meat color and appearance are the most important, followed by flavor and taste. In the past, meat from uncastrated boars was known to have an unpleasant odor and taste and was treated differently from normal meat. Recently, as consumers' awareness of the importance of animal welfare has increased, especially in developed pig farming countries, the production rate of non-castrated boar has increased, and various studies have been conducted on boar taint. In general, boars are surgically castrated within 7 days of age to improve meat quality and facilitate feeding management [11]. In pigs, boar-taint occurs mainly in non-castrated boars, and when such pork is heated, a unique flavor occurs, and in severe cases, it is so strong that it is impossible to eat. Boar taint occurs when three hormones, androstenone, skatole, and indole, accumulate excessively in the fat and lean meat [6,12,13]. On the other hand, non-castration of boars has been reported to improve feed efficiency by 9%, increase growth rate by 14%, and increase meat yield by 20% [7,14]. Since feed costs account –for 60%–70% of production costs in the pig farming industry, reducing feed costs is essential for reducing production costs [15].

To reduce off-odor, immunocastration or surgical castration is usually applied to male piglets in many countries. But to ensure animal welfare issue most European countries have imposed a voluntary ban on this method [16]. Ban of surgical castration without anaesthesia became a frequent topic [17]. Environmental condition and diet manipulation could be associated with genetic selection [18] and genomic selection seems to be beneficial to reduce boar taint [19]. Previous literatures also showed that a number of long-term (genetics) and short-term strategies (management practices) have been executed to control boar taint, but these can have inconsistent results and much variability. Therefore, in addition to the animal welfare aspect, a non-castrated boar production method is very necessary from an economic point of view. This study was conducted to present basic data for the production of non-castrated boars by analyzing the meat quality and sensory characteristics according to androstenone concentrations in non-castrated boars.

## MATERIALS AND METHODS

### Ethics statement

This study was approved by the Animal Ethics Committee of Jeonbuk National University (approval number: CBNU2018-097). All the experiments were conducted following the guidelines and regulations of Jeonbuk National University.

### Animals

A fat biopsy was collected by the method of Baes et al. [20] from 26 non-castrated 3-way crossbred (Landrace × Yorkshire × Duroc) pigs with an average body weight of 115.6 kg prior to slaughter. The biopsy instrument was used to extract the fat of a living pig. Boston butts (*M. subscapularis*) were collected from the slaughterhouses. All pigs were raised under uniform housing conditions and fed ad libitum commercial diet.

### Experimental design

In experiment 1, to analysis the meat quality traits three treatment groups were divided according to the androstenone concentration based on the research of Meier-Dinkel et al. [21]: low concentration (LC, 0.64–0.69 µg/g, n = 9), medium concentration (MC, 0.70–0.99 µg/g, n = 7) and high concentration (HC, 1.00–1.69 µg/g, n = 10). In experiment 2, for sensory evaluation carcasses were also selected based on the abovementioned conditions.

### Analysis of boar taint compounds

Concentration of boar taint compounds were measured by gas chromatography–mass spectrometry (GC-MS) from fat samples. Pure fat sample in the vial without muscle and skin was melted in microwave oven (700 W) for 1 min. Liquid fat of 0.2 g was taken, transferred at centrifuge tube (2 mL) and mixed with 0.8 mL of reagent (methanol:n-hexane, 9:1, v/v). The centrifuge tubes were vortex mixed for 1 min, and incubated at ultrasonic wave incubation at 50 °C for 40 min with vortex mix every 5 min. After incubation, samples were cooled at room temperature and centrifuged at 15,000 rpm for 30 min and supernatant was collected into injection vial for boar taint compound analysis.

The GC-MS system from Shimadzu (GC-MS, QP-2010, Kyoto, Japan) and column was Rtc-5Sil MS column (30 m × 0.25 mm, 0.25 µm, film thickness, Restex, Centre County, PA, USA). During whole analyze times, inject was split mode (split ratio, 10:1) at 300 °C and inject volume was 1 µL. The oven temperature was programed at 40 °C for 1 min, increased the temperature of 10 °C/min to 250 °C (5 min hold), and then again increased 15 °C/min to 300 °C and hold 10 min. The ionization performed using electron impact ionization (EI) method at voltage 70 eV and the ion source temperature was 260 °C. A scan range of m/z 40–550 was chosen and MS spectrum was referred to the Wiley library. In order to analyze the correct BTCs, qualification was performed using selective ion monitoring (SIM) mode with m/z 257 (androstenone), 130 (skatole) and 117 (indole).

### Proximate component

Proximate component analysis was performed according to AOAC [22], moisture content was determined by oven drying method, fat was partially modified from Folch et al. [23] was used, and the raw material was incinerated at 550 °C for 5 hours in an incinerator (FPX-14, Daihan, Wonju, Korea), then the content was measured and the results were expressed as the percentage (%).

### Meat quality

The meat color (L\*, a\*, and b\*) per sample were taken at three different locations on the bloomed cut surfaces of the sample blocks was measured using a Minolta chromameter (CR-410, Minolta, Osaka, Japan) calibrated by a black-and-white calibration plate. The color results were reported as CIE L\*, a\*, and b\* (lightness, redness and yellowness), analyzed by Spectra Magic Software (Minolta).

For pH measurement, 2 g of meat sample was homogenized with 18 mL of distilled water at 11,000 rpm for 1 minute using a homogenizer (Polytron PT 10-35 GT, Kinematica AG, Luzern, Switzerland). The filtrate of each sample was filtered with filter paper (followed by Whatman No. 4) and measured with a pH meter (Seven Excellence™, METTLER TOLEDO, Greifensee, Switzerland) at room temperature.

To measure the water holding capacity (WHC), 5 g of the pulverized sample is placed in a 50 mL tube with a filter with pores, and the weight of the sample is measured after centrifugation by centrifugation (Combi-514R, HANIL) at 1,000 rpm at 5 °C for 10 minutes. Thus, the value was calculated by the formula: [(weight of total sample (g) - weight of free water (g))/weight of total sample (g) × 100].

Cooking loss was measured by the method of Honikel [24]. Samples were weighed and put in a plastic bag, which was placed in an 80 °C water bath until the internal temperature reached 75 °C. When this temperature was reached, the samples were cooled and weighed again. The difference in weight before and after boiling was expressed as percentage cooking loss.

The Warner-Bratzler shear force (WBSF) was determined by taking meat sample blocks using an Instron Universal Testing Machine (Model 1011, Instron, Canton, MA, USA). Meat samples were cooked and cooled before measurement of WBSF parallel to the muscle fiber direction. Samples were cut into a size of 30 × 50 × 10 mm, heat it to a core temperature of 75 °C (LLOYD instruments, Bognor Regis, UK) was equipped with a Warner-Bratzler blade and the shear force (unit: kgf) was measured while the muscle texture of the sample was perpendicular to the blade. The speed was 2.0 mm/s and the post-test speed were 5.0 mm/s.

### Fatty acid composition analysis

The fatty acids composition of porcine M. subscapularis muscle was estimated by the method of [25], with a minor modification. The assay was performed using a Gas Chromatograph-Flame Ionization Detector (7890 series, Agilent, Santa Clara, CA, USA) under the following conditions: injector split mode with split ratio of 25:1, temperature 250 °C. High purity air, high purity H<sub>2</sub>, and high purity He were used as carrier gases. The flow rate was maintained at 40 mL/min for H<sub>2</sub> and 400 mL/min for air. An HP-88 column (60 m × 250 μm × 0.2 mm) was used for the analysis. Fatty acid composition is expressed as a percentage.

### Sensory attributes evaluation of pork by trained sensory panelists

The use of trained persons as instruments for the evaluation of sensory properties of pork is a common practice. To conduct sensory evaluation, three specific areas have to be considered: 1) panel conditions used for sensory evaluation; 2) training and selection of sensory panelists; and 3) the step and structure of evaluation that will be used to address sensory characteristics in pork. For the sensory test, the longest abdominal muscle containing back fat was heated to a core temperature of 75 °C under the same cooking conditions, and a certain amount of the sample was presented to the sensory evaluator. For the evaluation of the sample, a 9-point scale was used based on the 5-point scale of uncastrated pigs, and broth boar odor (1 point = very weak, 9 points = very strong), broth flavor preference (1 point = very bad, 9 points = very good), meat odor (1 point = very weak, 9 points = very strong), and meat flavor preference (1 point = very bad, 9 points very good).

### Statistical analysis

All data were analyzed using analysis of variance (ANOVA) followed by the Duncan's multiple range test procedure by SAS software (version 9.3, SAS Institute, Cary, NC, USA). All data were presented as mean ± standard error (SE). Statistical significance was set at  $p < 0.01$  and  $p < 0.05$ .

## RESULTS

### Boar taint compounds

Table 1 showed the concentrations of boar taint compounds based on treatment groups. The androstenone, skatole and indole concentrations ranged from 0.610 to 1.685  $\mu\text{g/g}$ , from 0.081 to 0.092  $\mu\text{g/g}$ , and from 0.043 to 0.074  $\mu\text{g/g}$ , respectively. Various studies have been conducted to determine the minimum detectable concentrations of androstenone and skatole in the boar taint compounds. Bonneau and Chevillon [26] reported that the minimum androstenone concentration detectable by humans is around 2–3  $\mu\text{g/g}$  in fat. In another study, Xue et al. [27] suggested that androstenedione and skatole concentrations should be at least 1.5  $\mu\text{g/g}$  and 0.25  $\mu\text{g/g}$  or higher for detection. Bañón et al. [28] also stated that people can detect androstenone and skatole concentrations of at least 0.5  $\mu\text{g/g}$  and 0.1  $\mu\text{g/g}$ , respectively, in heat-treated loin meat.

### Proximate compositions

Table 2 presents the results of proximate compositions. Results revealed that boar taint hormone concentration not effect on proximate components. Moisture content refers to the content of fixed and free water present in meat, and these moisture contents have a close relationship with the WHC of meat and juiciness when chewing meat, depending on the degree of electrical bonding between proteins and water molecules in the meat. Meat have fat, along with carbohydrates and proteins, is one of the main nutritional components of food, and gives food a unique rich flavor and texture.

### Meat quality

Table 3 showed meat quality parameters such as color, pH, WHC, cooking loss and shear force. It was observed that no significant differences in the meat qualities according to the concentration of androstenone. However, pH and WHC were increased in the LC group than other two groups without any significant.

**Table 1.** Least-square means and standard error of boar taint compounds concentration of porcine *M. subscapularis* muscle for the three treatments

Boar taint Compound ( $\mu\text{g/g}$ )	LC (n = 9)	MC (n = 7)	HC (n = 10)	Total (n = 26)
Androstenone	0.651 $\pm$ 0.046 <sup>c1</sup>	0.844 $\pm$ 0.114 <sup>b</sup>	1.426 $\pm$ 0.263 <sup>a</sup>	1.035 $\pm$ 0.469
Skatole	0.086 $\pm$ 0.046	0.086 $\pm$ 0.046	0.089 $\pm$ 0.026	0.087 $\pm$ 0.036
Indole	0.046 $\pm$ 0.027	0.053 $\pm$ 0.024	0.058 $\pm$ 0.019	0.055 $\pm$ 0.014

<sup>1</sup>Means in the same row with different letter are statistically significant at 10% of significance.

LC, low concentration; MC, medium concentration; HC, high concentration.

**Table 2.** Effects of androstenone concentration on proximate composition of porcine *M. subscapularis* muscle

Proximate component (%)	LC (n = 9)	MC (n = 7)	HC (n = 10)	SEM
Moisture	75.38	74.88	75.22	0.16
Crude protein	23.65	24.44	23.8	0.19
Fat	1.64	2.02	1.81	0.14
Crude ash	1.14	1.13	1.11	0.01

LC, low concentration; MC, medium concentration; HC, high concentration.

**Table 3.** Effects of androstenone concentration on meat quality traits of porcine *M. subscapularis* muscle

Variable	LC (n = 9)	MC (n = 7)	HC (n = 10)	SEM
Color				
CIE L* (Lightness)	56.43	56.10	53.10	1.22
CIE a* (Redness)	15.81	16.81	16.83	0.36
CIE b* (Yellowness)	6.10	6.70	5.78	0.47
Other quality trait				
pH (24-hour)	5.56	5.57	5.75	0.11
WHC (%)	69.67	69.5	73.73	2.04
Cooking loss (%)	24.08	22.3	20.83	1.03
Shearing force (Kgf)	4.92	5.79	4.93	0.55

LC, low concentration; MC, medium concentration; HC, high concentration.

### Fatty acid composition

The results of fatty acid compositions are presented in Table 4. Palmitoleic acid (C16:1), which is one of the major fatty acid of monounsaturated fatty acids (MUFA) was significantly higher in LC and MC groups than HC group. In addition, polyunsaturated fatty acid (PUFA) is lower in LC group than HC group without any significant differences.

### Sensory evaluation

Comparison on sensory properties of pork between LC, MC and HC groups is shown in Table 5. Data showed that boar taint and meat boar taint were significantly increased in a concentration-dependent manner from low to high, whereas, gravy and meat flavor preference were significantly increased in LC group than HC group.

### Correlation index between boar taint hormones and sensory characteristics

The analysis of the correlation index between androstenone, indole, and skatole, which are boar odor hormones, and the sensory characteristics of pork are presented in Table 6. In the primary sensory evaluation, boar odor felt when eating broth and meat, and androsterone, indole, and skatole in pork showed a positive (+) correlation. A negative (-) correlation was shown in the preference for gravy and meat flavor preference.

## DISCUSSION

In this study, androstenone concentrations not affect the general compositions and meat quality traits of pork. It is known that pH has a high correlation with meat qualities such as meat color and WHC. Generally, the meat pH is related to WHC, and the higher pH, the higher WHC. Some previous studies showed that better pH values [29], higher WHC [30] and lower pale, soft, exudative (PSE) [31] in entire male pigs when compared to the castrated pig. Cooking loss refers to the degree to which meat drips are released during the heating stage. The age of meat can be changed by complex effects such as the amount of moisture and fat, the amount and chemical state of connective tissue, and whether or not actomyosin is formed. Our results indicate that a high concentration of androstenone slightly effects on quality traits of meat in uncastrated pigs because it accumulates in the fat and when heated up, androstenone becomes volatile and can be detected in the cooked pork.



**Table 4.** Effects of androstenone concentration on fatty acid compositions (% of total fatty acids) of porcine *M. subscapularis* muscle

Fatty acid (%)	LC (n = 9)	MC (n = 7)	HC (n = 10)	SEM
C10:0 (Decanoic)	0.11	0.11	0.09	0.00
C12:0 (myristic)	0.10	0.10	0.10	0.00
C14:0 (myristic)	1.29	1.36	1.26	0.06
C16:0 (palmitic)	21.37	21.74	21.15	0.40
C16:1 (palmitoleic)	2.75 <sup>a1)</sup>	2.84 <sup>a</sup>	2.35 <sup>b</sup>	0.13
C18:0 (stearic)	11.15	10.78	11.43	0.26
C18:1n9c (oleic)	38.81	39.94	37.93	0.87
C18:2n6c (linoleic)	14.90	14.21	15.85	0.66
C18:3n6 (gamma-linolenic)	0.58	0.63	0.62	0.02
C20:2 (eicosadienoic)	0.36	0.37	0.41	0.02
C20:3 (Dihomo-γ-linolenic)	0.47	0.43	0.47	0.03
C20:4 (arachidonic)	3.45	3.26	3.58	0.30
C20:5n3 (eicosapentaenoic)	0.11	0.10	0.11	0.01
C22:6 (Cervonic)	0.10	0.11	0.10	0.02
C24:1 (Nervonic)	0.60	0.52	0.59	0.05
ΣSFA	34.01	34.08	34.02	0.64
ΣUFA	62.12	62.39	62.00	0.50
ΣMUFA	42.15	43.30	40.86	0.95
ΣPUFA	19.97	19.09	21.14	1.01
ΣUFA/SFA	1.83	1.84	1.83	0.04
Σn-6/n-3	14.84	14.11	15.21	0.45

<sup>1)</sup>Values in a row with different superscript letters are significantly different ( $p < 0.05$ ).

Lack of superscript letters indicates no significant difference.

LC, low concentration; MC, medium concentration; HC, high concentration; SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; PUFA, poly-unsaturated fatty acid; USFA, unsaturated fatty acid; ω6, omega-6 fatty acid; ω3, omega-3 fatty acid.

**Table 5.** Comparison of sensory evaluation of pork at different androstenone concentrations of porcine *M. subscapularis* muscle

Variable	LC (n = 9)	MC (n = 7)	HC (n = 10)
Boar taint <sup>1)</sup>	5.29 ± 0.25 <sup>b2)</sup>	5.47 ± 0.13 <sup>ab</sup>	5.65 ± 0.14 <sup>a</sup>
Gravy flavor preference <sup>3)</sup>	4.55 ± 0.10 <sup>a</sup>	4.29 ± 0.08 <sup>b</sup>	4.16 ± 0.03 <sup>b</sup>
Meat boar taint <sup>1)</sup>	5.41 ± 0.05 <sup>b</sup>	5.57 ± 0.08 <sup>ab</sup>	5.69 ± 0.04 <sup>a</sup>
Meat flavor preference <sup>3)</sup>	4.59 ± 0.03 <sup>a</sup>	4.47 ± 0.01 <sup>ab</sup>	4.20 ± 0.01 <sup>b</sup>

<sup>1)</sup>Boar odor attributes are scored on a 9-point scale where 1 point very weak ~ 5 points (control) ~ 9 points very strong.

<sup>2)</sup>The results are represented as the mean ± SE.

<sup>3)</sup>Flavor preference attributes are scored on a 9-point scale where 1 point very bad - 5 points (control) - 9 points very good.

<sup>a,b)</sup>Means with different superscripts differ ( $p < 0.05$ ).

LC, low concentration; MC, medium concentration; HC, high concentration.

Individual fatty acid plays a significant role not only in the taste, but also in the formation of flavor by decomposing fat during cooking or creating volatile substances in meat. In addition, fatty acids affect the color, hardness, and storability of meat, and excessive intake of saturated fatty acids is known to cause heart disease. The foremost MUFA of palmitoleic acid (C18:1) showed

**Table 6.** Correlation index between boar taint compounds and sensory attributes of porcine *M. subscapularis* muscle

Variable	Androstenone	Indole	Skatole
Boar taint	0.356*	0.574*	0.583**
Gravy flavor preference	-0.521*	-0.633*	-0.642**
Meat boar taint	0.447*	0.595**	0.603**
Meat flavor preference	-0.528**	-0.740**	-0.748**

\* $p < 0.05$ , \*\* $p < 0.01$ .

a significantly higher content at low and medium concentrations than at high concentrations. In addition, PUFA is lower in LC group than HC group without showing any significant. The previous study Mörlein and Tholen [16] explored that extremely low androstenone containing boars had lower saturated fatty acid (SFA) and higher PUFA in subcutaneous adipose tissue. However, these results are totally opposite from our study. As the most abundant MUFA in meat, oleic acid, which is known to differentially affect the flavor of meat, showed an average content of about 37% to 39%, and have no significant differences between the treatment groups. Cameron and Enser [32] reported that a higher MUFA concentration and a lower PUFA concentration had a positive effect on the taste of meat. Also, among PUFA, there was a study result that linoleic acid (18:2) was affected by the type of feed rather than the variety, and that the higher concentration, negatively affected the flavor of meat [33]. In this study, the MUFA were low, the PUFA were high, and the concentration of linoleic acid (18:2) was high in the HC group when compared to the LC and MC groups. It is known that the fatty acid content differs slightly by breed and that there is a difference in the content due to feed ingredients during breeding rather than breeding. During oxidative processes, the flavor is affected by fatty acids, which is well documented. Literature also showed that higher concentrations of n-3 PUFA are accountable for the production of some lipid degradation products, mainly aroma active aldehydes in meat [34]. Specifically, the aldehyde is responsible for off-flavors in food [35].

In sensory evaluation, flavor (scent) is evaluated as a sense that is felt by combining the stimuli of taste felt by the tongue and smell felt by the nose. As a result of comparing the sensory evaluation (which revealed that it was the subjective evaluation of the sensory evaluation personnel who participated in this experiment) conducted twice on pork, the difference between high and medium concentrations was not significant, but at low concentrations it was clearly found that there was a difference. At high concentration, the boar taint of the broth was stronger and the flavor preference of the broth was lower than that of the low concentration treatment group. Since these results are the result of limited evaluation personnel, additional consumer investigation is necessary, and it is judged that more specific experimental studies are needed on the direct causes (flavor substances such as free amino acids, nucleic acids, etc.).

Correlation index between sensory attributes (trained panel) and boar taint compounds (analytical values) were significantly correlated in pork (Table 6). Boar taint and meat boar taint assessed by the trained panel were significantly correlated along with androstenone, indole and skatole levels. The boar taint attribute and analytically evaluated androstenone, indole and skatole levels were significantly correlated ( $r = 0.356$ ,  $0.574$  and  $0.583$ , respectively). On the other hand, gravy flavor and meat flavor attributes were negatively correlated with androstenone ( $r = -0.521$  and  $-0.528$ , respectively), indole ( $r = -0.633$  and  $-0.740$ , respectively) and skatole ( $r = -0.642$  and  $-0.748$ , respectively) levels. Other previous studies also exposed that boar taint and both androstenone (ranges 0.42 to 0.60) and skatole (ranges 0.46 to 0.83) contents were significantly correlated [36–39]. These findings are supported our hypothesis. Several researchers also acknowledged that



the excess accumulation of boar taint hormones (androstenone and skatole) are the potential causes for decreased consumer preference of boar meat. Besides, some short chain fatty acids and other compounds (16-androstenone steroids, 4-ethylphenol, p-cresol) are also intricately with sensory boar taint.

In conclusion, androstenone concentration had no effect on proximate components and meat quality traits but sensory properties like boar taint and meat boar taint were significantly increased in HC, whereas, gravy and meat flavor preference were significantly increased in LC group. Our data indicate that a high concentration of androstenone has a negative effect on the sensory characteristics in uncastrated pigs and could create complications for consumer preferences and commercial pig production. However further research will warrant this association.

## REFERENCES

1. Lee SH, Kim JM. Breeding potential for pork belly to the novel economic trait. *J Anim Sci Technol.* 2023;65:1-15. <https://doi.org/10.5187/jast.2022.e118>
2. Pauly C, Spring-Staehli P, O'Doherty JV, Kragten SA, Dubois S, Messadène J, et al. The effects of method of castration, rearing condition and diet on sensory quality of pork assessed by a trained panel. *Meat Sci.* 2010;86:498-504. <https://doi.org/10.1016/j.meatsci.2010.05.042>
3. Tomasevic I, Bahelka I, Čandek-Potokar M, Čitek J, Djekić I, Kušec ID, et al. Attitudes and beliefs of Eastern European consumers towards piglet castration and meat from castrated pigs. *Meat Sci.* 2020;160:107965. <https://doi.org/10.1016/j.meatsci.2019.107965>
4. Lundström K, Matthews KR, Haugen JE. Pig meat quality from entire males. *Animal.* 2009;3:1497-507. <https://doi.org/10.1017/S1751731109990693>
5. Pokorná K, Čitek J, Doležal P, Małopolska M, Tyra M, Okrouhlá M, et al. Changes of androstenone concentrations in saliva of boars with age. *Animals.* 2022;12:157. <https://doi.org/10.3390/ani12020157>
6. Squires EJ, Bone C, Cameron J. Pork production with entire males: directions for control of boar taint. *Animals.* 2020;10:1665. <https://doi.org/10.3390/ani10091665>
7. Babol J, Squires EJ. Quality of meat from entire male pigs. *Food Res Internat.* 1995;28:201-12. [https://doi.org/10.1016/0963-9969\(95\)93528-3](https://doi.org/10.1016/0963-9969(95)93528-3)
8. Stookey JM, Gonyou HW. The effects of regrouping on behavioral and production parameters in finishing swine. *J Anim Sci.* 1994;72:2804-11. <https://doi.org/10.2527/1994.72112804x>
9. Morrow-Tesch JL, McGlone JJ, Salak-Johnson JL. Heat and social stress effects on pig immune measures. *J Anim Sci.* 1994;72:2599-609. <https://doi.org/10.2527/1994.72102599x>
10. Bonneau M, Weiler U. Pros and cons of alternatives to piglet castration: welfare, boar taint, and other meat quality traits. *Animals.* 2019;9:884. <https://doi.org/10.3390/ani9110884>
11. Lealiifano AK, Pluske JR, Nicholls RR, Dunshea FR, Campbell RG, Hennessy DP, et al. Reducing the length of time between slaughter and the secondary gonadotropin-releasing factor immunization improves growth performance and clears boar taint compounds in male finishing pigs. *J Anim Sci.* 2011;89:2782-92. <https://doi.org/10.2527/jas.2010-3267>
12. Beery KE, Sink JD, Patton S, Ziegler JH. Characterization of the swine sex odor (sso) components in boar fat volatiles. *J Food Sci.* 1971;36:1086-90. <https://doi.org/10.1111/j.1365-2621.1971.tb03352.x>
13. Thompson RH Jr, Pearson AM, Banks KA. Identification of some C19-.delta.16 steroids contributing to sex odor in pork. *J Agric Food Chem.* 1972;20:185-9. <https://doi.org/10.1021/jf60180a020>
14. Bonneau M, Squires EJ. Boar taint: causes and measurement. In Jensen WK, Devine C,

- Dikeman M, editors. Encyclopedia of meat sciences. Oxford: Academic Press; 2004. p. 91-7.
15. FAO [Food and Agriculture Organization of the United Nations]. The future of food and agriculture – trends and challenges. Rome: FAO; 2017.
  16. Mörlein D, Tholen E. Fatty acid composition of subcutaneous adipose tissue from entire male pigs with extremely divergent levels of boar taint compounds - an exploratory study. *Meat Sci.* 2015;99:1-7. <https://doi.org/10.1016/j.meatsci.2014.08.002>
  17. Falk L, Vrtková I, Bartoňová P. Boar taint through the eyes of genetics: A comparison of the Czech indigenous pig breed and commercial breeds in four gene polymorphisms related to skatole and androstenone levels. *Acta Vet Brno.* 2023;92:181-7. <https://doi.org/10.2754/avb202392020181>
  18. Duarte DAS, Schroyen M, Mota RR, Vanderick S, Gengler N. Recent genetic advances on boar taint reduction as an alternative to castration: a review. *J Appl Genet.* 2021;62:137-50. <https://doi.org/10.1007/s13353-020-00598-w>
  19. Brinke I, Große-Brinkhaus C, Roth K, Pröll-Cornelissen MJ, Henne H, Schellander K, et al. Genomic background and genetic relationships between boar taint and fertility traits in German Landrace and Large White. *BMC Genet.* 2020;21:61. <https://doi.org/10.1186/s12863-020-00865-z>
  20. Baes C, Mattei S, Luther H, Ampuero S, Sidler X, Bee G, et al. A performance test for boar taint compounds in live boars. *Animal.* 2013;7:714-20. <https://doi.org/10.1017/s1751731112002273>
  21. Meier-Dinkel L, Sharifi AR, Tholen E, Frieden L, Bücking M, Wicke M, et al. Sensory evaluation of boar loins: trained assessors' olfactory acuity affects the perception of boar taint compounds. *Meat Sci.* 2013;94:19-26. <https://doi.org/10.1016/j.meatsci.2012.12.009>
  22. AOAC [Association of Official Analytical Chemists] International. Official methods of analysis of AOAC International. 16th ed. Washington, DC: AOAC International; 1995.
  23. Folch J, Lees M, Sloane SGh. A simple method for the isolation and purification of total lipides from animal tissues. *J Biol Chem.* 1957;226:497-509. [https://doi.org/10.1016/S0021-9258\(18\)64849-5](https://doi.org/10.1016/S0021-9258(18)64849-5)
  24. Honikel KO. Reference methods for the assessment of physical characteristics of meat. *Meat Sci.* 1998;49:447-57. [https://doi.org/10.1016/S0309-1740\(98\)00034-5](https://doi.org/10.1016/S0309-1740(98)00034-5)
  25. O'Fallon JV, Busboom JR, Nelson ML, Gaskins CT. A direct method for fatty acid methyl ester synthesis: application to wet meat tissues, oils, and feedstuffs. *J Anim Sci.* 2007;85:1511-21. <https://doi.org/10.2527/jas.2006-491>
  26. Bonneau M, Chevillon P. Acceptability of entire male pork with various levels of androstenone and skatole by consumers according to their sensitivity to androstenone. *Meat Sci.* 2012;90:330-7. <https://doi.org/10.1016/j.meatsci.2011.07.019>
  27. Xue J, Dial GD, Holton EE, Vickers Z, Squires EJ, Lou Y, et al. Breed differences in boar taint: relationship between tissue levels boar taint compounds and sensory analysis of taint. *J Anim Sci.* 1996;74:2170-7. <https://doi.org/10.2527/1996.7492170x>
  28. Bañón S, Costa E, Gil MD, Garrido MD. A comparative study of boar taint in cooked and dry-cured meat. *Meat Sci.* 2003;63:381-8. [https://doi.org/10.1016/s0309-1740\(02\)00097-9](https://doi.org/10.1016/s0309-1740(02)00097-9)
  29. Boler DD, Puls CL, Clark DL, Ellis M, Schroeder AL, Matzat PD, et al. Effects of immunological castration (Improvest) on changes in dressing percentage and carcass characteristics of finishing pigs. *J Anim Sci.* 2014;92:359-68. <https://doi.org/10.2527/jas.2013-6863>
  30. Sather AP, Jones SDM, Joyal S. Feedlot performance, carcass composition and pork quality from entire male and female Landrace and Large White market-weight pigs. *Can J Anim Sci.*

- 1991;71:29-42. <https://doi.org/10.4141/cjas91-004>
31. Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M, Diestre A. Risk assessment of DFD meat due to pre-slaughter conditions in pigs. *Meat Sci.* 2005;70:709-16. <https://doi.org/10.1016/j.meatsci.2005.03.007>
  32. Cameron ND, Enser MB. Fatty acid composition of lipid in Longissimus dorsi muscle of Duroc and British Landrace pigs and its relationship with eating quality. *Meat Sci.* 1991;29:295-307. [https://doi.org/10.1016/0309-1740\(91\)90009-F](https://doi.org/10.1016/0309-1740(91)90009-F)
  33. Alonso V, Campo MM, Español S, Roncalés P, Beltrán JA. Effect of crossbreeding and gender on meat quality and fatty acid composition in pork. *Meat Sci.* 2009;81:209-17. <https://doi.org/10.1016/j.meatsci.2008.07.021>
  34. Wood JD, Richardson RI, Nute GR, Fisher AV, Campo MM, Kasapidou E, et al. Effects of fatty acids on meat quality: a review. *Meat Sci.* 2004;66:21-32. [https://doi.org/10.1016/S0309-1740\(03\)00022-6](https://doi.org/10.1016/S0309-1740(03)00022-6)
  35. Rius MA, Hortós M, García-Regueiro JA. Influence of volatile compounds on the development of off-flavours in pig back fat samples classified with boar taint by a test panel. *Meat Sci.* 2005;71:595-602. <https://doi.org/10.1016/j.meatsci.2005.03.014>
  36. Nute GR, Whittington FM, Warriss PD, Wood JD. Sensory analysis of boar taint. Influence of skatole on abnormal odour and flavour ratings. In: EAAP working group 'production and utilisation of meat from entire male pigs'; 1995; Milton Keynes.
  37. Andressen Ø, Frøystein T, Rødbotten M, Mortensen HP, Eik-Nes O, Lea P. Sensoric evaluation of boar meat with different levels of androstenone and skatole. In: Bonneau M, editor. Measurement and prevention of boar taint in entire male pigs. Paris: Institut National de la Recherche Agronomique. 1993. p. 69-73.
  38. Lundström K, Malmfors B, Malmfors G, Stern S, Petersson H, Mortensen AB, et al. Skatole, androstenone and taint in boars fed two different diets. *Livest Prod Sci.* 1988;18:55-67. [https://doi.org/10.1016/0301-6226\(88\)90067-X](https://doi.org/10.1016/0301-6226(88)90067-X)
  39. Hansson KE, Lundström K, Fjelkner-Modig S, Persson J. The importance of androstenone and skatole for boar taint. *Swed J Agric Res.* 1980;10:167-73.