

Correlations between PORCUS classification and androstenone in boars, and effects of cooking methods thereon

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Abstract

The aim of this research was to evaluate relationships between the PORCUS classification system and factors affecting boar taint in pork. Intact male pork carcasses ($n = 176$) were randomly selected in a South African commercial abattoir from three PORCUS carcass classification groups (P, O and R) and samples from their *Longissimus lumborum* (LL) were obtained at 24 hours post mortem. Correlations between carcass weight, backfat depth, intramuscular fat percentage and subcutaneous fat androstenone concentrations were estimated. A sub-sample of O carcasses ($n = 12$) with high levels of androstenone levels were used to determine the influence of pan-frying, oven-roasting and *sous vide* cooking methods on meat proximate composition and fat androstenone concentration. Although O carcasses were heaviest, backfat depth increased over the carcass classifications. Intramuscular fat percentages were lowest in O carcasses, and crude protein percentages were higher in O compared with R carcasses. The correlation between percentages of backfat depth and LL intramuscular fat was insignificant. No differences were observed between classifications in androstenone concentration, which had a weak positive correlation with carcass weight. All cooked samples exceeded the established sensory threshold for androstenone (>0.45 $\mu\text{g/g}$). Cooking methods were ineffective in decreasing the potential for consumers to experience boar taint. Therefore, alternative processing methods should be considered for these carcasses. In addition, the PORCUS classification system cannot be used reliably to estimate the intramuscular fat content or androstenone concentration of a carcass. These findings are interpreted to suggest a revision of the application of the current classification system is required.

Keywords: androstenone-related boar taint, backfat, carcass, *longissimus*, pork

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Introduction

In South Africa, male pigs are generally not castrated, because intact boars have a faster growth rate, superior feed conversion efficiency, and produce leaner carcasses (Rius, 2005; Pieterse *et al.*, 2016). However, the pork from intact boar carcasses may contain the volatile compounds androstenone (5 α -androst-16-en-3-one) and skatole (3-methylindole), which produce an offensive odour and flavour, collectively known as 'boar taint' (Patterson, 1968). Boar taint is caused by the male pheromones androstenone (Patterson, 1968), skatole (Vold, 1970) and, to a lesser degree, indole (Bonneau, 1982; Garcia-Regueiro & Diaz, 1989). Androstenone is a steroidal male pheromone, which is produced in the testes (Zamaratskaia & Squires, 2009). Owing to their lipophilic properties, these compounds accumulate in the fat of entire male pigs (Babol *et al.*, 2002). The odour of androstenone has been described as 'offensive', 'sweaty', and 'sexual' (Font-i-Furnols *et al.*, 2003), and is typically experienced when the pork is heated. Further sensory odour descriptors include 'faecal', 'boar', 'urine', and 'perspiration' (Bonneau *et al.*, 1992). The tendency for consumers to reject pork that contains boar taint is influenced by the concentration of androstenone (Blanch *et al.*, 2012; Font-i-Furnols, 2012) and consumers' sensitivity to it, which differs depending on their human odorant receptor *OR7D4* genotype (Keller *et al.*, 2007) with *OR7D4* RT/WM and

WM/WM genotypes being less sensitive or anosmic to androstenone than consumers with *OR7D4* RT/RT genotypes. The percentage of consumers that are sensitive to boar taint differs among geographical regions (Lundström *et al.*, 2009), while women are more sensitive to androstenone than men (Gilbert & Wysocki, 1987). Typically, consumers' odour detection threshold for androstenone is 0.426 µg/g, and 0.026 µg/g for skatole (Annor-Frempong *et al.*, 1997). According to a consumer sensory study of various ethnic groups in South Africa, as the concentration of boar taint compounds increased, the acceptance of the pork fat decreased (De Kock *et al.*, 2001), which is the consensus of other international studies (Bonneau *et al.*, 1992; Font-i-Furnols *et al.*, 2003; Pauly *et al.*, 2009; Whittington *et al.*, 2011).

Because of the trend towards increased carcass weights in South Africa (Pieterse *et al.*, 2016; Siebrits *et al.*, 2012), the risk of androstenone-related boar taint in male carcasses may have increased, because heavier pigs have a greater probability of having higher concentrations of androstenone (Aluwê *et al.*, 2011). The PORCUS classification system relies on subcutaneous backfat depth and *Longissimus thoracis* (*LT*) muscle depth to estimate the lean meat percentage of the carcass (Table 1). The carcass is first classified according to weight and then according to lean meat percentage. However, sex and genotype may be used to determine the price per kg that is paid to the producer (Pieterse *et al.*, 2016). Typically, "RCUS" categorized carcasses are less desirable because they are considered older with more subcutaneous fat and a higher potential for boar taint. The risk of androstenone-related boar taint in a carcass is influenced by an array of factors, such as slaughter weight, age, castration status and genetics, while skatole levels are influenced largely by dietary ingredients and hygienic circumstances on farms (Aluwê *et al.*, 2011). The typical fresh pork carcass weight in South Africa is currently about 70 kg (also known as porkers), while heavier (75 to 95 kg live weight) pigs are supplied to the processing market (Mugido, 2017). Anecdotal information indicated that producers believe that lighter weight 'porkers' would be less prone to androstenone-related boar taint. However, the effectiveness of this approach to prevent boar taint in carcasses is still not clear, because low to moderate correlations have been reported between androstenone concentration and live weight of boars (Babol *et al.*, 2002; Aluwê *et al.*, 2011). The presence of boar taint in boar carcasses can be determined on the slaughter line with sensory evaluation of the subcutaneous fat after heating with boiling water, microwaving or using soldering irons (Whittington *et al.*, 2011). However, in South Africa these detection techniques are not used to evaluate carcasses for boar taint and thus little is known of current prevalence in the industry.

A percentage of the androstenone and skatole in the pork fat evaporates during heating, owing to their volatile nature. However, certain cooking methods may improve the flavour of cooked pork products. Typically, pork is prepared with pan-frying and oven-roasting (Font-i-Furnols *et al.*, 2012). However, the *sous vide* method is a relatively new preparation method for pork that is growing in popularity. Thus, the current study aimed first to characterize the POR class boar carcasses for androstenone content and proximate composition, and to determine the correlation between the classification parameters and androstenone content. Second, this study evaluated the effects of cooking methods (pan-frying, oven-roasting, and *sous vide*) on carcasses with high levels of androstenone.

Table 1 Current classification of pork carcasses in South Africa according to the PORCUS system¹

| Classification | Subcutaneous fat thickness (mm) | Estimated percentage lean meat in carcass ² |
|----------------|---------------------------------|--|
| P | ≤ 12 | ≥ 70 |
| O | 13 - 17 | 68 - 69 |
| R | 18 - 22 | 66 - 67 |
| C | 23 - 27 | 64 - 65 |
| U | 28 - 32 | 62 - 63 |
| S | > 32 | ≤ 61 |

¹ Government Gazette, 2015

² Lean meat percentage = 72.5114 – (0.4618 x fat thickness (mm)) + (0.0547 x muscle thickness) as estimated with the Hennessey grading probe

Materials and Methods

Measurements were taken from 176 intact boars that were selected at random at a commercial abattoir in the Western Cape, South Africa. At the time of slaughter, warm carcass weight (including skin, trotters and head), subcutaneous backfat depth and carcass classification were recorded. The Hennessey grading probe (Hennessey Grading Systems, Auckland, New Zealand) was used to determine the thickness of subcutaneous fat and depth of the *Longissimus thoracis* (LT) between the second and last ribs, 45 mm from the dorsal midline (Government Gazette, 2015). Subsequently, the average lean meat yield percentage was calculated to determine the PORCUS classification for each carcass (Table 1). Of the 176 carcasses that were sampled, 45 boars were classified as P; 82 were O; and 49 were R.

After the carcasses had hung at 4 °C for 24 hours, five chops with subcutaneous fat about 2.5 cm thick per pig were cut from the left *Longissimus lumborum* (LL) muscle from the last rib towards the caudal end of the carcass. The subcutaneous fat from the first chop was removed, vacuum packed and frozen at 20 °C until the androstenone concentration was determined. The endomysium was trimmed from the remaining LL muscle of the first chop before the muscle was homogenized, vacuum packed and frozen at -20 °C until proximate analysis. At the time of proximate analysis, this muscle sample were thawed at 4 °C for 12 hours before the proximate composition was determined according to the methods described by the Association of Official Analytical Chemists (AOAC, 2002) for moisture (method 934.01), protein (method 992.15) and ash (method 942.05). Briefly, the LL intramuscular fat content was determined according to the chloroform/methanol (2:1 v/v) extraction gravimetric protocol (Lee *et al.*, 1996). Crude protein analysis was performed using a LECO nitrogen/protein analyser (FP-528, LECO Corporation, Michigan, USA), calibrated with ethylenediaminetetraacetic acid. The nitrogen content per sample was multiplied by 6.25 to obtain the total crude protein percentage of each muscle sample. All analyses were performed in duplicate. A further four chops were cut from each carcass and kept at -20 °C for selection after subcutaneous androstenone concentration was determined to evaluate the effects of cooking method.

Androstenone was extracted according to Verheyden *et al.* (2007) and Bekaert *et al.* (2012). Subcutaneous fat samples from the first chop were removed from the freezer and allowed to thaw for 12 hours prior to analysis. Two grams of fat per sample were cut into small cubes and placed in 50 mL glass beakers. These beakers were covered with glass lids and placed in a microwave oven at 700 W for three minutes. Subsequently, 150 µL of melted fat was transferred to a 2 mL Eppendorf tube and 750 µL of methanol was added, which contained the internal standard 2-methylindole (2-MID) (200 µg/kg), and then the mixture was centrifuged for 10 minutes at 14 000 rpm. The samples were heated at 60 °C for an hour before being transferred to a -20 °C freezer for a further 60 minutes. Samples were then centrifuged again at 14 000 rpm for 10 minutes. Finally, 500 µL of the supernatant was transferred to sterile 1.5 mL glass HPLC vials and closed with crimp-top caps containing silicone septa, and analysed immediately. Androstenone was analysed on all 176 samples with HPLC and mass spectrometry (Verheyden *et al.*, 2007). The extracted samples were analysed using a Waters Acquity ultraperformance liquid chromatography system (Waters Corporation, Milford, USA) fitted with a Kinetex[®] C18 column (2.6 µm, 150 x 2.1 mm) (Phenomenex, Torrance, USA) and a Waters Xevo TQ triple quadrupole mass spectrometer (HPLC-MS/MS-FD, Waters Corporation, Milford, USA), using the solvents 7.5% formic acid and 49:49:2 methanol:acetonitrile:isopropanol. The column temperature was set at 40 °C. A standard curve was produced using androstenone to establish a calibration range and limit of quantification of 0.01 to 13 µg/g and 0.02 µg/g, respectively.

After the subcutaneous fat androstenone concentrations had been determined, 12 muscle samples with the highest concentration were selected from the O class LL chop samples which had been frozen for selection prior to androstenone evaluation. These muscle samples were subsequently used to evaluate the effects of cooking method on fat androstenone content. Prior to cooking, photographs were taken of the four chops selected for each cooking method, to calculate a crude estimate of the subcutaneous fat volume and contact area between the subcutaneous fat and LL muscle volume using ImageJ (Java). One chop was left raw, and the second, third and fourth chops were cooked by pan-frying, oven-roasting and *sous vide*, respectively. For the pan-frying method, a chop was placed in a pan that was heated to a medium to high temperature on a Eurogas stove (Eurafrican, Cape Town, South Africa) and covered with a lid. Every 60 seconds, the chop was turned, and 5 mL of water was added. The chop was removed when a core temperature of 70 - 72 °C was reached, as measured with a thermocouple probe attached to a digital temperature monitor (Hanna instruments (Pty) Ltd, Johannesburg, South Africa) and cooled for 20 minutes at room temperature. Another chop was put in an individual disposable aluminium foil tray with 10 mL of water and placed in a Eurogas oven (Eurafrican, Cape Town, South Africa), pre-heated to 150 °C using both elements. The chop was placed at random in the oven and removed when the core temperature reached 70 - 72 °C, as measured with a thermocouple probe, and cooled for 20 minutes at room temperature. The last chop was vacuum packed and placed in a water-bath (SMC water bath, Table View, Cape Town) for one

hour at 65 °C, another hour at 70 °C, and a further 30 minutes at 72 °C, following standard protocol provided by a local culinary school. These *sous vide* chops were then removed and placed in an ice-bath for 10 minutes to cool to room temperature. Then the subcutaneous fat was removed from each of the chops after their respective cooking methods, vacuum packed and frozen at -20 °C until chemical analysis for androstenone concentration, as described above. The cooked meat/muscle was then cleaned of the endomysium and homogenized before freezing at -20 °C until required for proximate analyses (moisture, protein, lipid and ash), as described above.

All data were analysed with Statistica 64 version 13.2 (StatSoft Inc.). Residuals were tested for normality, and homogeneity was ensured with Levene's test. Subsequently, one-way analysis of variance was used to compare first the PORCUS classification classes P, O and R and, second, the effects of the various cooking methods. Fisher's least significant difference (LSD) was used to compare treatment means for parametric data, and Bootstrap comparison was used for non-parametric data. Correlations between the parameters were investigated using Pearson correlation coefficients. Androstenone concentrations were categorized as low (< 0.31 µg/g), medium (0.31 - 0.45 µg/g) and high (> 0.45 µg/g), before being analysed with cross tabulation and the chi-square test. Significant differences and correlations were reported at a significance level of 5%.

Results and Discussion

The results for the POR carcasses are summarized in Table 2, and the correlations between the parameters can be found in Table 3. Lastly, the effects of the cooking methods on subcutaneous fat androstenone concentration are reported in Table 4.

The warm carcass weights were heaviest for the O carcasses ($P < 0.001$), but did not differ between P and R (Table 2). The subcutaneous backfat thickness increased over the classifications, with R having the thickest fat cover over the *LT* muscle ($P < 0.001$). Although the intramuscular fat percentages of the *LL* from the O carcasses were lower ($P = 0.006$) than those of the R carcasses, there were only small differences in the *LL* crude protein percentages ($P = 0.048$). Neither O nor R carcasses differed from P for *LL* intramuscular fat content (Table 2). P and O carcasses produced pork with higher moisture percentages than R ($P = 0.004$). However, these differences appeared minor. No differences were found for subcutaneous fat androstenone concentrations among the carcass classifications ($P = 0.367$) (Table 2).

Table 2 Mean \pm standard error of carcass weight, backfat thickness and androstenone content, and chemical composition of *Longissimus lumborum* muscle for South African pork carcass classifications P, O and R

| | P (n = 44) | O (n = 82) | R (n = 46) | P-value |
|------------------------------------|-------------------------------|------------------------------|------------------------------|---------|
| Warm carcass weight, kg | 74.4 ^b \pm 1.54 | 81.9 ^a \pm 1.13 | 74.7 ^b \pm 1.51 | <0.001 |
| Lean meat yield, % | 70.3 ^a \pm 0.09 | 68.7 ^b \pm 0.07 | 65.2 ^c \pm 0.12 | <0.001 |
| Subcutaneous fat: | | | | |
| Thickness, mm | 11.5 ^c \pm 0.37 | 14.8 ^b \pm 0.27 | 16.1 ^a \pm 0.36 | < 0.001 |
| Androstenone concentration, µg/g | 0.27 \pm 0.039 | 0.32 \pm 0.033 | 0.36 \pm 0.047 | 0.367 |
| <i>Longissimus lumborum</i> muscle | | | | |
| Moisture, % | 73.1 ^a \pm 0.20 | 72.7 ^a \pm 0.15 | 72.0 ^b \pm 0.19 | 0.004 |
| Crude protein, % | 22.8 ^{ab} \pm 0.29 | 23.3 ^a \pm 0.21 | 22.4 ^b \pm 0.27 | 0.048 |
| Intramuscular fat, % | 3.3 ^{ab} \pm 0.33 | 2.8 ^b \pm 0.24 | 4.2 ^a \pm 0.31 | 0.006 |
| Ash, % | 1.2 ^b \pm 0.05 | 1.4 ^a \pm 0.05 | 1.2 ^b \pm 0.05 | 0.002 |

^{a,b,c} Values with different superscripts within rows differ significantly ($P \leq 0.05$)

When the androstenone concentrations were classified as low (< 0.31 µg/g), medium (0.31 - 0.45 µg/g), or high (> 0.45 µg/g), O had the greatest percentage (30.12%) of carcasses with high levels of androstenone (Figure 1).

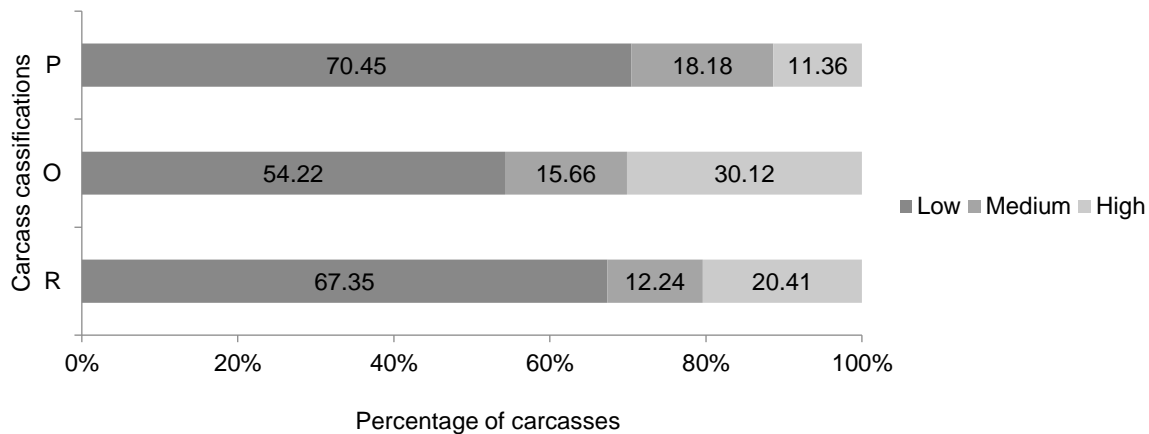


Figure 1 Percentage of carcasses in each classification group that have low (< 0.31 µg/g), medium (0.31 - 0.45 µg/g) and high (> 0.45 µg/g) subcutaneous fat androstenone concentrations

The warm carcass weight had a weak negative correlation with lean meat yield (-0.277) ($P < 0.001$), a weak positive correlation with subcutaneous fat androstenone concentration (0.278) ($P < 0.001$) and crude protein percentage of the *LL* muscle (0.155) ($P < 0.001$), and a moderate positive correlation with subcutaneous fat thickness of the *LL* (0.495) ($P < 0.001$) (Table 3). Thus, as the warm carcass weight increased, so the lean muscle yield decreased while the subcutaneous fat depth, crude protein content and subcutaneous fat androstenone concentration of the *LL* increased. The lean muscle yield of the carcasses showed a weak positive correlation with *LL* moisture percentage (0.275) ($P < 0.001$), a weak negative correlation with *LL* fat percentage (-0.197) ($P = 0.009$) and a strong negative relationship with *LL* subcutaneous fat thickness (-0.937) ($P < 0.001$). Therefore, as the lean meat yield of the carcasses decreased, subcutaneous fat thickness and *LL* intramuscular fat content increased, and *LL* moisture content decreased. Subcutaneous fat thickness was weakly positively correlated with fat androstenone content (0.216) ($P = 0.004$), moderately and negatively correlated with *LL* moisture content (-0.235) ($P = 0.002$) but showed a strong negative correlation with *LL* crude protein content (-0.937) ($P < 0.001$). Thus, an increase in subcutaneous fat thickness was associated with decreased *LL* moisture and protein content, but an increase in fat androstenone concentration. The *LL* moisture content showed a moderately negative correlation with intramuscular fat percentage (-0.489) ($P < 0.001$), which in turn was strongly negatively correlated with *LL* muscle protein content (-0.852) ($P < 0.001$).

The changes in the proximate composition of the *LL* muscle after the various cooking methods are summarised in Table 4. As expected, the raw meat had the highest moisture content, followed by oven-roasted then pan-fried, and the *sous vide* meat was the driest ($P < 0.001$). After cooking, the crude protein content of the *LL* increased ($P < 0.0001$), but there was no difference in protein content between pan-fried and *sous vide* meat or oven-roasted and *sous vide* meat. The *LL* intramuscular fat percentage also increased after cooking ($P < 0.001$). However, none of the meat samples from the various cooking methods differed for intramuscular fat percentage. The ash percentage of the cooking methods did not differ. No differences were calculated for the subcutaneous fat volume or contact area or muscle volume of the *LL* samples and there was no correlation between the contact area (cm²) of the subcutaneous fat and androstenone concentration (0.184) ($P = 0.284$). There were no differences for subcutaneous fat concentrations between the raw and cooked samples and the cooking methods did not decrease the fat androstenone concentrations to below the sensory threshold level of < 0.45 µg/g.

Table 3 Correlations and *P*-values (in parenthesis) for pork carcass traits and *Longissimus lumborum* muscle proximate composition measured over South African pork carcass classifications P, O and R

| | Lean meat yield, % | Fat depth, mm | LL moisture, % | LL crude protein, % | LL fat, % | LL ash, % | Androstenone concentration of fat, µg/g |
|-------------------------|--------------------|-----------------|----------------|---------------------|-----------------|----------------|---|
| Warm carcass weight, kg | -0.277 (<0.001) | 0.495 (<0.001) | -0.063 (0.406) | 0.155 (<0.001) | -0.092 (0.228) | 0.07 (0.336) | 0.278 (<0.001) |
| Lean meat yield, % | | -0.937 (<0.001) | 0.275 (<0.001) | 0.113 (0.137) | -0.197 (0.009) | 0.049 (0.517) | -0.139 (0.068) |
| Fat depth, mm | | | -0.235 (0.002) | -0.937 (<0.001) | 0.091 (0.235) | -0.021 (0.784) | 0.216 (0.004) |
| LL moisture, % | | | | 0.017 (0.827) | -0.489 (<0.001) | -0.008 (0.918) | 0.132 (0.082) |
| LL crude protein, % | | | | | -0.852 (<0.001) | 0.075 (0.327) | 0.072 (0.345) |
| LL fat, % | | | | | | -0.069 (0.368) | -0.123 (0.106) |
| LL ash, % | | | | | | | -0.94 (0.220) |

¹LL: *Longissimus lumborum* muscle

Table 4 Chemical composition of the *Longissimus lumborum* muscle and androstenone concentrations in subcutaneous fat (mean ± SE) as influenced by different cooking methods

| | Cooking method | | | | <i>P</i> -value |
|------------------------------------|--------------------------|--------------------------|--------------------------|---------------------------|-----------------|
| | Raw | Pan-fried | Oven-roasted | <i>Sous vide</i> | |
| <i>Longissimus lumborum</i> muscle | | | | | |
| Volume, cm ³ | | 138.1 ± 6.07 | 145.0 ± 5.22 | 149.2 ± 4.67 | 0.349 |
| Moisture, % | 72.5 ^a ± 0.39 | 64.9 ^c ± 0.61 | 67.0 ^b ± 0.53 | 65.6 ^c ± 0.39 | < 0.001 |
| Crude protein, % | 24.9 ^c ± 0.43 | 29.7 ^a ± 0.61 | 28.2 ^b ± 0.52 | 29.2 ^{ab} ± 0.39 | < 0.001 |
| Intramuscular fat, % | 1.6 ^b ± 0.23 | 3.6 ^a ± 0.32 | 3.1 ^a ± 0.48 | 3.6 ^a ± 0.35 | < 0.010 |
| Ash, % | 1.2 ± 0.04 | 1.7 ± 0.22 | 1.2 ± 0.06 | 1.6 ± 0.20 | 0.133 |
| Subcutaneous fat | | | | | |
| Volume, cm ³ | | 82.6 ± 3.65 | 83.6 ± 3.93 | 83.4 ± 3.4 | 0.978 |
| Contact area, cm ² | | 32.2 ± 0.60 | 34.8 ± 2.64 | 32.5 ± 0.37 | 0.435 |
| Androstenone concentration, µg/g | 0.75 ± 0.11 | 0.49 ± 0.18 | 0.85 ± 0.23 | 0.86 ± 0.34 | 0.636 |

^{a,b,c} Within rows values with a common superscript do not differ significantly (*P* ≤ 0.05)

The PORCUS classification system, which is used to evaluate pork carcasses in South Africa, was developed in 1992. It has not since been updated, except for increasing the carcass weight of 'sausage pig' carcasses from 90 kg to 100 kg (Siebrits *et al.*, 2012). The system is constructed on the estimation of lean meat yield, but often anecdotal assumptions are made about other properties of the carcass based on its PORCUS classification or carcass weight. Such assumptions include that heavier male carcasses are fatter and more mature, and have a higher risk of high androstenone concentrations. However, pig carcasses have increased on average in weight over the past years (Mugido, 2017), but still produce lean carcasses owing to advances in pig genetics (Siebrits *et al.*, 2012). Furthermore, other than recording the sex, no parameters are measured on the carcass to directly estimate the presence of androstenone or boar taint in general.

According to anecdotal information, this risk is managed by slaughtering non-castrated pigs before they attain sexual maturity, resulting in light carcasses that may not represent the current most economical slaughter weight in the growth curve of the pig, because Pieterse *et al.* (2016) have indicated that slaughtering heavier pigs appears to be more profitable. Nonetheless, the question is often posed by the industry of whether the current South African system may be used to predict potential boar taint levels and thus minimize the risk of unacceptable levels of androstenone entering the consumer market.

The results of this study seem to indicate that the classification system is not suitable as a screening method for boar taint, because the R carcasses had the most subcutaneous fat, but the O carcasses were the heaviest and had the most androstenone concentrations over 0.45 µg/g (Figure 1). Furthermore, warm carcass weight and subcutaneous backfat depth did not correlate with intramuscular fat content. Nor did either measurement show a strong correlation with androstenone concentration. Thus, the POR section of the PORCUS classification may not be used to infer information about the fat content of the LL muscle itself, or the subcutaneous fat androstenone content. The results for the correlation between body mass and androstenone levels in pigs vary (Aldal *et al.*, 2005; Chen *et al.*, 2007; Nicolau-Solano *et al.*, 2007; Zamaratskaia & Squires, 2009). However, comparisons of results are confounded by slaughter age and breed (Xue *et al.*, 1996), which may have a more pronounced effect on androstenone levels. Thus, slaughter weight is not a reliable predictor of androstenone concentration.

There is a moderate correlation between warm carcass weight and subcutaneous fat thickness, which is in accord with previous research (Beattie *et al.*, 1999). Although Beattie *et al.* (1999) reported a positive correlation between carcass weight and intramuscular fat percentage, no correlation was found between these parameters in the current study. The warm carcass weight also showed poor correlation between lean meat yield and crude protein content of the LL muscle. Thus, warm carcass weight is a poor indicator of these two parameters. As the lean meat yield of the carcass decreased, its subcutaneous fat depth increased. However, changes in the lean meat yield were poorly associated with changes in intramuscular fat percentages of the LL muscle. As fat content of the LL muscle increases, it is likely that both moisture and crude protein have decreased due to the correlations among these variables. However, there is variation in intramuscular fat content (Faucitano *et al.*, 2004) in the whole *longissimus thoracis et lumborum* (LTL) muscle, with the highest intramuscular fat percentages at the middle of the thoracic region and in the mid-caudal section of the lumbar area. Thus, further studies would benefit from taking multiple samples across the entire LTL to further investigate the correlation between the amount of intramuscular fat content and similar parameters measured in the present study.

A large percentage (62%) of the 176 carcasses had low androstenone levels (< 0.31 µg/g), while 15% were in the moderate androstenone category (0.31 - 0.45 µg/g) and 22% had high levels of androstenone (> 0.45 µg/g) (Figure 1). This result differs from that of Aluwé *et al.* (2009), who found that only 10% of entire male carcasses that were slaughtered in their trial had high levels of androstenone when the cut-off level was 0.50 µg/g, although only one animal had a level above 1.0 µg/g. Not only did the carcasses in this study have a higher percentage of carcasses with androstenone, but the average androstenone levels were higher than those reported by Aluwé *et al.* (2009) and were above the sensory threshold for consumer detection. Since the carcass classifications that are currently most in demand by the retail market were sampled in this study, the prevalence of high androstenone in South Africa should be addressed by implementing an online boar taint detection system or by considering welfare-friendly castration methods such as immunocastration. In fact, Needham *et al.* (2017) showed that under South African conditions immunocastrated pigs can have satisfactory growth rates. When the dietary amino acid profiles are satisfactory, good feed conversion ratios are also achieved when immunocastrated pigs are fed ractopamine.

In terms of the effect of cooking on the chemical composition of pork, oven-roasted meat had greater moisture content than pan-fried and *sous vide*, and thus potentially resulted in more tender and juicier meat. The higher moisture content of the oven-roasted samples could be because water was added to the aluminium trays, which resulted in water uptake or less water being lost during cooking. Because of their decreased moisture content, protein and fat percentages were higher in pan-fried and *sous vide* meat. Pork preparation methods influence consumer detection of androstenone. Methods such as *sous vide* and breading with garlic and parsley can mask androstenone to some extent (Borrisser-Pairó *et al.*, 2017). However, the current study showed no differences between the raw and cooked samples, despite the method, and all subcutaneous fat samples from these methods still had androstenone concentrations that exceeded the sensory threshold. The lack of significant differences between the treatments appears to be influenced by the large range of androstenone concentrations that were recorded for the carcasses (0.38–2.20 µg/g), which was exacerbated by the small sample size. Although this was an initial investigation, the sample size in future trials needs to be increased, preferably after a calculation of the required degrees of freedom because of the variations in androstenone levels. In addition, the effect of the potential release of androstenone odour during cooking could influence consumer acceptance. Thus, alternative processing

methods should be developed for tainted carcasses, in which the compound is masked prior to cooking and eating, such as using caraway essential oil in products (Šojić *et al.*, 2018).

Conclusion

The androstenone concentration or proximate content of the *LL* muscle cannot be inferred from the carcass classification parameters that are currently measured on the South African slaughter line. Despite the use of carcass weight and lean meat percentage to classify the carcasses, there were few differences between P, O and R classifications beyond subcutaneous fat thickness. Additionally, a large overall percentage of the carcasses that were analysed were found to have moderate to high levels of androstenone, which is cause for concern as this probably results in consumer dissatisfaction with pork. Common cooking methods such as pan-frying, oven-roasting and *sous vide* are not reliable means to decrease subcutaneous fat androstenone concentration, and other meat processing methods have yet to provide a solution. Thus, these results promote the need for welfare-friendly pre-slaughter interventions such as immunocastration. This study emphasises the need to re-evaluate the efficacy of the current South African PORCUS classification system, together with effective control of boar taint.

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Authors' Contributions

KVZ conducted the research trial as part of her MSc research thesis. TN performed the statistical analyses with assistance from Prof. M Kidd and wrote the manuscript. LCH was responsible for the supervision of the MSc research, development of the project, and writing and editing the manuscript.

Conflict of Interest Declaration

There are no conflicts of interest.

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