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Moving towards taint-free pork – alternatives to surgical castration

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Introduction

Surgical castration of entire male pigs is routinely performed to eliminate the risk of boar taint, an off-flavour in heated pork products. Boar taint occurs in some entire male pigs at slaughter weight and is primarily due to high levels of androstenone and/or skatole in pig carcasses. Although castration reduces the levels of both compounds and, therefore, decreases boar taint, this approach is not entirely satisfactory. Entire male pigs compared to castrates have an improved feed conversion and carcass leanness. Additionally, surgical castration is more and more viewed as a profit at the expense of reducing animal health and welfare. Therefore, to prevent boar taint, methods other than castration are desirable. To facilitate the development of such method(s), factors affecting the levels of skatole and androstenone have to be well understood.

Multiple factors regulate the levels of skatole and androstenone in pig carcasses and this subject has been regularly reviewed [1-5]. The purpose of the present mini-review is to update the existing data gathered over the past few years, and highlight selected aspects of the boar taint problem. Further points and suggestions for future research will be proposed.

Factors affecting boar taint

In entire male pigs at slaughter weight, the levels of skatole and androstenone vary considerably. The main factors responsible for these variations are summarised in Figure 1. Physiological factors (rate of synthesis and metabolic clearance, and overall hormonal status) are crucial in the regulation of the levels of both compounds. Genetic and environmental sources for the variation in skatole and androstenone levels have also been identified. The present review will focus on some of these factors.

Biosynthesis and metabolism

Androstenone is a steroid produced in the Leydig cells of the testis near sexual maturity. The andien-β synthase enzyme system is responsible for the first step of androstenone biosynthesis [6]. Androstenone is metabolised in the liver with the formation of two major metabolites, 3α- and 3β-androstenol [7,8]. Part of the androstenone is transported to the saliva where it serves as a pheromone to stimulate the sexual responses in female pigs. Part of the androstenone is accumulated in the adipose tissue. Androstenone levels are low in blood and tissues of young male pigs and then dramatically increase near sexual maturity [9,1]. In sexually mature pigs, androstenone production primarily depends on the individual ability of the pig to produce [10] and probably metabolise [8] androstenone.

Skatole is produced by bacteria in the large intestine of the pigs from tryptophan. Part of the skatole is excreted with faeces and the residual part is absorbed through the intestinal walls, released to the blood and metabolised in the liver by cytochrome P450 enzymes (CYP450) and aldehyde oxidase [11,12]. Un-metabolised skatole can accumulate in adipose tissue, causing faecal-like odour in the heated meat. The impact of liver metabolism on skatole levels in fat has been well documented [11,13-15]. Pigs with high skatole production and low levels and activities of hepatic CYP450 will accumulate high skatole levels in fat.

Genetics

There is increasing evidence that the levels of both skatole and androstenone show large genetic variation. Genomic regions to harbour QTL for the variation of skatole and androstenone levels in fat have been identified [16].

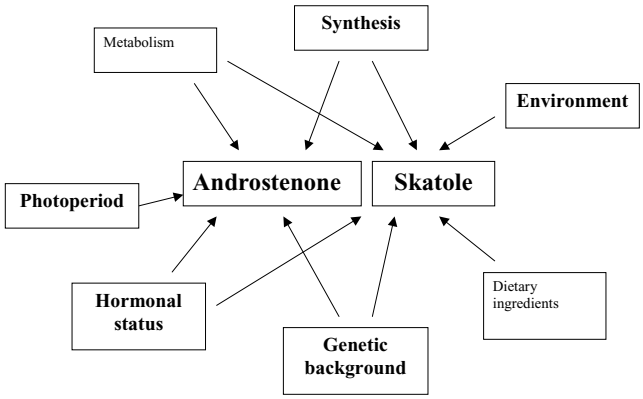

Figure 1
Factors affecting skatole and androstenone in entire male pigs.

Recent molecular genetic studies have indicated that genetic polymorphisms in the enzymes involved in skatole metabolism and androstenone production, such as cytochrome P4502A6 [17], thermostable phenol sulphotransferase SULT1A1 [18] and cytochrome b5 [19], might be associated with the risk of boar taint development.

Nutrition

The production of skatole to a great extent depends on the intestinal micro-flora and the availability of the substrate, which may be altered by dietary means. Recent studies have indicated that a reduction in skatole levels in fat may be achieved by using carbohydrate-rich diets, although conflicting results with carbohydrate feeding have also been reported. For example, feeding with sugar beet pulp significantly reduced fat skatole levels in some studies [20,21], whereas other [22] found no effect of sugar beet pulp on skatole levels. Over the last few years interest is growing in the use of raw potato starch (RPS) as a skatole-reducing additive. The inclusion of RPS into the diet repeatedly decreases skatole levels in tissues of boars (fat and plasma, [23]), barrows (fat and plasma, [24]), and gilts (liver, [25]).

There is limited information about the effect of nutrition on androstenone levels. It is generally believed that feeding intensity rather then specific dietary components influences androstenone levels by accelerating puberty. However, our recent study demonstrated that androstenone levels in fat slightly decreased after feeding RPS for 2 weeks, although this decrease did not reach statistical significance. The levels of androstenone in plasma (measured after extraction with ethyl acetate) were significantly lower in the pigs fed RPS. These data offer new challenges. Maybe, increased feeding period with RPS (above 2 weeks) will decrease androstenone in fat below threshold levels.

Effect of surgical castration on androstenone and skatole

The levels of androstenone and skatole are usually undetectable in the fat of castrated male pigs. Surgical castration simply removes the source of androstenone production (and also the production of anabolic hormones); thus, androstenone levels drop rapidly and remain low. The reasons for the reduction of skatole levels in castrated pigs are not well understood. It is likely that testicular steroids are important regulators of either skatole production or metabolism. *Claus et al.* [2] suggested the role of anabolic hormones in intestinal turnover and thus skatole synthesis. However, recent studies showed that testicular steroids are also involved in the regulation of skatole metabolism. It was shown that pubertal increase in the levels of testosterone, oestrone sulphate and androstenone coincided with decreased activities of CYP2E1 and CYP2A6, the main enzymes of skatole metabolism [26]. The role of androstenone in skatole metabolism was investigated in *in vitro* studies, and androstenone was recognised as an inhibitor of the skatole-induced CYP2E1expression [27]. Our own results (unpublished) suggested that androstenone might also be involved in skatole metabolism directly through the inhibition of CYP2E1 activity. We also found that oestradiol has an inhibitory effect on the activity of CYP2E1 (unpublished), although the mechanisms by which androstenone and oestradiol influence CYP2E1 are not identical. The close correlation between skatole and oestrone sulphate [28,23] suggested that besides androstenone, oestrogens might be involved in the regulation of skatole levels.

Alternatives to surgical castration and future research

If surgical castration is to be banned, a reliable alternative is needed to reduce the risk of high levels of taint in the carcasses. Some possible alternatives are listed in Table 1. It is not yet possible to be totally confident that any of the alternatives provide a reliable method to produce taint-free pork. The advantages and disadvantages of the alternatives should be cautiously studied before the final decision is made how to prevent boar taint without surgical castration.

Several issues need to be clarified in future research. The elimination of boar taint from the meat of entire male pigs should be achieved without negative effects on other carcass characteristics and economic efficiency. Indeed, slaughter at lower weight might reduce (though incompletely) the risk of tainted carcasses, but is not attractive from an economical point of view. Selection against high androstenone levels might lead to the reduction in anabolic hormone levels and, therefore, negatively affect growth performance and age at puberty [29,30] unless

Table 1: Some alternatives to surgical castration

Technique	Description	Reference	Advantage	Disadvantage	Considerations
To use methods for the screening of taint on-line	Colorimetric measurement of skatole equivalent	*Mortensen & Sørensen* [34]	Simple and rapid	Does not discriminate between skatole and indole. Does not measure androstenone levels	Nowadays, used in Denmark to sort out tainted carcasses
	Colorimetric measurement of 16-androstenes	*Squires* [35]	Simple and rapid	Does not measure skatole levels. Never been validated at slaughterhouse settings	
	Electronic nose	*Annor-Frempong et al* [36]	Sensitivity and good correlation with records from human sensory panels	Does not discriminate between skatole and androstenone. Never been validated at slaughterhouse settings	
Immunocastration	Active immunization against gonadotropin-releasing hormone at the end of the fattening period	*Bonneau et al.* [31] *Dunshea et al.* [32] and other	Reduced boar taint, aggression behavior and mountings	Some variability between studies. Not all pigs responded to immunocastration	Consumer reaction on the meat should be studied!
Slaughter at lower weight	90 kg or below	*Bonneau* [10] *Zamaratskaia et al.* [23] *Aldal et al.* [37]	Reduced the risk of boar taint. Common practice in UK.	Reduced economy. Does not entirely eliminate the problem (*Aldal et al.* 2005)	Methods for androstenone measurements differed between studies
Feeding diets rich in indigestible carbohydrates	E.g. inulin; raw potato starch; sugar beet pulp (short feeding period)	*Jensen et al.* [20]; *Zamaratskaia et al.* [23]; *Rideout et al.* [38];	Reduced skatole levels. No adverse effects on growth performance or animal health.	Does not reduce androstenone levels.	Indications of lower androstenone levels after feeding raw potato starch (unpublished)
Genetic selection	Against androstenone only	*Willeke & Pirchner* [29]; *Sellier et al.* [30]	Reduced androstenone levels	Reduced growth performance and delayed puberty in female pigs	Pigs with low androstenone when sexual mature should be chosen for such selections
Gender selection	Elimination of male type sperm cell	*Johnson* [39]	Production of female-only herds	Expensive. Possibility of sperm losses and cell damages during selection	Not commercially available

appropriate genetic markers are used. Selection against high skatole levels has not been performed. Any genetic selection would have to be performed with caution in order not to affect overall carcass quality. Additionally, it should be remembered that some genotypes would perform better in certain environments. For example, pigs with high potential to accumulate skatole (genetic component e.g. low skatole metabolism) would not necessarily produce tainted carcasses if the environment would not favour high skatole production.

Additionally, more work needs to be done on the role of other compounds potentially leading to boar taint such as indole, androstenol and phenylbutenone.

Active immunisation against gonadotropin-releasing hormone (GnRH), so called immunocastration, is a potential alternative to surgical castration [31,32]. Besides reduction in boar taint, immunocastration improves meat and carcass characteristics relative to surgical castrates, and reduce male aggressive behaviour relative to entire males. However, the consumer reaction to the products from immunocastrated pigs needs to be investigated.

Finally, solving the "castration problem" also depends on collaborative connections. Building strong research collaboration should be the primary goal for multidisciplinary projects investigating factors affecting boar taint and alternatives to surgical castration.

Other considerations

Animal welfarist's concerns are mainly focused on the negative consequences of surgical castration. However, animal behaviour is a central part of animal welfare. Entire male pigs show a higher frequency of aggressive behaviour compared to castrated males and females [33].

The housing and management of entire male pigs is an issue that should be considered if castration is to be banned.

Conclusion

Nowadays, there is no suitable alternative to surgical castration to produce taint-free pork. More research is needed to clarify the factors involved in the development of boar taint and to find a method to prevent the accumulation of high concentrations of skatole and androstenone in fat.

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